Construction of Concrete Pavements in West Germany

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In West Germany, the concrete pavements of the "autobahns" are generally constructed by the slip form method, usually on top of a hydraulic- or bituminous-bound base. The thickness of these pavements has recently been increased from 22 cm (9 in.) to 24–26 cm (9.5–10 in.). To control the formation of cracks and to relieve the stresses caused by restraint of volume changes, these pavements are divided by joints into slabs 5 m (16.5 ft) long and 4.25 m (14 ft) wide. The slabs are not reinforced, and ordinary portland cement is used. The transverse joints are doweled, and the longitudinal joints are anchored. Both dowels and anchors are vibrated into the compacted concrete. The aggregates used within the concrete surface must have a high frost resistance, and at least half of the coarse aggregate has to be crushed. To withstand the effects of frost and deicing agents, the concrete must also contain entrained air. When damaged slabs are reconstructed, a high–early strength concrete containing superplasticizer is used. In summer, the reconstructed segments can be reopened to traffic in as little as 12–14 hr. When old concrete pavements are renewed, either the old concrete is broken and new pavement laid on it, or the old concrete is crushed by a breaker and used as an aggregate for the cement-bound base.

In 1888, the first concrete pavement was built in Germany in the city of Breslau (*1*). Today, the majority of the new "autobahns" in West Germany are constructed with concrete pavements. Airport runways, taxiways, and aprons are also built of concrete. In West Germany, there are 8,400 km (5,040 mi) of autobahns, of which 2,800 km (1,680 mi) are paved with concrete (Figure 1). All autobahns built before World War II have been repaved since that time. In general, the choice between an asphalt or concrete pavement depends on the cost. Because some 30 percent of the autobahns in West Germany are more than 25 years old, the maintenance and renewal of these roads has become increasingly important (*2, 3*).

PRINCIPLES FOR PLANNING AND CONSTRUCTION

The standard specification for the construction of concrete is the *Additional Technical Specifications for the Construction of Concrete Pavements* (*4*), which is currently under revision. For nearly 50 years, autobahn concrete pavements have been built with a thickness of 22 cm (9 in.). Under the standards that have been imposed within the European Common Market, the maximum axle load was increased from 10 to 11.5 metric tons (MT) (22.5 to 26 kips) in 1988. As a result, the standard thickness of the autobahn concrete pavement has been increased to 24–26 cm (9.5–10 in.), depending on the volume of truck traffic. Beneath the concrete surfaces of the autobahns is a hydraulic or bituminous-bound base and an unbound subbase.

The concrete pavements are divided into slabs to control the formation of cracks and to relieve stresses caused by restrained volume changes. During rapid cooling and heating, thermal gradients can reach 0.09 K/mm (4°F/in.), resulting in stress because the curling of the concrete slabs is hindered. The length of the slabs is limited to 25 times their thickness so that these bending stresses will not exceed the tensile strength of the concrete. Normally, the joint spacing is 5 m (16.5 ft).

Until a few years ago, all slabs were made as wide as a lane (3.75 m; 12.5 ft). Currently, the slabs are 4.25 m (14 ft) so that the outer wheels of trucks will not run too close to the edge of the slabs.

In most cases, contraction joints are used. The depth of the initial saw cut is 25–40 percent of the thickness of the concrete slab. The contraction joints are cut so that they are wider at the top, forming a reservoir 8–15 mm (⅜–½ in.) wide and 25–35 mm (1–1½ in.) deep. All joints are sealed (Figure 2). Expansion joints are only provided in special cases, such as between concrete pavements and bridge abutments.

During hot weather, the omission of expansion joints can cause compressive stresses. There are several advantages to this effect: tensile stress is reduced; the width of the joints

FIGURE 1 Autobahn with two lanes in one direction.

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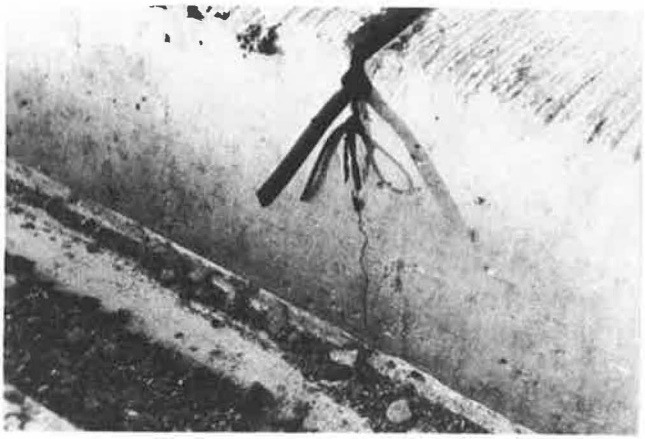

FIGURE 2 Sealed transverse contraction joint.

remains small; the stresses on the joint sealant are low; and because of aggregate interlock, the load transfer is higher (*5*).

