
GERMANY

## 3.3 Germany

- Concrete Pavements in Germany

Germany has constructed many concrete pavements since the 1920's, mostly on the autobahn (freeway) system and at airports. Bus stops constructed of concrete were observed in Berlin. The Study Tour observed firsthand many original sections of the German autobahn system in the former east Germany constructed with concrete in the 1930's. Many of these original pavements are carrying heavy traffic today, although they are quite rough and many of them are under major rehabilitation. Fifty years of no maintenance has left these pavements in deteriorated condition, and Germany is making a huge effort to rebuild all of these highways to link all areas of the country, which they feel is vital to their economic growth.

A photograph of a 50-year-old (1930's) jointed concrete pavement section on the autobahn approaching Berlin from Munich is shown in Figure 3.8. These were the divided controlled-access highways that impressed many Americans returning from World War II, including President Eisenhower, to sponsor the development of the USA Interstate highway system.

Figure 3.8 Photo of a 1930's German autobahn concrete pavement near Berlin. (Note cracking in outer truck lane of the 12-m (39-ft) slabs.)

Approximately 30 percent of the former west German autobahn and 82 percent of the former east German autobahn are constructed with concrete pavement (approximately 4,168 km (2588 mi) of concrete out of 10,900 km (6769 mi) total). The West German pavements constructed prior to 1970 are jointed plain and jointed reinforced concrete, and only dowelled JPCP was constructed after 1970. Germany favors dowelled JPCP because of the extensive use of deicing salts and the potential for corrosion of reinforced pavements. Over the years, the design of the German concrete pavements has changed considerably; however, the current JPCP design has been built extensively since the early 1970's both as new pavement and as overlays of old concrete pavements.

An extensive research and development program has been underway in Germany for many years, at such institutions as the Federal Highway Research Institute (BAST) and the Munich Technical University to improve concrete pavement materials, construction and design. Many excellent technical articles can be found in the literature from this research.

Concrete pavements have also been constructed at airports in Germany. The Study Tour visited the new Munich II International Airport that was just opened in May, 1992. This airport was constructed with more than 2 million square meters (2.4 million square yards) of 36-cm (14.2 in) dowelled JPCP for runways, taxiways and aprons. For comparison, Dulles International Airport has 1.2 million square meters (1.4 million square yards) of 38.1-cm (15-in) undowelled JPCP.

. Pavement Designs

Original Autobahn Concrete Pavement Design. The following information was obtained during a meeting of the Study Tour and German highway officials in Berlin and also from references 3 and 7.

Planning and initial construction of the German autobahn was started in the 1920's. The first German autobahn ideas were based on car-only highways, built in northern Italy by Piero Puricelli in the 1920's. (7) The first cross-section of a four-lane divided highway was created in 1926, the word "autobahn" first appeared in 1928 (7), and the design speed was 160 km/h (100 mph) in non-mountainous areas. These pavements were conceived as two lanes in one direction with 7.5-m (24.5ft) pavement width. A policy statement on the principle of performance required of the construction industry and also on contract and procurement procedures was issued by Fritz Todt, Inspector General of the German Highway Administration, in 1933:

"It is not always the lowest bid which should be given preference. Quality is the most important criterion." (7)

A decision was made about that time to construct the autobahn highway network with concrete pavements. By 1940 approximately 4000 km (2480 mi) of four-lane divided autobahn highways were constructed. During the war years the government prohibited using steel for any purpose other than military. A concrete pavement research program was carried out in the 1930's with the construction of many test sections. The general design evolved as follows, although there are some variations of this design.

Slab: Uniform thickness, 20-25 cm (8-10 in) JPCP (some thinner and thicker), mostly two-layer construction. Top slab layer is 9 cm (3.5 in) thick and contains high-quality aggregate (3-cm (1.2-in) maximum size). The lower slab layer is 13 cm (5 in) thick and contains local gravel aggregates (5cm (2-in) maximum size).

