Concrete Pavement Restoration: French Maintenance Strategy and Load Transfer Device

P. GUINARD, J. L. NISSOUX, AND P. ORSAT

The development, implementation, and practical performance of the following maintenance operations, with which France has had experience, are presented: maintenance of surface roughness, lateral drainage for old pavement, and restoration of load transfer at joints with connectors. These connectors are steel cylinders in two half-shells linked together by a steel pin sliding in a horizontal plane. The connectors are in holes bored vertically across the joint between slabs. The faces of the half-shells are glued with resin to the concrete on which they bear. This method has been used to reinforce several sections of motorways and airport runways in the past 2 years. Measurements made before treatment revealed joint movements of more than 0.5 mm. The same measurements made following treatment showed that movements had been reduced and limited to 0.05 mm. This second figure is fully satisfactory because it is currently accepted that disorders occur when possible movements are on the order of 0.2 mm and if they exceed 0.7 mm. Numerous laboratory tests have been performed on the connectors, particularly to determine their fatigue characteristics.

The maintenance strategy set up in France at the end of the 1970s was presented at the International Conference on Concrete Pavement Design and Rehabilitation (*1, 2*). This strategy was suited to the condition of the network of concrete pavements in service at that time. Main French motorways were built at the beginning of the 1960s with plain concrete pavement over a cement-treated base without dowels and lateral drainage; this concrete road network received no maintenance for many years.

The present maintenance strategy makes use both of maintenance methods already used by countries that have networks of concrete roads and of original methods developed in France to attain the objectives set by the French Highway Department for the safety and maintenance of the national road network.

The evolution, effectiveness, and functional performance of operational maintenance methods, including maintenance of surface roughness and lateral drainage for old pavements, will be described. The present state of research and a method of restoring load transfer invented in France will be discussed.

P. Guinard and P. Orsat, Freyssinet International, z.a. des Marais, 28 rue des Osiers, 78310 Coignières, France. J. L. Nissoux, Laboratoire Central des Ponts et Chaussées, Centre de Nantes, B.P. 19, 44340 Bouguenais, France.

MAINTENANCE OF SURFACE ROUGHNESS OF CONCRETE PAVEMENTS

For a number of years, two techniques for restoring the surface condition of concrete pavement have been widely used on the French highway network:

1. Longitudinal grooving (grooves 2.4 mm wide, 6 mm deep, and 25 mm apart) had a number of advantages: higher coefficient of friction (Figure l), fewer accidents (a reduction of about 50 percent in the number of accidents on wet pavement on the privately operated A6 motorway), and a reduction in tire noise.

Despite these advantages, this technique has been dropped because of the unpleasant effects on motorcyclists of pavements so treated, which are only intermittently encountered by users because of the short length of pavement grooved.

2. A surface dressing was developed for motorway pavements by the Société des Autoroutes Paris Rhin-Rhône and the Viafrance contracting firm, with the assistance of the Laboratoire Central des Ponts et Chaussées (LCPC). The first operational applications date from 1973, and, as experience has been acquired, a standardized technique has been developed (Table 1).

To minimize the risk of heaving, which would have especially grave consequences on motorways, precautions are taken: preheating of aggregates, dust removal, high-precision binder and gravel spreading equipment, and finishing by suction sweepers before the pavement is reopened to traffic. This work is done by highly specialized contractors and crews.

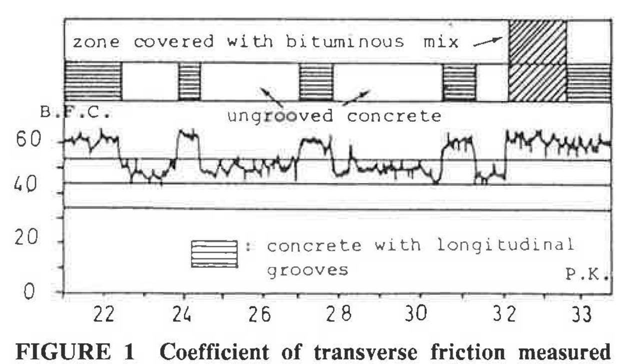


FIGURE 1 Coefficient of transverse friction measured by SCRIM.

