Monitoring of European Concrete Pavements

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As part of the European Concrete Pavement Evaluation System (COPES) program, 77 concrete pavement sections from France, Italy, the United Kingdom, and Belgium are being monitored and the data evaluated with the objective of providing continual improvements to the design, construction, and maintenance of concrete pavements. An overview of the data collected under the European COPES program is presented, and a general look at overall performance trends is provided. The European sections are all characteristic of the wet-freeze environmental region. Because of higher legal axle weights and longer design periods, European pavements are often exposed to many more equivalent-single-axle-load applications than pavements in the United States. Of the sections evaluated, the most common pavement type is jointed plain concrete pavement. Extensive use of stabilized bases, positive drainage features, and dowel bars is also evident. A qualitative analysis was conducted using present serviceability rating (PSR), age, and traffic as the principal parameters. The use of lean concrete bases and incorporation of a greater number of modernity elements (e.g., dowel bars and positive drainage) were found to improve the performance of the sections. Models predicting the PSR of the pavement sections were also developed.

Under the auspices of the Technical Committee on Concrete Roads of the Permanent International Association of Road Congresses (PIARC), several European countries have been monitoring the performance and behavior of their concrete pavements. The ultimate purpose of this monitoring is to obtain feedback on concrete pavement performance so continual improvements can be made in design, construction, and maintenance.

This interest in monitoring pavement performance parallels a similar interest that has developed in the United States over the last 10 years. For example, the Concrete Pavement Evaluation System (COPES) report, developed at the University of Illinois, not only documented concrete pavement data collection and monitoring procedures but also developed several prediction models for the development of concrete pavement distresses (*1*). Portions of that work served as a building block for the long-term pavement performance studies launched by the Strategic Highway Research Program (SHRP) in 1987 and now being administered by FHWA. In addition, FHWA has sponsored several research studies evaluating the performance of concrete pavements and has shared that data with the European community and with PIARC in particular.

An initial evaluation of performance data from 53 European concrete pavement sections has been conducted, and the results presented at the 19th World Road Congress held in Marrakech in 1991 (*2*). Since that time, additional sections have been incorporated into the study, and further evaluation is being conducted as part of a comprehensive FHWA study on concrete pavement performance, Performance Evaluation of Experimental Rigid Pavements–Data Collection and Analysis. An analysis of the data provides information to PIARC and the participating European countries that may be useful in future concrete pavement design and construction activities. Furthermore, because the European sections contain some unique design features (e.g., widened lanes, thickened slabs, and trapezoidal cross sections), pavement design engineers in the United States may also find this information useful.

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MONITORING PROGRAM

PIARC has been conducting the pavement monitoring of European concrete pavements in accordance with the aforementioned COPES procedures. It has also included involvement with and cooperation from FHWA and University of Illinois researchers.

Participating Countries

France, Italy, the United Kingdom, Belgium, Switzerland, and Germany are participating in this cooperative study. However, only 77 concrete pavement sections representing four countries are currently available:

- France—29 sections,
- Italy—6 sections,
- United Kingdom—17 sections, and
- Belgium—25 sections.

These sections represent pavements with a range of design features, including widened lanes, trapezoidal cross sections, and nonerodible bases. Roughly one-half of the sections are more than 10 years old, and many are subjected to very heavy traffic loadings. Although most pavement sections are jointed plain concrete pavements (JPCP), several jointed reinforced concrete pavement (JRCP) and continuously reinforced concrete pavement (CRCP) sections are included.

Data Collection

The data collection activities followed the procedures in the original COPES report (*1*). The data can be broadly classified into the following categories:

- Section identification data,
- Pavement design data,
- Distress data,
- Roughness data,
- Patching data,
- Environmental data, and
- Traffic data.

The data were first collected by the participating countries using the International System of Units (SI) and European terminology. Once the data were prepared for entry into an electronic data base, the units were converted to English equivalencies and American terminology to be compatible with the COPES format.

Range of Design Features

The European COPES data base includes a variety of pavement sections in terms of design, age, and traffic. A summary of the design features and performance data for the European COPES sections is given in Table 1. In general, the design practices in Europe do not appear to vary drastically from one country to another, and in many ways, the designs are similar to those in the United States. The following sections illustrate the range of design features encountered in the European COPES sections.

Pavement Type

Of the 29 pavement sections from France, all but one are JPCP designs. The one reinforced pavement section is a JRCP with 0.06 percent longitudinal reinforcing steel. The Italian data consist of four JPCP sections and two JRCP sections with 0.06 percent longitudinal reinforcing steel. One pavement section from the United Kingdom is a JRCP with 0.12 percent longitudinal reinforcing steel, and the other 16 sections are JPCP. The Belgian data consist of 14 JPCP sections and 11 CRCP sections, the latter containing longitudinal reinforcing steel ranging from 0.63 to 0.85 percent of the cross-sectional area.

Overall, the predominant pavement type among the European COPES sections is JPCP. The JPCP sections make up 80 percent of the sections evaluated. The JRCP sections make up only 5 percent of the sections, and the remaining 15 percent are CRCP. All CRCP sections included in the European COPES program are from Belgium.

Joint Spacing

All but two of the JPCP sections from France have joint spacings of either 4.5 or 5.0 m (14.8 or 16.4 ft). Interestingly, the lone JRCP section has a joint spacing of only 5.0 m (16.4 ft). For Italy, the joint spacings are 5.0 m (15.7 ft) for the four JPCP sections and 12.3 m (40.3 ft) for the two JRCP sections. For the United Kingdom, 11 JPCP sections have 5.0-m (16.4-ft) joints spacings and five JPCP

