
SWITZERLAND
PORTUGAL
ITALY
SPAIN

3.6 Other Countries (Spain, Portugal, Switzerland, Italy)

Due to travel and time constraints the US TECH Study Tour could not visit all of the countries in Europe that are building concrete pavements. The countries of Spain, Portugal, Switzerland and Italy, among others, have built concrete pavements to varying degrees. A representative from each of these countries graciously agreed to make a presentation to the Study Tour in Dusseldorf, Germany. In addition, a representative of CEMBUREAU, a cement industry association which represents 19 countries, gave a presentation on the use of cement and concrete pavements in Europe. A summary of only the key points of their brief presentations follows.

- Spain

Early Concrete Pavements. The first concrete pavement in Spain was built in 1915. A few concrete pavements were built thereafter until the 1960's when a few dowelled JPCP pavements were constructed. The first was a section of dowelled JPCP near Madrid in 1963 having a 25-cm (9.8 in) slab thickness, a sand base and 5 and 6 m (16.4 and 19.7 ft) joint spacing. This pavement gave good performance for many years until it was widened and overlaid in 1981. (1)

In 1968 the first freeway JPCP was constructed near the 1963 project with doweled joints spaced at 6 m (19.7 ft), a 25-cm (9.8 in) slab thickness, a 15-cm (5.9-in) CTB and a 10-cm (3.9-in) sand cement subbase. The shoulders were AC. All joints were sealed with neoprene compression seals. The traffic level is now about 5000 trucks per day in each direction and the ADT is 80,000. This section is still in good condition, having carried over 30 million trucks in each direction with no significant structural distress.

California JPCP Design. In 1971, extensive construction began using slipform pavers and the "California" JPCP undowelled pavement was adopted by the toll roads. Over 700 km (440 miles) of two-lane one-direction freeways of this pavement had been constructed up to 1985, mostly by toll roads. These pavements were generally 25 cm (9.8 in) thick, had skewed joints, and 15 cm (5.9 in) of CTB. A nonplastic granular material was placed under this layer in areas of poor subgrade. No subdrainage pipes were placed. AC shoulders had a granular base. Heavy traffic on these pavements resulted in pumping and faulting, followed by cracking which has caused considerable roughness.

Design modifications made in the late 1970's included thicker slabs, trapezoidal sections (24 to 28 cm (9.4 to 11.0 in)), reduction of joint spacing (3.7-4.6-4.0-4.3 m (12.1-15.1-13.1-14.1 ft)), lean concrete base, cement-stabilized granular base for the AC shoulder, and slotted longitudinal pipe for subdrainage. This pavement design has performed well and faulting is not significant.

Current Design Catalog. For heavy truck highways (800 trucks per day in the design lane), due to the availability of automatic dowel inserters, and to provide more reliability against faulting, the conclusion has been reached that dowels must be used. This is now standard practice in Spain. Contractors are now equipped with automatic dowel insertion equipment. The cross-section is trapezoidal and the thickness depends on the truck traffic and subgrade support. A design catalog is available that specifies the following slab thicknesses:

First Year Trucks per lane per day	Trapezoidal Slab Thickness
> 2,000	26-30 cm (10.2118 in)
< 2,000	23-27 cm (9.1-10.6 in)

A 15-cm (6in) base, usually lean concrete, is specified for either case. If the subgrade CBR exceeds 20 percent no granular subbase is required. If the subgrade CBR is between 10 and 20 percent, a 20-cm (7.9 in) granular subbase layer is required. If the subgrade CBR is less than 10 percent the soil is unacceptable and must be replaced. (1)

Dowels (2.5cm (l-in) diameter) in a plastic tube are clustered in each wheel path (18 dowels spaced over two traffic lanes with six dowels in the outer wheel path spaced every 30 cm (11.8 in)). Transverse joint spacing is 5 m (16.4 ft), perpendicular to the centerline, and sealed in wet areas but not sealed in dry areas. Longitudinal joints are sealed in all pavements and include tie bars. (1)

Concrete for Slab and Base. Concrete containing crushed limestone as the coarse aggregate 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) in third-point loading. Lower-strength concrete can be used but the slab thickness must be increased. Blended cements containing flyash are used in the concrete (38 percent) and lean concrete base (50 percent). A large cost reduction was obtained by the government for these blended cements. The water/cement ratio is between 0.44 and 0.50, slump is between 2 and 4 cm (0.8 and 1.6 in), and plasticizers are used in drier mixes.

The lean concrete or cement-treated bases must have a minimum compressive strength of 8 MPa (1143 psi) at seven days; or alternatively not less than 12 MPa (1714 psi) at 90 days for slower-strength-gaining mixtures. To prevent reflection cracks from the base to the slab, a plastic sheet is laid on top of the base.