Dowels are installed at all transverse joints to prevent faulting. The dowels used are round, smooth steel bars, 50 cm (20 in.) long and 25 mm (1 in.) in diameter. To prevent corrosion and bonding with the concrete, these bars are completely coated with a layer of plastic 0.3 mm (0.012 in.) thick. In the case of expansion joints, additional plastic expansion caps are inserted on one side to allow longitudinal movement of up to 15 mm (0.5 in.).

Tie bars are installed across the longitudinal joints to prevent joint opening. These anchors are ribbed bars, 80 cm (32 in.) long and 16 mm (⅝ in.) in diameter, with the middle 20 cm (8 in.) coated with plastic. Reinforced concrete is used only in a few special cases, such as when the length of the slab exceeds 25 times its thickness or if uneven settlement of the road base is expected.

CONCRETE TECHNOLOGY AND REQUIREMENTS

Ordinary portland cement, similar to the U.S. Type I cement, is used for all of the larger projects. Because slowly setting cements are preferred, retarding mixtures are unnecessary, even for large hauling distances. To ensure a low risk of irregular cracks before the initial saw cut, the portland cements that are used have a low zero-stress temperature and a low cracking temperature in the cracking frame test.

The aggregate used within the concrete surface must have a high frost resistance, and at least half of the coarse aggregate must be crushed. In areas in which such aggregate is too expensive, the concrete is poured in two layers. The specification for the aggregate of the lower layer is not as high as that for the upper layer. Washed natural sand, which is mainly quartz, is usually used as the fine aggregate.

The water-cement ratio of the fresh concrete is between 0.42 and 0.48, and the cement content is between 320 and 350 kg/m^3 (540 and 590 lb/yd^3). The workability of the concrete is low. Concrete used for autobahns must have an average cube strength at 28 days of at least 40 N/mm^2 (corresponding to a compressive strength of 4,440 psi for 6 × 12–in. moist-cured cylinders). A high resistance to alternate freezing and thawing and to deicing chemicals is required, so the fresh concrete must have an average of 4 percent entrained air.

Concrete for all autobahns is produced in on-site mixing plants (Figure 3). Modern mixing plants can be set up in 2–4 days without much excavating work (*6, 7*). The capacity of ready-mixed concrete plants is not usually large enough to produce the amounts of concrete necessary for the continuous slip form paving. Interruptions in the placement of concrete must be avoided to prevent unevenness in the pavement. The twin–pug mill mixers that are most commonly used have a production rate of 100–240 m^3/hr (130–310 yd^3/hr). If the pavement has to be constructed in two layers, the concrete for the upper and lower layers is usually mixed at two different mixing plants.

The cement is stored in silos and is measured by weight. A high degree of accuracy is necessary in proportioning the air-entraining agents. The aggregates are separated according to size and are stored at ground level. When needed, they are loaded into the silo compartments with wheeled loaders. From the silo, they fall onto a conveyor-type scale, and then they are transported to the feeder unit.

A concrete laboratory is located within each mixing plant. Every day, the aggregates, workability, and water content of the fresh concrete are tested, and the air content is tested every hour. Cubes for testing the compressive strength are made daily.

CONCRETE PAVEMENT CONSTRUCTION

The concrete is generally laid with slip form pavers (Figure 4). The maximum operating width of the largest slip form paver is 15.25 m (50 ft). For the construction of an autobahn with two lanes in one direction, the concrete shoulder is normally placed with the lanes. Two construction joints in the longitudinal direction are avoided, and the bending stress at the edges of the outer slabs is reduced. The concrete is transported from the mixing plant to the site in dump trucks.

FIGURE 3 Mixing plant for a concrete pavement construction site.

FIGURE 4 Complete paving plant train.

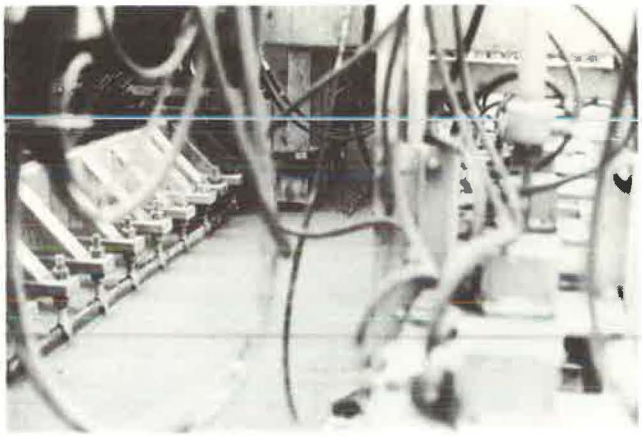

FIGURE 6 Anchor-vibrating device.