Width of traffic lane = 3.75 m (12.3 ft) (two lanes in one direction)

Joints: Spacing for plain jointed concrete sections = 8-12 m (26.539 ft)

Spacing for jointed reinforced sections = 1230 m (39-98 ft) (stopped in 1937)

Typical expansion joint spacing 12-18 m (39-59 ft). (Note: It was common practice to systematically increase the joint spacing from slab to slab in increments of 1 m (3.3 ft) or so, with periodic return to the first spacing.)

Dowels 35.6 cm (14 in) long, 2.2cm (0.875 in) diameter round steel dowels with a sleeve on one end.

Dowels spaced 30.5 cm (12 in) near center of slab with closer spacing toward edge.

Longitudinal joints tied (3.75-m (12.3-ft) lane width).

Concrete: Most pavements were constructed in two courses for ease in compaction of very dry concrete and to use different quality aggregates in each layer. The upper layer used only high-quality aggregate as judged by compressive strength and wear tests (typical types were granite, basalt and quartzite) and the elimination of impurities and flat particles. A somewhat inferior aggregate (local gravel) was used for the lower layer for economic reasons.

Aggregate gradation was closely controlled through use of several size requirements. It appears that a fairly uniform dense aggregate gradation resulted from this specification.

Flexural strength requirements included 3.7 MPa (540 psi) minimum and 4.4 MPa (640 psi) average. Compressive strength requirements were 32 MPa (4,700 psi) minimum and 39 MPa (5700 psi) average. Strengths were tested with specimens made during construction and by means of tests on cores made at approximately 60 days. (3)

Very dry (zero-slump) concrete with a water/cement ratio usually of 0.45 or less. No air entrainment admixture was used.

Foundation:

Considerable effort made to reduce the damaging effects of frost heave and excess moisture. This was done by placing longitudinal drains to intercept ground water flowing towards the highway or to lower the ground water table, and by placing layers of granular materials (often sand was used) between the slab and the subgrade. Often the grade line was raised 0.9 m (3 ft) or more above the natural ground level, and in cuts the roadway was excavated below grade and backfilled with selected material. (3) In the Berlin area, the concrete pavement was often placed on the sand subgrade.

Shoulders: Usually 0.38 m (1.25 ft) wide inner (left) and 2.2 m (7.33 ft) wide outer (right). Pavement included 17.8 cm (7 in) of concrete capped with 7.6 cm (3 in) of AC for color delineation. In cases where dark-colored concrete was used in the traffic lanes, plain concrete was used in the top course of the paved shoulder strip for color delineation. (3)

Construction: Usually two lanes formed at same time with a tied weakened-plane longitudinal joint. The concrete base for the shoulder strip was constructed before the pavement slab and was used as a base upon which to mount the rails carrying the heavy construction equipment used in the mixing, placing, and finishing operations. Tamping and some vibration of the concrete was performed. (3)

All placing, finishing, and preliminary curing operations were completed under sunshades that spanned the entire pavement. Woven-reed curing mats were left in place for 3 weeks and were kept continuously wet during that period.

Surfaces were dense and compact, with the coarse aggregate either just below the top or actually exposed to some degree. No thick layer of mortar exists. (3)

Many original sections of the German autobahn are still in place and serving heavy traffic in the former East Germany, whereas the former West Germany has previously rehabilitated most of the old pavements. The Study Tour had the unique opportunity to observe many of these old pavements during the trip from Munich to Berlin and also on the freeway loop surrounding Berlin (Berliner Ring). They are fairly rough, due mainly to the many transverse cracks that have spalled and faulted. No obvious pumping was observed and the 50-year-old concrete showed no durability problems. A large reconstruction effort is currently underway in the former East Germany and the concrete from these pavements is being recycled into either lean concrete base or the upper layer of the granular blanket.

During the visit to a reconstruction site on the A10, described below, a piece of old concrete pavement was obtained and submitted to the Construction Technology Laboratories (CTL) for analysis. The official petrographic analysis is given in the Appendix and a summary is provided here.

1. The sample is a hard, dense, good-quality concrete consisting of siliceous and calcareous aggregates in a portland cement paste. The paste-aggregate bond is tight and the concrete fractures through coarse and fine aggregate particles.

