2 TECHNICAL SYNTHESIS

2.1 Innovative Concrete Pavement Technology in Europe

The US TECH Study Tour observed many interesting and innovative ideas, technologies, procedures, equipment and processes related to concrete pavements that will be of interest to engineers and administrators in the USA. Many of these have been researched in the USA before but have not been widely implemented.

Pavement Design

A summary of typical designs for freeway type highways is shown in Table 2.1. Several countries are also building unbonded CRCP or JPCP overlays over existing concrete pavements. A summary of European practices for concrete pavements is reproduced in the Appendix.

Table 2.1 Summary of concrete pavement designs for countries visited.

Country	Slab	Joints*	Base**	Subbase
France	CRCP 17-25 cm (6.7-10 in)	---	LCB	n/a
	JPCP 22-28 cm (8.7-11 in)	45.5 m (13.1-18 ft)	LCB	n/a
Austria	JPCP 18-25 cm (7-10 in)	5.5-6 m (18-19.7 ft)	5 cm (2 in) AC CTB	Min. bearing capacity required
Germany	JPCP 20-30 cm (7.9-11.8 in)	5 m (16.4 ft)	CTB/LCB (bonded)	Granular blanket 30-90 cm (11.8-35.4 in)
Netherlands	JPCP 26-28 cm (10.2-11 in)	3.5 - 5 m (11.5-16.4 ft)	LCB	Sand layer
Belgium	CRCP 20 cm (7.9 in)	---	LCB	20 cm (7.9 in) minimum granular
	JPCP 23 cm (9 in)	5-6m (16.419.7 ft)	LCB	20 cm (7.9 in) minimum granular

* All joints dowelled, 26 mm (1 in) diameter typical

** LCB = lean concrete base, AC = asphalt concrete, CTB = cement-treated base

• **Catalog of Designs**

Most countries have developed a catalog of pavement designs-for asphalt and concrete pavements. These designs appear to be based upon both theoretical analyses and practical experience from a team of experts. They are based on data unique to a given country or region. A design catalog is helpful in communicating the appropriate design to administrators and to the field.

Especially for concrete pavement, having the details of the cross section clearly defined may help avoid construction problems. In addition, project designers do not need to understand all of the theory involved to design a pavement when using a catalog. Germany has a catalog for both new pavement design and another catalog for rehabilitation design, part of which is shown in Figure 21.

JPCP overlay on interlayer of lean concrete or AC on fractured old pavement.

Traffic Class	SV	I	II	III
JPCP overlay	26	24	22	22
Interlayer	≥10			
Fractured old slab				
Subbase				

JPCP overlay on geotextile on fractured old pavement.

Traffic Class	SV	I	II	III
JPCP overlay	27	25	23	23
Geotextile				
Fractured old slab				
Subbase				

JPCP full-depth reconstruction with untreated, open-graded permeable base.

Traffic Class	sv	I	II	III
JPCP	120* 30	120* 28	120* 26	120* 26
Open-graded permeable base	45*	45*	45*	45*

* Moduli in MPa (1 MPa = 145 psi), thicknesses in cm (1 cm = 0.3937 in)

Figure 2.1 Portion of the German design catalog for rehabilitation alternatives. (Note that many other factors are specified such as minimum foundation bearing capacity, concrete strength, drainage, joint design, etc. See cross-sections shown in Figures 2.4 and 2.10).

- **Thick Granular Layer Over Subgrade (Beneath LCB or CTB)**

Nearly all countries provide a thick granular layer (20 to 90 cm (8 to 35 in)) between the subgrade and the treated base course to control frost heave and increase support to a minimum specified bearing design level. Note in Figure 2.1 the minimum modulus of elasticity that must be met at the top of the subgrade (45 MPa (6,500 psi)) and at the top of the granular layer (120 MPa (17,400 psi)). This plate load test (German standard test DIN 18134, June 1990) involves a circular plate loaded in several stages. In each load stage there is a wait until the change in settlement does not exceed a specified value. The minimum modulus of elasticity required results in a relatively stiff foundation upon which the treated base course (i.e., lean concrete) and concrete slab are supported.

- **Long Design Lives**

Many of the countries structurally design concrete pavement for long design lives of 30 to 40 years. This long design life may be in part responsible for the excellent performance of concrete pavements in Europe.

- **Heavy Truck Traffic**

This situation currently exists in Europe and the expectations in every country visited are that traffic will continue to increase in volume and weight even more rapidly with the economic growth that the EC will bring. Some countries will be increasing their legal axle weights to match the EC standard of 11.5 t single axle (25,300 pounds), while others exceed this already. A summary of legal axle loads which shows the large differences from the USA load limits is provided in Section 1. Most trucks in Europe observed by the Study Tour had super-single tires.

France provides one example of growth in heavy truck traffic. France has had large increases in its volume of trucks and expects an 8 percent annual growth in trucks. Truck volumes on the outer lane of urban freeways range from about 2,000 to 10,500 per day. Legal axle loads are among the highest in the world: 13 t (28,600 pounds) for single axles and 21 t (46,300 pounds) for tandem axles.

- **Life-Cycle Cost Analysis**

Some countries such as France conduct life-cycle cost analyses of pavement alternatives over a 25 to 40-year design period using a discount rate, no user costs and a new surfacing at specified times. Other countries include only the construction cost in the economic analysis. The French philosophy is expressed by the following remarks:

"The pavement structures given in the catalogue of standard designs are equivalent and offer the same service life. However, the amount of maintenance needed to prevent premature aging of the structures and to guarantee satisfactory surface characteristics differs. One of the advantages of concrete pavements is that they require very little maintenance. This is why an economic comparison of pavement structures must also look at the global investment cost including maintenance."

- Full-Width Paving for Future Traffic Control

Several countries such as Germany, the Netherlands, and Austria build their standard two-lane, one-direction freeways with the full-depth concrete slab wide enough (11 m (36 ft), 11 m (36 ft), and 11.5 m (38 ft) in those three countries respectively) to be capable of handling four lanes of traffic for any future emergency (such as a landslide) or planned rehabilitation. This makes it possible to completely close the opposite direction for rehabilitation. Shoulders are called "emergency lanes" in Europe for this reason.

- Widened Truck Lanes

This has been a widely used concrete pavement design in most European countries for many years to reduce edge and corner loadings. The Study Tour observed many pavements with a widened truck lane during the trip. The edge stripe is placed at its normal lane width position. Some countries also include tied concrete shoulders, as shown in Figure 2.2.

Figure 2.2 Typical widened traffic lane (4.25 m (13.9 ft)) with paint stripe placed 0.5 m (1.6 ft) from edge of pavement.

- **Trapezoidal Cross-Section**

This interesting design concept has been used in several countries, most notably France and Spain. The purpose of this design is to provide the thickest slab in the most critical area of loading (the outer edge of the pavement) while minimizing the amount of concrete used. The French use a trapezoidal cross-section on new pavements as well as reconstructed lanes. In the French trapezoidal cross-section, as shown in Figure 2.3, the slab thickness varies from 26 to 29 cm (10 to 11.5 in) across a 7-m slab (23-ft) (two lanes).

- **3-D Finite Element Use in Design.**

The French developed and use a three-dimensional finite element analysis program called CESAR to assist them in developing their concrete pavement designs.

- **Unique German Concrete Pavement Design**

This pavement design impressed the Study Tour by its proven history of excellent performance and for conceptual reasons. It is shown in Figure 24 and has several unique characteristics listed.

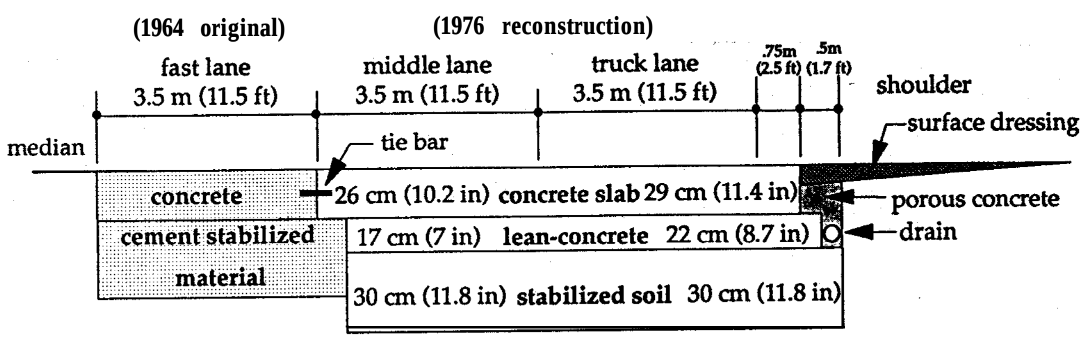
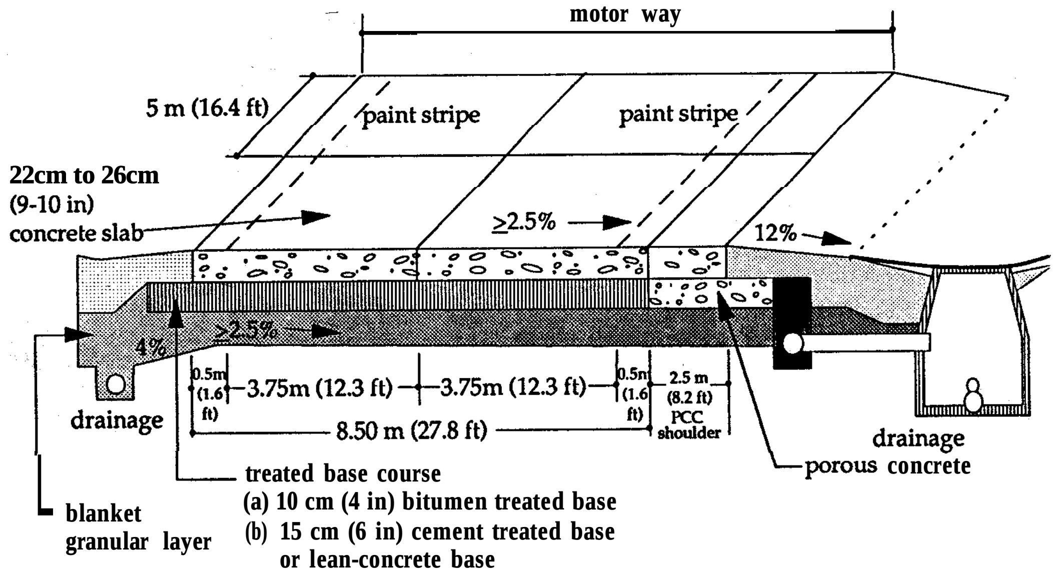


Figure 2.3 Example French trapezoidal cross-section design for reconstructed traffic lanes.

