The Paving of Low-Volume Roads in Spain With Roller-Compacted Concrete

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The technique of paving low-volume roads with roller-compacted concrete (RCC) has been used for 17 years in northeastern Spain. The construction costs of this technique are economically favorable when compared to other structurally equivalent alternatives. Maintenance costs are also lower and the pavement is highly durable because the strength of roller-compacted concrete is similar to that of a conventional vibrated concrete. These are some of the reasons that justify its use. The advantages of the use of concrete as a paving material can be summarized as follows: conventional machinery can be used that is not specific to concrete; the newly paved surface can usually be traveled on immediately; and the materials are very economical because binders with a high fly ash content can be used. About 4 million m² of low-volume roads have been paved using this technology. An experimental study was undertaken in which tests were performed on core samples to check the performance of these RCC pavements during their years of service. The result is a detailed file on the performance and current condition of many of them.

Low-volume roads have generally received little attention in Spain in terms of their typology, design, construction, and maintenance. The central government's attention has instead been directed toward the main network, which has gradually been subjected to greater levels of traffic (*1*). However, data from the late 1970s indicated that the length of the network of Spanish roads with an average daily traffic (ADT) below 250 was 262 000 km (160,000 mi), or 84 percent of the total (*2*). This figure provides some indication of the importance of this secondary network to the country's communications. It forms an essential infrastructure for access to and communication between population centers, agricultural concerns, factories, and mines.

The characteristics of low-volume roads and the extent of their use require that cheap pavements be constructed that require little maintenance. Up to the present date the solution usually chosen has been that of a granular base course with successive surface dressings. This has resulted in pavements that are very cheap to construct but very expensive in the long run because of the need for frequent maintenance. Concrete pavements began to be used as an alternative. Contributing factors include the rise in the price of oil products during the 1970s and the acceptance of the partial replacement of cement (fly ash, slag, etc.), which reduces RCC costs and makes it competitive with alternatives. Concrete pavements also last longer and can go without maintenance for long periods of time, which leads to further savings in cost.

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The use of RCC in low-volume roads in Spain for the past 17 years represents a special case in the use of concrete pavements (*3*). The characteristics, behavior, and advantages of this technique are described in the following sections (Figure 1).

CHARACTERISTICS OF ROLLER-COMPACTED CONCRETE

Roller-compacted concrete is a uniform mix of aggregates, binder, and a small quantity of water that is laid and compacted by a roller, not by vibration (*4*). Its structure is similar to a cement-treated base, but its cement content and strength make it behave more like a traditional concrete. Its low water content does not allow it to be compacted by conventional concrete vibrators; heavy vibrating rollers are needed to compact it.

As a result of compaction, the aggregate skeleton attains a stability that allows the pavement to be opened to traffic immediately. Roller-compacted concrete at first behaves as a granular untreated base. For this reason, high short-term strength is not necessary, provided sufficient long-term strength is achieved, and the concrete does not deteriorate in the short term.

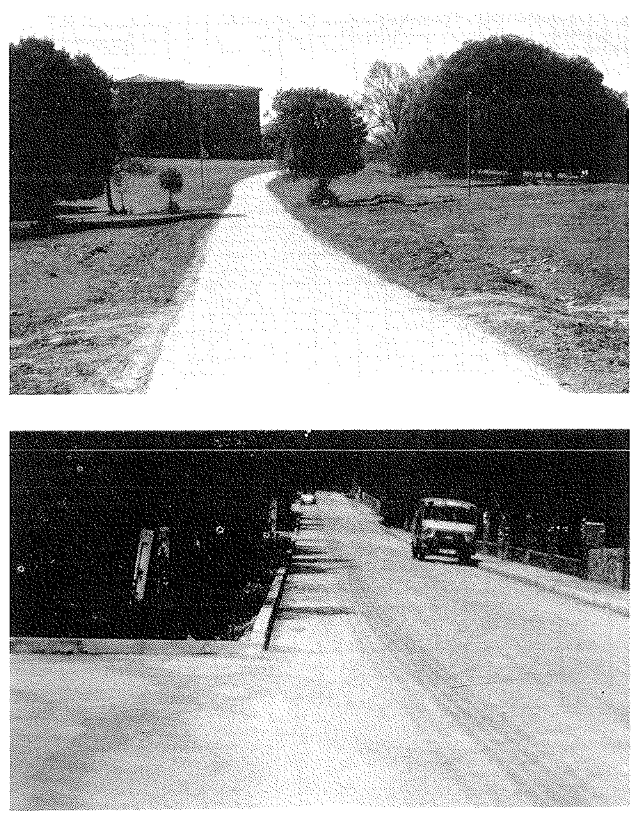

FIGURE 1 Low-volume, roller-compacted concrete roads in Spain.

Roller-compacted concrete is currently being used in dams and pavements. It has been used on roads with heavy traffic and on rural roads, and has a special application as an overlay, because traffic can be allowed onto it immediately (*5, 6*).

Materials

Aggregates

Grading limits established by practice are used to ascertain the grading of the aggregate. An example of the grading limits, including binder, that are provided in the Spanish specifications for RCC is shown in Figure 2 (*7*). It is particularly important to avoid an excess of the fraction passing the No. 200 sieve, which could cause surface depressions during compaction.