TABLE 1 DOUBLE-GRAVELED SINGLE-LAYER SURFACE DRESSING FOR CONCRETE MOTORWAYS

Component	Proportion (kg/m^2)
Bitumen-elastomer binder	1.5
10/40-mm aggregate	13
4/6-mm aggregate	7

This fully operational technique gives good results on motorways that carry as many as 50,000 vehicles per day. The curve of evolution of the coefficient of longitudinal friction as measured by the LCPC skidding resistance test trailer shows that, up to 106 cycles (total truck traffic), the braking force coefficient (BFC) at 120 km/hr is better than 0.32 (Figure 2).

There has also been a reduction in the number and gravity of accidents of as much as 65 percent on wet pavements and 78 percent on icy pavements.

The surface dressings have an average life of 7 years on truck lanes of heavily traveled motorways. A new surface dressing of the same formulation (Table 1) applied directly over the old is sufficient to restore skid resistance.

Transverse grooving of the surface of the concrete slabs has undeniable advantages in terms of durability, effectiveness, and the preservation of the specific qualities of rigid pavements—light color and the absence of a bituminous wearing course.

Furthermore, when one travel lane, generally the truck lane, of a pavement on which it would be difficult to apply a surface dressing is rebuilt, the need to maintain the homogeneity of the surface properties of the old and rebuilt lanes dictates mechanical treatment of the old lanes. For this reason, the Gailledrat contracting firm has developed a machine to saw transverse grooves using diamond discs that is better suited to road work than the equipment hitherto available.

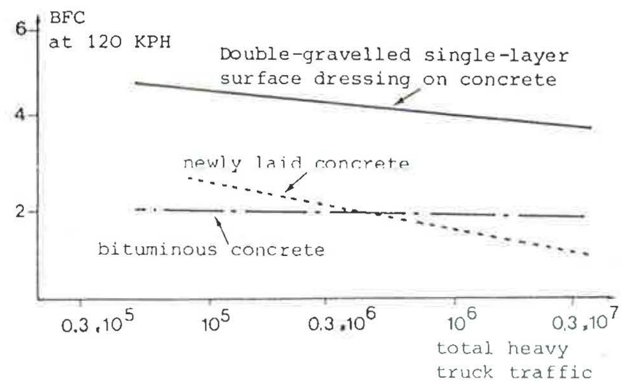


FIGURE 2 Braking force coefficient versus total heavy-truck traffic.

This machine occupies only one lane, has an automatic advance device, and is guided by a wire. The operating rate attained on silico-calcareous concrete is 75 m^2/hr, which makes it possible to treat 500 m of lane per day in three shifts.

The Laboratoire Central des Ponts et Chaussées has designed and developed a noncontact measurement device (laser); its accuracy, coupled with modern signal processing techniques, provides statistical information about the geometric properties of the grooves that is quite representative of the actual condition of the pavement.

LATERAL DRAINAGE FOR OLD PAVEMENT

The water trap that characterizes old pavements is well known, and various attempts to control this phenomenon have been described (Figures 3 and 4) (*3, 4*).

The data given in Table 2 indicate that shallow drainage trenches can be valuable, provided the pavements are still in

TABLE 2 ASSESSMENT OF 6 YEARS OF FRENCH EXPERIENCE

Type of Drainage	Old Pavement in Good Condition[a]	Old Damaged[b] Pavement with Subbase: Little or not Erodible	Old Damaged[b] Pavement with Subbase: Erodible
Lateral drainage	Yes, shallow drainage trench against slab and drain	Possible	No
Reconstruction of shoulder with nondraining trench		Yes, if shoulder is damaged: greater faulting on shoulder side[c], danger to motorist, pavement already deteriorating	
Deep, distant-draining trench	To be used only for special cases of external water penetration (after special study)		

[a] Limited slab deflection and faulting, subbase little or not erodible.
[b] Slab deflection or faulting.
[c] Greater slab deflection on the shoulder side is a sure sign that the fines responsible for deflection come primarily from the shoulder.

