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Publication of this paper sponsored by Committee on Chemical Additions and Admixtures for Concrete.

A New Process for the Laying of Monolithic Composite Continuously Reinforced Concrete Pavements

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Technical as well as financial developments have led to a new approach to rigid pavement techniques in France for heavy-traffic roads. Continuously reinforced concrete with the use of local aggregates is currently preferred. A monolithic composite structure made up of two layers of concrete of different composition is increasingly used. New techniques, involving continuous reinforcing and double-layer rigid pavement, have called for the development of specific equipment in order to produce good functional characteristics while allowing for construction performance and quality equivalent to that found at more traditional construction sites. Analysis of the results obtained on the highway construction site discussed in this paper reveals that the aims set by the designers have been fully met.

The use of cement concrete pavements on the French national highway network has been intermittent for the past 20 years. After a period of uncertainty, new market conditions have boosted the use of hydraulic concrete in conjunction with the use of continuous reinforcing. New equipment had to be designed to adapt to the functions required. The construction of the highway section described in this paper allows an assessment to be made of the progress.

REQUIREMENTS FOR ROAD CONSTRUCTION IN FRANCE

In 1985, some 850,000 m^2 (1 million yd^2) of concrete pavement were built on heavy-traffic roads, including new lanes and overlays. This work, considered a substantial amount for France, accounted for the efforts made by companies to develop high-performance equipment.

Opening of the Market

Although there were other factors involved, this renewal of construction techniques was the result of three factors:

1. Highway administrators' taking into account maintenance costs and disruption to users by the performance of such maintenance;
2. Officials of the Direction des Routes (Public Roads Authority) wanting to apply appropriate techniques to specific cases; and
3. Prime contractors and users becoming more familiar with such techniques as a result of increasing small-scale road networks made of concrete.

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Construction of Heavy-Traffic Roads

Because there is direct competition between manufacturers of different pavement types, the economic aspect often determines the choice. Thus, the equipment referred to in this paper has been designed to minimize the costs of materials as well as manpower and to reduce the total working area required, as much as possible, particularly breadthwise. Savings on materials and manpower were noted as follows:

1. The suppression of the transverse reinforcing steel supporting the longitudinal reinforcing steel and the butt welding of the longitudinal steel leads to a saving of about 15 percent compared with the previous continuously reinforced concrete (CRC) projects.
2. The construction of a thick slab with no subbase results in a 15 percent overall saving on materials compared with those used in traditional structures.
3. The construction of a pavement with two layers laid simultaneously accounts for substantial savings, depending upon the amount and quality of aggregates to be found in an area. This will be illustrated through an example given later in this paper.
4. Owing to the automation of the machines as well as to the preparation of a number of operations (such as the butt welding of the longitudinal steel ahead of the concreting spread) the manpower can be reduced by 30 percent.

Overlaying of Heavy-Traffic Roads

Considering the high volume of traffic generally borne by highways by the time they need resurfacing or rehabilitation, it is usually impossible to close them down while the work is in progress. The traffic must then be funneled onto a reduced number of lanes. It is therefore easy to understand why the concession companies are seeking to reduce both working time and the encroachment of the paving spread on the construction site, particularly breadthwise.

Under such conditions the paving contractor has to improve the work efficiency and site organization while still maintaining the high quality of the final product. This has led to the development of a front-fed spreading machine that allows the use of an extra lane of traffic compared with work sites where side-fed slipform pavers would normally be required to produce a monolithic composite pavement.

Other innovations of site organization are illustrated by examples such as:

- The preparation beforehand of a number of operations such as the butt welding of the longitudinal reinforcing bars.
- The gathering of the longitudinal reinforcing bars in the center of the roadway waiting to be processed, leaving enough space for two trucks to deliver concrete simultaneously (Figure 1).

This has enabled work to progress on the complete job at a mean of 300 ft/hr in 26-ft paving width, with firm concrete (1 to 1.5 in. slump).