2. Estimated water-cement ratio, based on paste properties, is less than 0.35. Large residual cement particles (unhydrated portland cement clinker, UPC's) are abundant.

3. The concrete is not air entrained. Estimated air content is 1 to 2 percent. Most air voids are small and lined or filled with secondary deposits, mostly ettringite.

Some reasons for the good performance of these pavements:

✓ Lower traffic loadings during early life,

✓ Relatively mild climate,

✓ Highly durable concrete (achieved by care in proportioning uniform gradation mixes; 3-cm (1.2-in) maximum size, high-quality, hard top-course aggregate; consolidation by vibration; dry mix with low water/ cement ratio; 21-day water curing and protection from sun and wind with a cover; no deicing salts used for many years),

✓ Thick granular layer between slab and subgrade for frost protection and some bottom drainage (sometimes this layer included fine sand and was not adequate),

✓ Backfilling with select material of very soft soil,

✓ Ground water moisture control, and

✓ Dowelled joints.

The long joint spacing (12 m (39 ft) in the Berlin area and especially when steel mesh was not used) appears to be the only major deficiency noted for this design, and resulted in many transverse cracks that spalled and faulted in the truck lane.

Current German Concrete Pavement Design. Following World War II, the concrete pavement designs varied considerably between West and East Germany. Prior to 1970, the West German design included jointed wire mesh-reinforced pavement with a joint spacing of 7.5 to 10 m (24.5 to 33 ft), including expansion joints at 60- to 100-m (197- to 328-ft) spacing. (1) Due to various problems, this design was changed to a jointed plain concrete pavement beginning in 1970. (1) This design has been improved since that time, evolving into the current autobahn highway JPCP design cross-section shown in Figure 2.4. Some details of this design are as follows.

JPCP Slab:

2226 cm (8.7-10.2 in) thick, depending on truck traffic volume in design lane (see design catalog, reference 2). Top 7-cm (2.8-in) layer contains high-quality crushed aggregate for freeze-thaw durability and friction. The w/c ratio for both layers must be equal.

0.5 m (1.6 ft) widening for both traffic lanes.

Full 11-m (36-ft) width paving thickness for future traffic control during rehabilitation (four lanes of traffic can be accommodated).

Shoulder: Tied concrete shoulders both lanes (avoids differential frost heave that occurred on AC shoulders). (1)

Concrete: Exceeding 5.5 MPa (798 psi) in center-point loading (about 10-15 percent greater than third-point loading).

Base: 15-cm (6-in) cement-treated or lean concrete, exceeding 9 MPa (1305 psi), usually about 12 MPa (1740 psi) compressive strength after three days of wet curing, base bonded to slab, joints (or notches) provided in base (35 percent thickness) just beneath joints in slab. (Figure 2.5)

Some use of 25-cm (10 in) cement-treated base with cement-stabilized subgrade.

10-cm (4in) bitumen-treated base also used sometimes.

Subbase: Granular blanket, 30 to 90 cm (1236 in) thick, depending on frost penetration and bearing capacity, less than 5 percent 0.063-mm (0.0025 in) fines allowed before compaction (less than 7 percent fines after compaction).

Transverse Joint: 5.0-m (16.5ft) spacing.

2.5cm-diameter (1 in) dowels, unevenly spaced across section as shown in Figure 2.7, plastic coating with thickness greater than 0.3 mm (0.012 in) covers the total length of dowels, no oil used.

Automatic dowel placement, no baskets.

Saw depth: 0.25-0.30 slab thickness.

Sealant: Compression seal.

Longitudinal Joint: Saw depth: 0.40-0.45 slab thickness.

Tie: Deformed 20-mm-diameter (0.8 in) steel tie bar, plastic coating with thickness greater than 0.3 mm (0.012 in) covers center 20 cm (8 in).

Spacing of ties: three bars per 5 m (16.5 ft) of slab at centerline joint, five bars per 5 m (16.5 ft) of slab at lane/ shoulder joint.