- **Unique JPCP and CRCP Pavement Design from Belgium and Austria**

Placement of an AC layer between a PCC slab and a base (lean concrete, cement treated, or untreated granular) is required in some countries, including Belgium and Austria. The AC layer provides a bond between the slab and the base and reduces erosion. Some sections in Belgium where the AC layer was eliminated have resulted in erosion and punchouts in CRCP.



- Jointed plain concrete pavement.
- Slab thickness depends on traffic.
- Usually two-layer construction with slab containing highquality crushed aggregates.
- Widened traffic (both passing and truck) lanes.
- Full-width paving thickness for future traffic control during rehabilitation.
- Shoulder is tied concrete.
- Concrete strength is similar to USA.
- Base is cement treated or lean concrete.
- Base is bonded to slab, reflection cracking is avoided by providing joints (or notches) in the base just beneath joints in slab.
- Subbase consists of a thick granular blanket.
- Transverse joint spacing is relatively short.
- Doweled joints, unevenly spaced, plastic-coated dowels, automatic dowel placement.
- Transverse and longitudinal joint sealant is neoprene compression seal.
- Longitudinal joint saw depth is 0.40 - 0.45 of slab thickness.
- Subdrainage with a porous concrete layer beneath the outer shoulder plus circular pipes connected to a closed drainage system. The underlying granular blanket provides some bottom drainage.
- Surface texture currently used is a light longitudinal brush (burlap drag) to produce a low-noise surface. The hard highquality aggregates used in the top layer provide adequate friction. The uniform cross-slope required is 2.5 percent.

Figure 2.4 German jointed plain concrete pavement design.

- **No Crown, Straight Cross-Section**

Most countries have a straight 2.5 percent cross-slope across all traffic lanes and shoulders to promote rapid drainage and smoother pavements.

- **Notched and Bonded Lean** Concrete or Cement-Treated **Base**

Germany bonds a lean concrete base or CTB to the slab with good success without the risk of reflection cracks. This is accomplished by notching the base immediately after placement exactly beneath the transverse and longitudinal joints of the concrete slab. The bond lasts at least 10 years and provides a monolithic slab which reduces curling stresses and erosion at the interface, which often occurs when the layers are debonded (See Figure 25).

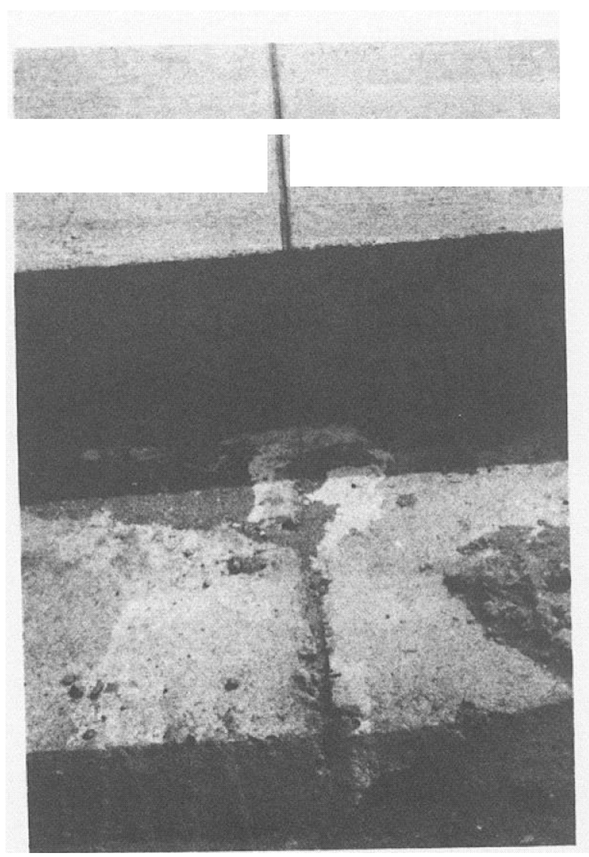


Figure 2.5 German JPCP slab on lean concrete base that has been notched or jointed. (Note: all joints along project showed an initial crack like this joint after a few days curing.)

- **Longitudinal Edge Drains Connected to Closed Drainage System**

The German cross-section (Figure 2.4) shows a porous concrete layer beneath the shoulder that provides a flow channel to a longitudinal subdrain. This empties at regular intervals into a lateral pipe and finally into a larger longitudinal closed drainage system.

- **Ditch Line One Meter (Three Feet) from Bottom of Base**

The Netherlands requires this to help drain the cross-section. Pavements in other countries also appeared to have deep ditch lines.

- **Geotextile Drainage Fabric Between Slab and Base**

This is specified in Germany to be placed between a new JPCP overlay and old fractured concrete slab. In France, the Study Tour observed a thick fabric placed beneath the slab on top of a granular base.

- **Porous Concrete Base Under Shoulder**

A porous concrete base about 15 cm (6 in) thick is specified in Germany's cross-section under the outer concrete shoulder to facilitate base drainage, as shown in Figure 2.4. This is also used in France and Italy to drain the cross-section. The porous layer is connected into a drainage system in all cases.

- **Reinforcement in CRCP**

Some unique and interesting reinforcement designs were found in Europe:

✓ Rectangular flat steel high-strength strips (FLEXARM): A coilable reinforcement was developed in France (Figure 2.6) to shorten the length of the construction train, reduce the complexity of bar reinforcement placement, reduce the labor involved and make the reinforcement easier to transport. This reinforcement has been used in France since 1988 for several major freeway projects under the commercial name of FLEXARM. This carbon steel has a high yield strength of 790 MPa (114,550 psi), a flat rectangular section (4 cm (1.6 in) wide and 2 mm (0.08 in) thick), a corrugated surface which is corrosion-proofed by continuous hot galvanization, is supplied in coils and is joined in the field by rapid pneumatic riveting.

✓ Using an increased steel percentage has shown excellent performance in Europe: Belgium used 0.85 percent from 1970 to 1978 and obtained excellent long-term performance on over 100 km (62 miles) of heavily trafficked freeway with no punchouts. Projects in France and Spain with 0.72 to 0.85 percent steel have shown excellent performance also.

✓ Placing the steel above mid-depth: A depth of approximately one third of the slab thickness holds cracks tighter and results in better performance according to experienced engineers from Belgium and France.

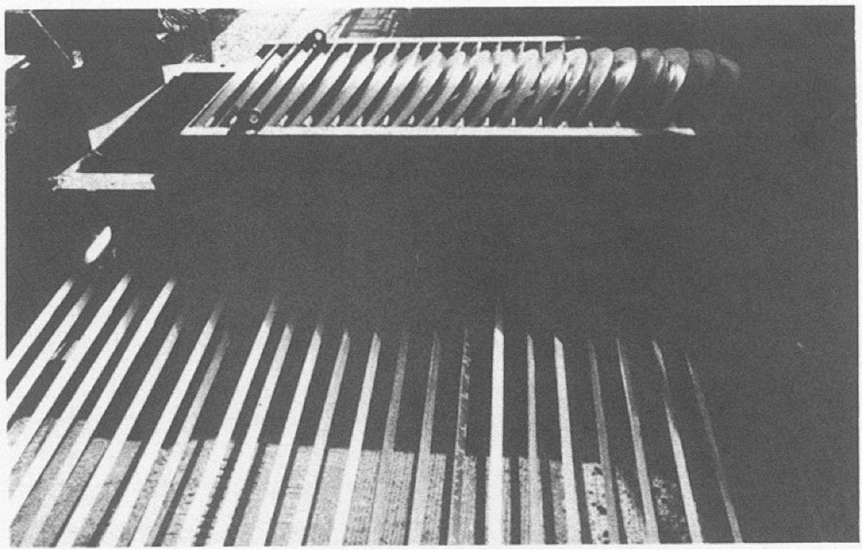


Figure 2.6 Coilable rectangular reinforcement (FLEXARM) developed in France.
(Note: coils held in diagonal position at top of photo.)

✓ Skewed transverse steel: Used in Belgium to prevent any transverse cracks from forming over transverse steel.

- CRCP with Porous Asphalt and Concrete Surfacings

CRCP is surfaced in the Netherlands, France and Italy with porous asphalt. Porous concrete has also been used in Netherlands and France. This design has some strong advantages and disadvantages, as described in the section on surfacings.

- Dowels Required to Control Faulting

Based upon experience in many countries, the overall conclusion is that dowels are required to control faulting in transverse joints for JPCP for heavily trafficked highways in Europe. This was strongly stated, based upon field experience, in Belgium, Germany, Netherlands, Austria and Spain. This conclusion was painfully learned in several countries that adopted the typical original “California” design for JPCP with no dowels, an erodible base and no subdrainage. This led to pumping, faulting, and slab cracking.

- Varying Dowel Placement Across Traffic Lanes

Nearly all countries vary the dowel placement across the traffic lanes and emergency lanes (shoulders) to economically place adequate load transfer devices at the locations where the greatest number of heavy wheel loads pass. Automatic dowel placement equipment can place nonuniform dowel patterns. An illustration of dowel spacing in Germany is given in Figure 2.7.

- Plastic-Coated Dowels and Deformed Tie Bars

Germany uses 25-mm-diameter (1 in) dowels with a plastic coating at least 0.3 mm (0.01 in) thick covering the total length of dowels and no oil used at construction. They are placed with automatic dowel inserters. The apparent quality of the coating was impressive.

- Short Transverse Joint Spacing

Joint spacing in JPCP is critical to minimize transverse cracks due to curling and warping. European countries have clearly recognized this for many years and joint spacing in most of these countries ranges from 4.5 to 6 m (15 to 20 ft), with 5 m (16.5 ft) being the most popular. Since most joints are doweled, the transverse joints are perpendicular to the centerline. Slab thicknesses range from 22 to 28 cm (9 to 10 in) for these joint spacings. A 5-m (16.5ft) joint spacing was also used at the new Munich II airport for slab thicknesses up to 40 an (16 in).

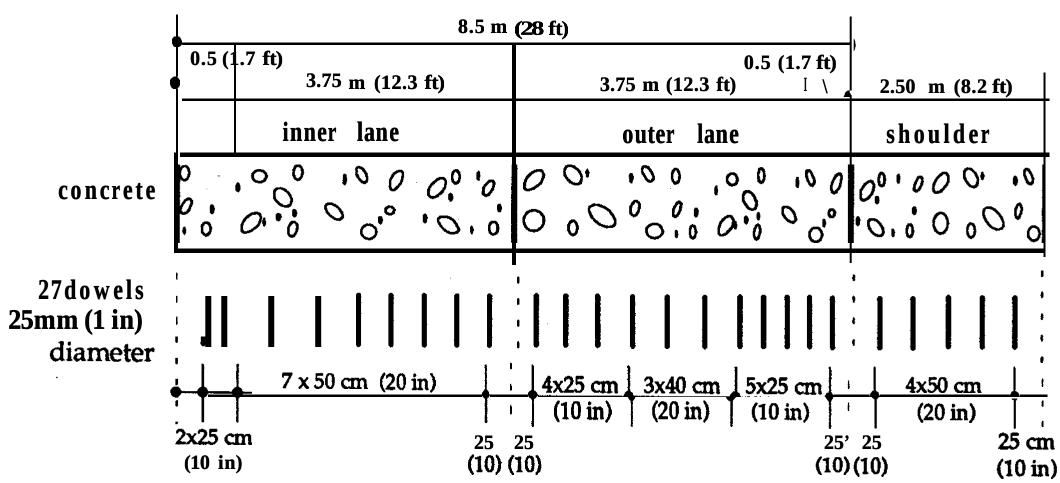


Figure 2.7 Varying dowel bar spacing across pavement in Germany. (See Figure 2.4.)