TABLE 1 Summary of Design Features and Performance Data

Country	Project	Highway	Year Built	Slab Design	Lane Width	Joint Spacing	Dowels	Base Type	Reinf Steel	Drainage	Shlder Type	Age	ESALs, x 10^6	PSR
France	55001_01	A6	1981	280 mm JPCP	3.75 m	5.0 m	None	150 mm LCB	None	Edge	AGG	5	26.5	3.5
France	55001_02	A6	1986	280 mm JPCP	3.75 m	5.0 m	20 mm	200 mm PCTB	None	Edge	AGG	3	29.3	2.0
France	55001_03	A6	1980	280 mm JPCP	3.75 m	5.0 m	None	150 mm LCB	None	Edge	AGG	9	52.3	4.0
France	55001_04	A6	1983	250 mm JPCP	3.75 m	5.0 m	None	200 mm LCB	None	None	AGG	6	52.4	4.5
France	55002_01	85	1986	200 mm JPCP	3.5 m	4.8 m	None	120 mm ATB	None	Porous AGG	ST	3	1.5	3.5
France	55002_02	85	1986	230 mm JPCP	3.5 M	4.8 m	None	220 mm ATB	None	Porous AGG	ST	3	2.8	3.5
France	55003_01	N6	1985	200 mm JPCP	3.5 m	4.8 m	None	150 mm ATB	None	Porous AGG	AGG	4	2.2	3.0
France	55003_02	N6	1985	200 mm JPCP	3.5 m	4.0 m	None	150 mm ATB	None	Porous AGG	AGG	4	2.2	3.0
France	55003_03	N6	1985	200 mm JPCP	3.5 m	4.8 m	None	250 mm ATB	None	Porous AGG	AGG	4	2.2	4.0
France	55004_01	N57	1987	370 mm JPCP	3.5 m	10.0 m	None	500 mm AGG	None	Porous PCC	AGG	2	0.9	3.5
France	55004_02	N57	1987	220 mm JPCP	3.5 m	5.0 m	25 mm	150 mm LCB	None	Porous PCC	AGG	2	0.9	3.5
France	55005_01	A42	1983	260 mm JPCP	3.5 m	5.0 m	None	150 mm LCB	None	Porous PCC	AC	6	5.9	3.3
France	55006_01	A1	1977	280 mm JPCP	3.5 m	5.0 m	None	200 mm LCB	None	Porous PCC	AC	9	15.2	3.5
France	55006_02	A1	1977	490 mm JPCP*	3.5 m	5.0 m	None	None	None	Porous PCC	AC	11	43.1	3.5
France	55006_03	A1	1964	275 mm JPCP*	3.5 m	5.0 m	None	200 mm CTB	None	None	AC	22	24.6	2.5
France	55006_04	A1	1976	280 mm JPCP*	3.5 m	5.0 m	None	210 mm CTB	None	None	AC	10	36.3	3.5
France	55007_01	A6a	1960	260 mm JRCP	3.5 m	5.0 m	25 mm	100 mm SC	0.06%	Transverse	AC	26	21.2	1.5
France	55008_01	26	1983	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	AC	6	9.2	4.0
France	55008_02	26	1983	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	AC	7	5.6	5.0
France	55008_03	26	1981	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	AC	9	9.0	4.0
France	55008_04	26	1981	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	PCC	9	9.2	5.0
France	55008_05	26	1982	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	AC	8	8.4	4.0
France	55008_06	26	1982	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	AC	8	8.4	4.0
France	55008_07	26	1985?	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Edge	AC	8	4.2	4.0
France	55008_08	26	1985	370 mm JPCP	3.5 m	4.5 m	None	250 mm AGG	None	Yes	AC	5	6.8	4.0
France	55008_09	26	1985	370 mm JPCP	3.5 m	4.5 m	None	250 mm SC	None	Yes	??	5	6.8	??
France	55009_01	4	1976	290 mm JPCP	3.5 m	5.0 m	None	150 mm CTB	None	No	AC	10	3.3	3.5
France	55009_02	4	1976	220 mm JPCP	3.5 m	5.0 m	None	150 mm CTB	None	No	AC	10	3.3	3.5
France	55010_01	A13	1966	250 mm JPCP	3.5 m	5.0 m	None	250 mm CTB	None	No	AC	20	22.5	2.5
Italy	56001_01	SS7	1958	220 mm JRCP	5.25 m	12.3 m	28 mm	250 mm Pozz	0.06%	No	AC	31	62.3	2.5
Italy	56001_02	SS7	1958	220 mm JRCP	5.25 m	12.3 m	28 mm	250 mm Pozz	0.06%	No	AC	31	62.3	2.5
Italy	56002_01	E45	1985	260 mm JPCP	3.5 m	5.0 m	30 mm	150 mm LCB	None	Edge	PCC	4	7.8	2.8
Italy	56002_02	E45	1985	250 mm JPCP	3.5 m	5.0 m	30 mm	200 mm CTB	None	Edge	PCC	4	8.0	2.8
Italy	56002_03	E45	1985	260 mm JPCP	3.5 m	5.0 m	30 mm	150 mm CTB	None	Edge	PCC	4	8.0	2.4
Italy	56003_01	21	1971	240 mm JPCP	3.75 m	5.0 m	None	160 mm CTB	None	None	AC	18	0.9	1.0
UK	57001_01	M20	1972	275 mm JPCP	3.65 m	6.0 m	20 mm	150 mm AGG	None	Edge	AC	16	52.2	2.3
UK	57001_02	M20	1972	275 mm JPCP	3.65 m	6.0 m	20 mm	150 mm AGG	None	Edge	AC	16	52.2	2.3
UK	57002_01	M25	1979	305 mm JPCP	3.65 m	5.0 m	20 mm	225 mm AGG	None	Edge	PCC	9	55.7	2.3
UK	57002_02	M25	1979	305 mm JPCP	3.65 m	5.0 m	20 mm	225 mm AGG	None	Edge	PCC	9	55.7	2.3
UK	57003_01	A2	1973	250 mm JPCP	3.65 m	6.0 m	20 mm	150 mm CTB	None	Edge	AGG	14	40.4	1.2

(continued on next page)

TABLE 1 (continued)

