Use of geotextiles in concrete pavement construction

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ABSTRACT: As investigations by BASt have shown, a bond between concrete surfaces and bases may be a disadvantage when water penetrates via joints and from the sides if the bond becomes partially detached at an early stage. Free water may penetrate into the area between the concrete surface and the base and build up in areas where the bond is still intact. The high pressures caused by lorry wheels rolling over the pavement causes hydrodynamic pumping. This creates very high flow speeds with considerable corrosion power. This results in the base course surface being eroded in the areas where heavy vehicles drive over the road and may even lead to water and fine particles from the base courses being expelled through the longitudinal joints between the pavement slab and the lower hard shoulder or first overtaking lane.

The erosion of the base leads unavoidably to the bearing conditions deteriorating and increased loading of the concrete surface. Cracks may occur and, later, stepping-off and tilting of the plates and plate components. This significantly deteriorates the evenness and consequently the service value of the road. This finally leads to a reduction in the service life of the concrete surface.

To avoid such damage water which has penetrated must be able to lose pressure and to then seep away. Possible solutions are:

- a thick concrete surface on a base without any binder;
- nonwoven fabric substances between concrete surface and bound base course.

Both construction methods have proved themselves on numerous test road sections and were rightly included in the new Codes of Practice for the Standardisation of the Upper Structure of Traffic-Bearing Surfaces.

1 INTRODUCTION

Under the current RstO (Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen), only bases with hydraulic binders (Tragschicht mit hydraulischen Bindemitteln – THB) or asphalt bases (Asphalttragschicht - ATS) may be used as a direct base for construction methods with concrete pavement surfaces in construction categories SV and I to III. Common to all these construction methods is the fact that the concrete surface is bound with the respective base. THB's have a firm hydraulic bond with the concrete surface, ATS's an adhesive bond.

2 PROBLEM

Even with careful observation of the supplementary contract conditions and codes of practice it is not possible in the long term to avoid water from penetrating via the transverse and longitudinal joints or via the sides into the area between the concrete surface and the base. Problems occur when the bond at the corners of the plates begins to become detached and a small gap appears between concrete pavement plate and the bonded base, into which water can penetrate. As the hydraulically or bituminously bound bases are practically impermeable the water builds up in areas in which the bond still exists and remains in the longer term as free water between the concrete surface and the base. The deformations to the plates and particularly the plate ends which occur when lorry wheels drive over the plates, place pressure on the water and cause it to move. Hydrodynamic pumping occurs. Very high flow speeds occur which have considerable erosion force.

This results in the base course surface becoming eroded in the areas of the motorway which are driven over by heavy vehicles and may even lead to water being and fine particles from the base courses being expelled, particularly through the longitudinal joints between the right lane and the lower-lying hard shoulder or first overtaking lane (if there is a cross slope towards the middle of the roadway) as the bond which holds for longer in this area prevents the water from being discharged (fig. 1).

Fig. 1: Water being ejected from the longitudinal joint between roadway and hard shoulder together with fine particles and sand from the THB

This state can be recognised by dirt stripes, which may range from light to dark depending on the bond and the composition of the base, near the longitudinal joint and by the water fountains which are expelled from the joint when a lorry drives over it.

The erosion of the base leads unavoidably to the bearing conditions deteriorating and increased loading of the concrete surface. Cracks may occur and, later, stepping-off and tilting of the plates and plate components. This significantly deteriorates the evenness and consequently the service value of the pavement. This leads finally to a reduction in the service life of the concrete surface (fig. 2).

Fig. 2: Concrete surfaces on a federal motorway shortly before being renewed

3 POSSIBLE SOLUTIONS

To avoid such damage the water which has penetrated would have to be able to lose pressure and to then seep away.

The following solutions are of practical relevance:

- thick concrete surface on crushed stone base (base without binder – Tragschicht ohne Bindemittel, TOB);
- nonwoven fabric substances laid over the whole area between concrete surface and base.