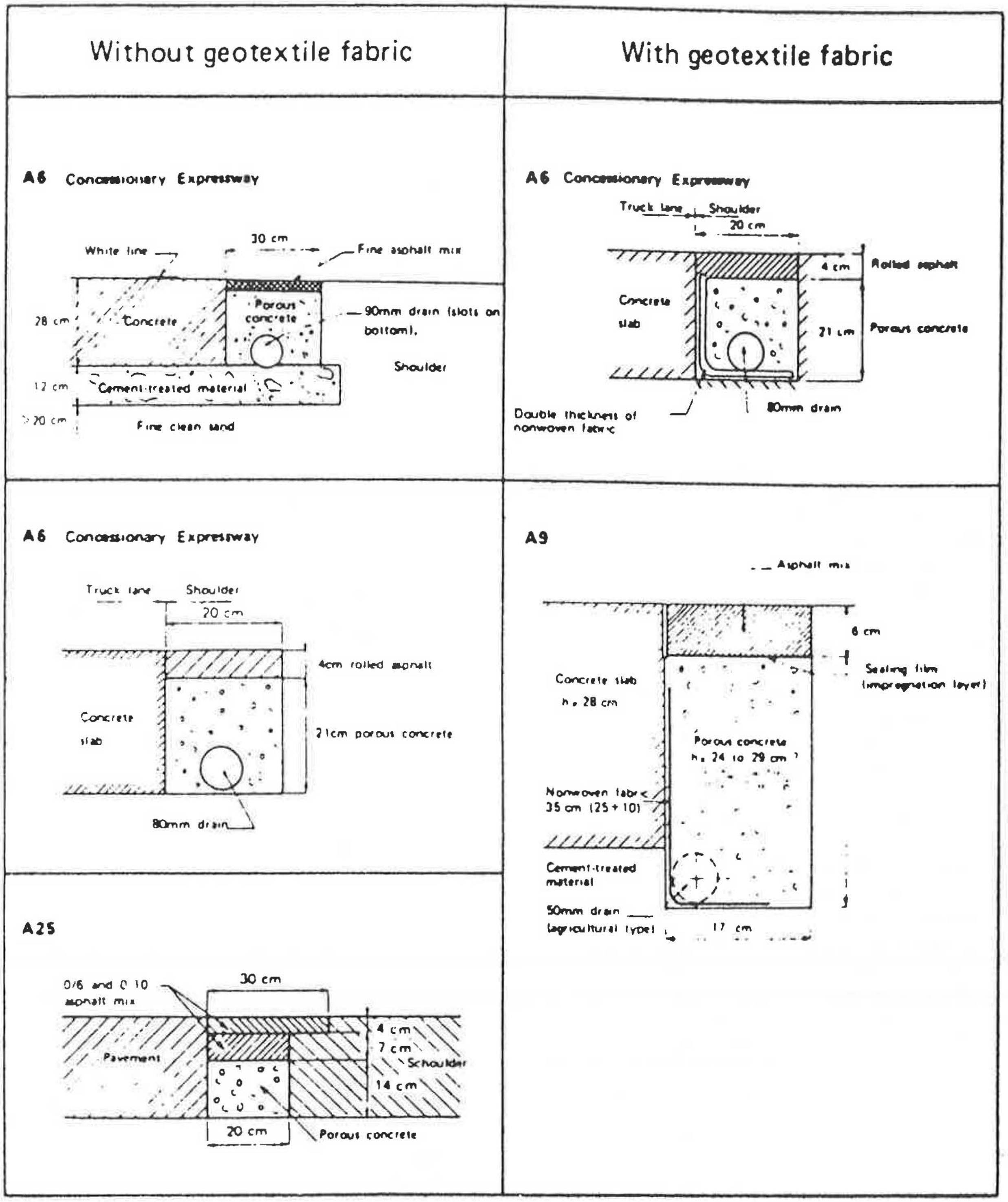


FIGURE 3 Solutions to water trap on old pavements: shallow pervious trenches with and without geotextile (A6, A25, and A9 expressways in France).

good condition and not liable to change (discharge of fines by drainage, especially if subbase erodibility may be involved).

If drainage by means of pervious trenches is not possible, it is preferable to reconstruct the shoulder and provide impervious shallow trenches (Figure 4). This solution reduces water penetration and thus eliminates pumping pit damage and improves motorcycle safety. An allowance of 25 mm × 25 mm (1 in. by 1 in.) for the placement of a joint product can lead to some damage. It is also possible to provide a sawn and filled joint 8 mm (0.32 in.) wide and about 30 mm (1.2 in.) deep.

