
FRANCE

# 3 COUNTRY SUMMARIES

This chapter provides summaries of the US TECH Study Tour of concrete pavements in France, Austria, Germany, Netherlands and Belgium. In addition, brief summaries of information obtained from presentations by representatives of Spain, Italy, Switzerland and Portugal are provided.

## 3.1 France

- Concrete Pavements in France

Concrete pavements have been used on the French freeway system since its beginning, starting with a few sections built from 1939 to 1960. The real growth dates from the 1960's when the "California" design was adopted with undowelled jointed plain concrete pavements (JPCP) placed on an erodible cement-treated base with no subdrainage. The rapid growth of heavy truck traffic in the 1970's (10 percent per year) led to problems with pumping, joint faulting and slab cracking. (Note that there is considerably more rainfall in France than in southern and central California.) These problems damaged the quality reputation of concrete pavements in France and limited their use. (1)

It should be pointed out, however, that a number of these pavements are still in service on various heavily trafficked freeways in France. The Study Tour traveled on several of these pavements, such as the 30-year-old section of the heavily trafficked A6, shown in Figure 3.1, built in the 1960's south of Paris (an outer lane has been added).

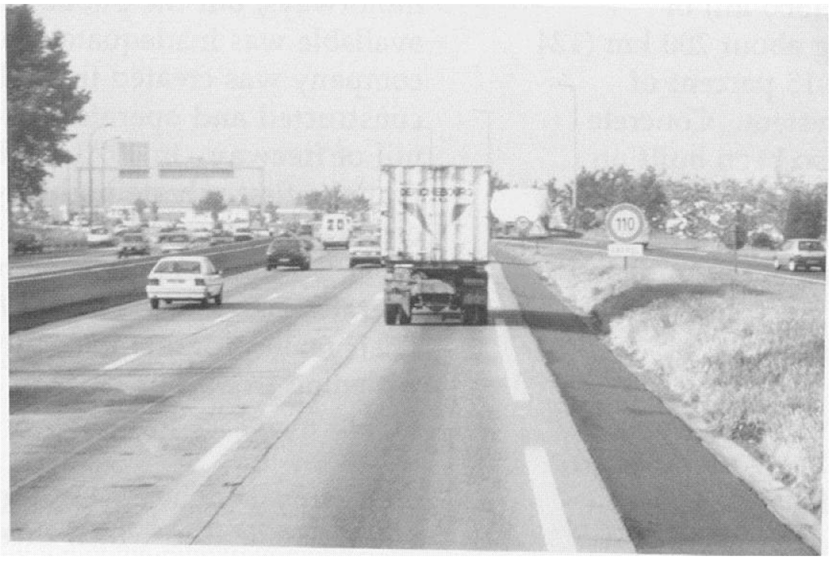


Figure 3.1 Thirty-year-old JPCP section of the A6 south of Paris. (Note added lane with widened edge.)

It should be noted that these JPCP have carried many times their original design traffic and have actually performed extremely well on that basis. For example, one undowelled, undrained JPCP section had received 17 million heavy commercial vehicles over a 12-year span before it was rehabilitated. These vehicles are more heavily loaded than in the USA: the legal single-axle limit is 13 metric tons (t) (28,700 pounds).

However, in France as in every country visited, this level of quality is not acceptable and there has been a continuing effort to improve this design. Through the years, French engineers, researchers, contractors and industry have worked hard to improve concrete pavement design, materials, and construction. Many innovative designs have been adopted as the result of this highly cooperative work

Concrete pavements today account for more than 900 km (560 mi) of freeways, including about 200 km (124 mi) of overlays, or 15 percent of France's freeway system. Concrete pavements have also been built on secondary roads and airports. This share is growing steadily. Currently 30 percent of the pavements completed each year on the French freeway system are concrete. (2)

All of the early pavements were JPCP, and these are still being constructed with modified designs. However, CRCP has become very popular in certain areas of France. CRCP was first constructed in France in 1983 and now France has over 550 lane-km (342 lane-mi) of CRCP freeways. CRCP has been used in rebuilding over 100 km (62 mi) of truck lanes on existing concrete and AC highways. It has also been used on airports. (1)