Country	Project	Highway	Year Built	Slab Design	Lane Width	Joint Spacing	Dowels	Base Type	Reinf Steel	Drainage	Shlder Type	Age	ESALs, x 10^6	PSR
UK	57003_02	A2	1973	250 mm JPCP	3.65 m	6.0 m	20 mm	150 mm CTB	None	Edge	AGG	14	40.3	1.2
UK	57004_01	A12	1987	280 mm JPCP	3.65 m	5.0 m	20 mm	130 mm CTB	None	Edge	PCC	2	10.8	4.5
UK	57005_01	M25	1976	275 mm JPCP	3.65 m	5.0 m	25 mm	150 mm AGG	None	Edge	PCC	12	106.4	1.2
UK	57005_02	M25	1976	275 mm JPCP	3.65 m	5.0 m	25 mm	75 mm AGG	None	Edge	PCC	12	106.4	1.2
UK	57006_01	M1	1981	300 mm JPCP	3.65 m	5.0 m	20 mm	225 mm LCB	None	Edge	PCC	7	27.3	3.4
UK	57006_02	M1	1982	300 mm JPCP	3.65 m	5.0 m	20 mm	150 mm LCB	None	Edge	PCC	6	24.2	3.4
UK	57007_01	M11	1975	275 mm JPCP	3.65 m	5.0 m	25 mm	150 mm CTB	None	Edge	AC	14	39.7	2.3
UK	57008_01	A12	1971	250 mm JPCP	3.65 m	5.0 m	25 mm	150 mm CTB	None	Edge	??	18	39.5	3.4
UK	57008_02	A12	1971	250 mm JPCP	3.65 m	5.0 m	25 mm	150 mm CTB	None	Edge	??	18	39.5	1.2
UK	57008_03	A12	1969	250 mm JPCP	3.65 m	6.0 m	30 mm	150 mm LCB	None	Edge	??	20	47.8	3.4
UK	57008_04	A12	1965	200 mm JRCP	3.65 m	25.0 m	30 mm	150 mm LCB	0.12%	Edge	??	24	62.0	3.4
UK	57009_01	A120	1982	250 mm JPCP	3.65 m	5.0 m	25 mm	230 mm CTB	None	Edge	??	7	8.3	??
Belgium	58001_01	411	1979	200 mm CRCP	3.75 m	n/a	n/a	150 mm LCB	0.85%	Edge	AC	11	29.5	3.5
Belgium	58001_02	411	1979	200 mm CRCP	3.75 m	n/a	n/a	200 mm LCB	0.85%	Edge	AC	11	29.5	3.5
Belgium	58001_03	411	1973	200 mm CRCP	3.75 m	n/a	n/a	200 mm LCB	0.85%	Edge	AC	17	37.6	3.5
Belgium	58001_04	411	1978	200 mm CRCP	3.75 m	n/a	n/a	200 mm LCB	0.67%	Edge	AC	12	17.9	3.5
Belgium	58001_05	411	1987	200 mm CRCP	3.75 m	n/a	n/a	200 mm LCB	0.67%	Edge	AC	3	6.2	4.5
Belgium	58001_06	411	1988	200 mm CRCP	3.75 m	n/a	n/a	200 mm CTB	0.67%	Edge	AC	2	3.6	4.5
Belgium	58002_01	4	1979	230 mm JPCP	3.75 m	5.0 m	None?	150 mm CTB	None	Edge	AC	10	30.8	3.0
Belgium	58002_02	4	1979	230 mm JPCP	3.75 m	5.0 m	None	150 mm CTB	None	??	AC	10	30.8	3.0
Belgium	58002_03	4	1979	200 mm JPCP	3.75 m	5.0 m	25 mm	150 mm CTB	None	Edge	AC	10	30.8	3.0
Belgium	58002_04	4	1979	200 mm JPCP	3.75 m	5.0 m	25 mm	150 mm CTB	None	Edge	AC	10	30.8	3.0
Belgium	58002_05	4	1979	200 mm JPCP	3.75 m	5.0 m	25 mm	150 mm CTB	None	Edge	AC	10	30.8	3.0
Belgium	58002_06	4	1979	200 mm JPCP	3.75 m	5.0 m	25 mm	150 mm CTB	None	Edge	AGG	10	30.8	3.0
Belgium	58002_07	4	1979	200 mm JPCP	5.0 m	5.0 m	25 mm	150 mm CTB	None	Transverse	AC	10	30.8	3.0
Belgium	58002_08	4	1979	200 mm JPCP	4.0 m	5.0 m	25 mm	150 mm CTB	None	??	AC	10	30.8	3.5
Belgium	58002_09	4	1979	230 mm JPCP	4.0 m	5.0 m	None	150 mm CTB	None	??	AC	10	30.8	3.0
Belgium	58002_10	4	1979	230 mm JPCP	4.0 m	5.0 m	None	150 mm CTB	None	??	AC	10	30.8	3.0
Belgium	58002_11	4	1979	230 mm JPCP	4.0 m	3.5 m	None	150 mm CTB	None	Edge	AC	10	30.8	3.0
Belgium	58002_12	4	1979	200 mm JPCP	4.0 m	5.5 m	25 mm	150 mm CTB	None	??	AC	10	30.8	3.0
Belgium	58002_13	4	1983	200 mm CRCP	3.75 m	n/a	n/a	150 mm CTB	0.63%	Edge	AC	6	21.3	4.0
Belgium	58002_14	4	1979	200 mm CRCP	3.75 m	n/a	n/a	150 mm CTB	0.63%	??	AC	10	30.8	3.5
Belgium	58002_15	4	1985	200 mm JPCP	3.5 m	5.0 m	25 mm	150 mm CTB	None	Edge	AC	5	3.8	4.0
Belgium	58002_16	4	1984	230 mm JPCP	3.5 m	5.0 m	None	150 mm CTB	None	Edge	AC	6	4.4	4.5
Belgium	58003_01	97	1984	200 mm CRCP	3.75 m	n/a	n/a	150 mm CTB	0.85%	Edge	Turf	5	2.9	4.5
Belgium	58003_02	97	1975	200 mm CRCP	3.5 m	n/a	n/a	150 mm CTB	0.85%	Edge	Turf	14	8.0	2.5
Belgium	58003_03	97	1983	200 mm CRCP	3.75 m	n/a	n/a	250 mm CTB	0.85%	Edge	Turf	6	4.5	4.5

* Trapezoidal section

Key:
PSI = Present Serviceability Index (0 to 5 scale)
JPCP = Jointed Plain Concrete Pavement
JRCP = Jointed Reinforced Concrete Pavement
AC = Asphalt Concrete
CRCP = Continuously Reinforced Concrete Pavement
PCC = Portland Cement Concrete

1 in = 25.4 mm, 1 ft = 0.305 m
CTB = Cement-Treated Base
ATB = Asphalt-Treated Base
LCB = Lean Concrete Base
AGG = Aggregate
SC = Sand Cement
PCTB = Permeable Cement-Treated Base

sections have 6.0-m (19.7-ft) joint spacings. The one JRCP section has a joint spacing of 25.0 m (82.0 ft). The Belgian sections contain joint spacings ranging from 3.5 to 5.5 m (11.5 to 18.0 ft).

Overall, the joint spacings for the European JPCP sections typically range from 4.5 to 5.0 m (14.8 to 16.4 ft), although one section in France has a joint spacing of 10 m (32.8 ft), and four sections in the United Kingdom have a joint spacing of 6.0 m (19.7 ft). The joint spacings for the JRCP sections range from 5 to 25 m (16.4 to 82.0 ft). The joint spacings for both JPCP and JRCP are similar to those encountered in the United States.

Slab Thickness

Figure 1 illustrates the range of slab thicknesses for the European COPES sections. The French sections have slab thicknesses ranging from less than 200 mm (8 in.) to more than 400 mm (16 in.), although most sections are either between 250 and 300 mm (10 and 12 in.) or between 350 and 400 mm (14 and 16 in.). At least three pavement sections contain trapezoidal cross sections. The slab thicknesses for the Italian sections range from 220 to 260 mm (8.7 to 10.2 in.). The sections from the United Kingdom range in thickness from 200 to 305 mm (8 to 12 in.), although most are between 250 and 280 mm (10 and 11 in.). Of the 25 Belgian sections, 19 sections have a slab thickness of 200 mm (8 in.), and 6 sections have a slab thickness of 230 mm (9 in.).

Overall, the thicknesses range from less than 200 mm (8 in.) to more than 400 mm (16 in.), but most sections fall under three thickness categories: less than 200 mm (8 in.), 200 to 250 mm (8 to 10 in.), and 250 to 300 mm (10 to 12 in.). Considering that a 50 mm (2 in.) difference in the slab thickness can mean an order of magnitude difference in fatigue life of concrete pavements, these slab thicknesses represent a considerable range in structural capacity.