3.1 *Concrete surface on a crushed stone base*

The method of construction involving a concrete surface being laid on a crushed stone base (base without binder) enables the water which has penetrated to flow downwards through the base and the frost protection layer and then across the formation into the lateral drainage lines. The crushed stone base must be sufficiently water-permeable (k value $\geq 1 \cdot 10^{-5}$ m/s), and remain so in the long term,. As, on the other hand, a deformation module $E_{V2} \geq 150$ MN/m^2 is required for the crushed stone base, the composition of the aggregate is optimised with regard to CBR value and water permeability. Due to the generally good experiences made on tests road sections, this construction method will be included in the new Guidelines for the Standardisation of the Upper Structure of Traffic-Bearing Surfaces for construction categories SV and I to III.

The crushed stone base is 30 cm thick for all construction categories. The concrete surface is in each case 4 cm thicker than in the construction methods with binder. It is therefore 26 cm thick for construction category III and 30 cm thick for construction category SV.

This type of construction can therefore be characterised as a construction method with a thick concrete surface on an unbound base which is not sensitive to displacement.

3.2 *Concrete Surface on Nonwoven Fabrics*

Applying nonwoven fabrics to the whole area of the bound base has proved to be a promising method for enabling water which has penetrated to beneath the concrete base to be discharged harmlessly. Investigations into the draining of concrete surfaces started at the Federal Highway Research Institute in 1980 initially concentrated on the installation of a longitudinal drainage system in the vicinity of the critical joint between the right-hand lane and the hard shoulder. This was the correct approach for cases where, as discovered for instance on the A 67 near Darmstadt, the water was able to be discharged as far as the hard shoulder down the cross slope on the ATS which was separated from the concrete surface by bearing paper and which only built up there on account of a 30 cm-thick marginal strip (fig. 3).

Fig. 3: Water build-up and erosion of the ATS in front of a marginal strip

When large-area erosion is possible under the entire roadway (this must always be assumed for construction methods using binders), installing a longitudinal drainage system will reduce the erosion but will not prevent it (fig. 4).

Fig. 4: Large-area erosion of a THB

A repair contract in 1981 on the A5 motorway near Mörfelden, where 10 ruined plates from the first lane had to be replaced, prompted the idea of installing a drainage system for the whole area between surface and base as well as the longitudinal drainage system. There were large amounts of fine particles from the THB on the hard shoulder, most of which had been pumped out through the longitudinal non-expansion joint. Installing concrete with plasticising agents without any additional measures would have created a tight connection between surface and base which would only have shifted the problem of water build-up on the right-hand side of the plate one lane farther in and the water would not have reached the longitudinal drainage system envisaged for it.

For this reason, prior to the laying of the concrete, nonwoven fabrics were laid on the whole area of the eroded base right into the longitudinal drainage system which consisted of a slotted tube in a crushed-stone bed (fig. 5).

Fig. 5: Installation of the concrete on nonwoven fabric with longitudinal drainage

Readings made with tipping bowls on the side drainage exits showed that the drainage system worked; the discharged water did not contain any fine particles. The installation of other drainage test road sections led to the consideration that nonwoven fabrics could be laid on the whole area of all lanes, i.e. including under the hard shoulder (without longitudinal drainage). This created a new construction method which was used in the 80s on a series of longer test road sections. The substances normally used were alkali-resistant polypropylene nonwoven fabrics with a weight of 500 g/m^2.

4 EFFECTIVENESS OF THE NONWOVEN FABRICS

The advantages of the construction method using nonwoven fabrics between the concrete surface and the bound base, which are far more extensive than first supposed, can be described as follows.
Using nonwoven fabrics means that the concrete plate and the base are completely separated by the bond from the very start (fig. 6).

Fig. 6: Nonwoven fabric laid over the entire area

There is therefore no horizontal secondary bending stress between the THB and the concrete surface. Notches in the THB are no longer required. Internal stress due to temperature and dampness gradients in the concrete surface are also reduced through the separation. Observations of the cracking behaviour of the transverse dummy joints on the test road sections have shown that the joints open very equally.