Sealant: Compression seal.

Subdrainage: Variations in subdrains have been used. The latest cross-section (Figure 2.4) shows a porous concrete layer beneath the shoulder that provides a flow channel to a longitudinal subdrain which then empties at regular intervals into a lateral pipe and finally into a larger longitudinal pipe. The system observed on the A10 project included catch basins at regular intervals that were connected to the longitudinal subdrain (and were extended vertically to the surface of the shoulder and a catch basin with a surface grate to collect surface water) as shown in Figure 3.9. These catch basins were connected to the deeper manhole which was connected to a longitudinal drain pipe.

Porus concrete layer under shoulder: a 15-cm (6-in) layer of porous concrete is being evaluated beneath the concrete shoulder to promote drainage of the treated base layer.

Surface: Textured by light longitudinal brush (burlap drag) to produce low-noise surface with some macrotexture. Hard aggregate provides friction.

Cross slope: 2.5 percent uniform across lanes.

Figure 3.9 Construction site on the A10 south of Berlin showing catch basins at edge of slab that are connected to longitudinal pipe under the lean concrete base and connected to the manhole shown on the left.

Bridge Ends: End lug is placed more than 15 m (49 ft) from backwall of structure and then an AC surface over a CTB are placed to the backwall, as shown in Figure 3.10.

A four-year warranty system exists for concrete and asphalt pavements, during which the contractor is responsible for repair of any problems that develop.

The government relies on the warranty and on the contractor protecting his reputation if problems develop. A small amount of money is withheld until final acceptance at the end of the warranty period. If major problems develop, the project is not accepted and the contractor is warned that further repairs may be needed. Originally this occurred more often; now it seldom occurs. If the project is not accepted it affects the contractor’s reputation and it is considered in future contract awards. Since performance on previous contracts is considered in awards, the contractor’s reputation is important.

The words “emergency lane” are used to describe the shoulder because these pavements are constructed to a full 11-m (36-ft) width so that during any future rehabilitation, four lanes of traffic can be carried on one side of the divided highway.

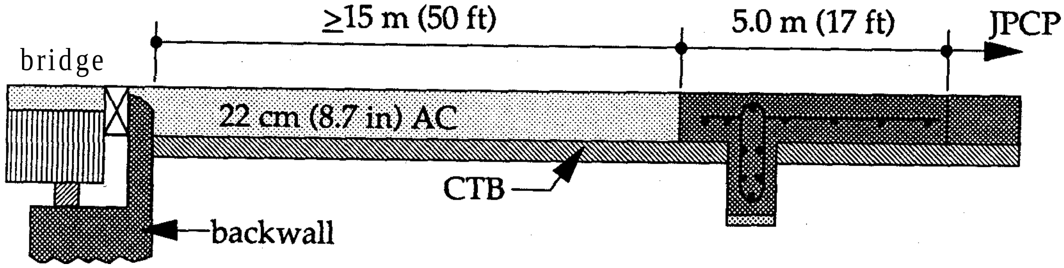


**Figure 3.10 Bridge approach design for JPCP in Germany.**

Projects constructed without dowel bars have faulted significantly. Many of these are in the former East Germany where the government prohibited dowels. Dowels are needed in the German climate and traffic to control faulting.

A plate load test in which pressure is repeatedly applied to and removed from the soil in stages is conducted in the field to ensure that a minimum bearing elastic modulus is achieved on top of the subgrade (minimum is 45 MPa (6,525 psi)) and on top of the granular blanket layer (minimum is 120 MPa (17,400 psi)) for concrete pavements. (8)

The German pavement design catalog is an excellent method to communicate the details of the pavement design to the field. (2) There is now a new catalog for rehabilitation alternatives also. The Study Tour rode over several sections of the design and also observed a construction site. It was observed and reported from various sources that this design is performing very well under heavy traffic.

The catalog provides for a direct comparison between concrete and asphalt designs. The granular blanket is the same for both concrete and asphalt pavements to control frost heave, provide uniform support and to provide some bottom drainage. The AC pavement layers are built on top of this, as are the concrete base and slab.