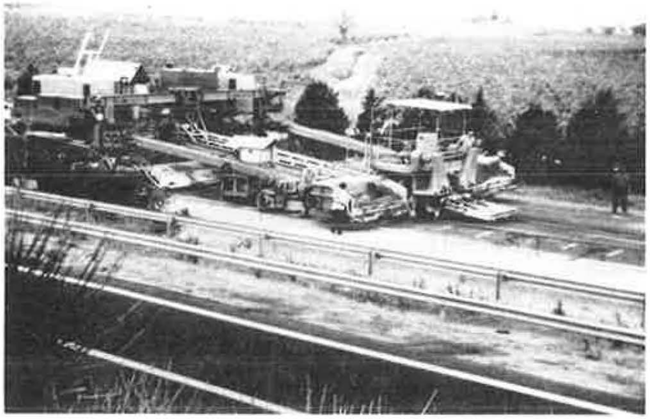


FIGURE 1 A compact paving spread.

Adaptation of Concrete Characteristics to Composite Pavements

Taking into account the relative scarcity of hard aggregates and the abundance of soft aggregates such as limestone in France, studies were carried out to extend the use of the latter. These resulted in the differentiation within the pavement of the structural function, for which a high resistance to bending must be sought, and the surface function, for which a high resistance to wear is essential.

It is well known that if calcareous or limestone aggregates are adapted to the first function, they are by nature quite unsuitable for the second. In France such a distinction was made starting in 1980, first by applying an asphalt surface coating after the first year of life to the concrete pavement, then by inserting hard, coarse aggregates superficially in the newly laid concrete pavement before it dried so that they would protrude slightly above the surface. The old concept of composite concrete pavement was only reconsidered in 1983 and research work was carried out to come up with a new laying process that would make it monolithic as well.

The method was in fact very simple: placing two layers of different concrete in a short time while causing the mortars of each concrete to mix. The results obtained have shown that the pavement no longer has a double layer structure but has continuous mechanical characteristics instead.

DESCRIPTION OF SITE EQUIPMENT

An existing slipform paver was modified for the project described and a sophisticated frontal feeding system was added to it. These modifications were patented under a U.S. patent. The research phase lasted 6 months and the manufacturing and engineering phase lasted one year. It was first used in 1985 for a CRC overlay of a 16-mi section of four-lane highway, and then in the first half of 1986 for the construction of a new section of a 19-mi four-lane highway.

Dual Front Feeder

The feeding system is made up of two transverse receiving hoppers separated by a tunnel through which the longitudinal reinforcing steel passes. Two extraction belts placed under the receiving hoppers direct the concrete toward two conveyor belts that convey it to the feed hoppers (see Figure 2). These conveyor belts can pivot so that the material can be delivered to any part of the feed hoppers or vibrating tanks. Spacers and guides fixed under the belts spread the longitudinal steel out on the whole width of the pavement. There are two distinct feeding circuits that allow for the construction of the pavement with two different types of concrete.

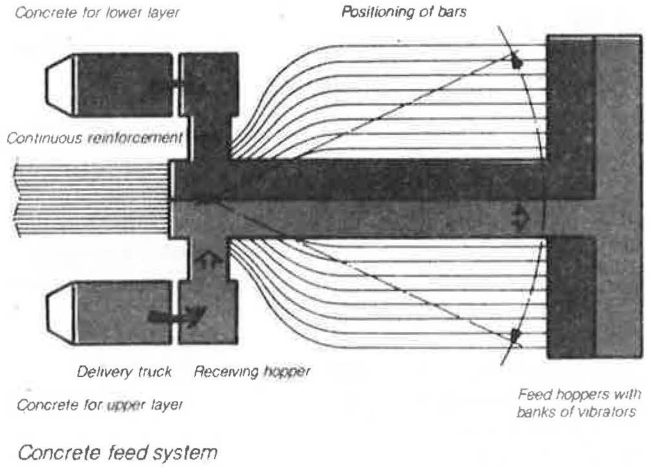


FIGURE 2 Dual front feeder.