The good permanent elasticity of the nonwoven fabric means that the concrete surface retains good bearing qualities, even under different deformations. In contrast to concrete surfaces on a rigid undelay the construction is similar to a plate on elastic bedding. The brief impulses caused by the dynamic loading of the moving traffic are evenly cushioned when nonwoven fabric is used and transferred to the whole surface of the base. Rigid unbound underlays with an eroded surface, on the other hand, are extremely unfavourable for the lasting quality of concrete surfaces (fig. 4).

The nonwoven fabric meets all the requirements of the original task which was to prevent the base from becoming eroded. The nonwoven fabric substance fills the gap between concrete plate and base and is able to adapt to the normal changes resulting from temperature and dampness gradients and traffic loads. Water which has penetrated to underneath the concrete surface is therefore always in the nonwoven fabric substance and cannot be made to flow as fast by lorry wheels as free water can. Eisenmann and Birmann showed that the erosion of less solid bases, which was otherwise ascertained on their testing facility in time-accelerating tests, did not occur when a nonwoven fabric substance was laid between THB and concrete surface.

The geotextile should allow water transportation, i.e. drainage, both when being subjected to traffic loading and when there is no traffic; it must not, however, have a large drainage capacity. Water seeps at a speed of $k_H \geq 5 \cdot 10^{-4}$ m/s through the most commonly used and recommended nonwoven fabric substance when this substance is subjected to a load of 20 KN/m^2. Thus the nonwoven fabric reduces the water speed and sends most of it to the external drainage system via the joints and the road surface.

The long-term behaviour of concrete pavement systems with nonwoven fabric inlays are currently being tested on BASt’s test road sections which were installed in the 80s; these tests are being carried out as part of a research project commissioned by the Federal Ministry of Transport, Building and Housing. It is intended that the results should be used as a basis for elaborating further requirements and recommendations for the use of nonwoven fabric inlays. The good experiences made so far with this pavement system have already led to this method of construction being used to a greater extent. Eight large motorway sections in eastern Germany have for example been built with a nonwoven fabric inlay between concrete surface and THB (fig. 7).

Fig. 7: Installation of the concrete surface on nonwoven fabric

Examples showing the good behaviour of concrete surfaces on a nonwoven fabric inlay can be found in the results of investigations which were carried out on 11 year-old concrete surfaces by the Institute for Roads and Railways at the University of Karlsruhe as part of research project FE 09.134. The project investigated the long-term behaviour of a 30 cm-thick concrete surface on a 55 cm crushed stone base and a 22 cm-thick concrete surface on nonwoven fabric lying on top of a 8 cm-thick ATS and a stabilised frost protection layer and compared this behaviour with that of a standardised construction with a 24 cm-thick concrete surface on a 15 cm-thick THB and frost protection gravel on the A3 motorway near Hilden.

The final report draws attention to the following points when summarising the three structures:

The structure involving a thick concrete surface on a crushed stone base showed positive behaviour on certain sections but also displayed damage which was localised using parameters for the plate bearing capacity and the effectiveness of transversal force transfer; the damage took the form of horizontal cracks at dowel level where the plates sagged and must be regarded as serious. In view of the fact that pertinent investigation results and other indications coincide with apparently poor drainage, much of the damage to the pavement surface can be regarded as being connected with water movements and erosion, and possibly with concentrations of fine particles in the joint which, under traffic loading and particular temperature conditions, may have led to overloading of the plates.

Dowel support frames have had a positive effect when installed as stiffening elements in the construction method involving geotextiles on ATS. The nonwoven fabric inlay also has a positive effect, albeit in a different respect. Nonwoven fabric is thought to allow water pressure to be reduced and, to a limited extent, water to be transported; this meant that there were no signs of erosion on the asphalt base although the binder levels were relatively low and the voids content was comparatively high.

The readings taken using the falling weight deflectometer (FWD) showed very even deflections. The concrete plates themselves and the joint areas did not show any signs of damage to the concrete which could have been caused by the concrete pavement system. The samples of the nonwoven fabric substance which were taken were sufficiently water-permeable, both longitudinally and laterally.