The pavement design used for the new Munich II International Airport is given under the description of projects visited.

- Concrete Material and Construction

An extensive research program was started in the 1930's into cements and concrete mixtures that included the construction of many test sections. A detailed description of the old 1930's autobahn concrete mixtures is given in reference 3. Reasons for the excellent durability of the old autobahn concrete are previously given.

Current German concrete requirements are as follows:

✓ 4 to.6 percent entrained air, including air void system requirements.
✓ Water/cement ratio <0.42 to provide dense mixture.
✓ 340 kg/m$^3$ (573 pounds/yd$^3$)) cement.
✓ Mixing time is 45 seconds minimum.
✓ Graded aggregates.
✓ Aggregates must pass freeze-thaw and alkali-silica reaction tests.
✓ Freeze-thaw tests are run on aggregates for 300 cycles in aggressive solution and loss cannot 0.2 percent maximum.
✓ If reactive aggregates are present, low-alkali cement (less than 0.6 percent alkali) is specified. If problems still exist, the aggregate is changed.
✓ No flyash is used in highway pavement.
✓ Germany uses the center-point loading flexural beam test, which they found to be 10-15 percent higher than the third-point loading test. A minimum of 5.5 MPa (800 psi) for the center-point loading flexural strength at 28 days, which corresponds to about 4.9 MPa (711 psi) in third-point loading.
✓ Compressive strength is measured with a 3-cm cube. The minimum strength is 35 MPa (5075 psi).

✓ It was stated that some AC can be used in recycled concrete mixtures.

✓ Air void content and void system quality control are specified in reference 2. Tests are conducted the first day of production and again if there is any doubt as to air content. The bubble spacing must be less than 0.2 mm (0.008 in) and the micropores must be at least 1.8 percent.

The air void system may be tested in equipment viewed by the Study Tour at the Cement Research Facility in Dusseldorf. The equipment labelled "DBT" costs about $20,000 and is manufactured by a Danish company. It relies on Bernoulli's principle that larger air bubbles, representing air voids, rise to the surface faster. A small tube sample, 2.5 cm (1 in) in diameter, of fresh concrete is taken from the newly placed slab, placed in the equipment, and the amount of air per time period is measured. This equipment can produce results in about 20 minutes on the air void content and spacing and can be used on the construction site. It reportedly correlates well with linear traverse results on hardened concrete.

Some ASR distress has recently developed on the northern Berliner Ring autobahn pavement due to high-alkali cement used on project (in the former East Germany). The East German government dictated the source of the aggregate and cement for this project. No "D" cracking problems were observed, probably due to the use of only high-quality hard aggregates in the slab surface.

Various construction items:

✓ The use of a "tent" to protect the newly placed concrete from rain and sun may provide a significant effect. This procedure also would reduce the temperature and thermal gradient of the fresh concrete, which would reduce detrimental curling of the slab. This is still being done today as discussed under the Munich airport project description.

✓ Curing is done with either water sprinkling or wax-based curing compounds.

✓ The two-lift construction of the slab results in smoother profile as well as a more economical mixture where high-quality stone is expensive.

Cement-treated base compressive strength requirement is a minimum of 9 MPa (1305 psi) to provide resistance to erosion.

Germany believes strongly in bonding the lean concrete base or CTB to the slab to reduce curling and erosion. This is accomplished by notching the base 35 percent of its thickness immediately after placement exactly beneath the transverse and longitudinal joints of the concrete slab.

- **Rehabilitation**

A new rehabilitation catalog is available. Selection of the rehabilitation alternative depends on the following criteria: (6)

✓ Traffic restrictions during reconstruction,
✓ Possibility of the use of recycled materials,
✓ Adequate clearance for bridges,
✓ Required improvements of cross-slope and other geometrics,
✓ Required widening of the cross section (lane or shoulder), and
✓ Economics.