Base Type

A variety of base types are represented in the European COPES sections, as shown in Figure 2. The French sections contain a wide distribution of base types, with thicknesses ranging from 75 to 250 mm

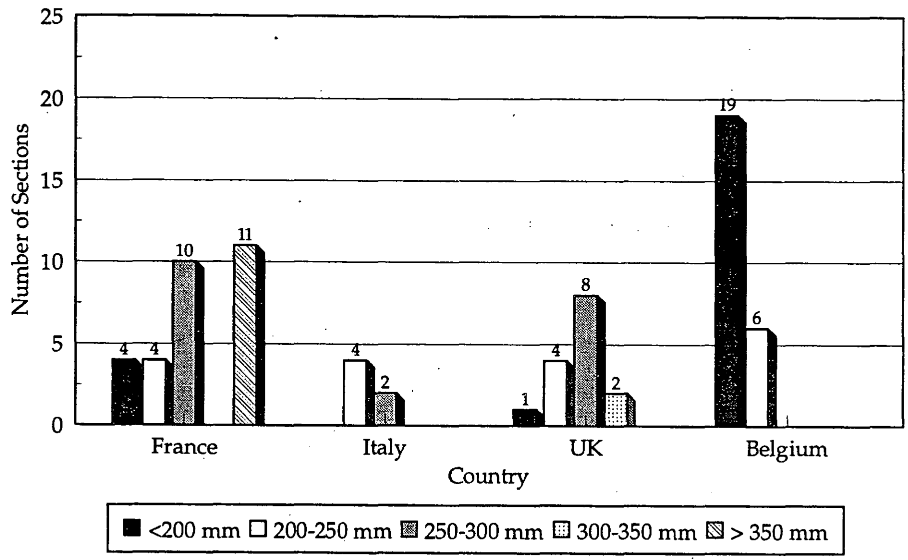

FIGURE 1 Distribution of slab thicknesses.

(3 to 10 in.). The Italian pavement sections contain three different base types—lean concrete base (LCB), cement-treated base (CTB), and pozzolan—with thicknesses ranging from 150 to 250 mm (6 to 10 in.). The pavement sections from the United Kingdom contain three different base types—LCB, aggregate-treated base (AGG), and CTB—with thicknesses ranging from 75 to 225 mm (3 to 9 in.). Five pavement sections from Belgium contain an LCB with a thickness of 200 mm (8 in.), and the remaining 20 sections contain a CTB with thicknesses ranging from 150 to 200 mm (6 to 8 in.). The CRCP sections with 0.85 percent steel have a 60-mm (2.4-in.) bituminous interlayer between the LCB and CRCP.

Overall, stabilized bases are used extensively in the European COPES sections; 80 percent of the sections evaluated have either a stabilized base or a lean concrete base. The most common type of base is the cement-treated base, followed by the lean concrete base, the asphalt-treated base, and the aggregate base.

Dowel Bars

With the exception of the French sections, dowels are provided at transverse joints in nearly all European COPES sections. Dowel diameters range from 20 to 30 mm (0.8 to 1.2 in.). However, only 3 of the 29 French sections contain dowel bars. Although many have experienced high traffic levels, most of the nondoweled French sections are less than 10 years old, making it difficult to judge long-term performance.

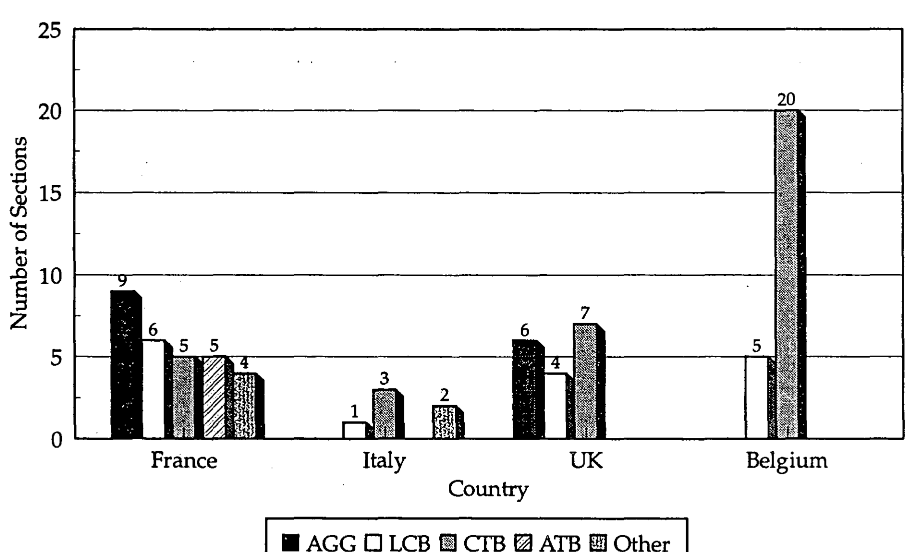

FIGURE 2 Distribution of base types.

Drainage

Nearly all of the European COPES sections were provided with edgedrains or transverse drains. Most of the French sections contain positive drainage features, generally achieved by placing either longitudinal edgedrains or a longitudinal drainage trench of porous aggregate. In addition, one section contains transverse drains, and only six sections contain no positive drainage features. For the Italian sections, three sections have longitudinal edgedrains, and three sections have no drainage system. Every pavement section from the United Kingdom contains longitudinal edge drains. Of the 25 Belgian sections, 18 sections contain longitudinal edgedrains and one section contains transverse drains; drainage information is not available for the remaining six sections.

Shoulder Type

Most of the European COPES sections from France include asphalt concrete (AC) or aggregate shoulders; only one section contains a tied concrete shoulder. Three of the Italian sections contain AC shoulders, and three sections contain porous portland cement concrete (PCC) shoulders. The sections from the United Kingdom consist of three sections with AC shoulders, seven with PCC shoulders, and two with aggregate shoulders. (The type of shoulder is not provided for five pavement sections.) Most of the Belgian sections (21 of 25) contain AC shoulders, one section contains an aggregate shoulder, and three sections contain turf shoulders.

The use of aggregate shoulders appears to be more common in Europe. More than 15 percent of the European sections contain aggregate shoulders, whereas aggregate shoulders are seldom used on higher volume highways in the United States. Concrete shoulders are also used in Europe, but it does not appear to be a common design feature in these sections.

Slab Width

In France, slab widths are either 3.5 m (11.5 ft) or 3.75 m (12.3 ft), whereas the slab widths for the Italian sections are all 5.0 m (16.4 ft). The sections from the United Kingdom are constructed with a slab width of 3.6 m (12 ft). The slab widths from the Belgian sections range from 3.5 to 5.0 m (11.5 to 16.4 ft). The normal slab width for European COPES sections ranges from 3.5 to 3.75 m (11.5 to 12.3 ft), although the use of widened lanes appears to be more common than in the United States.