A maximum aggregate size of 20 mm (0.8 in) is specified for main roads; however, aggregate sizes of up to 38 mm (1.5 in) have been used on low-volume roads (*6*). A higher risk of segregation exists when high maximum aggregate gradings are used and special precautions have to be taken to avoid it.

Round natural aggregate and crushed stone have both been used. In the case of the former, compaction is easier but the resulting bearing capacity of the aggregate skeleton is reduced. In the case of the latter, compaction is more difficult but the bearing capacity is greater. At least 66 percent of the aggregates should be crushed stone.

Water

Water content is adjusted to obtain maximum density on compaction when laying. The maximum density obtained through the Modified Proctor Test (MPT) is used as a reference for this. However, because the compaction energy employed in the MPT is different from that applied on site, a difference exists between the optimum moisture content in the field and in the laboratory. In accordance with the experience to date, the field moisture content should be approximately 1 percent less than that determined in the MPT. However, it is advisable to err on the moist side of the moisture-density curve if the pavement is to be textured.

The customary values for water content in low-volume roads are 4.5 to 6.5 percent by weight, which implies a water-cement ratio of 0.36 to 0.42.

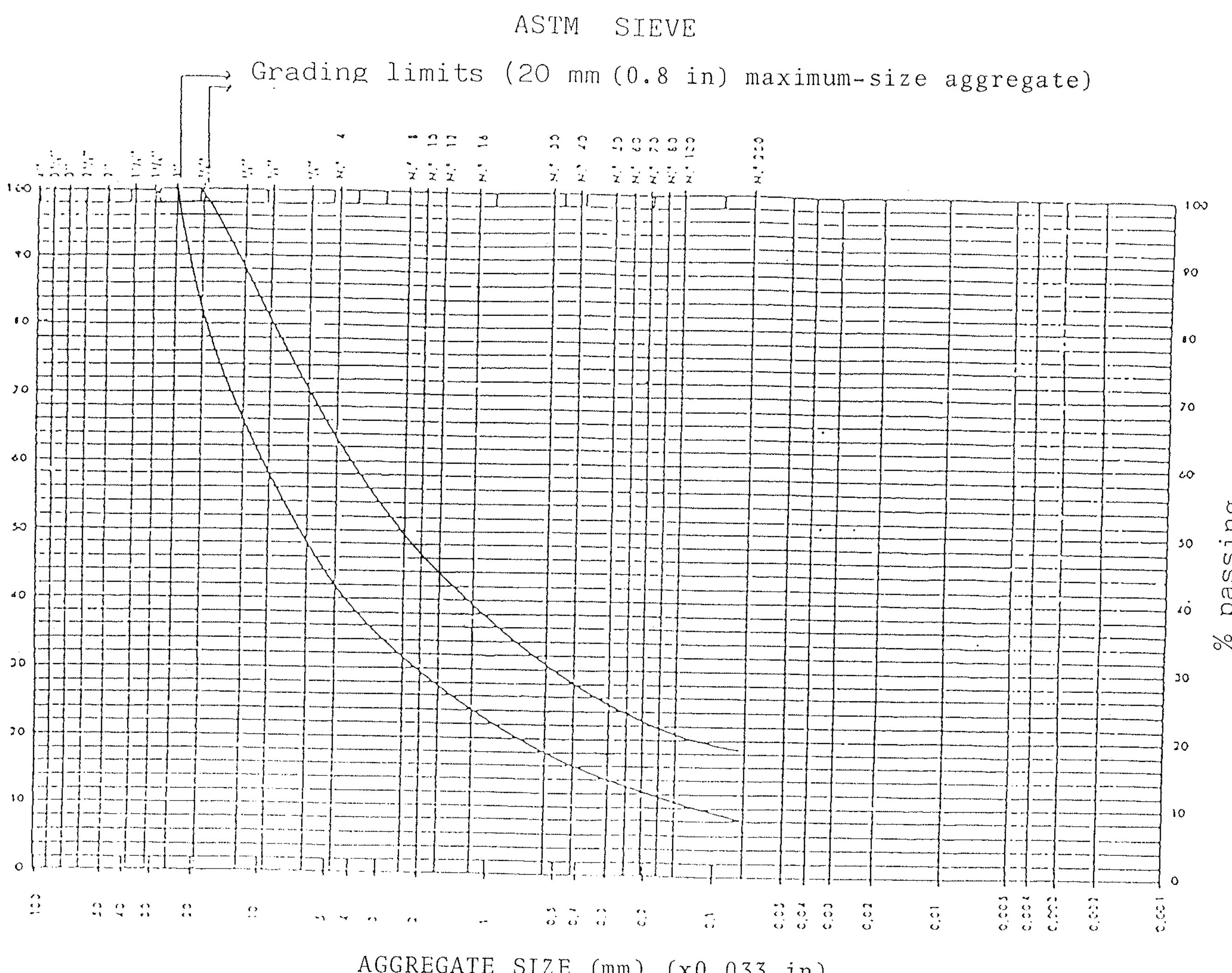

FIGURE 2 Grading limits specified for roller-compacted concrete.