- **French Toll Road Companies**

One of the most significant aspects of the French highway system is the eight toll road companies that build and operate 6,000 km (3,730 mi) of major freeways (7,000 km (4,350 mi) total). Seven of these are semi-private (over 50 percent of the shares are owned by the government) and one is private (owned by several contractors). The Study Tour was hosted by two toll road companies: Societe des Autoroute Paris-Rhine-Rhone (SAPRR), a semi-public company, and Compagnie Financiere et Industrielle des Autoroutes (COFIROUTE), a private company. In the 1960's there was a great need to build the proposed 4,000-km (2,580) nationwide network of motorways, but the public funding available was inadequate. The SAPRR company was created in 1961, and has constructed and operates 1300 km (808 mi) of freeway. In 1970, COFIROUTE, France's first private highway concessionary company was created. COFIROUTE has now constructed and operates 730 km (454 mi) of freeways. Their main program currently is widening from four lanes to six lanes due to increases in traffic.

The Study Tour was very impressed with the extent to which these toll road companies are vitally concerned with providing the highest quality service to users and are constantly seeking to improve service levels. They 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 very good condition and to widen and construct pavements that will provide a long service life with low maintenance. These pavements appear to be maintained in better condition than pavements which are not on toll roads.

- **Designs**

A comprehensive design catalog was published in 1988 for the standard design of pavements in France. This catalog provides alternative designs based upon traffic level and foundation support. France has designed and constructed two general types of concrete pavements: JPCP and CRCP.

Original JPCP Design. The original 1960's design for JPCP had two major flaws: it did not include adequate load transfer at the joints and the cross-section was a bathtub with no subdrainage. Due to very large truck axle loadings (13-t (28,652pound) single-axle loads), large numbers of loadings and a wetter climate than California, these pavements developed pumping, faulting and then cracking.

Design Modifications to JPCP. To eliminate the above problems, major design changes have been made over the years.

✓ The cross-section was modified to a trapezoidal section so that a thicker slab is on the outer edge of the truck lane as illustrated in Figure 2.3, while the amount of concrete material and cost are not increased. The truck lane was widened so that loads do not roll along the edge causing high bending stresses and high corner deflections.

✓ An erosion-resistant lean concrete base (7-8 percent cement) is also placed under the slab and longitudinal drainage of various types is placed along the edge joint.

✓ Load transfer at transverse joints was improved through use of dowels, shorter joint spacing (4 to 5.5-m (13 to 18 ft)) and/or a thicker slab. Most of these pavements have not been built with dowel bars as France has used dowels only on selected projects.

The above JPCP designs have been used on new construction as well as major reconstruction of existing lanes on freeways. For example, the very heavily trafficked Al freeway originally had an undowelled JPCP without drainage that required rehabilitation after 12 years and 17 million heavy trucks (one lane).

In 1976 this pavement was partially reconstructed as shown in Figure 2.3. This new pavement had carried some 35 million trucks on the most heavily loaded lane by 1988, or more than twice its design traffic. Pumping developed gradually on this pavement until 1988 when the subdrainage system was found to be completely clogged. (7)

Another example of a heavy-duty lane reconstruction included dowelled joints on the A6 freeway in 1985.

An example of a JPCP built in 1978 was a thick concrete slab (39 cm (15.5 in)), no subbase, a geotextile drain placed over the subgrade, and short joint spacing (4.5 m (15 ft)). After 14 years of traffic, this pavement is performing well. France considers this a good design for routes with less than 1500 trucks per day.

A very important issue in France is the wearing surface of the pavement. Several types of surfaces have been constructed for reducing noise, increasing friction, and reducing hydroplaning, including stone chips on the fresh concrete surface, an exposed aggregate finish, a thin surface layer of porous asphalt, a thin double layer surface treatment, and some porous concrete surfaces. These are described under Surfacings.