The feeding system is mounted on an automotive frame that is guided by means of a string line. Its speed is regulated by that of the spreading machine. During the concrete delivery, the trucks are out of gear and pushed forward by the machine. The resulting movements imposed on the feeding system are compensated for by means of articulated and telescopic arms that connect it to the slipform paver (spreading machine). Possible jolts to the slipform paver are thus avoided and this allows bridge approaches, curves, starts, and stops to be performed as though the slipform paver were operating alone. It should be noted that the outline or gauge of the machine remains that of the slipform paver. The conveyor belt throughput can be modulated and is able to deliver up to 420 yd^3/hr.

The Slipform Paver

The feeding system's steel frame bears on the front crawlers of the slipform paver, thus only transmitting to the paver's vertical forces.

A second conforming plate has been added at the front of an existing slipform paver that separates the two feed hoppers or vibrating tanks. Thus two concretes of different composition can be placed in two different layers practically simultaneously. The number and the positioning of the vibrating needle ramps can be adjusted according to the characteristics of the concrete and thickness of the layers to be poured. The vibrating power inside each tank can also be adjusted according to the desired concrete consistency. A special device fixed between the two vibrating tanks allows the introduction of transverse tie bars in the longitudinal joint that separates the lanes. In addition, the slab can be 45 cm (18 in.) thick at most and the thickness of each layer can be adjusted from 0 to 45 cm (Figure 3).

Guiding of the Longitudinal Reinforcing Steel

In order to achieve an accurate positioning of the continuous longitudinal reinforcing steel within the pavement, the bars must be guided and maintained in place during the vibration of the first layer on which they rest. For this purpose, trumpet guides are fitted under the first vibrating tank.

Reinforcing

The number, diameter, and positioning of the longitudinal steel depend on the project rather than on the equipment. The adaptation of the equipment to each project is achieved by adjusting the number of trumpets and by repositioning them. The maximum number of $^5/_8$-in. diam rebars positioned in the slab currently is 51 for a 7.85-m (26-ft) pavement width. The steel can be placed at any level in the slab section as required.

The trumpets are 1.6 m (5 ft 3 in.) long and their inside diameter is adjusted to the reinforcing bar diameter (clearance of less than 4 mm, or $^5/_{32}$ in.). Such tight dimensions prevent the penetration of medium-size and coarse aggregates, thus avoiding their jamming in the guides. The reinforcement is kept in position by the guides on the one hand and by the vibration-compacted concrete on the other hand (lower layer) (see Figure 3).

A device for the continuous control of the steel positioning in the slab at the rear of the spreading machine is under study.

Welding of the Longitudinal Reinforcing Steel

In order to save on the quantity of reinforcing steel used, the steel bars are flash-butt welded rather than spliced. Such a process creates a bond that allows trucks to ride on them. The welding machines are of the automatic type and are fed by a 300 kVA generating set. Welding power is 12,000 amp, 15 volts, and forging pressure 250 MPa. These machines allow 120 welds/hr to be made including trimming (Figure 4).

One or two mobile welding stations are provided well in advance of the spreading machine ($^1/_2$ to 1 mi) for the prefabrication of the 54-m (177-ft) lengths from standard 18-m bars. A second or third machine welds the 54-m bars into continuous lengths at a distance of about 500 to 600 yd in front of the slipform paver. Such an arrangement makes it possible to

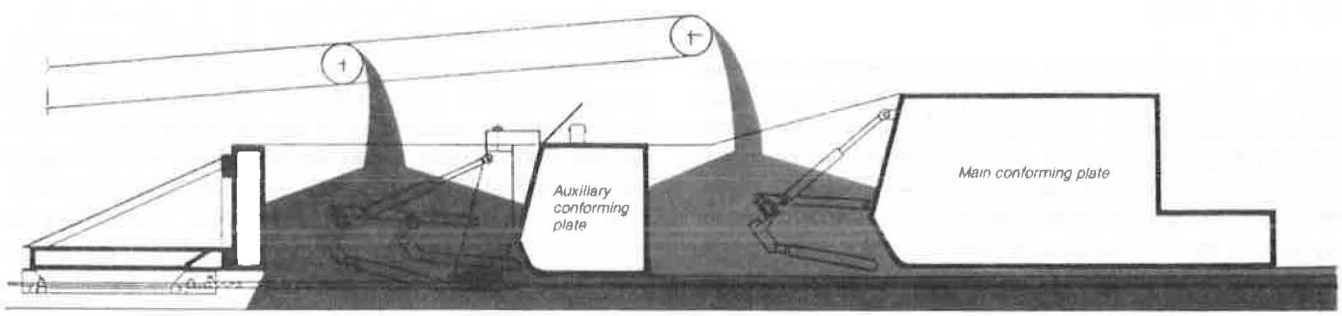


FIGURE 3 Longitudinal cross section of the modified slipform paver.