- **Sealing of Joints**

European countries differ as to whether or not they seal joints and as to what type of seal they use. Most countries seal transverse and longitudinal joints. An exception to this is Austria, where in some areas a narrow (3 mm (0.1 in) wide) joint is saw cut and not sealed, which reduces construction cost by about 10 percent. Spain seals transverse joints in wet areas but not in dry areas. Longitudinal joints are sealed in all areas in Spain.

- **Two-Layer Construction Concept**

This concept is used in several countries in Europe for economic and safety reasons. Equipment is available to slipform two layers in one pass as described below.

✓ Two-layer construction has been used extensively in Germany since the 1930's on highway and airport pavements. This provides an economical design, with the top layer containing hard, high-quality, smaller-sized, high-friction aggregates and the lower layer containing lower-cost, locally available gravel aggregates (which must be thermally stable). The top surface is more resistant to freeze-thaw damage, has a lower noise level due to the smaller aggregates, and has improved friction.

✓ Two-layer construction is used currently in Austria to provide a top layer with hard and durable smaller-sized aggregate (8 mm (0.3 in) maximum). An exposed aggregate surface is then created to provide a low-noise, high-friction surface. High-quality aggregates are expensive and cannot be used throughout the full slab thickness. Figure 2.8 shows a photo of a two-layer slab from Austria.

✓ Two-layer construction is used in France with hard aggregates in the surface layer to provide an exposed aggregate surface. These aggregates are very expensive compared to soft limestones used for the lower layer.

- **Pavement Placed Right Over Bridges**

Some countries such as Belgium and France design some bridges for the extra dead load of the pavement which is placed right over the bridge deck This avoids end movement problems.

- **Concrete Pavement Bicycle Paths and Local Traffic**

The Netherlands constructs many undowelled JPCP bike paths. These are also used by local farm equipment.

- **Prestressed Concrete Pavements**

This pavement type has been constructed by several countries in Europe, mostly at airports. Prestressed pavements have been used extensively at Schiphol Airport (Amsterdam) for 25 years and have provided low-maintenance long lives under heavy traffic. The first prestressed pavement in the world was built in Portugal at a NATO airfield in 1965.

Figure 2.8 Two-layer construction in Austria (high-quality smaller-sized aggregates in top layer, lower-cost locally available aggregates in lower layer).

- Concrete Block Pavers

This has been used to some extent in most European countries for local streets and other purposes. For example, they are used extensively in the Netherlands for a wide range of applications from domestic pavements to complicated industrial pavements.

- Reduced Electrical Energy

In Switzerland, lighting concrete pavements consumes about 20 percent less electrical energy than lighting asphalt pavements due to the lighter-colored surface.

Construction

Some interesting contracting arrangements are going on in highway design and construction in Europe. For example, Germany paid eight firms 150,000 DM each to develop proposals on a 30-km (l8.6-mi) highway reconstruction project. The low bid was 105 million DM, which was low enough to cover all of the money spent to develop the innovative proposals.

- Warranties for Construction

Most highway work in Europe requires warranties for highway construction and materials.

A few examples: Germany has a four-year warranty for concrete and asphalt pavements, and French contractors must warrant AC pavement for four to five years and concrete pavement for seven to nine years. The Freyssinet load transfer devices carry a five-year warranty.

While some sources claim that warranties contribute to the high quality of pavements in Europe, more evidence is needed to support this conclusion. Beyond qualitative evidence, cultural differences between contractor and owner on the two continents must be investigated. The interrelationships of workmanship, ability to pay, construction or design choices allowed, size of company, etc., lead us to believe that the word "warranty" may mean different things to Europeans than to Americans.

A primary reason for the achievement of quality highways in Europe is a longer original design life and a European mindset for-long term use of not only highways but also homes, cars and all other products. Europe is not a disposable-driven economy. Designs include a large safety factor. For example, concrete actual strengths regularly exceed by a considerable amount design strengths, and design strengths were considerably higher than ours. USA construction contracts and quality control programs are focused on uniformity and building as close as possible to specified requirements, whereas their designs and contracts are focused on getting the best, longest-life product possible. The European designs and specifications achieve and exceed desired results with minimum risk

- **Two-layer Paving Equipment**

This construction procedure is extensively used in Germany, France and Austria. For example, equipment used at the new Munich II Airport paved, in one pass, a 14-cm (5.5in) granite aggregate top course and a 22cm (9 in) lower course made of local round gravel, forming an economical 36-cm (14-in) monolithic structure. Dowel and tie bars were placed between these layers. A "double decker" slipform paver is available that can place two separate layers "wet on wet" to form a monolithic structure. The two layers are completely different concrete mixtures.

- **Workability Meter**

This is used in France to control workability of concrete. It consists of a box with a swinging door that opens up and lets concrete flow out depending on its flowability.

- **Lower Productivity Rates and Higher Costs**

Typical construction costs in Europe appear to be about double those of the USA. Of this higher cost, about 50 percent appears attributable to higher structural design standards and the balance to lower productivity from both an equipment and labor standpoint.

- **Short Construction Duration**

Several examples of relatively fast-track construction exist in Europe, A 17-km (10.6mi) project (11.25-m (37-ft width), which included crushing and recycling the concrete pavement, was completed in 26 weeks in Austria. The Base1 airport runway was reconstructed with only one week of actual closure and two weeks of replacing concrete slabs at night and opening at 5 AM. Early openings of slab replacements within 24 hours were reported in Vienna.

- **Uncrowned Pavement Cross-Slope Improves Ride**

Nearly all European countries are using an uncrowned straight cross-slope. This is believed to provide improved rideability.

- **Liquidated Damages = Incentives Rate / Day**

A project on the Al freeway in Austria has a specified maximum construction period with provisions that the damage rate per day is equal to the bonus rate per day. The contractor felt that this was fair and provided considerable incentive.

- **Re-bar Tubes Behind Vibrators for CRCP**

This procedure illustrated in Figure 2.9 provided an accurate final position of the reinforcement for a French project. They believe they are able to meet a specification of ± 1.5 cm (0.6 in) by putting the tube at the end of the liquid phase of the concrete.

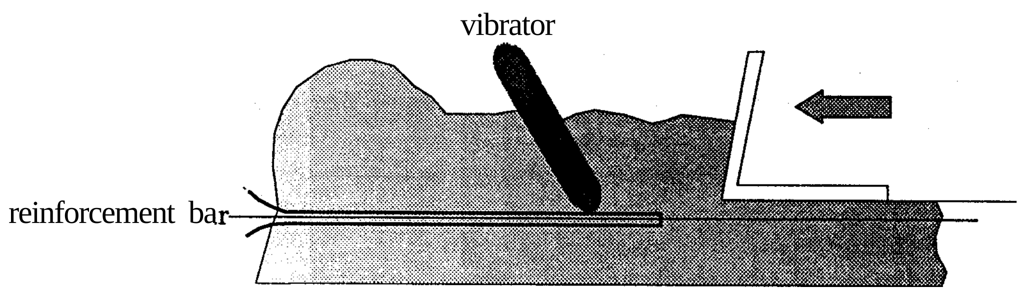


Figure 2.9 Positionof tubes and vibrators used in France to place CRCP to improve position of reinforcement.

- **Prevention of Sawing Residue from Entering Joint**

Germany and the Netherlands use a long elastic band to plug the first deep saw cut to keep residue from the second joint sealant reservoir cutting from infiltrating the crack This is considered important to keep incompressibles out of the joint prior to sealing.

- **Lean Concrete Temporary Widening for Traffic Control**

This was used on the A10 autobahn near Berlin to widen old concrete pavement to carry 4 lanes of traffic over an S-month period. The 22-cm (9-in) lean concrete will be recycled along with the old concrete after the other side of the highway is reconstructed.

- **Concrete Mixing**

The concrete plants observed were compulsory mixing plants, and in France, continuous mixing plants. No tilting drum mixers were seen, which is virtually the only kind of mixer used in the USA. Drum mixers are common but discharge by pulling apart rather than tilting. Europeans felt that their central mix plants produced higher-quality concrete. Further investigation is needed to find out whether or not this belief is justified.

- **Vibration**

Two slipform pavers observed were equipped with "T"-shaped vibrators. The USA needs to investigate this type of vibrator to determine its merits.

Maintenance and Rehabilitation

- **Extensive Recycling of PCC and Other Materials**

Recycling of concrete is performed all over Europe. Belgium recycles PCC into LCB. Germany recycles concrete into LCB and the granular blanket. Netherlands includes recycled rubble in LCB. Austria recycles old PCC into new PCC and believes that crushed concrete provides coarse aggregate of very good quality. To achieve low cost, Austria permits some existing AC overlay to be used in the recycled concrete. France has conducted several successful recycling projects since 1976 using crushed concrete in new concrete and in the lean concrete base.

- **Unbonded CRCP and JPCP Overlays (Some on Fractured JPCP)**

CRCP and jointed fiber-reinforced unbonded overlays of concrete and asphalt pavements are used often in Belgium with good success. In Germany, the existing concrete pavement is fractured into pieces and a 10-cm (4in) interlayer of either notched lean concrete or AC material is placed on top of the existing concrete pavement. A JPCP overlay is then placed with the same thickness as is used for new design. Another German option is to place a 6-mm-thick (0.2 in) geotextile between the fractured old concrete pavement and a slightly thicker JPCP overlay.

Austria has placed a JPCP unbonded overlay over a thin AC separation layer on top of fractured slab. France has placed a lot of CRCP overlays over old fractured JPCP. Typical design includes the following features: l&cm (7-in) CRCP with 0.67 percent steel and l&cm (7-in) lean plain concrete shoulders with transverse joints at 6 m (20 ft) placed on the fractured JPCP. A longitudinal drain is placed along the edge. The transverse cracks in the CRCP were tight and the pavement was in excellent condition. This CRCP overlay is typical of several observed.