Curing Compounds. The high temperatures and low relative humidity in Spain have made it necessary to use high-quality curing compounds based on organic resin solutions.

Joint Sawing. The extreme temperature gradients prevalent during construction produce high curling stresses. It is necessary to saw the longitudinal joint at the same time as the transverse ones instead of delaying its cutting which is the usual practice. All of the joints need to be cut the same day the concrete is placed.

More than 800 km (500 miles) of two-lane, on-direction freeways have been constructed with this general design. These pavements are performing very well in Spain.

CRCP Design. CRCP was constructed on one long section in northern Spain in 1975. This section has carried very heavy traffic (ADTT exceeding 5,000). Two traffic lanes are 7.5 m (24.6 ft) wide, 22 cm (8.7 in) thick, with a 16-cm (6.3-in) CTB, and a 22-cm (8.7-in) granular subbase. The amount of reinforcement was 0.85 percent. One test section had 0.73 percent with no change in the pattern of cracking. The steel was placed on chairs. The performance of the CRCP has been excellent and has required very little maintenance work Recently, other CRC pavements have been constructed. The design catalog allows a thickness reduction of 4 cm (1.6 in) from JPCP. (1)

Surface Texture. Many surface texturing techniques have been used in Spain, ranging from burlap to tining. Longitudinal texturing produced by a combination of brush and comb achieves both a microtexture (with the brush) and a macrotexture (with the comb), whose initial grooves are about 1.5 mm (0.06 in) deep. However, in the latest construction project a less rough texture is sought: 0.7 to 1 mm (0.03 to 0.04 in). Measurements of friction and rolling noise taken after several years of operation demonstrated that these procedures have given excellent results. (1)

Roller-Compacted Concrete. This material is defined as a homogenous mixture of aggregate, water and cement which is laid in similar fashion to CTB, although its cement content is similar to that of regular concrete pavements. Over 4 million square meters (4.78 million square yards) of roller-compacted concrete pavement have been constructed in Spain since 1970 on low- and high-volume roads, widening, and overlays.

Roller-compacted concrete requires no specialized equipment and enables the road to be immediately opened to traffic after compaction. This is particularly beneficial for overlays. Surface unevenness problems require an 8- to 10-cm (3.1- to 3.9-in) AC overlay for higher-speed pavements. The RCC ranges from 22 to 25 cm (8.7 to 9.8 in) and the soil cement base is 20 cm (7.9 in) thick Lighter roads require thinner layers.

Joints are now provided at 7- to 10-m (23- to 33-ft) intervals to try to reduce reflection cracking through the AC layer. One section recently constructed near Madrid had a joint spacing of 2.5 to 3.5 m (8.2 to 11.5 ft). After two years and over 1 million trucks, only 0.5 percent of the cracks have reflected through. (1)

Traffic. Truck traffic in Spain on freeways ranges from 1000 to over 5000 ADTT in one direction. The legal axle load limit in Spain is among the highest in the world: 13 t (28,600 pounds) for a single axle and 21 t

(46,300 pounds) for a tandem axle. The most recent weigh-in-motion data have shown 4 percent of axles above the legal limit, with some loadings of 20 t (44,000 pounds) on a single axle and 30 t (66,000 pounds) on tandem axles.

Spain Reference

1. Jofre, C., "Spanish Practice and Experience With Concrete Pavements," paper presented to the US TECH Study Tour in June, 1992.

- Portugal

Concrete pavements were constructed in Portugal during three time periods:

✓ 1935-1945, when 70 km (43 miles) of heavily trafficked routes were constructed with concrete. These are are all still in service.

✓ 1945-1965, when some concrete pavements were constructed on military bases. In 1965 the first prestressed pavement in the world was constructed at Beja NATO airfield.

✓ 1965 on, when construction of the national network of highways began. Because of increased axle loads and increased traffic, concrete pavements are very competitive with asphalt pavements. The design life used in Portugal is 30 to 40 years. From 1986 to 1992 about 130 km (80 miles) of concrete pavements (mostly JPCP) were constructed. This was 10 percent of the total highway mileage constructed, and included the first JRCP and CRCP. Concrete paving blocks are also used in Portugal.

It is expected that about 20 percent of the major highways will be constructed of concrete.

The current JPCP design used in Portugal is a 23-cm (9.1 in) slab with 15 cm (5.9 in) of CTB. The current JRCP design is a 20-cm (7.9 in) slab and a 15 cm (5.9-in) CTB. The longitudinal reinforcement is 0.06 percent area.