Hot-pour polymerized asphalt and preformed compression seals are used for JPCP joints. Joints are generally skewed 1:6 counterclockwise to allow wheels on the left, far from the outer slab edge, to hit the joint first.

Design of CRCP. The design varies in thickness depending on current truck traffic and subgrade soil modulus. Either a 15-cm (6-in) lean concrete base or a 5-cm (2-in) AC layer is used directly beneath the CRCP. In addition, a thick layer of select granular material or cement-stabilized soil is usually placed beneath this base layer. Total width paving for a freeway is 8 m (26.5 ft), two traffic lanes including 0.5-m (1.6ft) widening of the outer lane. Tied concrete shoulders (sometimes lean concrete) were observed on many highways. Some CRCP are constructed with a trapezoidal cross-section having varying thickness across two lanes. Some examples:

New freeway pavement = 19 to 25 cm (7.5 to 10 in) (thicker for heavier trucks observed)

New (truck) lane widening = 31.5 cm (12.5 in) observed on one section

Overlay placed on old JPCP = 180 cm (7 in) minimum

Overlay placed on old AC = 16 cm (6.5 in) minimum

Deformed longitudinal reinforcing bars (diameter 1.6 mm (0.63 in)) with a yield of 590 MPa (71,000 psi) have been used in the past. The steel percentage is 0.67 percent and is placed at a depth of 8 cm (3 in), about one third of the slab thickness, which helps greatly in holding the cracks tight. This design has resulted in very tight cracks with few punchouts. Transverse reinforcement is also used to tie the lanes together. One bar (l- to 1.4-cm-diameter (0.4 to 0.55 in)) is placed per meter (3.3 ft).

The shoulder is either AC with a pervious aggregate base or a porous concrete base, or tied lean concrete placed on a non-woven geotextile drainage layer (at least 5 mm (0.2 in) thick). Longitudinal drainage is provided at the edge of the slab to prevent erosion.

The French have several ways to treat the CRCP ends at bridges: provide expansion joints, roughen the surface of the subbase to promote high bonding, or if the bridge is designed for the extra weight, placement of the CRCP directly over the bridge deck (4)

The SAPRR toll road company does a 25-to 30-year life-cycle cost comparison among pavement types. About one half of the time concrete wins and the other half asphalt wins, depending on traffic and soils conditions.

New Reinforcement for CRCP. Due to the length of the construction train and the complexity of bar reinforcement placement, the possibility of using long coilable reinforcement was considered to reduce the length of the construction train and the labor required for steel connection. A photo of a construction site using coilable reinforcement is given in Figure 2.6.

Research in France had shown that it was critical for the concrete to bond to the steel to keep cracks tight, and this led to the idea of developing reinforcement which would have as large a surface area as possible in contact with the concrete, thus increasing bond. This led to flat reinforcement which had the advantage of being coilable for ease in transporting and in construction. The result was the development of coilable strips with high bond to concrete and a high yield strength.

This reinforcement has been used in France since 1988 for several major freeway projects under the commercial name of FLEXARM. (4) 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, corrugated by hammering both sides, and a surface which is corrosion-proofed by continuous hot galvanization. It is supplied in coils of 360 or 500 m (1180 or 1640 ft), and joined in the field by rapid pneumatic riveting. Advantages reported by users include a shorter work zone, increased construction productivity and associated decreased duration of the work, the ability to pave one lane of CRCP at a time, and improved safety. The Study Tour viewed two sections of the A6 freeway constructed with FLEXARM (discussed later in this report).

- Research Underway at LCPC Nantes

A national research project is underway at the LCPC Nantes laboratory on concrete pavements that includes a combination of public and private organizations (IREX). This research approach appears to be a model of cooperation to achieve the maximum of innovative and practical results for the funds spent. Research topics include design, crack control, porous concrete, and roller-compacted concrete. Three-dimensional finite element techniques are being used for developing structural designs (CESAR).

The thick porous concrete slab concept is under development. This is defined as a porous concrete base surfaced with a free-draining concrete layer having a total thickness of 40 cm (16 in). This pavement substantially reduces traffic noises and acts as storm reservoirs for runoff water in urban areas. This design is highly promising for urban highways and streets, but they must be maintained to prevent clogging. (1) One project was reported to be constructed in Paris for drainage and splash control.