The following types of rehabilitation are currently being performed on the German autobahn pavements. (6)

JPCP Overlay with Interlayer: The existing concrete pavement is fractured into pieces less than 0.5 m (1.6 in) in size. Then a 10-cm (4-in) interlayer of either lean concrete (notched) or AC material is placed on top of the existing concrete pavement. A JPCP overlay is then placed to the same thickness as a newly constructed pavement (i.e., 26 cm (10.2 in) for the heaviest traffic class).

JPCP Overlay with Thick Fabric Interlayer: The existing concrete pavement is fractured into pieces less than 0.5 m (1.6 ft) in size. Then a geotextile interlayer is placed on top of the existing concrete pavement. A slightly thicker JPCP overlay is then placed on top of the fabric (i.e., 27 cm (10.6 in) for the heaviest traffic class). The debonding with the underlying layer and the additional elasticity of the geotextile fabric requires a thicker slab. However, the softer fabric material may also reduce curling stresses in the JPCP overlay.

Total Width Reconstruction: The entire pavement is completely removed and a new JPCP with untreated crushed permeable base constructed. This pavement type is new for Germany; however, it makes it possible to recycle up to 100 percent of the old pavement. The JPCP thickness is increased (i.e., 30 cm (12 in) for the heaviest traffic class).

Lane Reconstruction. A cross-section is shown in Figure 2.10. A porous concrete base is recommended having a void content of more than 20 percent and compressive strength exceeding 15 MPa for a thickness of 40 cm (15.7 in). The permeability coefficient required for this base' is less than $10^{-6}$ m/s. The new JPCP is placed directly on this layer but is constructed thicker (i.e., 30 cm (12 in) for the heaviest traffic class). The new lane is tied securely to the adjacent slab by five corrosion-protected bars (Zcm-diameter (0.8 in)) per 5-m (16.5ft) slab).

AC Overlay: A 12-cm (4.7-in) AC overlay is sometimes placed where a rehabilitation life of six to eight years is desired.

- Noise Pollution

A major concern about traffic noise exists in Germany as in other European countries. Until recently, most of the concrete pavements were textured with transverse tining, which was very good for friction and hydroplaning but caused considerable road noise and vibrations. It was found that this texture produced 3 dB(A) greater rolling noise than AC pavements and was not allowed to be used in urban areas. If, however, a longitudinal burlap drag was used along with the smaller top-size aggregates, the noise level was about the same as a porous AC surface. This change was recently made in the construction specifications. Germany has experimented with various exposed aggregate surfaces but believes that the longitudinal burlap texture along with high-quality hard aggregates in the upper slab will provide low noise and good friction.

- Project Sites Observed

New Munich II International Airport. The Study Tour visited the newly opened airport and observed some of the 2 million square meters (2.4 million square yards) of concrete pavements as well as having a presentation on the construction of the pavements. Figure 3.11 shows a photo of a runway under construction. The JPCP constructed at Munich II Airport is defined as follows: (4, 5)

Slab: 36 to 40-cm (14.2 to 15.8-in) JPCP constructed in two layers.
40 cm (15.8 in) on ramps only.

Top 14 cm (5.5 in) includes crushed granite for better freeze-thaw resistance and friction.

Bottom 22-24 cm (8.7-9.5 in) used local gravel aggregate.

Double course construction was achieved in a single pass of a slipform paver in 15 m (49 ft) width.

Runway cross-section varied, with central 30 m (98 ft) being 36 cm (14.2 in) and outer 15 m (49 ft) on each side thinning to 26 cm (10.2 in). The total width is 60 m (197 ft).