Binder

The methods used to lay RCC are such that binders in which the cement is partially replaced with fly ash and slag can be used (*8*). Although these binders may also be used in traditional concrete pavements when the speed at which the road can be opened to traffic is not critical (*9*), they are especially suitable for RCC, because their slower setting speed facilitates compaction operations.

The typical evolution in strength is shown in Figure 3. In this example, the cement contained 50 percent ASTM Class F fly ash. The strength increased considerably between 28 days and 3 months; design strengths beyond 28 days can therefore be specified.

The usual quantities of binder range from 230 to 375 kg/m^3 (390 to 630 lb/yd^3), 10 to 12 percent by weight. The proportions must be determined by prior tests for each binder, and the quantity of water required should be based on the MPT. It is very important to check the sensitivity of the strength to variations in moisture content and density in these tests to determine the risk of lack of strength as a result of these variations.

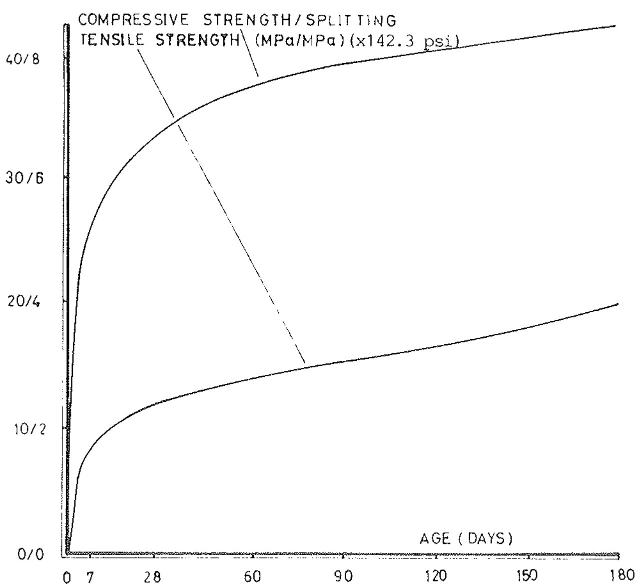

FIGURE 3 Compressive strength and splitting tensile strength versus age for roller-compacted concrete with 7 percent fly ash and 7 percent cement used in an overlay project.

Admixtures

It is sometimes advisable to use admixtures, particularly plasticizers that allow the quantity of water to be reduced and consequently increase strength. Admixtures can also be used that retard the setting of concrete. These admixtures are basically necessary when the pavement is laid in half-widths to avoid the occurrence of undesirable longitudinal joints.

Thickness Design of RCC Pavements

In the absence of a specific design method for RCC pavements, it is currently admitted that the same pavement thicknesses can be adopted for RCC or an ordinary vibrated concrete with a similar strength. The strength of RCC is controlled by means of splitting tensile tests using cylindrical samples 15 cm (6 in) in diameter and 18 cm (7 in) high, because it is very difficult to make true prismatic samples.

The testing age depends on the type of binder used, in accordance with the requirements of the specifications, and may be at 28, 56, or 90 days. The recommended minimum strength for low-volume roads is 2.8 MPa (400 psi).

A 20-cm-thick (8-in-thick) soil-cement subbase under the RCC layer is specified for main roads, whereas granular, untreated subbases are used for roads with medium levels of traffic. Roller-compacted concrete pavements are usually placed directly on the subgrade of low-volume roads; only a top layer of organic soil is eliminated, when necessary.

Shoulders are not normally provided on low-volume rural roads. This lack of lateral constraint results in some reduction in the degree of compaction obtained alongside the pavement. Curbs are usually placed on urban streets before the RCC is spread (Figure 4).

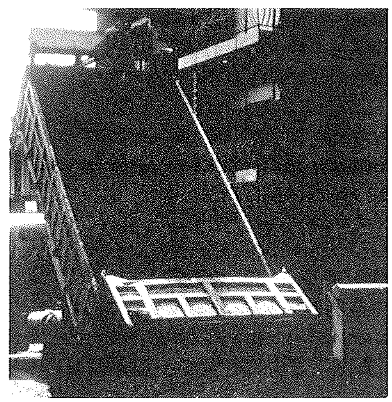

FIGURE 4 Hauling concrete with dump trucks.

Laying

Production

Either continuous plants or batch plants have been used to mix the RCC. Because the percentage of binder is similar to that of a vibrated concrete, the continuous plant must be able to proportion these quantities. In either case, a weight control is essential, particularly for the binder, to ensure that the material proportions are correct.

Transport

The RCC is transported in dump trucks (Figure 4). Desiccation of the material must be avoided, which makes the use of protective canvases essential if the distance is long or the temperature is high. The distance from the plant to the site should be limited for this reason.

Spreading

Spreading is usually accomplished with a motor grader (Figure 5), which can easily be adapted to complex geometrical shapes.

FIGURE 5 Spreading with motor grader.

Compaction

Vibrating rollers are normally used in combination with rubber-tired rollers for compaction (Figure 6 and 7). In the first stages of compaction, vibrating rollers are used without vibration to ensure that the surface is even. Rubber-tired rollers are used in the final stages to seal the surface of the concrete. The number of passes the vibrating roller makes must be sufficient to ensure that the density of the material is correct (97 percent of the MPT). The rubber-tired roller is not needed in cases in which the texture is created in the concrete itself.