The LCPC Nantes Test Track experiment is a major part of this national research project in concrete pavements. (li) The Study Tour observed the large test track (shown in Figure 2.17) in operation and saw some of the early results obtained. One million loads per month can be placed on the concrete pavements and with three separate tracks, testing can be maintained while new sections are constructed. Loads from 8 to 18 t (17,600-39,700 pounds) can be placed on single or dual tires. The current experiments underway include JPCP with and without dowels, lean concrete base (not bonded), aggregate base, geotextile layer for drainage and lean concrete as a slab. Some cracking of sections has occurred. The lower-strength lean concrete section has shown considerable fatigue cracking. This was an impressive experiment.

- Rehabilitation

French research has developed several types of pavement monitoring equipment. The Gerpho (similar to PASCO) takes 35-mm continuous strip photos of the pavement for visual distress. The APL provides longitudinal profile and also joint faulting. The LaCroix Deflectograph measures deflection. The SCRIM device measures friction. The latest equipment development is the SIRANO (profile, 35-mm film, and macrotexture, at a speed of 72 km/hr (45 mi/hr)) which was used to test 5500 km (3,415 mi) in 1991.

A comprehensive evaluation is conducted to determine the need for and design of pavement rehabilitation. A policy of prevention is encouraged, by which rehabilitation action is taken as soon as fatigue damage (cracking) is observed.

Several different rehabilitation alternatives have been used in France to rehabilitate the original JPCP built with no dowels.

Restoration of Load Transfer. Lack of adequate joint load transfer and poor subdrainage led to pumping, faulting and cracking of the original JPCP. The placement of shear devices, the latest version called LCPC / Freyssinet connectors, at transverse joints has extended the life of some projects. A description of this device is given under Project Sites Observed.

Lane Replacement or Addition with New JPCP. This technique has been used extensively in the Paris region for existing JPCP freeways. See discussion and typical designs described under Design and shown in Figure 2.1.

**Lane Replacement or Addition with New CRCP.** SAPRR stated that they expect continued large increases in trucks with the coming of-the EC and therefore, have constructed several projects involving the replacement of the outer traffic lane, originally AC pavement, that is used almost exclusively by heavy trucks. Because of serious deterioration in these outer lanes, they. began either rebuilding them or adding a new lane using CRCP. One site visited is described under Project Sites Visited. (6)

**CRCP overlays.** Many CRCP overlays have been placed on existing JPCP pavements. A description of one such project is given under the section titled Project Sites Visited. This alternative has performed very well.

**JPCP Overlays on AC Pavement.** Several experimental overlays were placed in the 1970's and have reportedly performed very well after many years. Their typical slab thickness was 21 to 25 cm (8.5 to 10 in), and the joints are typically spaced at 4.5 m (15 ft) and are undowelled. These projects carry 600 to 1000 trucks per day in one lane. The new JPCP overlay is placed directly on the old pavement, or onto a leveling course of lean concrete. (7) Others have been placed since that time.

- **Surfacings**

As in other European countries, pavements with low noise, high friction and smooth ride are extremely important in France. A good macrotexture is considered important in France, where the objective is a texture depth of more than 1 mm (0.04 in) by the sand patch test. The method of transverse grooving of the surface of the fresh concrete with a brush or tine is no longer used. Detailed descriptions of these techniques are given under Project Sites Observed.

**Porous Asphalt Surface.** Many concrete pavement sections have been overlaid with a porous asphalt layer to reduce noise, improve rideability, increase friction and reduce hydroplaning. COFIROUTE, for example, has constructed many porous AC surfaces and also a porous concrete surface on concrete pavements.

**Double Surface Treatment.** A thin surface called a double layer has been 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.