Pavement Age

Figure 3 shows the distribution of the age of the pavement sections from each country. These are the ages of the pavement from the time they were opened to traffic until the time they were surveyed under the European COPES program. Most of the French pavement sections are less than 10 years old, with an average age of 8.1 years. However, four sections are more than 20 years old. The Italian sections range from 4 to 31 years old, with an average age of 15.3 years. Although this is a wide range of ages, only three different ages are represented—three sections are 4 years old, one is 18 years old, and two are 31 years old. The sections from the United Kingdom range from 2 to 24 years old, with an average age of 12.8 years. The sections from Belgium range from 2 to 17 years old, with an average age of 9.1 years.

The distribution of pavement age at the time of the distress survey is shown in Figure 3. The overall average age of the pavement sections is 10.2 years. This includes five sections that are greater than 20 years old and 18 sections that are less than 5 years old.

Climatic Conditions

Two environmental measures—average annual precipitation and freezing index—can influence concrete pavement performance. The average annual precipitation indicates the amount of free moisture to which the pavement is exposed, although the relative evapotranspiration and the drainage characteristics of the pavement must also be considered (*3*). The freezing index indicates the amount of time throughout the year that the pavement is subjected to temperatures below freezing; it is the summation of the number of degrees that the average daily temperature is below freezing for each day throughout a year (*3*).

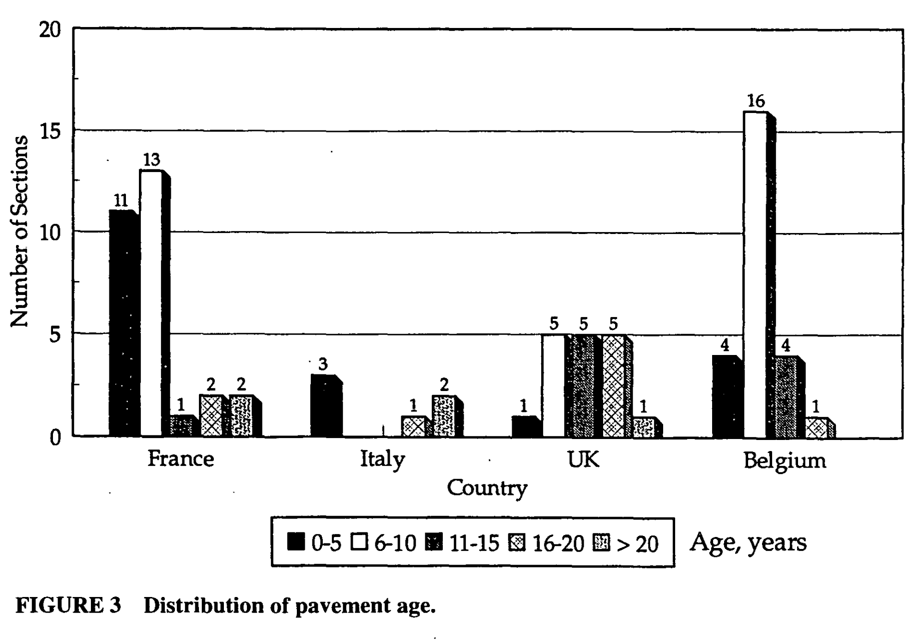

FIGURE 3 Distribution of pavement age.

The environmental conditions for the European sections are characteristic of the wet-freeze environmental region. The annual precipitation for the sections range from about 400 to 875 mm (16 to 34 in.), except for three sections in Italy. The freezing index for the sections range from about 165 to 330°C-days (300 to 600°F-days).

Traffic Loadings

One data item not included in the original European COPES summary tables is the estimated number of 80-kN (18-kip) ESAL applications that the pavement sections had sustained at the time of pavement survey. This factor converts the amount of damage inflicted on the pavement by a given axle load as compared with the amount of damage inflicted by a standard axle load using load equivalency factors developed from the AASHO Road Test (*4*). The European COPES data base contained information on traffic volumes (average daily traffic), truck volumes (percentage of trucks), and truck factors. Because these traffic data were not as complete as desired, several assumptions had to be made, such as assuming an average 4 percent growth rate in traffic volumes and truck factors for years when data were unavailable.

Although the truck volumes are similar to those on major U.S. highways, the axle loads are substantially higher in Europe. The legal load limit for single and tandem axles in Europe ranges from 98 to 128 kN (22 to 28.6 kilopounds) and from 186 to 205 kN (41.9 to 46.3 kilopounds), respectively (*5*). The consequence of the heavy axle loads and the longer design periods used in Europe is extremely high design equivalent single-axle loads (ESALs). Figure 4 shows the distribution of the estimated ESAL applications at the time of survey. Nearly 20 percent of the European sections have sustained more than 40 million ESALs, with over 50 percent of the European sections receiving more than 2 million ESALs per year.

Typical axle load distributions for France are shown in Figure 5 for single and tandem axles. This figure helps explain some of the heavy ESAL applications, because a significant amount of loading is at the higher end of the spectrum. For example, 25 percent of the single axles are greater than 9.1 t (20,000 lb), the legal limit for single axles in the United States. Similarly, 70 percent of all tandem axles are greater than 15.4 t (34,000 lb), the legal limit for tandem axles in the United States. Similar trends are also experienced in other European countries.

Performance Data

Many variables have been collected under the COPES study. The design variables, climatic information, and traffic data have already been discussed. The other major design category is performance data. Unfortunately, complete performance data are not available for all 77 pavement sections included in the evaluation. For example, data on transverse joint faulting, an important measure of concrete pavement performance, are available for only a few sections. Similarly, data on transverse slab cracking, an important indicator of fatigue in jointed plain concrete pavements, are unavailable or inconsistent for many pavement sections. These limitations greatly restrict the extent of the analyses that can be conducted on the pavement sections. The one performance indicator that is present for nearly every section is the present serviceability rating (PSR).

PERFORMANCE EVALUATION

As mentioned, the PSR is the only performance indicator consistently provided for each European section. The pavement serviceability concept, developed at the AASHO Road Test, indicates the ability of the pavement to provide a smooth-riding surface to the traveling public (*4,6*). Using the PSR, it is possible to compare the relative performance of the pavement sections. Presumably, those pavement sections with higher PSR values display less distress. Unfortunately, one drawback of the PSR is that the effect of a specific design feature (e.g., dowel bars) on pavement performance cannot be directly measured; rather, the effect can only be surmised based on whether the design feature reduced any pavement distress that would have otherwise detracted from the serviceability of the pavement.