Spain has used roller-compacted concrete (RCC) for overlays of pavements. An AC overlay is placed on top of the RCC to provide good rideability. Spain favors RCC for overlays because it can be opened to traffic very quickly.

- German Lane Reconstruction

The existing deteriorated traffic lane is completely removed and a new JPCP is constructed over a porous concrete base layer about 40 cm (16 in) thick The new 26-cm (10.5-in) JPCP is placed directly on the porous concrete layer. The new lane is tied securely to the old traffic lane with deformed reinforcing bars. This cross-section is shown in Figure 2.10.

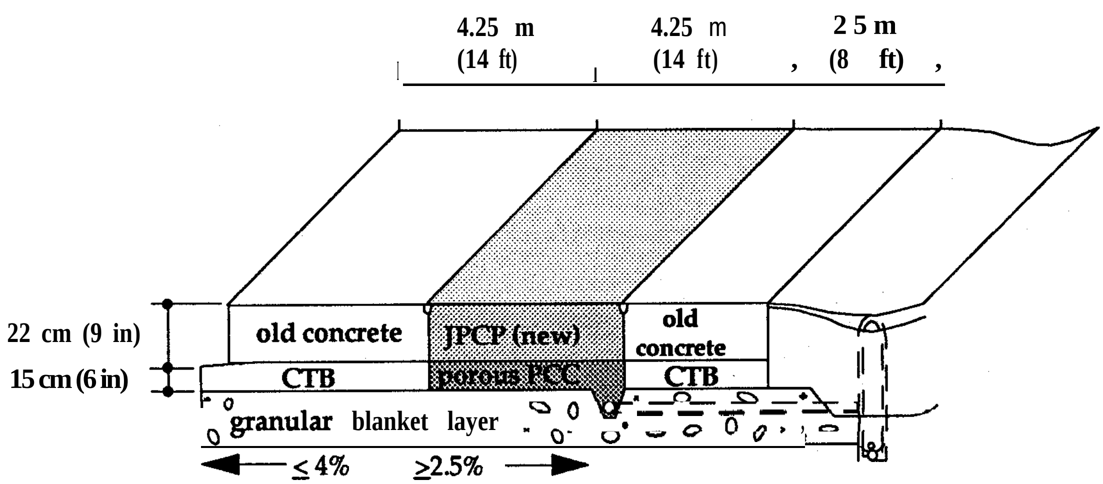


Figure 2.10 German cross-section for lane reconstruction with porous concrete base.

- German Total Width Reconstruction

In general, it appeared that Europeans tended to reconstruct or resurface rather than restore concrete pavement. All of the existing pavement is removed and a JPCP is placed on an untreated permeable base course. This base type is new for Germany; however, this technique makes it possible to use up to 100 percent recycled material from the old pavement. Slab thickness is increased for this option over that used for the normal lean concrete base.

- French Lane Reconstruction

Trapezoidal cross-sections have been used on many freeway reconstructions of one or two lanes. Typical thickness is 26 cm (10.5 in) at the inside edge to 29 cm (11.5 in) at the outside edge across two lanes, a 0.75-m (2.5 ft) widened traffic lane, a lean concrete base, and a cement-stabilized soil, as shown in Figure 2.3. Longitudinal subdrainage along the edge is used. This design carried more than three times the truck loadings than the original traffic lane having the conventional "California" design.

- CRCP Widening on AC Pavement for Added Truck Lane

Several major projects in France have been completed where either the outer AC traffic lane was removed and replaced with CRCP or a lane was added by removal of the shoulder and replacement with CRCP. A large proportion of trucks use this outer lane and due to the previous major deterioration in this traffic lane it is believed that the future will require a very heavy structural design. One project observed by the Study Tour had a 31.5cm (12.5in) CRCP slab, as shown in Figure 2.11.

Figure 2.11 CRCP truck lane addition to original AC pavement in France.

- **Automatic Faulting Measurements**

Faulting measurements taken directly from the APL profile were shown to the Study Tour. The extent of transverse joint faulting was readily observable and measurable.

- **LCPC/Freyssinet Load Transfer Devices**

The French LCPC laboratories and Freyssinet International have developed a device to restore high load transfer in the transverse joints of undowelled JPCP. These undowelled joints exhibit poor load transfer that leads to faulting and slab cracking of the original slab, plus deterioration of reflection cracks of an AC overlay. These devices have been placed on many sections of JPCP in France with good success in restoring load transfer from less than 50 percent to over 90 percent. They have been successfully used prior to placement of a porous asphalt surface to reduce reflection cracking. A Freyssinet load transfer joint or crack is shown in Figure 2.12. The device carries a warranty.

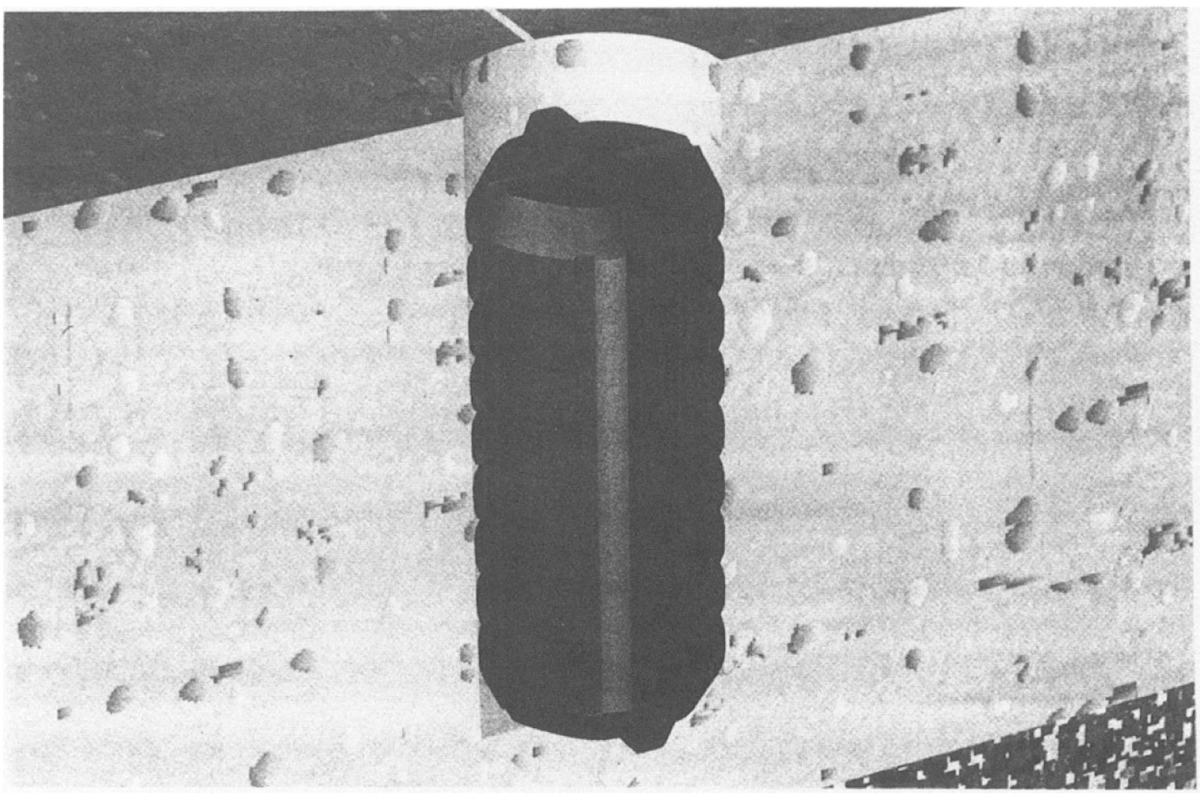


Figure 2.12 LCPC/Freyssinet French load transfer device.

- **Rehabilitation Programmed when Pavement Condition is "Good"**

It appeared to the Study Tour that far less pavement deterioration is allowed in European pavements before rehabilitation is done than in the USA. This was especially true for toll roads. The Study Tour was very impressed with the extent to which the toll road companies are vitally concerned with providing the highest-quality service to users and are constantly seeking to improve service levels.

- **Fiberlzed PCC Overlay of AC Pavement**

Used successfully in Belgium for several projects. One project observed by the Study Tour had a 12-cm (5-in) steel fiber-reinforced concrete overlay placed over a badly rutted AC pavement. A 10-m (33-ft) undowelled joint spacing was used; however, curl is considerable. The existing 22-cm (9-in) AC pavement was milled 12 cm (5 in) prior to placement of the 12-cm (5-in) fiberized concrete overlay. The pavement was in excellent condition after four years. A 5-m (16.5ft) joint spacing has been built and worked well. Belgium has constructed over 130,000 square meters (142,200 square yards) of this type of overlay on concrete and asphalt pavements.

- **JPCP Overlays of AC Pavements**

Several have been built in France starting in the 1970's. They have shown very good performance over many years. Their typical slab thickness was 21 to 25 cm (8.5 to 10 in), 4.5-m (14ft) undowelled joint spacing with 600 to 1000 trucks per day in one lane. The new JPCP overlay is placed directly onto the old pavement, or onto a leveling course of lean concrete.

- **Performance of Overbanding of Longitudinal Lane/Shoulder Joint Seal Performance**

The French used polymerized SBS asphalt hot-poured joint sealant in an overbanding configuration between the concrete traffic lane-and the AC shoulder. This sealant was observed to have performed very well in the 6 years since construction.

- **Thin Polymerized AC Layer for Studded Tire Wear in Austria**

Studded tires caused considerable damage to older Austrian pavements, resulting in ruts of 2 to 3 cm (0.9 to 1.2 in). Since Austria has a lot of rain, some type of rehabilitation had to be performed. A thin polymerized asphalt layer has been placed over the truck lanes of many older concrete pavements to fill in the studded tire damage. This layer has a life of only four to six years.

- **French Pavement Evaluation**

French research has developed several types of pavement monitoring equipment. The latest equipment development is called the SIRANO which measures profile, takes continuous 35-mm film for a lane width and determines macro-texture at a speed of 72 km/hr (45 mi/hr). The SIRANO successfully tested 5,500 km (3,415 mi) in 1991.

The French also conduct a comprehensive evaluation to determine the need for and design of pavement rehabilitation. A policy of prevention is encouraged, in which a rehabilitation action is taken as soon as fatigue cracking has initiated (i.e., before more serious structural deterioration of the slab and base occurs).

Concrete Materials

- Highly Durable Concrete Slabs

The Study Tour traveled extensively on the European freeway system and did not observe any concrete durability problems. Discussions with engineers in each country revealed that very few durability problems exist. Some examples that provide some possible reasons for this are provided.