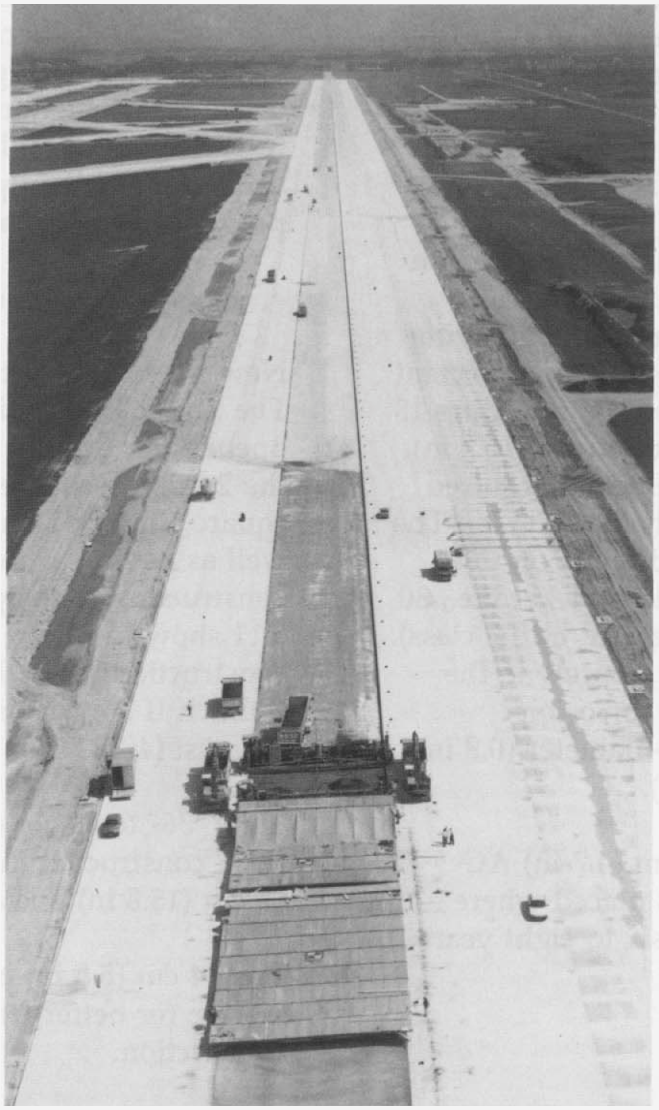

Figure 3.11 Photo of runway under construction at the new Munich International Airport. (Note the “tent” coverings placed behind the paver to provide curing protection to the surface for seven days.)

Dowels and tie bars were placed on top of the lower layer.

Concrete: Contractor subcontracts to testing lab that produces certified mix design.

Concrete strength for both layers was greater than 6 MPa (870 psi). Specifications required the mean of three center-point-loaded beams to be greater than 6 MPa (870 psi) at 28 days. Typically, the mean strength exceeded 7 MPa (1015 psi).

Continuous two drum plant used to achieve production of 200 cubic meters (262 cubic yards) per hour.

Water/cement ratio = 0.40 to 0.45.

340 $kg/m^3$ (573 $pounds/yd^3$) cement.

Air content measured once per hour in laboratory.

Cores were taken and density was measured (contractor specifies density).

Slab would be removed if strength or density deficiency existed.

Paving width = up to 15 m (49 ft) for three 5 m (16.5 ft) slabs.

Joints: 5 by 5 m (16.5 by 16.5 ft) square slabs, transverse joints dowelled, longitudinal joints tied and shaped with a sinusoidal vertical profile.

Dowels were placed automatically in all transverse joints.

Joints were sawed within 8 to 10 hours.

Tie bars were placed automatically in outer longitudinal joints.

Neoprene compression seals were used in joints.

Base: 20-cm (8-in) cement-treated base was constructed and immediately notched through about 35 percent of its thickness exactly beneath the joints in the concrete slab.

An attempt was made to bond cement-treated base to concrete slab through cleaning and wetting surface.

Subbase: A thick granular blanket was placed between the subgrade and the cement-treated base course.

Curing: The concrete was moist-cured for seven days under a “tent” as shown in Figure 3.11 and then curing compound was placed.

Profile: A high-speed profilometer was used to measure profile. Less than 3 mm (0.12 in) gap was permitted beneath a 4-m (13-ft) leveling beam.

Al0 Autobahn (Berliner Ring south of Berlin). This project involved the complete reconstruction of a four-lane divided autobahn highway concrete pavement, originally constructed in 1939, into a new JPCP. The following items describe the design and construction.