**Exposed Aggregate Surface.** France also uses an exposed aggregate technique similar to that used in several other countries. It is used with concrete containing aggregates that are not readily polishable. This may require two-layer construction where the two layers are placed simultaneously. The surface is sprayed with a retarder and then covered with a sheet of polyethylene to protect it from drying out and from the weather. After 24 hours the sheet is removed and the surface is scrubbed dry to expose the aggregate by removing the surface mortar. The surface is then covered with a conventional curing compound. The surface provides low noise, good rideability, and good friction characteristics. (4)

Porous Concrete. A slurry of cement, polymer additive, filler (limestone) and water is mixed and then added to the crushed hard aggregate (4 to 6 mm (0.16 to 0.23 in)). This mixture is poured onto the concrete slab placed not more than two days previously, at a thickness of 3 to 4 cm (1.2 to 1.6 in), using a finisher with a vibrating compacting plate. During this operation, some of the slurry settles to the bottom of the layer bonding it to the concrete slab. Porous concrete surfaces have worn well, with no significant stripping of surface aggregate. (4)

- Concrete Materials and Construction

The concrete pavements observed did not have any durability problems for concrete as old as 30 years. High-quality concrete is achieved in France through three steps:

(1) Aggregate properties optimized to minimize void content (continuous gradation),

(2) Water and plasticizer used to achieve workability, and

(3) Entrained air and cement contents selected for best strength.

After that, work at the job site must be performed well. Batch plants and continuous mixture plants are used.

The following are mean values for some large projects:

| | |
|---|---|
| Slump: | 5-8 mm (0.2-0.3 in) |
| Air content: | 5.0 percent |
| Modulus of rupture: | 5.2 MPa (754 psi) at 56 days, standard deviation 0.6 MPa (87 psi) |
| (Third-point loading | 3.6 MPa (522 psi) at 7 days, standard deviation 0.4 MPa (58 psi) |

Concrete recycling has been successfully done on several projects in France since 1976. (9)

Two-layer construction is done to provide a hard aggregate in the top surface. A description is given under Surfacings.

Contractors must warranty pavement projects for varying lengths of time: typically one year on the national highway system but longer on the freeway system. AC pavement is warranted for four to five years, concrete for seven to nine years and the various surfacings for five years for friction, cracks, spalls, etc. If problems develop, the contractor must repair the pavement over the warranty time period.

- Project Sites Observed

The US TECH Study Tour traveled extensively on the French freeway system, especially in the general vicinity of Paris and south. Several project sites were observed.

A10 CRCP Widening Project (COFIROUTE Toll Road). This highway carries 35,000 ADT and is being widened from 4 to 6 lanes as shown in Figure 2.11. This AC pavement was constructed in 1972, was overlaid in 1982 and again overlaid in 1989. The existing shoulder material was removed by milling down to the subbase, which was crushed limestone aggregate 30 cm (12 in) thick After replacing any weak areas the material was recompacted, a thick geotextile fabric layer was then placed, reinforcing steel was placed on chairs and finally the 31.5cm-thick (12.4 in) CRCP was slipformed. The fabric is a two-layer system with a filter fabric as the lower layer and a more permeable fabric as the top layer to control pumping.

The CRCP was 3.8 m (12.5 ft) wide and contained 24 bars with a diameter of 2 cm (0.8 in). The percentage of steel (0.63 percent) is based on the split tensile strength of the concrete. A photo of the steel layout on the fabric is shown in Figure 3.2 Also note the thick limestone aggregate subbase. The new CRCP lane included a 0.3 m (1 ft) extra widening. The steel was placed 9 cm (3.5 in) from the surface on chairs and transverse steel was also included, as shown in Figure 3.2. The higher placement of steel is considered important in keeping the transverse cracks tight.

Figure 3.2 CRCP lane addition on the A10 south of Paris.

After one year of service, the same CRCP in the other direction has tight cracks with a mean spacing of 0.8 m (2.6 ft). This CRCP lane will be surfaced after about one year with a porous AC layer for low noise and good rideability.

The concrete mixing plant operation was observed. The plant was unusual in that it was a continuous-mix type of plant that produced 200 cubic meters (262 cubic yards) per hour. Air entrainment and plasticizer were used in the mix. Six samples were tested each day for air content, slump and compressive strength. This contract includes a four-year warranty on design and performance.