Another factor complicating the comparison of the performance of the pavement sections is that they were not constructed as experimental sections with the sole purpose of evaluating design features. In addition, many sections within a country are located on the same highway and contain similar (if not the same) design features. Thus,

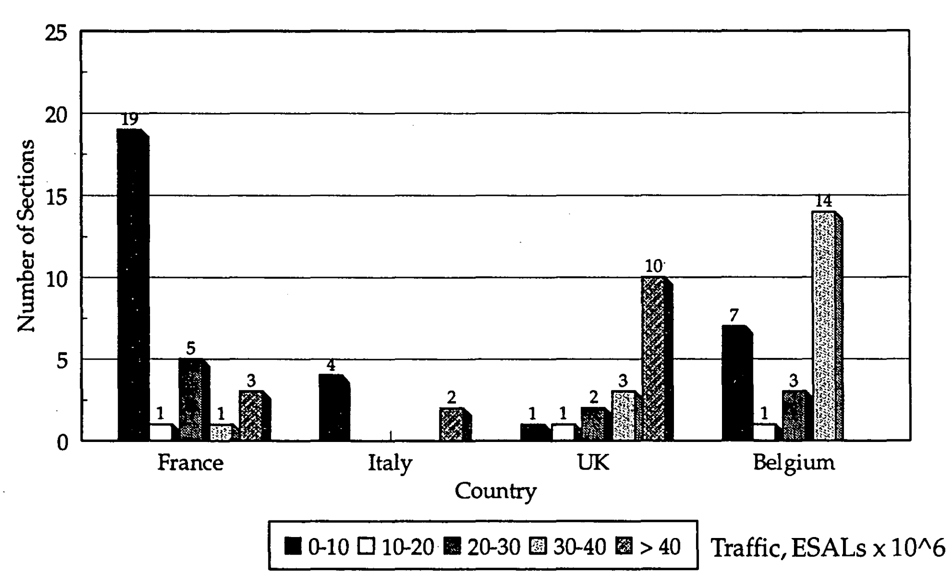

FIGURE 4 Distribution of ESAL applications.

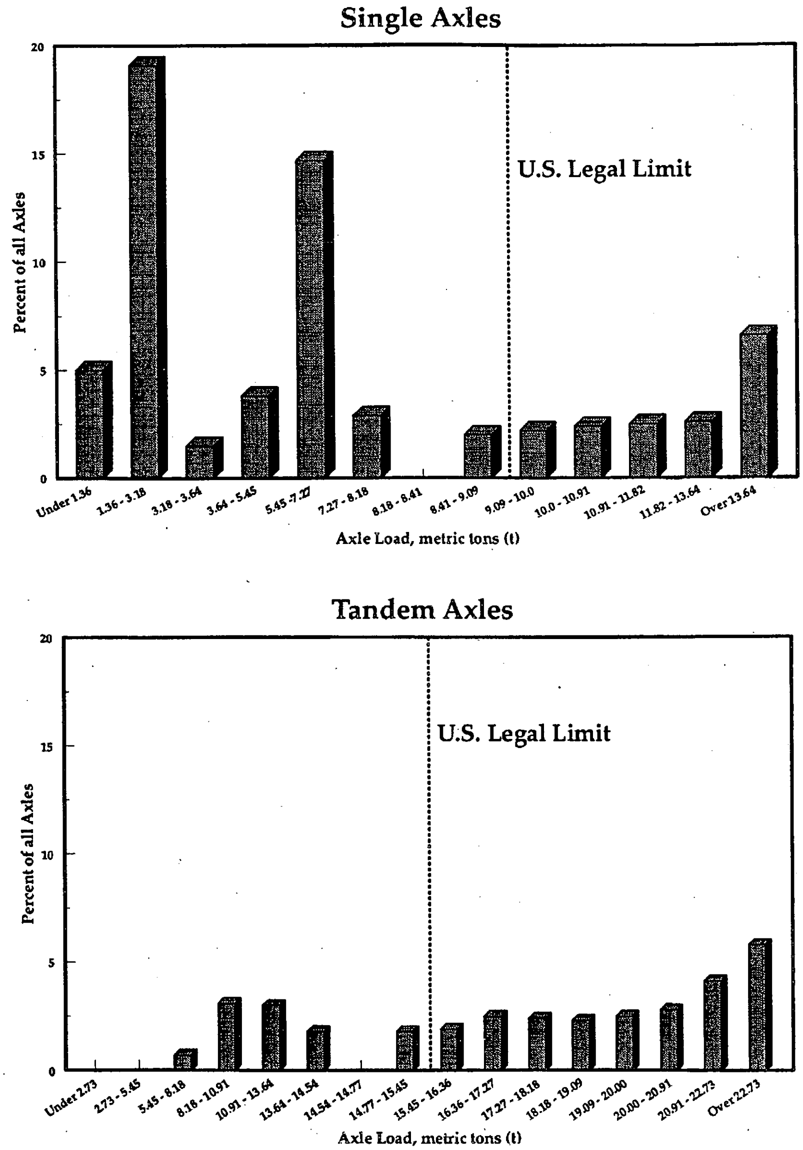

FIGURE 5 Typical axle load distribution from France.

not only are direct performance comparisons infrequent, they are also difficult because of differences in traffic loadings and aging and climatic effects.

Because of the absence of complete performance data and the difficulty in making direct comparisons between pavement sections, a more general evaluation of the performance of the European COPES sections was conducted. The purpose of this type of evaluation was examine the overall performance of the various pavement sections and to identify general performance trends.

PSR Trends

The performance data for the European COPES sections are provided in Table 1. Although only a qualitative analysis was made using three variables as the principal parameters—PSR, age, and traffic—a number of interesting performance trends were observed.

Figures 6 through 8 show the PSR as a function of age, of ESALs, and of the product of age and ESALs, respectively. The latter function, broken out by modernity elements, has been used as a means of analyzing pavement performance (*2*). Because environmental effects and traffic loads are responsible for the deterioration of pavements, in theory, one may expect the pavement condition to deteriorate with increasing age and traffic. Although these figures all show this general trend, considerable scatter is present in the data. Some scatter is expected because the figures include data from all European COPES sections, regardless of the pavement type, slab thickness, or other design feature. Some of these design features are expected to have a significant effect on pavement performance.

The PSR as a function of ESAL applications was also plotted as a function of pavement type, slab thickness, dowels, drainage, and base type. Sufficient data are unavailable to determine the effects of reinforcement or joint spacing. Pavement type does not appear to be a significant factor affecting pavement performance. The only noticeable trend is that CRCP may give better and perhaps more consistent performance than jointed concrete pavements.

The effects of slab thickness, dowels, and drainage were not evident from the data or the graphs. This does not mean that such important design features do not affect pavement performance; it means only that the effects of these variables on pavement performance could not be determined with the available data.

On the other hand, pavement sections with an LCB seem to perform better than those with other base types. However, further investigation may be warranted to determine the reason that those particular sections performed better. Most European COPES sections containing the LCB are JPCP, and the use of a very stiff base under JPCP requires careful evaluation to avoid cracking due to excessive thermal curling stresses.