FIGURE 4 A machine flash-butt welds the longitudinal rebars.

make up for accumulated slack in the continuous reinforcement on the inside of curves, for example, by periodic retensioning.

THE A71 HIGHWAY

In the first half of 1986, this equipment was used to place a new pavement 7.9 m (26 ft) wide and 31 km (19 mi) long.

Choice of the Structure

The parameters of the total cross section were as follows:

- A trapezoidal-shaped section with thicknesses of 18 cm (7 in.) in the fast lane and 20 cm (8 in.) in the slow lane (see Figure 5).
- Cement content: 330 kg/m^3 (0.27 short tons/yd^3).
- Hard aggregates (porphyritic).
- Longitudinal reinforcing steel 0.55 percent [i.e., 49 bars with a diameter of 16 mm ($^5/_8$ in.)].

The use of such hard aggregates and cement dosing is aimed at obtaining the required top layer characteristics, that is, good resistance to wear and sufficient ruggedness by exposing the coarse aggregates through chemical striping of surface mortar. The double layer structure of the pavement makes it possible to distinguish the wearing course from the base course and to offer the following:

1. For the base course (approximately 15 cm thick):
   - Local aggregates (limestone)
   - Cement content of 300 kg/m^3
2. For the wearing course:
   - Hard aggregates (10-14 mm)
   - Cement content of 330 kg/m^3(556 lb/yd ^{3})

The porphyritic aggregates had to be hauled in from a distance of about 80 km (50 mi), which made them cost more than twice as much ($11/short ton) as the local aggregates ($4/short ton). The savings on hard aggregate cost and on cement consumption alone represent 10 percent of the total cost of the constituents. The amount of reinforcement remains unchanged.

Carrying Out the Project

The mean concreting rate on the entire job was 90 m/hr (300 ft/hr). The field team (production and laying) was composed of 40 people distributed among the following categories:

Management of the project	2
Concrete production	10 (2 mixing plants)
Welding	10
Paving	12
Stripping and curing	6

FIGURE 5 A transverse section of the double layer monolithic continuously reinforced concrete pavement used on the A71 motorway.