The risk of destabilization, which may require the provision of drainage on old pavements, reached its worst point when deeper drainage structures at the edge of the slabs, cutting

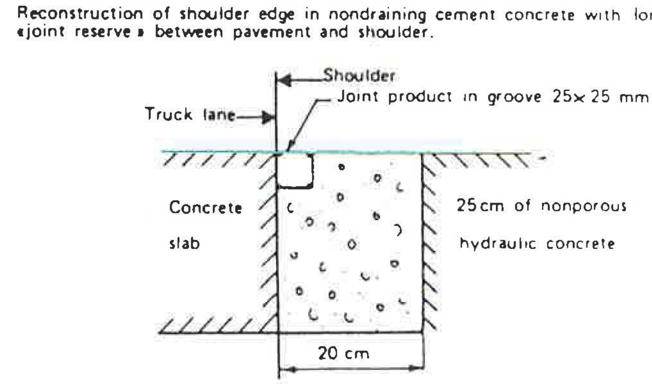


FIGURE 4 Shallow impervious trench (A6 expressway in France).

through the subbase, were used (Figure 5). Gulden (5) discusses the particle-size modifications that could be associated with the waterborne fines effect. Not only is it possible to remove fines from the slab-subbase interface, it is also possible to remove them from under the subbases and from the subgrade (Table 3).

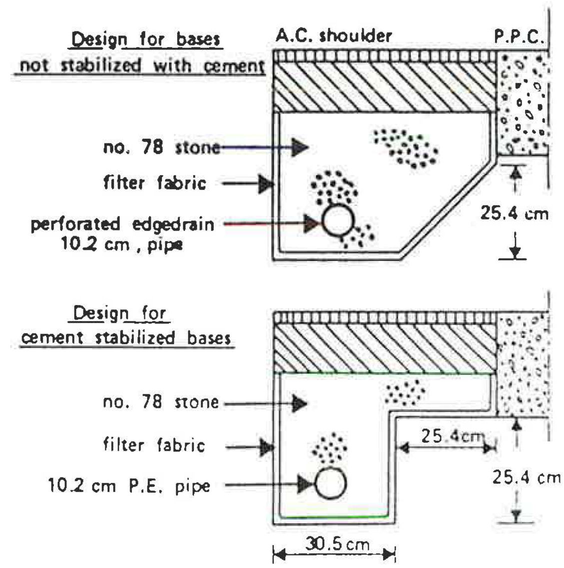
This ties in with notions about filter materials and stability criteria with respect to environments (soils to be drained and orifices receiving drainage pipes).

Verhée and Griselin (3) show that, to fully understand the hydraulic phenomena and in particular the risk of removal of fines, thorough experiments are necessary to check the efficiency of the structures (Table 4). As illustrated by Gulden (5) and brought out by these experiments, the use of geotextiles can limit the removal of fines, but it increases drainage time. Observations are lacking on possible clogging caused by ultrafines (< 80 mm) with time. Such clogging may occur during dry periods or between rains. Note, however, that the pressurizing of water under the slabs should allow dynamic leaching, which is not the case with pure gravity drainage. The experiments already carried out could provide some valuable in situ verifications.

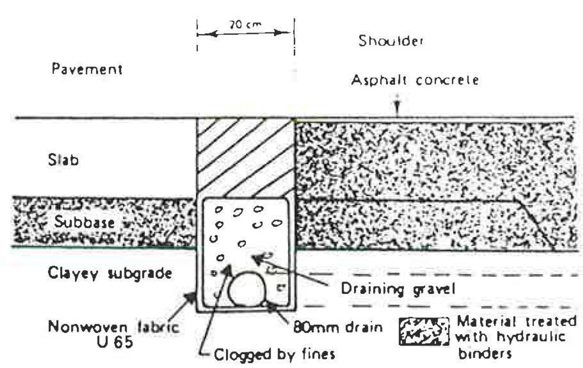
When precautions are taken, the immediate hydraulic efficiency of draining trenches can be easily verified by disappearance of pumping effects, measures of flows at trench outfalls, and disappearance of blasts of cloudy water through road joints (6).