Traffic: Traffic was routed on to one side where a 20-cm (Sin) unjointed lean concrete strip about Cm-wide (13 ft) was added to the original slab so that four lanes of traffic could be carried on one side. The lean concrete is expected to last through the eight-month construction duration and then be recycled with the old concrete. Very heavy truck traffic exists on this highway.

Pavement: The old concrete pavement was fractured with a drop hammer. Then a large back hoe was used to pick up large pieces and load onto trucks to haul to crusher. The concrete was crushed and sized into stockpiles.

Slab: 26-cm (10.3 in) JPCP constructed in two layers.

Top 7 cm (2.75 in) contains crushed granite for better freeze-thaw and friction.

Bottom 19 cm (7.5 in) contains local gravel aggregate.

Longitudinal burlap drag texture in the hard aggregate surface for low noise.

Joints: 5-m (16.4 ft) slabs, transverse joints dowelled, longitudinal joints tied.

Plastic-coated dowels were placed automatically in all transverse joints in a nonuniform pattern (clustered in wheel paths of the truck lane).

Compression seals were used in transverse and longitudinal joints.

Reservoir saw-cutting: after the first saw cut, an elastic band was placed to fill the narrow cut across the two traffic lanes, and a knot was tied in each end to keep the band tight. This was done to keep slurry from the second saw cut from flowing into crack and infiltrating the base and drainage filter.

The first saw cut was 6.5 cm (2.6 in) deep (one fourth of the slab thickness). Observation of a section of completed slab showed that all joint had cracked through at joints giving good uniformity of cracks. All joints were placed above notches in the lean concrete base.

Shoulder: Tied concrete shoulder on outer lane.

Concrete: Contractor subcontracts to testing lab that produces certified mix design.

Concrete flexural strength for both layers was greater than 5.5 MPa (798 psi) at 28 days (center-point loading).

Conventional paver was used for slipforming pavement. An unusual feature was "T" shape of the vibrators.

Base: 20-cm (7.9-in) lean concrete base slipformed.

Notched within 20 minutes to about 35 percent of its thickness exactly beneath the joints in the concrete slab as shown in Figure 2.5.

The goal is to bond the lean concrete to the concrete slab through cleaning and wetting the surface. The base is watered three to four times per day.

Dowels and tie bars were placed in the lower layer.

Lanes were widened 0.5 m (1.6 ft).

The slab has a 2.5 percent cross-slope for good drainage.

Figure 3.12 Thick granular blanket placed beneath lean concrete base in Germany.

Subbase: A granular layer exceeding 30 cm (11.8 in) was placed directly on the subgrade. Figure 3.12 shows the thick granular layer placed beneath the lean concrete base.

Profile: The new two-layer pavement rides very well.

Subdrains: The subdrainage system was detailed under the description of the current German cross-section.

. Traffic Loadings

Traffic loadings are very heavy today on the German autobahn. This network is only 1.7 percent of Germanys total highway length, but carries 27 percent of its traffic. A typical autobahn has an ADT of 40,000 with 25 percent heavy trucks. The legal maximum single-axle load was 10 tons (22,000 pounds) up to 1989. Today it is 11.5 tons (25,300 pounds) and it will probably be 13 tons (28,700 pounds) in 1993. A large amount of truck traffic exists on both east-west and north-south autobahn in Germany.

* Summary for Germany

The perfomance of the post-1970 jointed plain concrete pavements in Germany can only be described as exceptionally good. There are very few problems with the current design and it is competing economically with asphalt pavement.

The reasons for the good performance include the following:

✓ Variably spaced doweled joints,

✓ Bonding of the concrete slab to the cement-treated base or lean concrete base to reduce erosion and pumping at the interface and to reduce curling,

✓ A high-quality base that is resistant to erosion,

✓ Good-quality aggregates in the concrete, especially in the surface,

✓ The thick granular layer above the subgrade,

✓ The concrete's resistance to freeze-thaw damage due to careful air void control during construction, and

✓ The two-pipe surface and subsurface drainage system.

A long pavement life with low maintenance is expected. JPCP has been built as new pavement and as overlays.

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