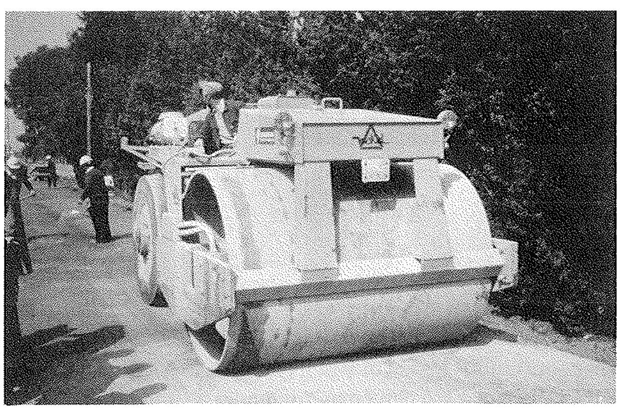

FIGURE 6 Compaction with smooth-drum roller.

FIGURE 7 Compaction with rubber-tired roller.

Surface Finishing and Curing

Two techniques are normally used to finish and cure the surface. In the first technique, a coat of curing compound (asphaltic emulsion) is protected with sand for provisional traffic; this is followed by a double surface dressing. In the second technique, a cement slurry is sprayed on the fresh concrete; this slurry is then promptly troweled by a machine called a "helicopter" (Figure 8 and 9).

In the second technique, the water content should err on the moist side of the moisture-density curve. It is therefore necessary to use aggregates that basically consist of crushed stone to be able to compact the material with this higher moisture content.

Sawing of Joints

The provision of joints in RCC pavements is a subject of controversy. If joints are to be created, they must be sawed. However, in many cases joints are not actually created, but are allowed to occur spontaneously. The sawing time is generally less critical than it is for vibrated concrete; in any case, it depends on the type of binder used and the temperature involved. Joints or cracks remain unsealed in all cases.

Other Operations

Other operations worthy of mention are the end-of-day joints (Figure 10), the elimination of longitudinal joints in the case of pavements that were laid in half-widths, and the moistening of the surface (Figure 11). This last operation is very important to prevent the surface of the concrete from becoming desiccated.

Advantages and Disadvantages

The advantages of roller-compacted concrete are as follows:

- No special machinery is necessary to lay concrete pavements (slip-form pavers) and the production rate is much better than laying forms by hand and using a vibrating beam (100 to 200 m/day or 330 to 655 ft/day).
- Roller-compacted concrete can be used as an overlay while the pavement is open to traffic in cases in which traffic cannot actually be stopped.

FIGURE 8 Texturing with power trowels.

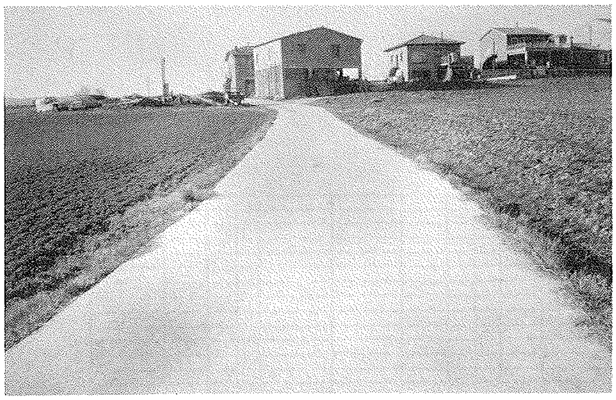

FIGURE 9 Texture obtained through use of power trowels.

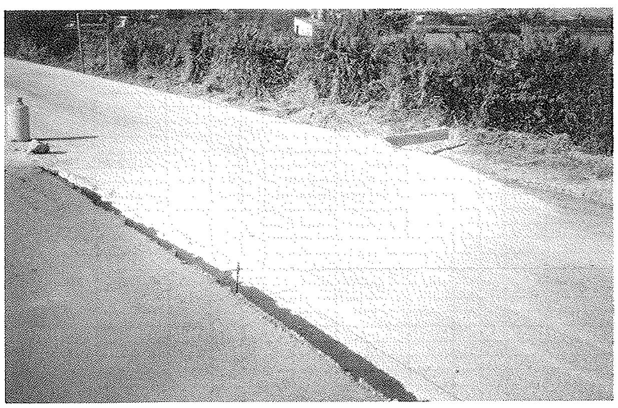

FIGURE 10 Sand wedge at construction joint.

FIGURE 11 Spraying of concrete surface to prevent moisture loss.

- Energy consumption is reduced when the concrete has a high content of additional binders such as fly ash.
- Less hydraulic shrinkage occurs as a result of the smaller water-cement ratio. This allows joints to be set further apart (up to 15 m or 50 ft).

One of the disadvantages of roller-compacted concrete is that it has a greater sensitivity to changes in humidity and density. Another disadvantage is that the road is rougher than it would be if slip-form pavers were used. This problem can be solved on main roads by using pavers instead of motor graders and, if necessary, placing a thin layer of asphalt concrete on top. This is not a problem for minor roads because there is no high-speed traffic. In any event, the skill of the motor grader operator is of paramount importance.