It is not certain that the same is true for road structures that are more delicate. A possible method of determining this is to compare the rapidity with which cracks increase with accumulated traffic on both drained and undrained sections. This method has been applied to new roads built in France before and after 1976 (7). The lack of systematic observations of old concrete roads that have had drainage trenches added does not allow any conclusion to be reached so far. A provisional estimation might show a reduction in the rapidity of degradation as evidenced by the extra traffic carried in comparison with a noncured road, which can be estimated at 4 × 106 trucks or about 5 years of use.

Figure 6 shows Henry's curves of slab cracking rates for different slab structures with and without lateral drainage.



Example 1 studied in USA (Georgia)



Cross section of a drainage trench cutting the subbase and penetrating into a subgrade containing fine elements. Pavement degradation was accelerated by this system which «drained» the fines from the subgrade to the outside of the pavement (A6 Expressway).

Example 2 studied in France

FIGURE 5 Dangerous drainage structures on old pavements: deep drain cutting the subbase.

TABLE 3 GRADATION OF DRAINAGE STONE AFTER 3 YEARS OF SERVICE (I-85 Troup County)

	Percentage Passing at Depth from Top of Pavement of					
Sieve Size	4 in.	7 in.	10 in.	14 in.	17 in.	19 in.
¾ in.	100	100	100	100	100	100
½ in.	89.6	83.3	92.2	94.4	94.4	94.4
⅜ in.	41.3	32.7	44.8	52.9	59.0	68.4
No. 4	8.0	6.5	9.2	9.0	23.0	46.8
No. 10	3.6	4.4	7.5	6.2	21.1	43.3
No. 16	2.5	3.8	6.9	5.8	20.7	41.4
No. 40	1.3	3.1	5.9	5.1	19.5	32.2
No. 60	0.9	2.0	3.9	3.5	13.3	17.7
No. 100	0.5	0.7	1.6	1.9	6.0	5.3

These curves are functions of cumulative truck traffic. On old pavements with cement-treated subbases and without drainage (Curves 1 and 2), it can be noted that there is a first period of normal and slow progression in the number of cracked slabs and a second period of faster, or critical, progression that corresponds to more or less marked pumping, deflection, and faulting defects that increase with fatigue of the material. On pavement with lateral drainage placed after a few years of service (Curve 3), the critical progression phase is ended by the placement of trenches, after which the progression in the number of cracked slabs resembles that of the first phase. Because the sections represented by Curves 1 and 3 are neither on the same road nor in the same area, this tentative evaluation of the positive effect of drainage needs to be verified in situ.

RESTORATION OF LOAD TRANSFER WITH SLAB CONNECTORS

Pumping, faulting, stepping, and failures of plain concrete pavements without dowels are well known and have been described by several researchers since the end of the 1960s (*8–10*). French and U.S. analyses show that the restoration of load transfer is a good alternative to other rehabilitation techniques such as reconstruction or overlays (*2, 10–13*). Such restoration is generally done in conjunction with the addition of shallow drainage trenches when this last repair is compatible with the state of the old pavement.

In cooperation with the Laboratoire Central des Ponts et Chaussées (LCPC), the Service d'Etudes Techniques des Routes et Autoroutes (SETRA), and the Services Techniques de l'Aeroport de Paris, Freyssinet International has designed and developed a repair system that meets the following criteria:

- Transfer of load from one slab to another provided entirely by the repair work; for example, four units of 3 t each per 3.5-m-wide road lane (standard axle load is 13 t);
- Reduction of the "step" from several millimeters to several tenths of a millimeter;
- Execution of repair work in all weather, especially in winter to take advantage of maximum slab shrinkage;
- Rapid construction to reduce traffic interruption; and
- Reduced repair costs compared with other methods.

TABLE 4 DISCHARGE OF FINES BY DRAINAGE STRUCTURES: OVERALL RESULTS OBTAINED ON INSTRUMENTED SECTIONS

	Without Nonwoven Filter Fabric[a]	With Nonwoven Filter Fabric[a]	On Old Pavement[b]
Amount of water drained per rainfall (%)	47	20	69[c]
Average response time (min)	14	20	16
Average duration of drainage after rainfall (hr)	7	8	3[d]
Concentration of suspended matter (mg/L)	220	200	1000[e]
Fines extracted annually (g/m)	67	26	449

[a] Shallow, pervious trenches.
[b] Deep, pervious trench.
[c] Very poor sealing.
[d] Large cavities under slabs favor water accumulation.
[e] Very erodible subbase.