✓ 1930's German autobahns show no durability problems after more than 50 years. This old concrete had the following characteristics: lower traffic during its early life, a relatively mild climate, care in proportioning uniform gradation mixes, 3-cm (1.2 in) maximum size, high-quality, hard aggregate in the top course, consolidation by vibration, a dry concrete mix (water-cement ratio less than 0.35), 21-day water curing, protection of concrete from sun and wind with 21-day tent cover, no deicing salts used for many years, and a thick granular layer between the slab and the subgrade (except in areas where a sand subgrade was present) that provided some bottom drainage. A photo of a 1939 concrete pavement on the German autobahn is shown in Figure 213.

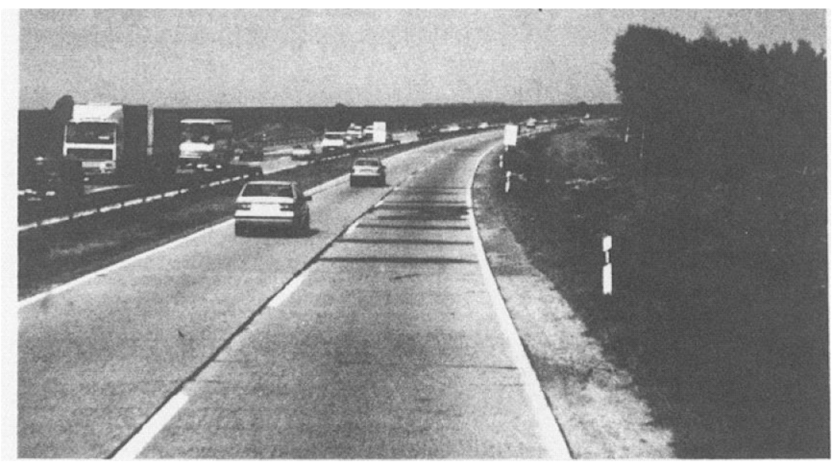


Figure 213 Photo of original 1939 concrete pavement on the German autobahn approaching Berlin from Munich.

✓ Germany has a quality testing program to achieve durable aggregates, correct gradation of aggregates, and a good air void system. The air void system is determined during construction using the Danish meter for fresh concrete to determine the air void content and void system. Tests are conducted the first day of production and again if there is any doubt as to air void system. The tent cover for a two-hour minimum (7 days at the Munich II Airport project) provides surface protection for early curing.

✓ Swiss quality control program for concrete durability. The measurement of the total content of air voids of the fresh concrete was not sufficient for the evaluation of frost and chloride durability in Switzerland. Only an appropriate testing method applied to the hardened concrete can give pertinent information. Rapid and practical procedures were developed to examine the hardened concrete. The microscopic control of concrete is carried out on thin sections made from a concrete core specimen impregnated with a special fluorescent dye and examined under the microscope in transmitted ultraviolet light.

Laboratory tests are conducted a few months before the project begins. Aggregates are submitted to quality tests. Several concrete mixes are prepared at the laboratory to work out a mix design of high durability with a good air void system (size, quantity and distribution in the cement paste are measured).

Trial run tests take place two to three weeks before construction to evaluate the batching, mixing plant, and placement equipment to test the suitability of the mix design from the laboratory under in situ conditions. The concrete is mixed, hauled and placed in two or three trial slabs. Several test cores are obtained and tested, and the results are compared to those obtained in the laboratory. Any needed adjustments to the mix or construction process are made.

During the first few days of construction, cores are taken from the pavement and tested. A microscopic analysis is again conducted to ensure that the hardened concrete maintains the proper air void system. These results are -available within 36 hours after the concrete is placed. If the air void system is inadequate, a rapid-cycle freeze-thaw test is conducted on one of the cores (Dobrolubov-Romer). If the air void system is inadequate, the surface of the concrete is impregnated with an agent. These quality control procedures have led to the elimination of frost-salt durability problems in concrete pavements in Switzerland.

Not many concrete pavement projects are constructed; however, when they are a comprehensive preparation is accomplished. This amount of preparation would increase our costs greatly in the USA.

✓ Austria has very durable concrete with no significant problems even in a harsh climate. Pavements built in early 1950's showed no durability problems.

✓ France requires the proportioning of aggregate to achieve minimum void content.

- Blended Cement and Concrete Mixtures in Spain

Spain uses concrete containing crushed limestone as the coarse aggregate, which has proven to yield low shrinkage and good flexural strength and facilitates joint sawing. The requirement that at least 30 percent of the fine aggregate be composed of siliceous particles has resulted in pavements without friction problems associated with texture wear. Concrete must attain a flexural strength at 28 days of 4.5 MPa (640 psi) from a third-point loading test. Blended cement containing flyash (blending must be done at the plant) is used in the concrete (38 percent flyash) and lean concrete base (50 percent flyash). A large cost reduction was obtained by the government for these blended cements for use in pavements! The water/cement ratio is between 0.44 and 0.50, slump is between 2 and 4 an (0.8 and 1.6 in), and plasticizers are used in drier mixes.

- Lean Concrete in Spain

Lean concrete or cement-treated bases must have a minimum compressive strength of 8 MPa (1160 psi) at seven days; or alternatively not less than 12 MPa (1740 psi) at 90 days for slower-strength-gaining mixtures.

- Steel-fiber Reinforced PCC

Belgium has built 12 or more projects as previously described. They include 5-cm-long (2 in steel fibers (30 kg/m^3 (50 pounds/ yd^4) steel) and performed well: no cracks were observed in the long slabs (10 m (33 ft) joint spacing). Shorter slabs are recommended.

- Higher-strength Concrete in Slabs

Some countries, particularly Belgium, use much higher-strength concrete than the USA. Belgium uses a high cement content (400 kg/m^3 (674 $pounds/yd^3$)) which produces a strong, dense concrete having a minimum compressive strength of 55 MPa (7975 psi) and a mean strength of about 70 MPa (10,150 psi) at 90 days. No freeze-thaw or any other durability problems exist. The high cement content helps reduce surface wear also. Austria has 28-day flexural strengths ranging from 6.5 to 9.5 MPa (942 to 1378 psi) with mean of 7.5 MPa (1087 psi) and Italy has a mean 28-day flexural strength of 8.3 MPa (1203 psi) and a mean compressive strength of 56.5 MPa (8193 psi).

- Lean Concrete Used for Shoulders or Emergency Lane

A French project had tied lean concrete shoulders that appeared to perform very well. This design reduced costs.

- **Thick Porous Concrete Slab**

Some countries are developing this design, such as the Netherlands and France where it is defined as a porous concrete base surfaced with a free-draining concrete layer, having a total thickness of 40 cm (16 in). These pavements substantially reduce traffic noises and act as storm runoff reservoirs in urban areas. These pavements must be maintained to prevent clogging.

- **Lower-Quality Aggregates in Concrete Slab with AC Overlay**

France uses lower-quality local aggregates in concrete pavements for which an AC overlay is also to be placed during construction. This reduces overall pavement costs in areas where only poor aggregates exist. There is little freeze-thaw cycling in these areas.

- **Recycled PCC Including Recycled Asphalt Concrete (RAP) Material**

Austria has conducted laboratory tests and several large field projects where the old concrete slabs with AC overlays have been recycled back into regular concrete for pavement. Recycled concrete pieces are being used as the coarse aggregate and the sand fraction used in cement stabilization of the existing granular subbase. The crushed concrete particles may contain up to 20 percent RAP particles without impairing the quality of the new concrete. However, only about 6 percent AC content is generally used because greater amounts of RAP require larger amounts of cement and this becomes uneconomical. Recycling concrete with asphalt provides a more economical mixture and a way to reuse RAP overlay material.

Surfacings

- **Emphasis on Reduction of Tire/Pavement Noise and Vibration**

Many concrete pavements were textured with transverse coarse tining that was very good for friction and hydroplaning but caused considerable road noise and vibrations. This technique is no longer used.

- **Longitudinal Light Texturing for Noise Reduction on New Pavement**

In Germany, significant noise reductions were achieved by creating a lightly rough longitudinal texture, using a burlap drag, a longitudinal smoother, and smaller top-sized aggregates. This produces a noise level about the same as that of a porous AC surface after a year. In Spain, low-noise surfacings are obtained using a combination of longitudinal brush and comb, achieving both a microtexture (with the brush) and a macrotexture (with the comb).

- **Porous AC Surface for Noise Reduction of New or Existing Pavement**

Many countries have used porous AC surfaces for old and new concrete pavements. It has some significant advantages and disadvantages. The advantages of this design are the following: it eliminates hydroplaning, eliminates tire spray, gives good friction resistance, has low tire/pavement noise emission, gives a smooth ride, does not have reflection cracks, and waterproofs cracks in CRCP. Its limitations include a significant decline in the noise-reducing effect over time as the layer fills with materials, a relatively short life, and higher deicing salt requirements to prevent icing. Unsafe conditions can develop when icing cannot be prevented completely.

- Porous Concrete Surface for Noise Reduction on New Pavement

The Netherlands (see Figure 2.14) and France have constructed porous concrete surfaces on newly constructed concrete pavements that give significant reduction in noise levels. The porous concrete surface has many of the advantages and disadvantages listed for porous AC surfaces, but this technique is still under development.

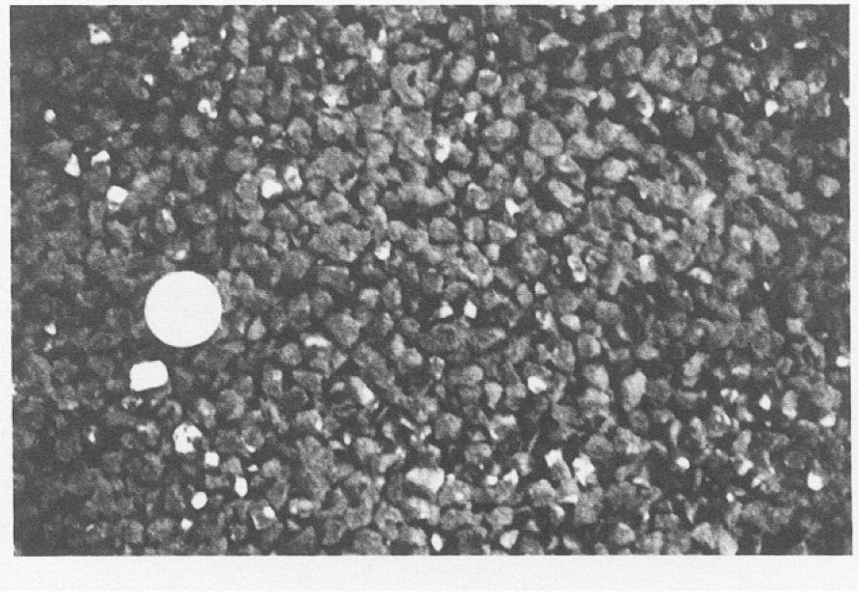


Figure 2.14 Photo of porous concrete surfacing placed on JPCP in Netherlands.