EXPERIENCE WITH RCC ON LOW-VOLUME ROADS IN SPAIN

The first known pavements that were built with RCC in Spain date from 1969 and 1970. They were constructed in the northeastern section of the country in small towns, housing states, and country roads. A single company constructed most of these pavements and continues to do so. A total of about 4 000 000 m^2 (4,800,000 yd^2) of pavement were laid. The following method was used:

- The material was produced in plants similar to those used for cement-treated bases.
- It was transported in dump trucks within a delivery radius that was limited to 30 to 35 km (20 to 22 mi).
- It was then spread with a motor grader.
- It was first compacted by a vibrating roller without vibration; four or five passes were made then with vibration.
- It was textured by the addition of cement slurry and mechanical troweling by a "helicopter."
- The joints were sawed every 10 to 12 m (33 to 39 ft) within 24 or 48 hrs after the material was spread.

Both the proportions used and the method of laying have developed over the years to reach a stage of technology that is very well-adapted to low-volume roads. Crushed limestone aggregates have generally been used. The mix has usually been based on three different sizes of aggregate to obtain the final grading curve. The binder that is currently being used is a mixture of Category P-450 cement and ASTM Class C fly ash. The proportions are as follows (Figure 12):

Gravel 10 to 30 mm (0.4 to 1.2 in)	230 kg/m^3 (390 lb/yd^3)
Gravel 0 to 10 mm (0 to 0.4 in)	1630 kg/m^3 (2,750 lb/yd^3)
Sand 0 to 5 mm (0 to 0.2 in)	240 kg/m^3 (400 lb/yd^3)
Category P-450 cement	170 kg/m^3 (290 lb/yd^3)
ASTM Class C fly ash	90 kg/m^3 (150 lb/yd^3)
Water	110 L/m^3 (185 lb/yd^3)

Normal structural sections have consisted of 15 cm (6 in) of concrete, or 20 cm (8 in) in the case of greater traffic levels, that were laid directly on the subgrade or on top of 15 cm (6 in) of granular subbase, in the case of low-quality subgrades. Pavements in rural roads have been an average of 3.5 m (11.5 ft) wide. It should be noted that the maximum single axle weight allowed in Spain is 130 kN (28 kips). The characteristic compressive strength of the concrete used at 28 days ranged from 20 to 25 MPa (2,850 to 3,560 psi).

Very few controls have been applied to RCC construction. The experience of the workers who laid the pavements has led to satisfactory results; most of the pavements have presented no problems, even after 17 years in service.

The reasons that led to the use of this technology were its competitiveness with other solutions in terms of cost (about 1,000 pesetas/m^2 or \$6.7/m^2 in 1985), and the fact that only a low level of maintenance is needed for a long period of time. The