Modernity Concept

In the initial evaluation of the European COPES data, the development of the modernity coefficient, or number of modernity elements, is described (*2*). The modernity coefficient is a number from 0 to 4 that indicates the number of specific design features in a pavement section that are expected to contribute to the overall performance of that pavement (*2*). The design features that are expected to contribute to the performance of a pavement are classified in the following four categories:

- Nonerodible base course (specifically, lean concrete base),
- Positive pavement drainage,
- Strengthened structure (thickened slab, dowel bars, or CRCP), and
- Optimization of materials with respect to loading (e.g., widened traffic lanes or trapezoidal cross sections).

For example, a pavement incorporating design elements from each of the categories is assigned a modernity coefficient of 4. Likewise, a pavement containing only dowel bars and positive drainage is assigned a modernity coefficient of 2.

Generally speaking, the pavements in Europe are provided with more features that are expected to promote long-term performance. Many of the European sections (74 percent) have two or more modernity elements. Only 8 percent of the European sections incorporate no modernity elements.

Figure 8 shows the PSR as a function of the product of age and ESALs broken into the number of modernity elements. This figure shows that the sections with three or more modernity elements give better and more consistent performance than other sections. Unfortunately, 14 of the 15 sections having three or more modernity elements also have an LCB. With the available data, it is impossible to determine whether the LCB or the combination of having three or more modernity elements provided the superior performance. Although it is more likely that the latter is the case, this cannot be shown conclusively.

Although the modernity concept provides a useful way of looking at the data, it does not distinguish the difference between the various design features. In addition, it assumes that every modernity element has the same positive effect on pavement performance. Because different design features have different relative effects on pavement performance, the modernity coefficient is only an approximate indicator of the design quality of a concrete pavement.

Prediction Models

Models that predict the PSR of the pavement sections were developed for France, the United Kingdom, and Belgium. (The number of sections was insufficient for developing models for Italy.) The models are based on a limited number of sections and design variables and were developed only as a means of evaluating the effect of the various design features on PCC pavement performance. In addition, the models are only accurate within the range of variables incorporated in the sections in which they were developed. Therefore, the prediction models should not be used for design purposes.

The models were developed using the least-square regression technique with the available data. The terms used in the equations are described as follows:

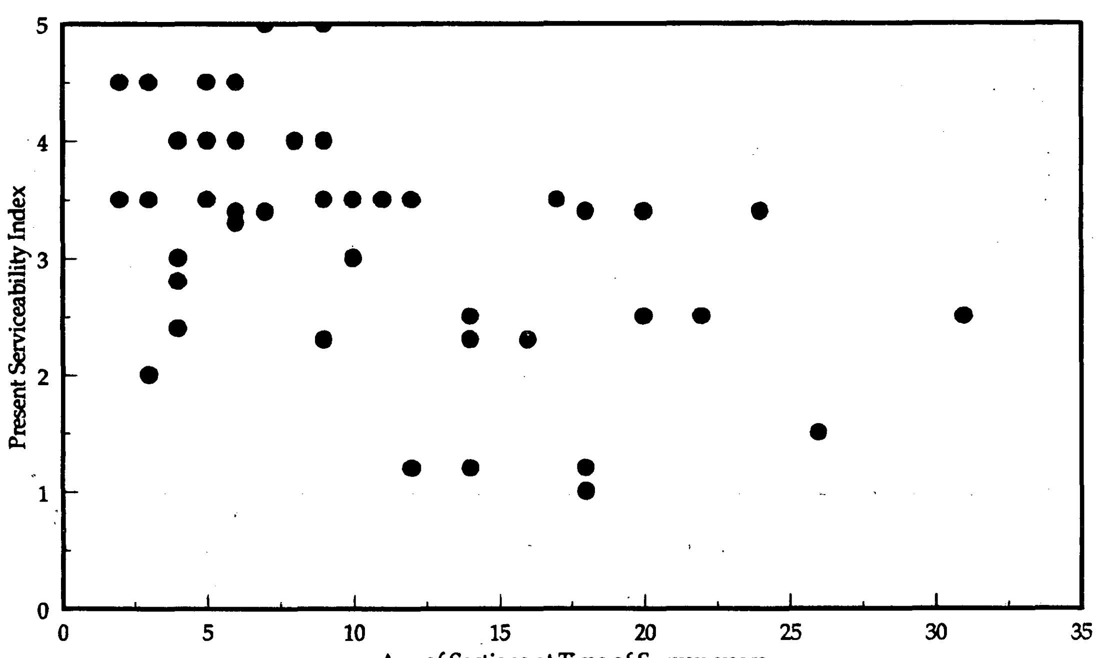

FIGURE 6 PSR versus age for European COPES sections.

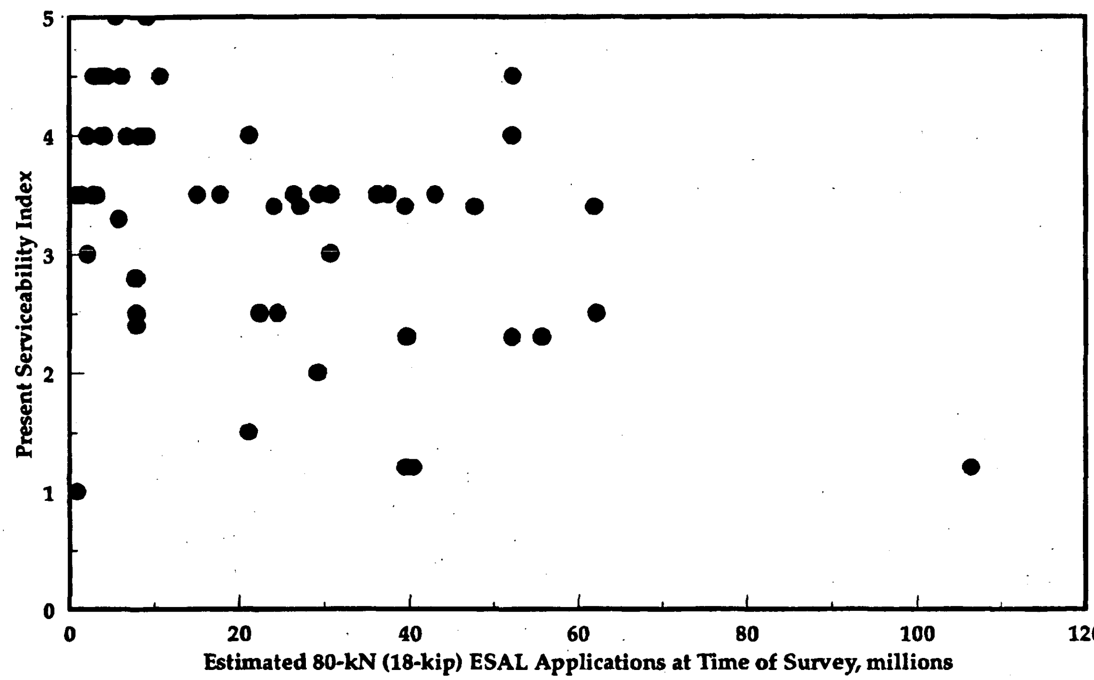

FIGURE 7 PSR versus ESALs for European COPES sections.