A71 CRCP Project (COFIROUTE). This project demonstrates the optimum use of aggregates in two-layer construction, the provision of an exposed aggregate surface with low noise and high friction characteristics, the accuracy to which reinforcement placed in tubes can be placed for a unique setup for the vibrators, and the construction of a trapezoidal cross-section. The CRCP was constructed in 1986 and consisted of a 7.85m-wide (25.75 ft) trapezoidal cross-section (two traffic lanes with the outer lane widened) varying from 18 cm (7 in) at the passing lane edge to 20 cm (8 in) at the truck lane edge. Deformed longitudinal steel (1.6 cm diameter (0.63 in)) was 0.66 percent of the cross-sectional area. The depth to the top of the steel was 8 cm (3 in), or 0.42 of the slab thickness. The CRCP rested on a 5-cm (2-in) AC layer on a 35-cm (14in) cement-treated sand layer. (3)

The CRCP slab was placed in two layers using specially designed equipment, separately vibrated in a single pass where the two layers did not mix. The top 5 cm (2 in) included hard aggregates (l-l.4 cm (0.4-0.55 in)) that give a low-noise, high-friction macrotexture. These aggregates had to be hauled a long distance and were expensive. The process to achieve the exposed aggregate surface is the same as that used in Belgium and several other countries. The bottom layer used local limestone aggregates for economy. Many cores were taken and the splitting tests showed an excellent bond between the layers. A substantial cost savings was achieved using the two-layer approach. (3)

The steel was placed using tubes on this project. The position of the tubes and vibrators are as shown in Figure 2.9 where the tubes extend almost to the front edge of the pan, which may improve the placement depth of the steel. Results of measurements show that the steel placement was excellent, with a mean depth to top of steel of 8 cm (3 in) and a standard deviation of only 8 mm (0.3 in). (3)

Figure 3.3 shows the widened lane CRCP with an AC shoulder (widening was 0.7 m (2.3 ft) from the inside edge of the paint stripe to the edge of concrete). The transverse cracks were closely spaced and very tight and the surface showed an excellent macrotexture. The longitudinal joint between the CRCP and AC shoulder was sealed with a polymerized asphalt sealant placed as an overband. This was performing very well after six

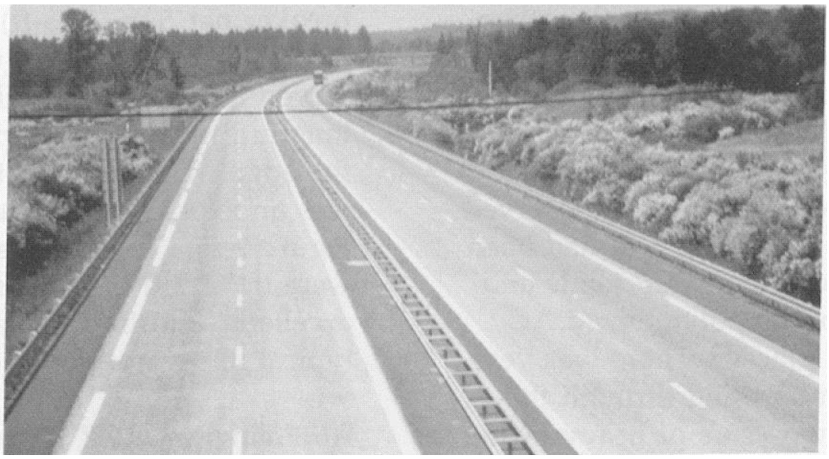

Figure 3.3 CRCP on the A71 trapezoidal cross-section with widened lanes.

years. Shoulders were 2 to 4 cm (0.8 to 1.6 in) of porous asphalt over 27 cm (10.6 in) of porous concrete. The section also has longitudinal edge drain under the lane/shoulder joint.