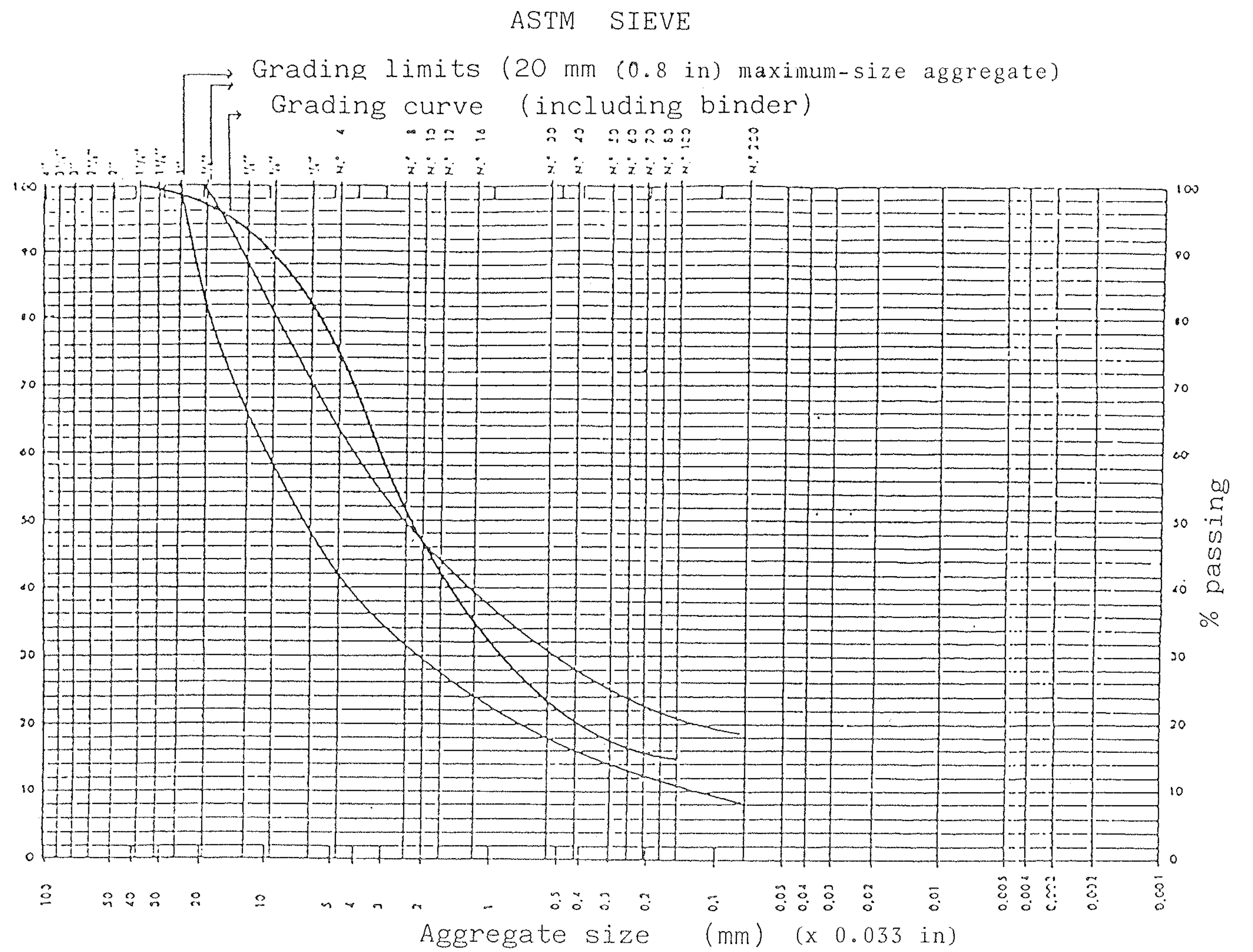

FIGURE 12 Grading curve used, including binder and grading limits.

latter is very important for local or private groups that do not have the means to perform such maintenance.

Several administrations have begun to use the RCC technique in two different ways. In the first method, the concrete has a water content that is on the moist side of the MPT and the surface is textured by a mechanical trowel called a "helicopter." This method is advantageous in that the surface texture is created in the concrete itself without the use of asphalt products. However, pavements textured in this manner cannot be opened to traffic immediately; a delay from 1 to 2 days has to be respected in this case.

In the second method, the concrete has a water content that is on the dry side of the MPT, and it is cured by spreading an asphalt emulsion on it. The surface is textured with a double surface dressing. This method is advantageous in that traffic can travel over the pavement immediately.

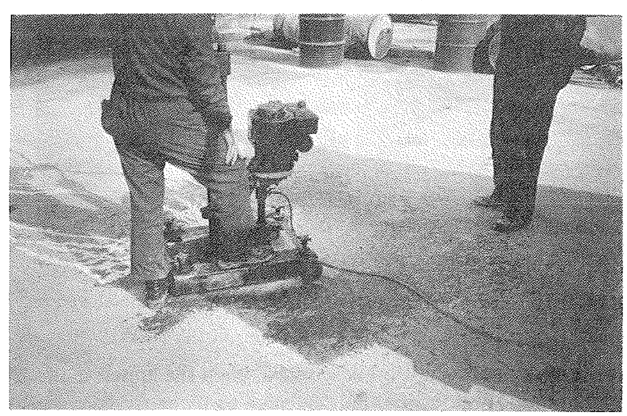

FIGURE 13 Extraction of cores.

STUDIES PERFORMED

As a result of the interest shown in this technique and the favorable results obtained from using it, it was decided in 1985 to extract cores from several of the completed projects (Figure 13). The aim was to check the current condition of the pavement and to obtain data in regard to the strength and density of the concrete. Twenty projects were chosen that were completed from 1969 to 1984; these included projects with slab thicknesses of 15 cm (6 in) and 20 cm (8 in).

The condition of each project was visually inspected and four cores (Figure 14) were extracted. Two of these cores were tested by compression (Figure 15) and two by the splitting tensile test (Figure 16). The densities of 20 cores were measured. The actual thickness of the slab was measured in each case and the condition of the extracted core was visually inspected to study such characteristics as porosity and degree of compaction.

The following conclusions were drawn from the findings:

- Although the results vary, the compressive strength was above 25 MPa (3,550 psi) in 80 percent of the cores and the splitting tensile strength was above 2.8 MPa (400 psi) (Figures 17 and 18). The variation in the results can be attributed to the limited control during construction. However, the strength rates were generally high and reached almost 60 MPa (8,500 psi).
- As was expected, a link existed between the density and strength of the cores; the greater the density, the greater the strength (Figure 19).
- As was also expected, the projects in the poorest visual condition (most cracking) were also those with lower strength, lower density, and the most porous cores, and vice versa.

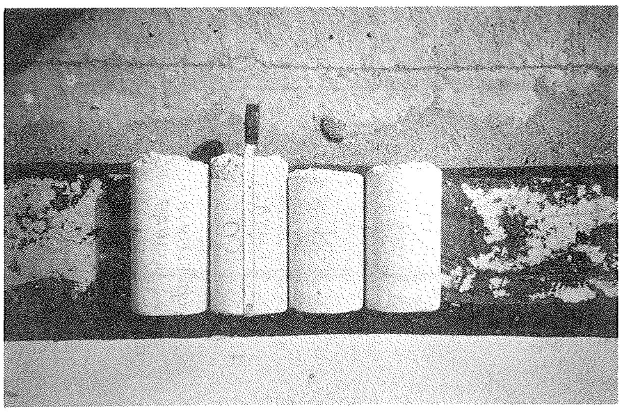

FIGURE 14 Cores extracted from a project.