- PSR = present serviceability rating,
- AGE = time since construction (in years),
- ESAL = estimated 80-kN (18-kilopounds) ESALs (in millions),
- THICK = PCC slab thickness (in mm),
- DRAIN = dummy variable for drainage design (1 for edgedrains, 0 for none), and
- PTYPE = dummy variable for pavement type (0 for JPCP, 1 for CRCP).

France

The prediction model developed for the French sections is shown in the following equation:

$$PSR = 3.0803 - 0.00043\ AGE^2ESAL^{0.5} + 0.00159\ THICK + 0.4945\ DRAIN \quad (1)$$

$R^2 = 0.75$ $R^2adj = 0.71$ SEE = 0.28 N = 24

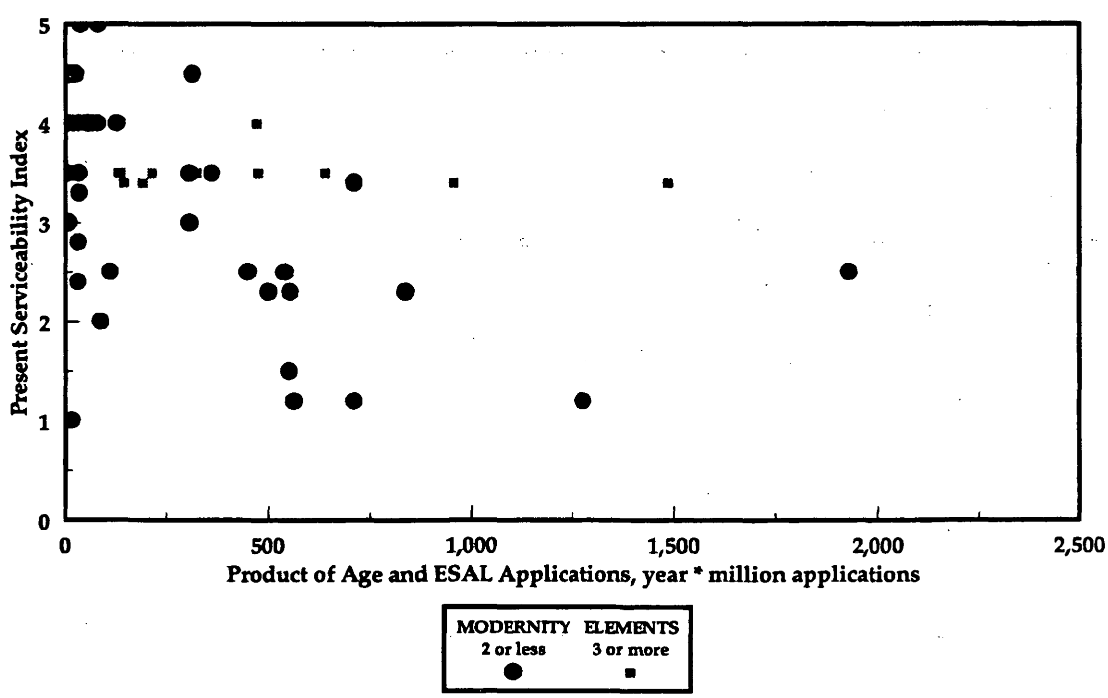

FIGURE 8 PSR versus age*ESALs for European COPES sections.

This model applies only to JPCP without dowel bars and is limited to the range of design features and conditions of the available sections. The model is sensitive to age and ESALs, especially after about 15 years. The use of edgedrains results in a PSR increase of about 0.5 (evident by the coefficient on the drainage variable). The model is not overly sensitive to changes in slab thickness.

United Kingdom

The PSR model for the United Kingdom is only applicable to JPCP sections with longitudinal edge drains and dowel bars. The model is also limited to variables used to develop the equation. The following model was developed:

$$PSR = 4.2561 - 0.0264\ ESAL - 2.460\left(\frac{AGE}{THICK}\right) \quad (2)$$

$R^2 = 0.78$ $R^2adj = 0.74$ $SEE = 0.44$ $N = 13$

The model is more sensitive to ESALs than to age, which indicates that heavy loads damage the pavement more than the environment. Slab thickness is not a significant variable in the model.

Belgium

The Belgian model was developed for both JPCP and CRCP sections and includes a dummy variable to distinguish the pavement type. The following model was developed for Belgium:

$$PSR = 4.1826 - 0.1134\ AGE - 0.00862\ ESAL + 0.00152\ THICK + 0.4763\ PTYPE \quad (3)$$

$R^2 = 0.76$ $R^2adj = 0.71$ $SEE = 0.33$ $N = 25$

Age is the most significant variable in the equation, whereas thickness and ESALs affect the model to a much lesser extent. CRCP sections have performed better than the JPCP sections, which is also evident in the model.

SUMMARY

This paper presents an evaluation of the performance of concrete pavement sections included in the European COPES program. Under this program, several European countries—France, Italy, the United Kingdom, and Belgium—have been collecting performance data on their concrete pavement sections. The overall objective of this program is to obtain feedback information on the behavior and performance of the European concrete pavements so improvements to their design and construction can continually be made. Such improvements may include the identification of particular design features (e.g., dowel bars) or combinations of design features (e.g., dowel bars and positive drainage) that greatly increase the performance capabilities of concrete pavements.

A qualitative analysis was conducted using the PSR, age, and traffic as the principal parameters. The following presents a summary of the observations from the European COPES data and the results of the analysis:

- The most common type of concrete pavement in Europe appears to be JPCP. The JPCP sections made up 80 percent of the European COPES sections.
- Stabilized bases are used extensively in Europe; 80 percent of the sections evaluated have either a stabilized base or an LCB.
- Nearly all European COPES sections are provided with positive drainage. With the exception of those in France, most sections are also provided with dowel bars at transverse joints.
- A much greater proportion of the European sections have two or more modernity elements as compared with the U.S. sections (74 percent for Europe versus 25 percent for United States).
- The European COPES sections are subjected to climatic conditions that are characteristic of a wet-freeze environmental region.
- The European highways are subjected to very high traffic loads. The high design ESALs are a result of the legal heavy-axle loads and long design life (30 to 40 years) that are common in Europe.
- The base type was found to have significant effect on pavement performance. Sections with LCB performed better than those provided with other base types.
- Pavement sections with three modernity elements performed better than those with two or fewer.
- PSR prediction models were developed and were found to accurately predict PSR for the limited number of design variables.

These observations and conclusions were made on the basis of a qualitative analysis conducted on limited data. Further investigations may be needed to verify some of the above findings.

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