Special supplementary investigations carried out by the Construction Material and Soil Testing Agency in Wetzlar into sections with nonwoven fabric substances produced the following results:

- the nonwoven fabric substance was connected with the concrete via the top layer of fibres;
- the nonwoven fabric substance was not filled with cement mortar;
- there were deposits of fine cement particles in the nonwoven fabric substance; these deposits did not, however, fill the voids in the fabric;
- a small amount of cement mortar was rinsed out of the lower surface of the concrete during laying: there were loose deposits of fine quartz sand and filler;
- near the joints, the nonwoven fabric substance was partially filled with fine sediment from crushed concrete and there were deposits on the surface between the nonwoven fabric substance and the lower surface of the concrete, ranging in size from sand to fine gravel, which had probably been rinsed out of the concrete;
- the concrete had been rinsed off the under side of the concrete plate near the joints to such an extent that coarse gravel elements were exposed;
- the nonwoven fabric substance did not exhibit any visible signs of damage either near the joints nor in the middle of the plate;
- the nonwoven fabric substance felt fleecy and was compressed when the area was subjected to a load.

The fact that the behaviour of the structure involving THB was comparatively worse was due to a large extent to the horizontal cracks in the upper zone within the base and accompanying erosion and loss of substance – despite the high strengths recorded for the THB. This erosion is supported by impulse radar readings, core investigations and plate components which were removed for investigation (fig. 8).

Fig. 8: View under a lifted concrete plate with partially attached THB

It cannot be assumed that all the bond between the concrete surface and the THB is equally firm; rather, the conditions are unclear and wouldl probably change rapidly as service life increased as the impulse radar readings of additional drill core samples indicated that the erosion of horizontal components had increased.

The respective frequency distribution of maximum deflections at the transverse dummy joints provides an example of how the different behaviour of the three construction methods is reflected by the results of the deflection readings, made using the FWD device (fig. 9).

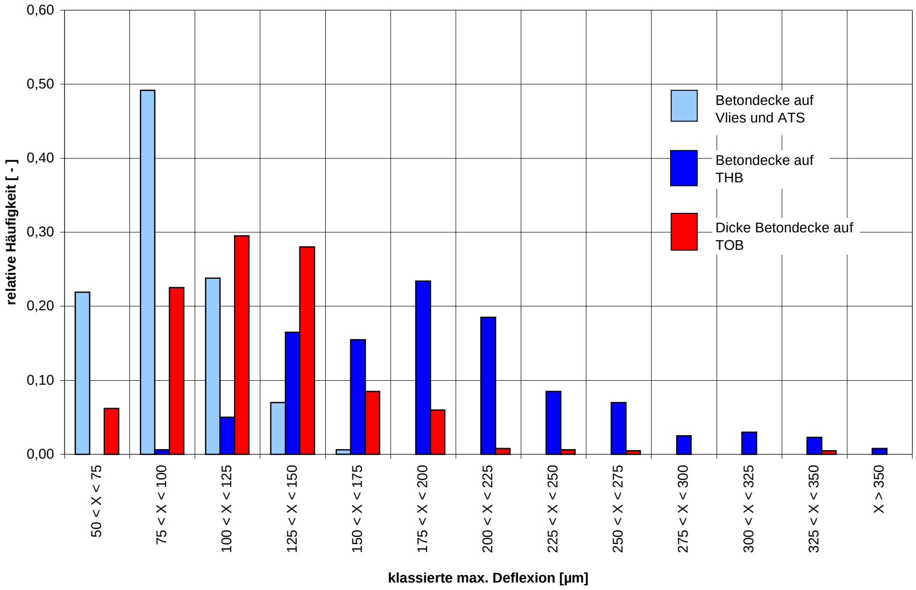

Fig. 9: Frequency distribution of the maximum deflections at the transverse dummy joints, load: 50 kN

It becomes evident that the construction method using nonwoven fabric shows the smallest and most even deflections at the transverse dummy joints while the construction method with THB shows the largest and most uneven deflections.

The construction method involving a concrete surface on a nonwoven fabric substance will be included in both the new Supplementary technical contract specifications and codes of practice for the construction of concrete pavements (Zusätzliche Technische Vertragsbedingungen und Richtlinien für den Bau von Fahrbahndecken aus Beton - ZTV Beton) and in the RStO. In view of the results of the investigations from Hilden, it must, however, be questioned whether the clause contained in these regulations which specifies that the concrete must be 1cm thicker than the bound construction methods is justified.