- Italy

The past (that brought about the present): Ancient Rome was the center of an extensive 80,000 km (50,000 mi) network of roads that crossed many countries. The first link to the south was the ancient Via Appia (or Appian Way) that radiates out from the center of Rome. Construction of the Via Appia began in 312 B.C., and it is still being used today after 2,000 years, as shown in Figure 3.20. The Via Appia has been called the "most famous road ever built in any age or any clime."(3)

"The prestige of the Via Appia has continued to grow with each succeeding century because of the excellence and durability of its construction." (3)

Grooves from ancient wheels were observed on some of the stones. The original surfacing layers are gone, and the existing surfacing consists of fairly large stones imbedded in the foundation. This pavement is up to 10.7 m (35 ft) wide with curbs on both sides.

Figure 3.20 Via Appia Roman road, built 312 B.C., south of Rome (note that the truck is parked off the main road).

"In the most advanced stage of its improvement, Via Appia was built by first excavating a trench in the natural soil down to a solid foundation. The earth was tamped with beetles and covered with a light bedding of sand or mortar upon which were laid four main courses:

(1) The 'statumen' layer of large, flat stones 25 to 60 cm (10 to 24 in) in thickness;

(2) Next the 'rudus' course of smaller stones mixed with lime, some 23 cm (9 in) thick;

(3) The 'nucleus' layer, about 30 cm (12 in) thick, consisting of small gravel and coarse sand mixed with hot lime; and

(4) On this fresh mortar was placed the 'summa crusta,' or wearing surface, of flint-like lava, about 15 cm (6 in) deep.

The total thickness of the four courses described above varied from 0.9 to 1.5 m (3 to 5 ft). The massive solidity of this thick roman cross-section was standard practice for more than 2,000 years until superseded by Macadam's light wearing surface in the nineteenth century." (3)

Although these roads were built primarily for military purposes, it is hard to imagine the long-term thinking that went into building such incredibly thick and durable pavements to carry the traffic that existed at the time.

Some interesting axle weights:

✓ Maximum Roman axle load for slow freight wagons: 0.7 t (1,436 pounds) (3)

✓ Recommended wagon axle load by Telford in 1819 (England):!' 1.8 t (4,000 pounds) (3)

✓ Current legal axle load in USA 9.1 t (20,000 pounds)

✓ Current legal axle load in some European countries: 13 t (28,652 pounds)

One historian stated that "As early as the eulogy of Appius Claudius the building of the Via Appia was put on the same plane as military victories or political deeds." Another historian stated, "The Roman engineers had a clear idea of the true value of the road and of false economy in materials and labor, and their technique has not been excelled until quite recent years."

These ancient Roman roads that were built over many parts of Europe must have had an influence on modern day Europeans as to the value of making a substantial investment in a quality highway infrastructure that will provide service for long time periods without disruption.

The present: JPCP without dowels and JRCP were built in Italy from 1950 to 1975. One heavily trafficked JRCP was observed in Rome by a Study Tour member, a four-lane highway (the modern Via Appia) constructed in 1950 (42 years old). The pavement has a 20-cm (7.9-in) thick slab, 12 m (39 ft) joint spacing, and was observed to be in fair condition with joint spalling and some deteriorated transverse cracks. Some joints had been repaired with concrete. The concrete is very dark because it contains a dark igneous rock Expansion joints had been cut in the pavement which allowed nearby cracks and joints to open up and deteriorate.

Traffic. On Italian highways, trucks are typically 25 to 30 percent of ADT. Axle load distributions from the weigh-in-motion scale on the Al freeway near Rome for singles and tandems are given in Figure 3.21. The measured maximum single axle load is 14 t (30,900 pounds), the tandem axle limit is 29 t (63,900 pounds), and the triple axle limit is 39 t (86,000 pounds).

The Autostrade toll road company has recently developed a design called Polyfunctional Composite Pavements (PCP). (1) This design consists of the following:

✓ 4 cm (1.6 in) porous asphalt surface
✓ 22 cm (8.7 in) CRCP (12.8 m (39 ft) wide with two longitudinal joints)
✓ 20 cm (7.9 in) CTB
✓ 20 cm (7.9 in) granular layer

PCP Al Project. Two major PCP projects were constructed in 1988 on the Al and the Al2 near Rome, both of which have very heavy truck traffic (approximately 5,000 trucks in one direction). The crack spacing in the CRCP was reported to be 1.2 to 2.5 m (3.9 to 8.2 ft). This section has three lanes in one direction and the CRCP slab is 12.8 m (42 ft) wide with two longitudinal joints. One key aspect is that the two longitudinal joints are spaced so as not to be in the wheel paths of trucks, so that truck wheels usually produce interior loads.