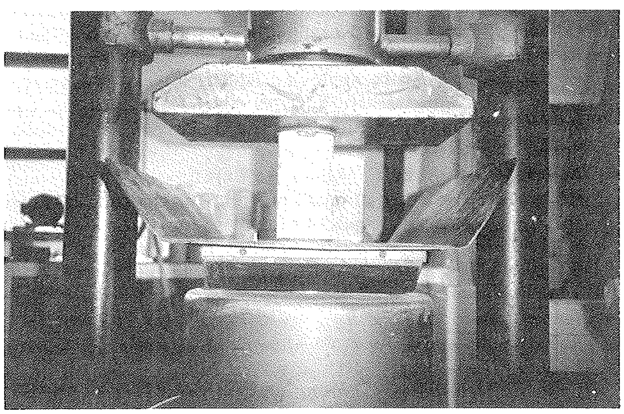

FIGURE 15 Compressive strength test.

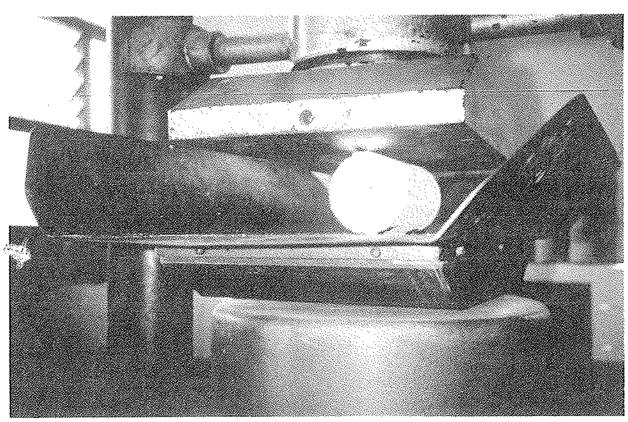

FIGURE 16 Splitting tensile strength test.

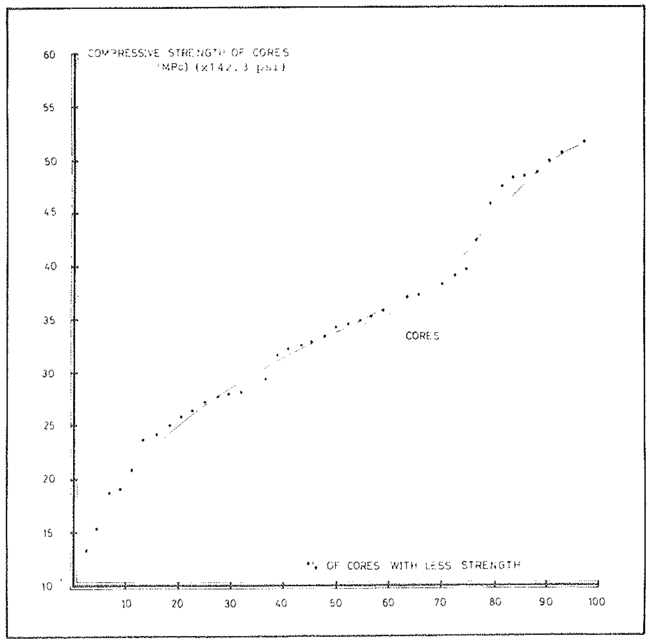

FIGURE 17 Compressive strength of cores versus percent of cores with less strength.

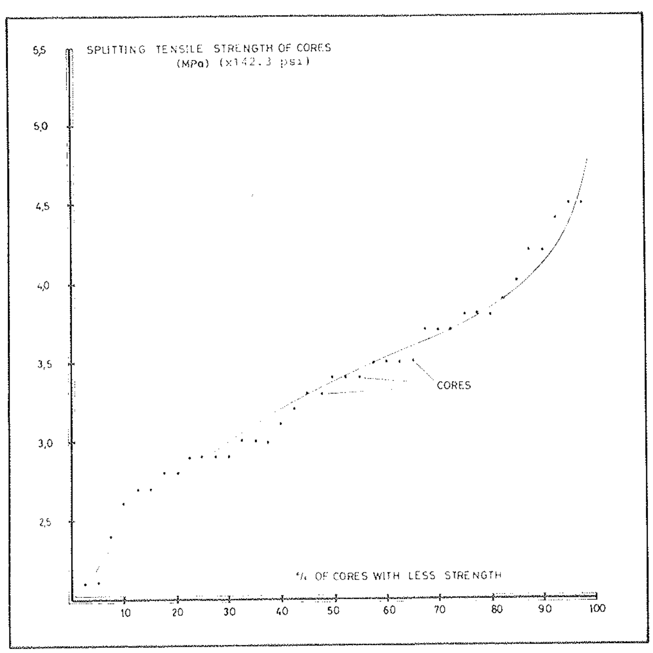

FIGURE 18 Splitting tensile strength of cores versus percent of cores with less strength.