5 NONWOVEN FABRIC REQUIREMENTS

At present, the requirements for nonwoven fabrics under concrete surfaces are laid down in Section 2.4.1.9 “Geotextiles” of the ZTV Beton, which is still being drawn up, as shown below:
Nonwoven fabric substances are to be used as geotextile inlays under concrete surfaces in accordance with the technical delivery terms TL Geotex E-StB. They must meet the following requirements:

- mass per surface unit: min. 450 g/m^2, max. 550 g/m^2;
- raw material: 100 % polyolefin (PE or PP) with details of the raw materials;
- alkali-resistant;
- stabilisation method: mechanical;
- maximum tensile strength, longitudinal and transversal > 10 kN/m;
- maximum tensile strength strain, longitudinal and transversal < 130 %;
- minimum thickness of 2.0 mm under a test load of 20 kN/m^2;
- a minimum water permeability co-efficient of $5 \cdot 10^{-4}$ m/s at the geotextile level k_H under a test load of 20 kN/m^2 and a hydraulic gradient of i = 1;

- a minimum water permeability co-efficient of $1 \cdot 10^{-4}$ perpendicular to the geotextile level k_V under a test load of 20 kN/m^2 at i = 1

Laying the nonwoven fabric does not present any fundamental problems, even in work site traffic. The installation strips must overlap both longitudinally and transversally by a minimum of 15 cm respectively; the higher strip must be laid over the lower strip. It must be ensured that no lateral impulses are imparted to the nonwoven fabric strips. The nonwoven fabric must be laid on the edge of the lower strip so that it protrudes over the outer edge of the concrete surface by 15 cm to guarantee that the water which collects can be discharged. A laying device should be used to avoid crease formation when the materials are rolled out; in this way the roller can be rolled under controlled pre-tension so that the nonwoven fabric substance is fixed tautly. The nonwoven fabric substance must be fixed at the edges and the overlapping areas with nails and galvanised washers with a diameter of 70 mm at intervals of a maximum of 2.0 m. The fabric can be fixed with pneumatic tools or bolt-firing tools, depending on the tautness of the base.

No general statement can be made on whether or not the nonwoven fabric should be dampened before the surface concrete is installed, as the qualities of the concrete and the base play an important role in this regard. The installation of a two-layer nonwoven fabric substance could make this question superfluous. A nonwoven fabric substance such as this would have to have a pore system in the area near the fresh concrete which would not let through the cement particles while letting through the water expelled in the compacting process. This would mean that the hardened cement paste could have a more dense structure at the edges and be more resistant to erosion.

As has been the case to date, the core of the nonwoven fabric substance would have to have a sufficiently high drainage capacity under the load from the concrete surface and the traffic.

It remains to be investigated whether the joint filler can be omitted. The lack of joint filler on a test road section which was installed in 1985 has not yet shown any negative effects.

6 CONCLUSION

The technical advantages provided by nonwoven fabric laid between the concrete surface and the bound base had already been noted 15 years ago. These have been confirmed through investigations into long-term practical behaviour of this construction method. The positive effect of this nonwoven fabric can mainly be put down to three functions.

1. A separating function:
   the nonwoven fabric creates a clearly-defined situation from the very beginning as the concrete surface is separated from the base. Secondary bending strains are avoided, internal strains are reduced.
2. A drainage function:
   Water which has seeped through joints and from the higher edges is discharged to the sides below the concrete surface by the nonwoven fabric.
3. A bedding function:
   the nonwoven fabric creates even bearing conditions for the concrete surface and functions similarly to elastic bedding. Dynamic traffic loads are cushioned and absorbed.

The construction method involving a concrete surface on a nonwoven fabric substance, which constitutes a convincing and clearly defined construction, was rightly included in the new ZTV Beton and the new RstO. It will in future be an official alternative to bound constructions and constructions involving a concrete surface on a crushed stone base. The overall economic costs will be the decisive factor in determining what status the geotextile construction method gains.