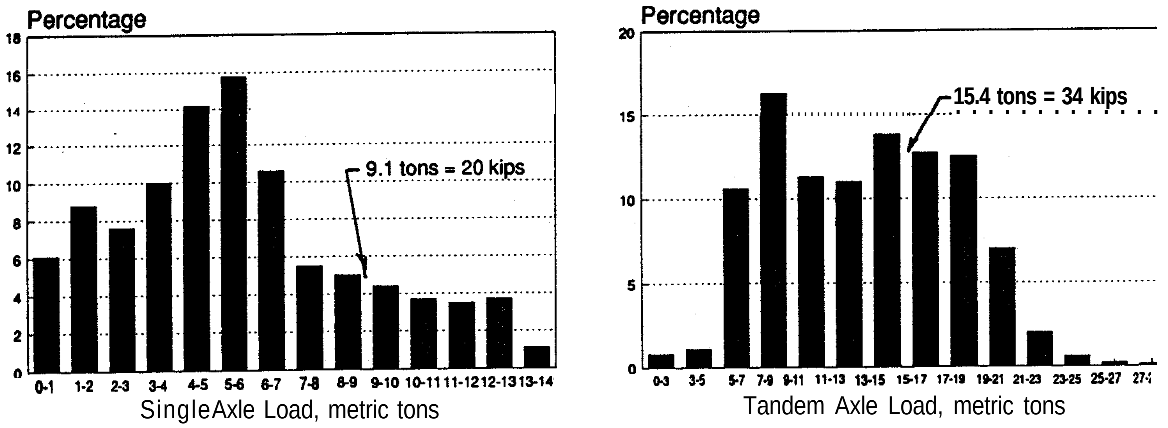

Figure 3.21 Italian axle load distributions measured near Rome on freeway system.

Also, the CRCP continues on 1.8 m (5.9 ft) beyond the painted edge stripe to eliminate any edge loading. At this point, a porous concrete base begins to provide for drainage. This pavement has a 2.5 percent cross-slope. No cracks or any other distress were observed after four years of service. The porous asphalt surfacing provides a very quiet ride. There is a noticeable difference (about 3-4 dB) between this surface and a conventional AC surface that exists on the next section of the Al.

Concrete properties measured on the Al CRCP project are as follows: (2)

✓ Mean flexural strength at 28 days: 8.3 MPa (1186 psi)

✓ Mean compressive strength at 28 days: 56.5 MPa (8072 psi)

✓ Water/cement ratio: 0.42

This design has the following advantages: (1)

- ✓ Eliminates hydroplaning,
- ✓ Eliminates tire spray,
- ✓ Good friction resistance,
- ✓ Low emission of tire/pavement noise,
- ✓ Smooth ride,
- ✓ Waterproofing of cracks in CRCP,
- ✓ Resistance to fatigue due to interior loadings, and
- ✓ Easier maintenance (surface replaced at seven years)

It is expected that about every seven years the porous AC will need to be milled off and replaced due to clogging from fines or other problems. The total structural design life is 40 years.

Cost Comparison. A cost comparison of the PCP versus the conventional semi-rigid pavement that has an AC surface over lean concrete or CTB was given as follows, where R equals the ratio of the cost of the PCP divided by the cost of the semi-rigid pavement:

Item	R
Construction	1.30
Maintenance	0.30
User costs	0.55
Total life-cycle costs	0.87

Italy References

1. Camomilla, G. and A. Marchionna, "P.C.P. Polyfunctional Composite Pavements," Technical Report, Autostrade Central Maintenance and Research Division, Rome, Italy, 1991.

2. Marchionna, A., et al., "Cement Concrete Characteristics for Road Pavements, Practical Experience with the Polyfunctional Composite Pavement," Proceedings: 6th International Symposium on Concrete Roads, Madrid, Spain, 1990.

3. Rose, A. C., "Public Roads of the Past - 3500 B.C. to 1800 A.D.," AASHTO, Washington, D.C., USA, 1952.

. Switzerland

Switzerland has a 70-year tradition in building concrete pavements. Several existing concrete pavements were shown to the Study Tour. A design catalog is available that was developed using the AASHTO design procedure and varying the subgrade and traffic level. A manual for concrete pavement design and construction practices dated 1992 will soon be available. It was reported that concrete pavements require about 20 percent less electrical energy for lighting than AC pavements due to the lighter surface. JPCP, CRCP and prestressed pavements have been constructed in Switzerland.