- Exposed Aggregate Surface for Noise Reduction on New Pavement

A surface texture with low rolling noise and low vehicle vibration but high friction is achieved through a technique for chemically exposing aggregate. This technique is used extensively in several countries, including Belgium, Austria, the Netherlands, and France. In Belgium, after the paver passes, the surface is immediately sprayed with a retarder which penetrates several millimeters into the mortar. A polyethylene sheet is then placed over the surface. This serves to protect the retarder from the effects of inclement weather and to protect the effectiveness up to the moment when the retarded surface mortar is removed through special wire brushing after 24 to 72 hours. The aggregate at the surface is then exposed and has the desired surface texture to reduce rolling noise and vehicle vibration. The surface has about the same rolling noise characteristics as porous asphalt after one year. A photo of an exposed aggregate surface is shown in Figure 2.15.

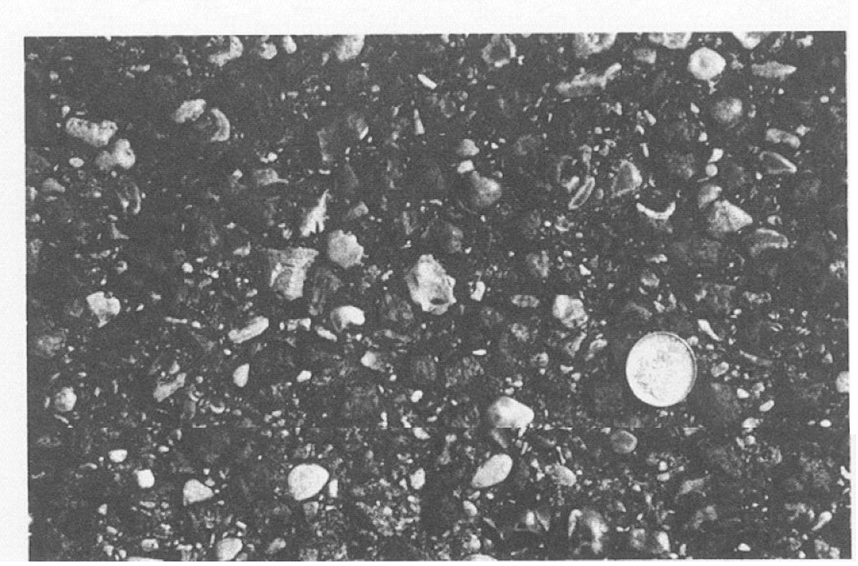


Figure 2.15 Photo of an exposed aggregate surface in France.

In Austria and France, the exposed aggregate technique is similar, however, a major difference is that in Austria the slab is placed in two layers so that the top layer can contain a high quality, smaller aggregate (maximum size 7 to 8 mm (0.27 to 0.31 in)) to maximize noise reduction. The two-layer method is used in Austria because the aggregates that are resistant to wear and polishing are expensive. The exposed aggregate surface also provides a high level of friction resistance.

- **Diamond Grinding Surface for Noise Reduction on New or Existing Pavement**

This is used very successfully in Belgium to reduce noise over the original coarse cross tining. It is also used in the Netherlands to reduce noise over original transverse brush texture.

- **Surface Layer of Epoxy/Aggregate for Noise Reduction on Existing Pavement**

The Netherlands uses an epoxy resin binder applied to a hardened concrete surface, followed by a layer of crushed 3- to 4mm (0.12 to 0.15-in) chromium ore slag (brand name Durop) and surface rolling to produce a mosaic-like structure. The Durop surface treatment achieves large noise reduction relative to the original brushed concrete surface. This treatment is comparable to porous asphalt.

- **French Double Surface Treatment for Existing Pavement**

A thin surface called a double layer is placed to improve the rideability of existing pavements. The surface treatment consists of a spray of polymerized asphalt on the concrete surface, a layer of 1.4-cm (0.55 in) chips, and then a layer of l-cm (0.4-in) chips placed with no compaction.

- **Overall Evaluation of Surfacings**

Figure 216 shows a plot of noise emission versus vehicle speed for old concrete surface (cross-tined), burlap drag, and exposed aggregate as measured in Austria. These and other data show that old concrete has the highest noise emission level, and the other treatments including porous asphalt, exposed aggregate and epoxy/ fine aggregate surface dressing are very similar.

Research and Development

The Study Tour was very impressed with the pavement research programs underway in most of the countries visited. Particularly impressive also was the very close working relationships that existed between public and private agencies.

- **Close Government and Industry Relationships**

✓ In Belgium, close cooperation exists between government and industry. The development of the exposed aggregate surface is an example.

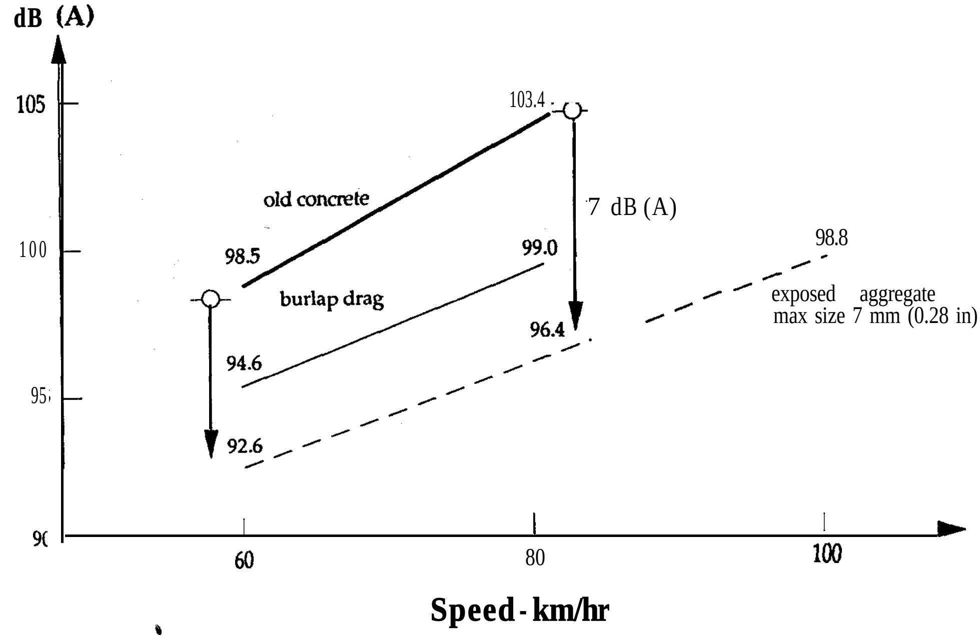


Figure 2.16 Measured noise emissions for various surfacings in Austria.

✓ **In Germany, Austria and the Netherlands, close cooperation exists between public and private organizations.**

✓ **The French national research study on concrete pavements appears to be an ideal example of the close cooperation between public and private organizations. Private organizations add funding to some of these studies that they consider very important. The great benefit of this appears to be considerable innovation and results that actually get used on the French highway system because all concerned were involved in its development.**

- **Accelerated Field Testing of Concrete Pavements**

The French LCPC/Nantes circular test track shown in Figure 2.17 is an excellent tool for accelerated testing of concrete pavement designs. The test track is part of the national research project in concrete pavements. The Study Tour observed the large test track in operation and saw some of the early results obtained. One million loads per month can be placed on the concrete pavements.

- **Higher R & D budgets than USA**

It appears that in most European countries the research effort underway was substantial. For example, the German cement institute has 4 times the budget of the USA's Portland Cement Association (PCA) and American Concrete Pavement Association (ACPA) combined.

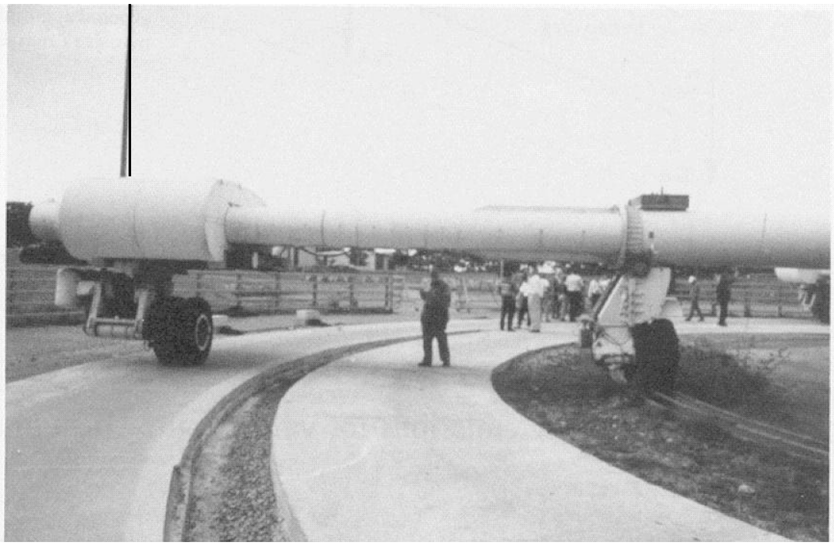


Figure 2.17 French LCPC/Nantes circular test track

- Willingness and Eagerness to Try New Ideas

Europe has a very strong commitment to research and development to improve concrete pavements. Germany has continued to improve its concrete pavement designs over many years through research studies carried out by government agencies and universities. The Netherlands is very willing to try new ideas and fully develop them until they work.

In France, tremendous energy goes into identifying and developing new and innovative ideas. One comment was that "the maintenance and growth of the competitiveness of concrete-based road techniques depends on constant innovation, the result of a partnership between the industry and operating authorities."

- Designated Percent of Construction for R & D

In Belgium, 0.8 percent of all construction projects goes to support research studies.

- A Global View: Exporting Technology by Licensing R & D Products

The French hold this point of view very strongly. Many developments by the French national laboratory LCPC are subsequently licensed for commercial use. Many products are jointly funded and developed.

- Implementation of Research

Dr. Sommer of the Austrian Cement Research Institute stated that implementation requires more effort than the original research. He believes that the researcher should guide the field implementation until the procedure is developed. This is an interesting concept which would develop a partnership between research and operations that is needed for implementation.

Engineering Expertise

Solid groups of experienced pavement engineers exist in most of the countries visited. It appears that it is the general practice for individuals to make their career in pavement engineering. The Belgium Road Research Center has an engineering group with many years of pavement engineering experience. The Technical University of Munich has a group of faculty and researchers that have worked in pavement research for many years and are at the forefront of pavement technology.

The French LCPC and SETRA have many experienced pavement engineers with careers dedicated to pavements. All French engineers in public works graduate from the same university. The French are clearly not satisfied with the status quo in pavement engineering. The French program of cooperative research was very impressive to the Study Tour. Many of these engineers have the ability to travel to international conferences and serve on international committees (e.g., PIARC and TRB).