During the transport, the fresh concrete is covered with tarpaulins to prevent drying out and to protect against rain. The bound base serves as the construction site road.

Single-Layer Construction

The concrete is poured into one or two parallel moving concrete spreaders for distribution. These concrete spreaders are followed by the slip form paver, which compacts the concrete with internal vibrators.

In the chassis of the slip form pavers is a special device that vibrates the dowels into the concrete (Figure 5). The horizontal position of the dowels is guaranteed by fixing them with two or four bifurcated plates during vibration. To minimize the faulting of the concrete structure, the dowel-vibrating device stops moving while the dowels are being vibrated into the concrete, and the slip form paver itself moves on without pausing. Dowels are placed into the dowel-vibrating device either by hand or automatically. The anchors are vibrated into the concrete in a manner similar to that used for the dowels (Figure 6). The last parts of the slip form paver are the transverse and longitudinal smoother (Figure 7).

Slip form paving requires a certain consistency of concrete to obtain a perfect finish and prevent the pavement from edge slumping after the finishing transition. A self-propelled working deck follows behind the slip form paver, from which the broom finishing is carried out (Figure 8) and the curing agent is sprayed onto the concrete surface. The broom finishing is still done by hand because even slight changes in the mortar content on the surface must be compensated for to achieve an almost constant roughness. The whole paving plant train is controlled by wires or laser beams.

Because studded tires have not been allowed in West Germany since 1975, the texture of fine mortar at the surface is decisive for skid resistance. High skid resistance is necessary because there is no speed limit for cars on the West German autobahns. A double-rowed spring steel broom is used to produce a roughness depth of 1–2 mm (0.04–0.08 in.). A larger degree of roughness is avoided to prevent a corresponding increase in noise.

The finished pavement is protected by a tent draft. The protective tents are not necessary if a film-forming curing agent that protects against heavy rain is used as required.

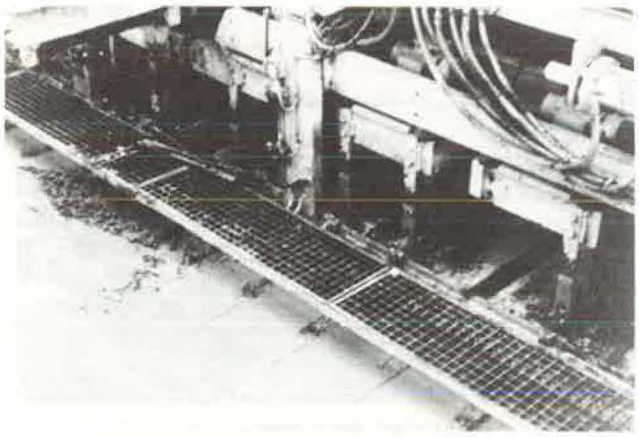

FIGURE 5 Dowel-vibrating device.

FIGURE 7 Transverse and longitudinal smoother.

FIGURE 8 Broom finishing.

Double-Layer Construction

Two slip form pavers are needed for the construction of a double-layer pavement. The concrete of the lower layer is spread and compacted by the first slip form paver, as described previously for a single-layer pavement. The lower layer, however, is 10 cm (4 in.) narrower on each side than is the upper layer. The edges of the pavement therefore consist only of the upper layer.

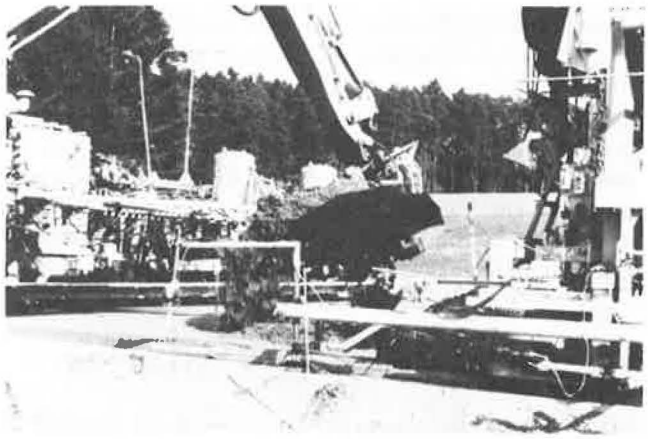

FIGURE 9 Backhoe placing the concrete of the top layer on the compacted concrete of the bottom layer.

FIGURE 10 Cutting transverse and longitudinal contraction joints with saws.