Example Project. The main runway at Basal airport was built in 1956 and was rehabilitated in 1986. Slabs were replaced during the night and opened to traffic at 5 A.M. with about 4.5 hours of curing time. The central keel section (24 m ((79 ft) wide by 2600 m (8530 ft) long) was completely replaced over a three-week period. This required only one week of complete closure for all traffic and then night work for two weeks where some heavier aircraft were restricted from using the runway during the day.

Concrete Durability. The key aspect of the Switzerland presentation was their quality control program to achieve high durability. Since 1965, highways in Switzerland have been deiced using large amounts of chemical deicing salts. This has increased the durability requirements for concrete pavement. Existing pavements at that time suddenly developed damage from scaling as well as concentrated disintegration of the concrete paste structure.

The durability of the concrete was improved by increasing the quantity of air voids, graded according to size and uniform distribution in the cement paste. The measurement of the total content of air voids of the fresh concrete was not sufficient for the evaluation of frost and salt durability. They believe that only an appropriate testing method applied to the hardened concrete can give valid information. (1)

The total air content should never be less than 4.5 percent of total mix volume. However, during placing, consolidating and finishing of concrete the total pore fraction, pore distribution, and pore size in the hardened concrete may be affected. Therefore, rapid and practical procedures were developed to examine these in the hardened concrete for construction projects. 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. The complete quality control process is as follows:

✓ Laboratory tests are conducted a few months before the project begins. Several concrete mixes are prepared to develop a mix design of high durability. The aggregates are submitted to quality control: grain shape, repartition, porosity, cracks, content of mica and impurities are checked. Attention is paid to the bond quality between aggregates and cement paste. The suitability of the selected air-entrainment agent is checked and the proper dosage determined. The air void system, size, quantity and distribution in the cement paste are measured. (1)

✓ Trial run tests take place two or 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 working conditions. The concrete is mixed, hauled and placed in two or three trial slabs that are constructed on site. Several test cores are obtained as soon as possible and tested in the laboratory. These results are compared to those obtained from the previous laboratory results and any adjustments needed are made to the mix or construction process. (1)

✓ During the first few days of construction, cores are taken from the pavement and tested in the laboratory. A microscopic analysis is again conducted to ensure 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 method). (2)

If the air void system is inadequate, the surface of the concrete is impregnated with an agent (3). These quality control procedures have led to the elimination of frost-salt durability problems in concrete pavements in Switzerland.

Switzerland References

1. Wilk, W. and G. Dobrolubov, "Microscopic Quality Control of Concrete during Construction," Bulletin of Betonstrassen AG, Concrete Roads Ltd., Wildegg, Switzerland, July/ September 1981.

2. Dobrolubov, G. and B. Romer, "Guidelines for determining and testing the frost as well as frost-salt resistance of cement-concrete," Bulletin of Betonstrassen AG, Concrete Roads Ltd., Wildegg, Switzeriand, June 1985.

3. Wilk, W., "The development of quantitative and qualitative microscopic control of concrete quality and durability," paper presented at the 6th International Conference on Cement Microscopy, March 26-29, 1984, Albuquerque, New Mexico, USA.

4 ACRONYMS, DEFINITIONS, AND TECHNICAL TERMS

AASHTO
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ACPA
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Phone (708) 3945577

F H W A
Federal Highway Administration
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Washington, D.C. 20590
Phone (202) 366-0660

PCA
Portland Cement Association
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Phone (708)966-6200

SHRP
Strategic Highway Research Program
818 Connecticut Avenue, N.W.
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TRB
Transportation Research Board
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Washington, D.C. 20418
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Definitions/Technical Terms

PCC - Portland cement concrete
AC - Hot-mixed asphalt concrete
RAP - recycled asphalt concrete (used in recycled concrete)
LCB - lean concrete base
CTB - cement-treated base
JPCP - jointed plain concrete pavements (with or without dowels)
JRCP - jointed reinforced concrete pavements
CRCP - continuously reinforced concrete pavements
dB(A) - noise emission level in decibels
US TECH - U.S. Tour of European Concrete Highways
NCHRP - National Cooperative Highway Research Program (USA)
LCPC - Laboratoire Central des Ponts et Chaussees - Central Laboratory of Bridges and Roads in France
CEMBUREAU - European cement association
BAST - Bundesanstalt fur Strassenwesen (Federal Highway Research Center in Germany)
ISTEA - Intermodal Surface Transportation and Efficiency Act of 1991 (USA highway legislation)
R & D - research and development

Common SI (modern metric) conversion units used in this report:

t - metric ton (1 t = 2204.62 pounds)
MPa - megaPascal (1 MPa = 145 psi)