A6 Freeway LCPC/Freyssinet Load Transfer Device. This pavement was an undowelled JPCP constructed in 1958-60, with a 25-cm (IO-in) slab on a 15-cm (6-in) CTB. The Freyssinet device is used to restore high load transfer in the transverse joints of undowelled JPCP. These undowelled joints exhibit poor load transfer, which leads to faulting and cracking of the original slab plus deterioration of reflection cracks in an AC overlay. These devices were developed by LCPC and Freyssinet International and 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.

A Freyssinet device placed in a transverse joint or crack is shown in Figure 2.12. Four devices are placed per joint if no pumping exists and six are placed per joint if pumping exists. They are placed using special equipment at a rate of 100 per hour. Devices are installed when joints are open so the device is always in compression. They consist of two symmetrical half-shells in cast iron, a steel key which slides in a housing machined in the half-shells, and a central elastomeric sleeve providing water tightness to the unit and bonding the half-shells to the concrete pavement. The wheel load is transferred from one edge of the joint or crack to the other with high efficiency: from the concrete to one half-shell through bonding with epoxy resin, from one half-shell to the other via the key, from the second half-shell to the concrete by epoxy resin bonding. They carry a five-year warranty. (8, 12)

Two sections on the A6 were observed where the Freyssinet devices had been placed in the original JPCP joints and then a thin porous polymerized AC surfacing was placed. There was very little reflection cracking through the surface after two years of heavy traffic. The company warranties that very little cracking will occur in five years.

**Porous Asphalt Surfacing on CRCP.** The Study Tour traveled over several sections of CRCP that had been overlaid with porous asphalt. These surfaces provided low-noise and good friction and there were no reflection cracks. Areas in France where there are only soft aggregates presents a problem as to finding hard aggregate for the surfacings. One project tried to seed the hard aggregate onto the plastic concrete surface, but it resulted in a rough ride. Placing the porous asphalt surface permits the use of local, lower-cost aggregates in the slab.

**A6 Freeway CRCP Overlay With Bar Reinforcement (SAPRR Toll Road).** Several CRCP overlays exist along the A6. One CRCP overlay containing conventional bars was placed in 1986 over an old JPCP (constructed in 1964), as shown in Figure 3.4. The design was as follows: 18-cm (7-in) CRCP with 0.67 percent steel and 18-cm (7-in) lean plain concrete shoulders, with transverse joints at 6 m (20 ft), placed on the fractured 25-cm (lo-in) JPCP over a 15-cm (6 in) cement-treated base. The existing slabs were fractured by three to four drops of a guillotine breaker per 5-m (16.5ft) slab. An existing asphalt surface treatment served as the bond breaker. A longitudinal drain was placed along the edge. The surface of the CRCP was an exposed aggregate as shown in Figure 215. The transverse cracks were tight and the pavement was in excellent condition. This overlay is typical of several observed.

**A6 Freeway CRCP With Surface Treatment (SAPRR Toll Road).** Some CRCPs had received a surface treatment called a double layer to improve the rideability. The performance of these appeared to be very good. The surface treatment consisted of a spray of SBS polymerized asphalt on the concrete surface, a layer of 1.4-cm (0.55 in) chips, and a layer of l-cm (0.4 in) chips.

**A6 Freeway CRCP With 0.30 Percent FLEXARM Reinforcement (SAPRR).** A nearby section of CRCP overlay identical to the previous one (with conventional reinforcing bars) contained the new rectangular steel strips called FLEXARM, placed in 1988.

Figure 3.4 A6 freeway CRCP overlay with bar reinforcement (SAPRR Toll Road) and lean concrete shoulders.

The CRCP contains 0.30 percent steel placed in two close but staggered layers and was constructed in near-freezing conditions. The crack spacing was longer than usual and some of the cracks were spalling and had opened slightly. One explanation for the spalling was that it was caused by the surface treatment. However, the longer crack spacing may also be a major factor as well as the amount of rectangular steel.

A6 Freeway CRCP With 0.34 Percent FLEXARM Reinforcement. This is a nearby section of CRCP overlay constructed in 1990, identical to the previous one with FLEXARM contained 0.34 percent steel content to reduce crack spacing. This pavement had a closer crack spacing, tighter cracks and no spalling. This steel content is currently being used on other projects.