The anchors and dowels are vibrated into the concrete lower layer, as mentioned previously. Until a few years ago, the concrete of the top layer was poured by a side feeder. Today, a backhoe is used to take the fresh concrete from the dump truck and place it on the compacted lower layer (Figure 9). The transverse spreader of the second slip form paver spreads the upper layer of concrete across the entire width of the pavement.

The concrete of the upper layer is also compacted by internal vibrators. The finishing and protecting of the concrete are similar to those used in single-layer construction (*5, 8, 9*).

Joint Construction

The transverse and longitudinal joints are normally saw cut with water-cooled diamond blades (Figure 10). All of the joints are cut wider at the top to form a reservoir and are then cleaned and dried. A rope is inserted into the bottom of the cut, the sides of the joint are primed, and then the joint is sealed.

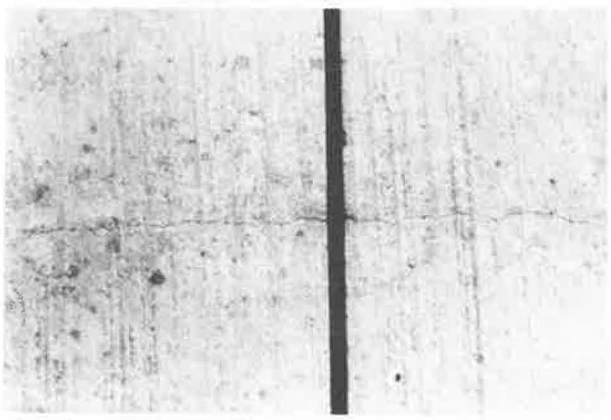

FIGURE 11 Longitudinal contraction joint placed in the compacted fresh concrete (crack), with sealed transverse contraction joint.

Longitudinal contraction joints can also be produced in the compacted fresh concrete by a vibrating metal strip fixed on the slip form paver. A small crack appears in the hardened concrete above this cut (Figure 11). No additional sawing or sealing of these joints is necessary.

In some cases, contraction joints are not sealed because the sealing of the joints is only waterproof for a short time (a maximum of 1 year) and the maintenance of the joints is expensive. On the other hand, unsealed joints require a bituminous base underneath. Road sections with drainage pipes underneath the joints or with geotextiles are now being tested (*9, 10*).

Evenness

Compliance with evenness requirements is determined by using a profilograph. In West Germany, a maximum unevenness of 4 mm (0.16 in.) within a 4-m (13-ft)–long beam is allowed. If this limit is exceeded, a fine must be paid. Large unevennesses are leveled with a bump-cutter.

FIGURE 12 Paving and compacting of high–early strength concrete for 1-day reconstruction of concrete slabs (fast track concrete paving).

FIGURE 13 Finished section of 1-day reconstruction.

ONE-DAY SLAB CONSTRUCTION ("FAST-TRACK" CONCRETE PAVING)

During warm weather, up to four slabs of concrete pavement can be reconstructed with high–early strength concrete. The concrete is transported to the construction site in truck mixers (Figure 12). The cement is placed in forms, and the surface is smoothed with a finishing screed. Dowels are placed in dowel baskets before the concrete is poured.

Joints are cut 6 hr after pouring, and the lanes are opened to traffic again (Figure 13). To achieve the required high strength of 10–12 N/mm^2 (1,111–1,333 psi) at 6 hours, a cement content of 360–400 kg/m^3 (607–674 lb/yd^3) is necessary. A superplasticizer makes a low water-cement ratio possible. The cement, superplasticizer, and air-entraining agent must be compatible so that the correct consistency is achieved and enough small air bubbles are produced (*9, 11*).

RENEWAL OF OLD CONCRETE PAVEMENTS

Many different techniques have been tested for renewing old concrete pavements. If the width of an old pavement is insufficient, the old pavement is broken into pieces smaller than

0.7 m (2.25 ft) and a strip of lean concrete is used for the outer lane. A new pavement is placed on top of the existing one. Unevenness is smoothed out with mortar as necessary. The new pavement is at least 22 cm (9 in.) thick and is constructed without a separating layer. If the design of the road has been changed, the old concrete is crushed by a breaker and used as an aggregate for the cement-bound base (*3, 12*).

SUMMARY

In West Germany today, the concrete pavements used on autobahns and at airports are usually constructed by the slip form method. The concrete pavement is divided into slabs by doweled transverse joints and anchored longitudinal joints. No reinforcement is used.

For the reconstruction of as many as four damaged slabs, a high–early strength concrete with superplasticizer is used (fast-track concrete paving). During warm weather, closure to traffic may be as brief as 12–14 hr with this technique.

When old concrete pavements are renewed, one of two procedures may be followed. Either the old concrete is broken and the new pavement is placed on top of it, or the old concrete is crushed by a breaker and used as an aggregate for the cement-bound base.

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