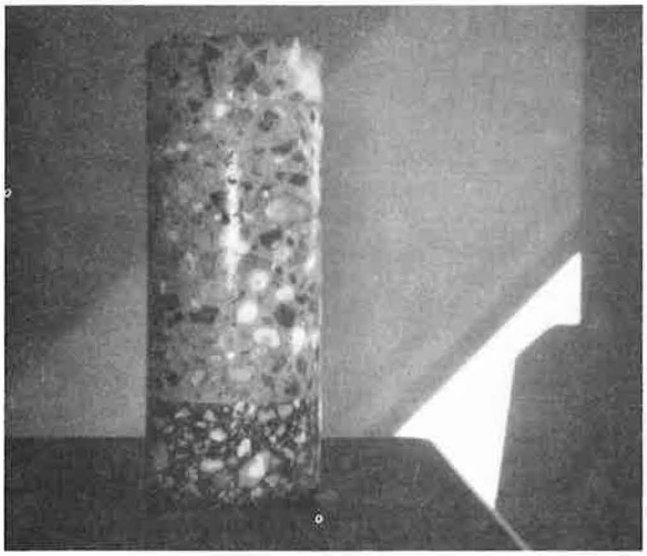


FIGURE 6 **View of core sample.**

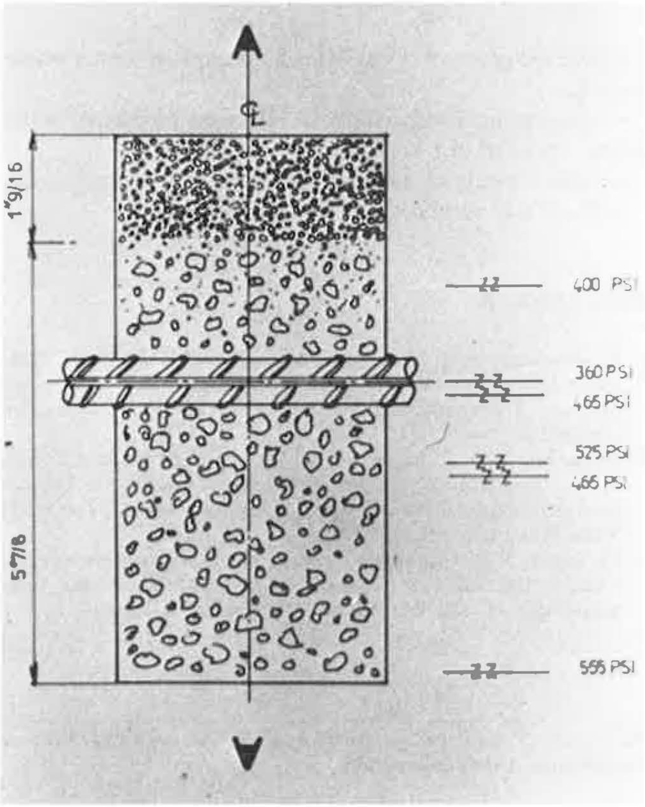


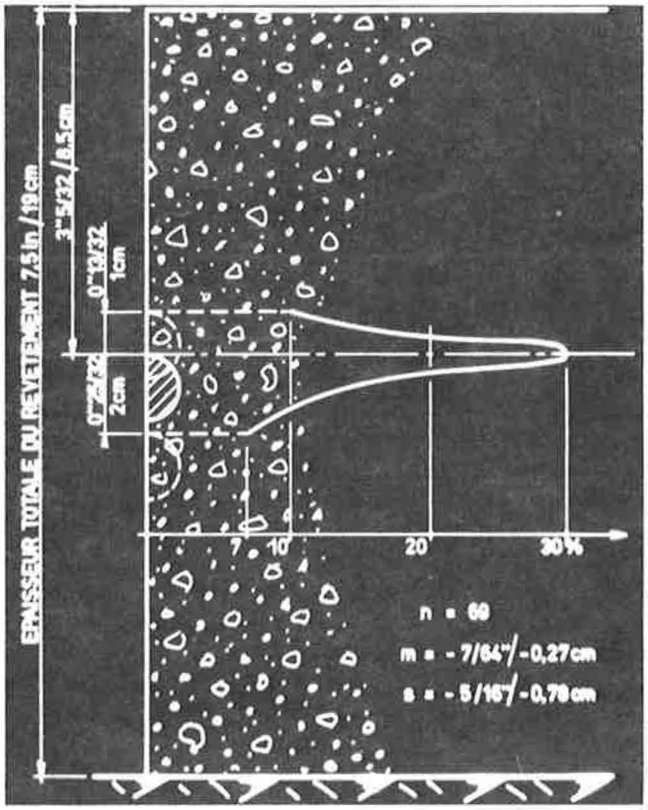
FIGURE 7 **Position of failures.**

Note the following observations:

1. No breaking of welded steel occurred under construction traffic.
2. Good vibration of concrete required that
   - Both layers be laid carefully to avoid concrete overrun on the top layer and any possible random mixing of the two layers (for economic reasons only).
   - The total amount of the concrete involved in the second tank be vibrated.

Experience has revealed the difficulties of such an adjustment. Although mixing of different concrete types was observed, the overall results were considered satisfactory.