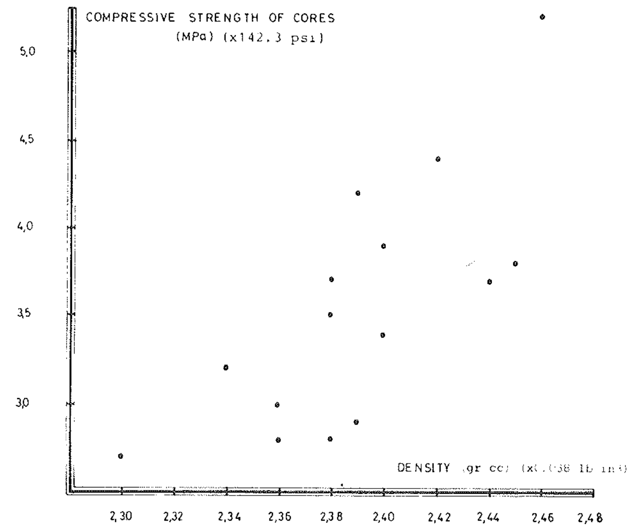

FIGURE 19 Compressive strength of cores versus density of cores.

- Thickness also varied; in some cases the slab thickness was either too little or too much. This can be attributed to defects in the leveling of the subgrade or subbase, among other things.
- Although an increase in strength was expected in older projects because of the increase in strength provided by the fly ash or slag in the binder, laying faults or variabilities in each project completely obscured this correlation (Figure 20).

CONCLUSIONS

The experience gained with the use of roller-compacted concrete on low-volume roads has demonstrated that this technology is highly appropriate. It meets the two conditions that are required of these pavements: competitiveness in construction cost and low maintenance over a long period of time. It appears that both conditions have been met in practice, and studies have confirmed that such roads have performed well.

REFERENCES

1. C. Kraemer. Why Concrete Pavements? (El Porqué de los Pavimentos de Hormigón). Seminar on Concrete Pavements for Rural and Urban Roads, León, Spain, Nov. 1984.

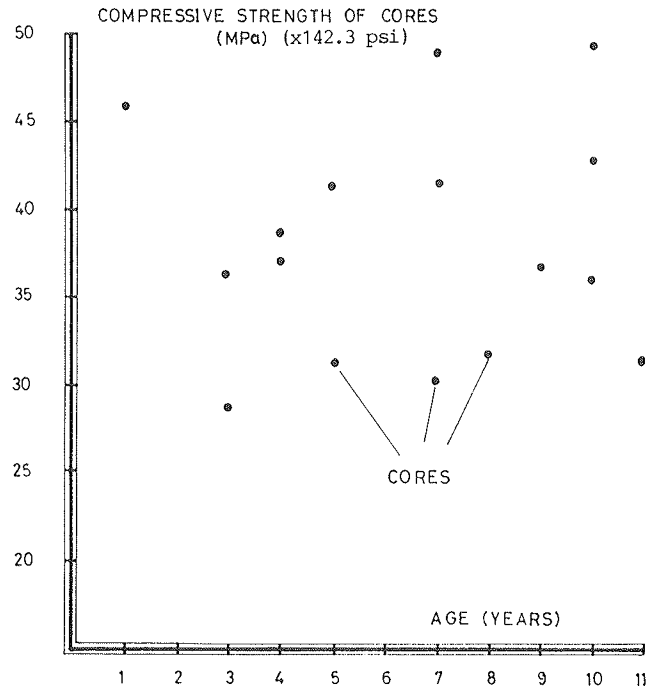

FIGURE 20 Compressive strength of cores versus age of cores.

2. C. Gasca. Low-Volume Roads Course. Spanish Roads Association, Madrid, 1982.
3. A. Josa. Roller-Compacted Concrete: Urban Streets and Rural Roads in Catalonia (Hormigones Secos Compactados con Rodillo: Vias Urbanas y Caminos Rurales en Cataluña). Seminar on Concrete Pavements for Rural and Urban Roads, León, Spain, Nov. 1984.
4. R. Fernández. New Technologies: Roller-Compacted Concrete (Nuevas Tecnologias: Hormigones Secos Compactados con Rodillo). Second Symposium on Concrete Pavements, Córdoba, Spain, March 1984.
5. A. Josa, C. Jofré and F. Molina. An Experimental Overlay with Rolled Concrete. International Conference on Concrete in Transportation, Vancouver, British Columbia, Sept. 1986.
6. R. L. Perona and J. Pleite. Spanish Experiences in Roller-Compacted Concrete Pavements in the Years 1984 to 1985. Symposium on Concrete Roads, Aachen, West Germany, June 1986.
7. R. Fernández and C. Jofré. *Standard Draft for Roller-Compacted Concrete.* I.E.T.c.c., Madrid, Spain, 1982.
8. *Cements: Definitions, Compositions and Specifications.* Spanish Standard UNE-80.301/85. IRANOR, Madrid, 1985.
9. F. Molina and A. Josa. Concrete Pavement Constructed in Extreme Atmospheric Conditions. 5th International Symposium on Concrete Roads, Aachen, West Germany, June 1986.