Toll Road Financing and Engineering

The Study Tour was very impressed with the French toll road companies (COFIROUTE and SAPRR). France has depended heavily upon toll financing for the development of their rural motorway system. Currently toll rates are about 11 cents per mile or about 50 percent higher than the USA average toll rate.

The pavements were in very good condition and COFIROUTE and SAPRR appeared to make efforts to provide exceptional service to highway users. Feedback from users was obtained continually and was used to improve service levels. The toll agencies seek constant feedback from motorists on pavement condition, safety, and various service area aspects.

Therefore, they choose their pavement designs based on both cost and quality-of-service considerations. High-quality pavements mean a smooth, low-noise surface and a safe ride. Adequate funds are available to maintain these pavements in a very good condition and to construct pavements that will provide a long service life with low maintenance. These pavements are maintained in a better condition than pavements which are not on toll roads.

2.2 Implementation of Promising Technology in USA

The mission of the Study Tour includes the development of appropriate recommended actions for enhancing our nation's highway system, productivity and economic future. Those technologies and ideas that may show promise for implementation are summarized. in this section.

- Design-related Technology

✓ CRCP/Dowelled JPCP: Use a long design life (30-50 years) for heavily trafficked highways, especially near or in urban areas. Future disruption of traffic will increase congestion and accidents. Concrete mixtures can be designed and constructed with durable characteristics to last even longer than this time period. Note that this recommendation is also given in the 1986 AASHTO Design Guide for urban areas.

✓ JPCP/CRCP: Continue to refine procedures for determining long-term increases in truck volumes, axle loads, tire pressures and use of super single tires in pavement design. Within this decade the USA is likely to experience the types of truck loadings now seen on Europe's highways.

✓ JPCP/CRCP: Emphasis should be on the total pavement system, not just the thickness of the concrete slab. Concrete pavement design in the USA seems to focus on the slab thickness, which, based upon observations of European pavements, is not the most effective design. Actually, the facts show that concrete pavement slabs being built in Europe today are not thicker than in the USA. However, they do have several design features which more than adjust for the need for thicker slabs, including the following: thicker and more durable bases and subbases, bonding of treated bases to the slab, interlayers to prevent erosion, doweled joints clustered in wheel paths, widened traffic lanes, tied concrete shoulders, subdrainage and higher concrete strength.

✓ JPCP: Unique German concrete pavement design. This jointed plain doweled concrete pavements design has proven to give excellent performance in Germany for many years. This design should be tested in the USA to determine its cost, constructibility and performance. Actually, some pavements in the USA have many of the same design features as the German design and have performed well. However it is the details (such as the bonding of the slab to the lean concrete base after jointing the base) that often make or break the success of a design.

✓ JPCP/CRCP: Thick granular layer on subgrade beneath treated base. This layer has the following characteristics: 30-cm (12-in) thickness or greater depending upon subgrade soil stability, adequate thickness to protect against frost heave, and limited fines content to allow for some drainage through the layer. The philosophy in several European countries is that this layer should provide a certain minimum level of support that is the same for all pavement types (a field bearing test is used to determine adequacy). This plate bearing test is not exactly the same as the conventional test used in the USA. The minimum required modulus of elasticity as measured on top of the granular layer appears to require very good support on which the lean concrete base or CTB is constructed.

✓ JPCP/CRCP: **Catalog of designs.** The design catalog has achieved widespread popularity in Europe, probably for at least three main reasons. First is the improved communication of specific pavement designs to management, contractors, and agency construction personnel. Second, the designs in the catalog are often the result of a combination of both theoretical analyses using sophisticated procedures and programs, and engineering and construction experience. Third, the design catalog can be easily modified.

Another reason, especially valuable for concrete pavements, is that all of the details of the specific cross-section can be provided including all transverse and longitudinal joints, load transfer, reinforcement, tie bars, drainage, shoulders, etc. to reduce the potential of errors in construction. The exact type of catalog and its format for successful use in the USA must be carefully planned. Such a catalog would help all involved in pavements to focus on the best practices.

✓ JPCP/CRCP: **Provide adequate full-width concrete and base paving thickness for future traffic control needs during rehabilitation of pavement or bridges or emergencies.** Change the terminology from "shoulder" to "emergency lane" to reflect this design philosophy.

✓ JPCP/CRCP: **Use widened truck lanes.** The advantages of widening truck lanes by approximately 0.5 m (1.6 ft) include greatly reduced edge stresses to almost interior loading levels. This reduces transverse cracking and reduces corner deflections which cause erosion, faulting, and diagonal/corner cracks. The best structural design is to have both a widened traffic lane and an adjacent tied concrete shoulder/ emergency lane. Note that the paint strip must be placed 0.5 m (1.6 ft) from the edge of the slab to achieve the benefits of reducing critical edge loads by trucks.

✓ JPCP: **Joint designs to improve performance.** Several transverse joint design improvements are described below.

☛ Notch or joint and then bond the lean concrete or cement-stabilized base to the JPCP slab. The bonding of these layers provides a thick monolithic slab, which decreases flexural edge stresses, deflections, thermal curling, moisture warping and interlayer erosion leading to faulting.

☛ Varying dowel placement across traffic lane to concentrate on heavy truck wheelpaths to reduce costs.

☛ Short (5-m (16.54) joint spacing used for JPCP over treated bases.

☛ Required use of dowel bars to control faulting for heavy traffic. (These are already used by most agencies in the USA.)

☛ Plastic coating on dowels and center third of deformed tie bars, as done in Germany. Epoxy-coated dowels are used extensively in the USA; however, the plastic coating used in Germany appeared to be quite substantial.

✓ CRCP: Longitudinal reinforcement. CRCP has performed extremely well in Europe (Belgium, Spain, France) for many years and has been built recently in several other countries. Some reasons for its good performance:

☛ Increased steel (0.85 percent) has given excellent long-term performance on many projects in Belgium and a few projects in France (0.72 percent) and Spain (0.73 to 0.85 percent).

☛ Steel placed closer to the surface will hold cracks tighter and greatly reduce punchout development. This is the experience of European engineers and experimental sections in the USA have shown the same results.

☛ Rectangular, coilable steel strips (product name FLEXARM) should be tested in the USA to assess their advantages and performance. The steel percentage must be carefully designed for USA conditions.

✓ JPCP/CRCP: Two-layer slab construction. This is an economical design, especially where either a longitudinal brush texture or exposed aggregate surface is desired and suitable hard aggregates are very expensive, or where local aggregates are too soft to be used for the surface layer. The water/cement ratios of the two layers must be equal.

✓ JPCP/CRCP: AC layer between the concrete slab and a treated base if notching or jointing is not done. The purpose of this layer is to reduce erosion between the slab and treated base. This has been tried in the USA in at least one State and stripping of the AC layer occurred. However, more effective anti-stripping tests and remedies are now available. This alternative deserves consideration by agencies unwilling to notch and bond lean concrete bases to the slab.

✓ JPCP/CRCP: Trapezoidal cross-section. This design has had widespread use in two countries. It basically provides, for the same cost, an additional safety factor for structural fatigue. For example, if a four-lane divided freeway pavement design requires a 25-cm (10 in) slab thickness for the outer lane, providing a slab that varies from 22 mm to 28 cm (9 to 11 in) from the edge of the inner lane to the edge of the outer lane would provide considerably more structural reliability at the thickened longitudinal edge (28 versus 25 cm (11 versus 10 in)). The lanes must, of course, have adequate tie bars to hold the slabs together tightly and maintain good aggregate interlock

✓ JPCP/CRCP: Geotextile drainage fabric between slab and base. The performance of this interesting design is not documented yet. This was being placed in France between the CRCP and the existing dense aggregate subbase of an old AC pavement. The thick fabric is supposed to provide both a filter to inhibit fines movement and a permeable layer to remove moisture.

✓ JPCP/CRCP: Porous concrete base under shoulder. This alternative seems to be very practical and useful to help drain the pavement section. An appropriate drainage system must exist for the porous layer.

✓ JPCP/CRCP: Longitudinal edge drains connected to closed drainage system. This German system of drains provided for both surface water and subsurface water drainage.

✓ JPCP/CRCP: Ditch line a minimum of one meter from the bottom of the base. This design should reduce the amount of water in the base layer and at the top of the subbase.

✓ JPCP/CRCP: Solutions for bridge approaches. Two interesting solutions to the problems of excessive pavement end movement and settlements at bridges were observed.

☞ End lug to protect structure and AC transition surface layer that can be easily leveled up.

☞ Paving directly over the bridge deck where the bridge is designed for the extra dead load.

- Construction-related Technology

✓ Warranties for pavement construction work. While warranties ranging from one to nine years are being used in Europe for various aspects of pavement construction, there was not adequate information available to assess their impact. Much more specific information is needed about the details of these warranties. Implementation of warranties would need a long phase-in period in the USA.

✓ Construct straight cross slope with no crown across traffic lanes. This technique should provide improved rideability. A 2.5-percent slope, used in Europe, may improve surface drainage also.

✓ Liquidated damages = Incentives rate per day for a given construction project time limitation. Contractors felt that this was a fair specification.

✓ Prevention of joint reservoir sawing residue from entering joint. The practice of using a long rubber band stretched across the joint and squeezed into the first narrow cut appeared to be simple and effective.

✓ Two-layer paving equipment. Paving equipment capable of placing two separate concrete mixes with a single pass is available.

✓ Re-bar tubes placed behind vibrators for CRCP. This should improve positioning of bars, but needs further study.

✓ Lean concrete used for temporary widening for traffic control. The Berlin A10 project included a lean concrete traffic lane placed adjacent to the existing old concrete pavement to increase the number of traffic lanes during construction. This lane was ultimately recycled along with the rest of the adjacent older concrete after fulfilling its purpose. This technique may be cost-effective on some projects.

- Maintenance and Rehabilitation Related Technology

✓ Unbonded CRCP and JPCP concrete overlays of existing concrete pavements. Designs included fracturing the existing concrete (pieces less than 0.5 m (1.6 ft)) and placing an interlayer of one of the following: thin AC, lean concrete, or thick geotextile fabric. Excellent performance was achieved in several countries.

✓ JPCP and Fiberized concrete overlays of existing AC pavements. This is potentially a cost-effective long-term solution for badly cracked or rutted AC pavements. Construction procedures are standard for JPCP and performance has been good. Fibrous concrete overlays of AC pavements have worked well in Belgium.

✓ Complete recycling of concrete and other materials on the job site. This requirement may become standard practice in densely populated areas of the USA, as it currently is in some European countries due to environmental concerns (shortage of landfill space, etc.)

✓ Rehabilitate pavements at a higher condition level. European agencies appear to rehabilitate pavements at higher levels of condition than USA agencies. This may have significant user-related, economic, and structural benefits for the infrastructure over the long run.