3. Bonding within the slab
   - Many core samples (120) were taken from the pavement to perform traditional controls (splitting) (Figure 6). They revealed an excellent continuity from one concrete to another via the mortar with no significant gravel transfer.
   - A few core samples were subjected to tensile stress testings in order to determine the breaking points. All core samples were broken in the low concrete (Figure 7).
4. Positioning of steel bars
   - Core sample inspection also demonstrated the position of the longitudinal steel bars in the slab. Their relative position in relation to the surface of the slab is indicated in Figure 8.



Note: n = The number of core samples taken containing some of the longitudinal reinforcing steel.
m = The mean deviation of the longitudinal steel centerline from the theoretical position compared with the slab surface.
s = The standard deviation of the longitudinal steel centerline in relation to the theoretical position.

FIGURE 8 **Position of the longitudinal steel bars in the slab.**

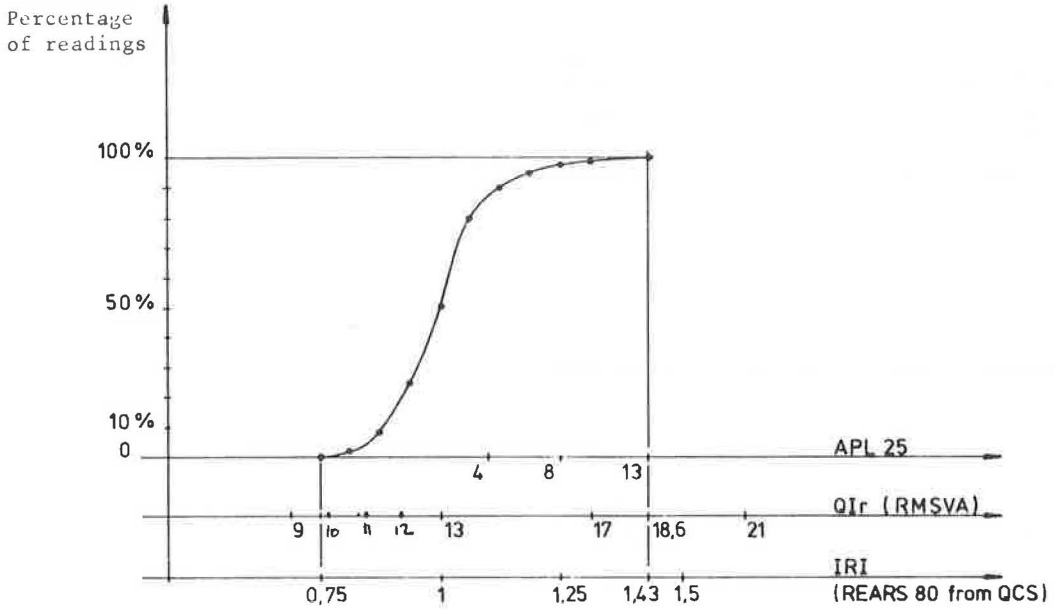


FIGURE 9 Pavement evenness.

Pavement evenness (see Figure 9) was measured using the French profilometer (APL25). By applying the transformation rules extracted from the reports of Paterson et al. *(1)* and Sayers et al. *(2, 3)*, it is possible to represent the results obtained in the Quarter-car Index (QIr) root mean squared vertical acceleration (RMSVA) and International Roughness Index (IRI) reference average rectified slope (RARS) 80 from Quarter-car Simulation (QCS) scales. The measurements were carried out on 8 km (5 mi) of pavement. According to the criteria, the pavement evenness is excellent when IRI readings are between 0 and 2, and QIr readings are between 10 and 20.

CONCLUSION

The development of cement concrete pavements for heavy-traffic roads in France depends on the technical advances achieved toward a lowering of maintenance costs, an increase in the use of local materials, and general savings in the constituents. The trend toward the use of a CRC pavement using two different kinds of concrete fully attains these aims.

The materials developed to meet such requirements have proved quite satisfactory, and examples of the performances attained are as follows:

- Average production was 300 ft/hr (estimated for the whole project).
- Longitudinal reinforcing steel bars were positioned to the nearest cm (5/16 in.).
- Good bonding of concrete existed between the two layers.
- There was excellent pavement smoothness.

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Publication of this paper sponsored by Committee on Rigid Pavement Construction and Rehabilitation.