A6 Freeway CRCP With 0.72 Percent Bar Reinforcement. This was the first CRCP placed in France, in 1983. It is a 20-cm (S-in) overlay that has performed with no structural deterioration under heavy traffic. This pavement had the highest steel content used in France.

The steel depth is 8 an (3 in), closer to the surface, which has helped to keep cracks tight. However, the original finished surface and soft aggregate polishing required that a surface treatment be placed. The Study Tour was able to observe the outer 0.5 m (1.6 ft) edge along the CRCP which was not covered by'the surface treatment. The transverse cracks were closely spaced and extremely tight. The local engineers stated that this was the best CRCP ever built in France.

A6 Freeway Old JPCP. A long stretch of 25-an (10-in) JPCP with an added traffic lane was observed. The added lane included a widened outer edge as shown in Figure 3.1. (Note that this is the same cross-section described under the section on Design with the cross-section shown in Figure 2.3). This original pavement is one of many that dates from the 1960's, and the lane reconstruction was done in the 1970's or 1980's.

- Traffic Loadings

Traffic loadings are heavy in France, where the legal single-axle load limit is 13 metric tons (t) (28,700 pounds). Truck volumes in the outer lane range from 5,500 trucks per day to an astounding 10,500 on the Al. (2) Most of these trucks have super-single tires also. The typical ADT on the SAPRR toll roads is 20,000 with 20 percent trucks.

- French Research Program

The LCPC Nantes Test Track experiment is a major part of this national research project in concrete pavements. (11) The Study Tour observed the large test track in operation and saw some of the early results obtained as discussed under the section "Research Underway at LCPC Nantes." The Study Tour participants were impressed with this experiment.

The French are clearly not satisfied with the status quo in pavement engineering. The French program of cooperative research conducted over many years was very impressive to the Study Tour participants. The SETRA and the national laboratories of LCPC have many experienced pavement engineers with dedicated careers in pavement engineering.

The national research study on concrete pavements appears to be an ideal example of the close working relationships 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 cooperation to be considerable innovation and results that actually get used on the French highway system. Presentations made to the Study Tour included a combination of engineers from the French government, private contractors, corporations and the semi-public toll roads.

As an example of how to obtain innovation, SETRA recently requested research needs statements which have resulted in some innovative proposals which they hope to fund.

- **Summary for France**

Concrete pavements have been constructed in France on some of its most heavily trafficked freeways and airports over the past 30 years. France has worked very hard to improve the design, construction, and rehabilitation of concrete pavements for many years. Many innovative ideas have been developed over the years, such as load transfer devices, rectangular steel for CRCP, subdrainage, construction warranties, low-noise high-friction surfacings, lane widening designs, and the trapezoidal cross-section. The strong efforts to bring together public and private organizations to work towards the solution of concrete pavement problems has had a major effect on the success of their research programs actually impacting design and construction practice.

The French stated 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." (5) It appears that the French are committed to a major research effort to improve concrete pavement technology.

The selection of a concrete pavement is usually the result of a life-cycle cost analysis over a 25- to 30-year period. When concrete can be constructed with a local aggregate, it is usually cheaper than AC. However, limestone is not good for the surface, which should contain a harder aggregate.

"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."(10)

In designing new concrete pavement today, the French would usually put SMA or a surface treatment on the surface to improve friction and smoothness, although the exposed aggregate surface is favored by many. There is very little snow in the Paris area, which is why SMA or porous asphalt does not get bladed off. Also, the two-layer pavement with the exposed aggregate surface is performing well.

The engineering philosophy of the French toll roads is very impressive with regard to their efforts to provide the highest quality of service to users. The excellent quality of their pavements speaks for itself.

It was stated at the Nantes LCPC research laboratory that a long life (more than 30 years) is expected from concrete pavements for two reasons: mechanical resistance to traffic (no rutting and control of fatigue damage) and ability to resist environmental problems. Truck traffic is expected to continue to increase greatly in France.

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