✓ Lane reconstruction designs. The French and German designs are quite different but both have some very interesting features that should be of interest in the USA. Lane reconstruction would be useful on many USA pavements where only the outer one or two lanes are badly deteriorated.

✓ Lane replacement or addition for AC pavements. Replacement of an existing deteriorated AC pavement outer truck lane with concrete or construction of an additional outer lane with concrete pavement to serve heavy truck traffic has worked well in France and has applicability in the USA.

✓French LCPC/Freyssinet load transverse devices. Extensive research shows that this device is effective in restoring load transfer. The cost-effectiveness is unknown.

- Concrete Materials-Related Technology

✓ Improved concrete quality control for durability. The absence of concrete durability problems in Europe speaks for itself in comparison to the many durability problems from "D" cracking, ASR and freeze-thaw spalling in the USA. Further investigation is needed of the specific QC programs in various countries such as Germany, Austria and Switzerland which have colder climates. Rapid determination (within an hour) of the air void system using fresh concrete in Germany (using the Denmark equipment) was impressive, as well as Switzerland's determination of the air void system in hardened concrete from cores in 36 hours.

✓ Higher-strength concrete for pavements. Several European countries are routinely specifying higher-strength concrete. Belgium specifies a minimum compressive strength minimum of 55 MPa (7975 psi). This results in a typical mean of 70 MPa (10,150 psi) at 90 days. Typical flexural strengths have a mean of 7.5 MPa (1,087 psi) in third-point loading at 28 days. The extremely good long-term performance of these concrete pavements is due in part to their high strength.

✓ Thick porous concrete slab. A French technological forecasting committee concluded that a free-draining surface would be a major improvement due to its noise reduction, elimination of hydroplaning and storm runoff reservoir capabilities. At least one street has been built in Paris having a porous slab about 40 cm (16 in) thick Further research is needed.

✓ Recycling concrete that includes AC material. This technique would reduce the cost of recycling concrete back into concrete, particularly where an AC overlay exists over a concrete slab. Extensive research in Austria shows that a limited amount of AC is not detrimental to a concrete mixture. A few recycling projects containing AC particles have been completed in the USA.

✓ Lean concrete used for shoulders (or emergency lanes) and lane widening during traffic control. There many be several innovative uses 'for lower-strength and lower-cost concrete.

✓ Fibrous PCC (steel fibers). The thin fibrous concrete overlay of a rutted AC pavement in Belgium was impressive. Some of these have been built in the USA also.

• Surfacings-Related Technology

✓ Longitudinal light texturing for noise reduction. Several different longitudinal methods are being used that significantly reduce noise levels yet still provide adequate friction.

☞ Longitudinal texturing produced with a burlap drag and smaller top-sized aggregates produce low noise levels in Germany.

☞ Longitudinal texturing produced by a combination of brush and comb achieves both microtexture and macrotexture (initial grooves were 0.7 to 1 mm (0.027 to 0.039 in) deep), which produces low noise levels in Spain.

✓ Porous surfacings. These surfaces produce the lowest noise levels, give a smooth ride, eliminate splash and hydroplaning, and provide good friction capabilities, but their life is short and they clog with fines.

☛ Porous AC surface (with polymer) 4 cm (1.6 in) thick Many countries have used a porous AC surface for old and new concrete pavements. It has some significant disadvantages such as clogging, poor durability and black ice formation in winter.

☛ Porous concrete (with polymer) surface 4 cm (1.6 in) thick. This has been built in at least two countries. It also has the same clogging problem as the porous AC surface but may have a longer life.

✓ Exposed aggregate surface. A surface texture with low rolling noise and low vehicle vibration but high friction is achieved through the chemically exposed aggregate technique. This surface has been shown to have a long life. It can be accomplished most economically using a two-layer slab with smaller hard aggregates in the upper layer or a hard aggregate of somewhat smaller maximum size through the full slab depth.

✓ Diamond grinding surface for noise reduction (existing pavement). Longitudinal grinding reduces noise.

✓ Surface layer of epoxy/fine grained aggregate for noise reduction (existing pavement). An epoxy resin binder is applied to a hardened concrete surface, followed by a layer of crushed 3- to 4-mm (0.12- to 0.16-in) chromium ore slag, and the surface is then rolled to produce a mosaic-like structure with a low noise level.

✓ French double surface treatment (existing pavement). A thin surface consists of a spray of polymerized asphalt on the concrete surface, a layer of 1.4-cm (0.55in) chips, and then a layer of l-cm (0.4 in) chips placed with no compaction. This surface treatment reduces noise significantly.

- Research and Development Related Technology

✓ Closer government and industry cooperation. It is obvious that Europe benefits greatly from close cooperation between public and private organizations. Cooperation is growing in the USA. The existence of close working relationships among industry, State, and Federal officials is one of the reasons why this tour took place. Institutionally, the USA needs to keep the momentum going by supporting activities such as the AASHTO-ARTBA-AGC Joint Task Force; industry involvement in research and technology advisory efforts with TRB, NCHRP, and FHWA Technical Working Groups and Expert Task Groups; the University Transportation Centers; and expanded partnerships in research agreements through implementation of the Stevenson-Wydler Technology Innovation Act of 1980 (ISTEA Sec 6001).

The great benefit of close interaction between groups appears to be considerable innovation and practical results that actually get used on the highways because all concerned were involved in their development and have a stake in their success.

✓ Construction of selected European concrete pavement designs in the USA to evaluate constructibility, costs, and performance. Several highly promising candidates are available. Note that different surfacings could be tested for any of these designs. The design and construction of several innovative European sections is recommended.

☛ The German design for JPCP has provided many years of excellent performance. The construction of the German section in Michigan is fully supported and should lead to special attention to increase foundation support.

☛ The Belgian design for CRCP (with the higher steel content) has performed for over 20 years under heavy traffic with no punchouts.

✓ The French trapezoidal CRCP or JPCP design (one or two layers) has been used extensively for one- to two-lane replacements with good success.

✓ The Austrian JPCP design with two layers is being constructed on many heavily trafficked highways.

The SHRP SPS-2 effort might be employed for at least some projects.

✓ Accelerated field testing of concrete pavements. The French LCPC / Nantes circular test track is currently testing a variety of concrete slab designs. It is recommended that a task group be formed to determine the USA needs in accelerated performance testing of concrete pavements. After the testing needs have been identified, the task group should develop a proposal outlining the requirements and procedures required to meet these needs.

✓ Increased R & D budgets for pavements. Most European countries appear to be conducting more pavement research than the USA, as a percentage of total funding spent on the highway network The Strategic Highway Research Program (SHRP) was a recent step forward to increased funding for pavement-related R & D, and now the new 1991 highway bill (ISTEA) provides additional R & D for highway research. The increased expenditures for R & D through ISTEA in both HP & R funding and in the NCHRP program are also very positive movements. This trend towards increased funding for highway R&D needs to continue. It would behoove the pavement-related industries to make a very strong case for the needs and the benefits of pavement research in order to obtain a fair share of this funding. While much of the funding is related to federal investment, more private sector funding, industry partnerships and implementation of the previously mentioned Stevenson-Wydler Technology Innovation Act of 1980 (ISTEA Sec 6001) can help stretch the funds.

✓ Innovation, willingness, and eagerness to try new ideas. State and local highway agencies are complemented on their increased commitment to research and development in improving concrete pavements as are similar organizations in Europe. In addition, an increased effort needs to be made in the USA for innovation in all aspects of pavement engineering as is being done in countries like France.

✓ Global view: exporting technology by licensing R & D products. The French hold this point of view very strongly. Many developments by the French national LCPC laboratory are subsequently licensed for commercial usage. Many products are jointly funded and developed. FHWA's recent opening of foreign exchange programs with Europe and Asia are to be complemented. The joining of PIARC, especially, is much appreciated. To help the American economy, we must continue to develop a global view of the enormous benefits in developing improved pavement designs, construction specifications and techniques, equipment, maintenance and rehabilitation designs and especially improved materials.

✓ Implementation of research. It must be realized that the level of effort needed to implement any procedure or product developed under a research study is significant, and may be several times more than the original research study. The researcher should guide the field implementation along with a team of engineers from operations and industry until the procedure or product is working as intended. This concept could help develop a partnership between research and operations that is needed for successful implementation. The increased funding and recent reorganization of FHWA's office of Technology Applications is a very positive step forward, as is FHWA's general direction toward a more technology-centered mission.

- Improving Engineering Expertise

With the complex changes that have occurred in pavement engineering – rehabilitation strategies, new materials, life-cycle costs, user costs, weigh-in-motion data, remaining life concepts, increased and varied truck traffic, and now feedback from pavement management systems – it is obvious that the education of the country's next generation of pavement engineer needs to be restructured. Needs include:

✓ Improved pavement engineering education in colleges and universities.

✓ Additional short courses in all aspects of pavement engineering for practicing engineers and construction and maintenance personnel.

✓ Increased priority in public and private organizations for training their staff in pavement engineering and construction.

✓ Increased interaction of pavement engineers and construction personnel, within States, regionally, and nationally. Additional travel funds must be made available for this important activity.

✓ Establish at the national level a focal point for collecting information about developments in the USA and other nations in pavement technology, and distributing the information to pavement engineers, researchers, and the construction industry. This effort should include and could be based upon the continuing SHRP effort, and should include a broad-based advisory board.

2.3 Benefits to the USA of Implementing Some Innovative Technology

Looking for a moment at the BIG broad picture of the nation in the context of what the Study Tour experienced in Europe, the following thoughts about the benefits of implementing the above recommendations emerged from the Study Tour participants.

- Improved pavements will result in fewer lane closures for pavement repairs: reducing congestion and its associated problems (i.e., wasted time, delivery delays, accidents, air pollution, and fuel consumption).

- Improved pavements will result in fewer accidents, injuries and fatalities due to improved pavement surfaces and fewer lane closures, which always increase the potential for accidents.

- Improved pavements will improve environmental conditions for people living and working near highways due to reduced noise levels and reduced air pollution from less congestion.

- Improved pavements will increase driver and passenger comfort and decrease vehicle user costs due to smoother, quieter surfaces and also fewer traffic delays from lane closures.

- Improved pavements will provide in a much more efficient highway transportation system overall that will greatly contribute to economic growth and help to keep the USA competitive with Europe, Japan and other countries with highly efficient transportation systems.

Concrete pavements will play an important role in the continuing improvement of the nation's highway, street and airport system, especially in light of growth in truck and aircraft traffic volumes and weights. This is also the belief of many pavement experts in Europe. However, new and innovative technology and training is needed, along with implementation of these innovations, to provide improved designs, materials, construction quality and rehabilitation of these pavements. To that end this report is dedicated.