Principle of the Freyssinet Connector

The solution involves drilling in the slab, over the width of the lane, vertical holes astride the crack but not completely through the slab and sealing them with connectors. The connectors take up the shear forces caused by the passage of vehicles by preventing vertical movements and allow longitudinal movements created by thermal changes. The connector consists of

- Two hollowed-out symmetrical half-shell castings [Part (a) of Figure 7];
- A flat, thick metal plate that slides freely within the housing formed by the half-shells [Part (b) of Figure 7];
- An elastomer lining placed between the two half-shells, which makes it possible to ensure watertightness and to retain the grease within the cells of the shells; the lining also provides a minimum permanent keying force [Part (c) of Figure 7]; and

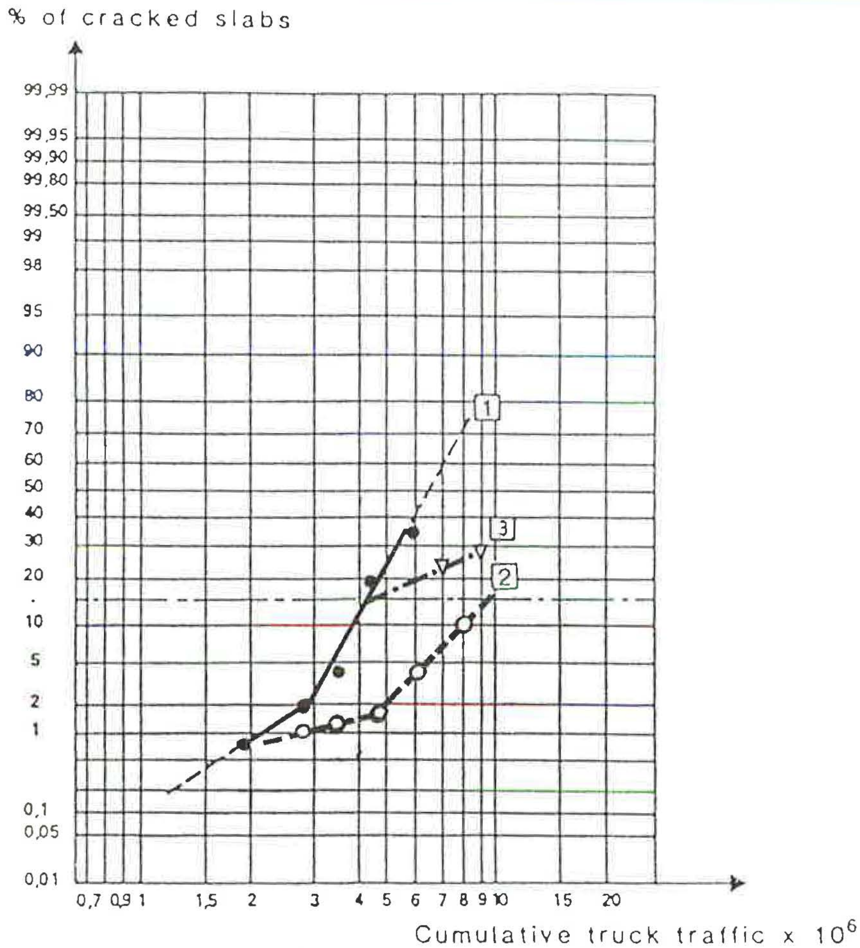


FIGURE 6 Curves of slab cracking as a function of cumulative truck traffic.

- Gluing, which retains the dowels in the holes (Figures 7 and 8).

Placing the Connectors

Motorway repair is done on one lane at a time while traffic is diverted to the adjacent lane. Placement is divided into three operations carried out by separate machines:

1. Simultaneous drilling of four holes on the axis of the shrinkage joint,
2. Simultaneous placement at the bottom of each hole of predetermined quantities of sealing resin followed by insertion of the connectors, and
3. Completion of the upper watertight seal by the placement of a flexible bituminous product.

For a dual-lane highway, four connectors are placed on the truck lane (13-t standard axle load); 30 connectors spaced

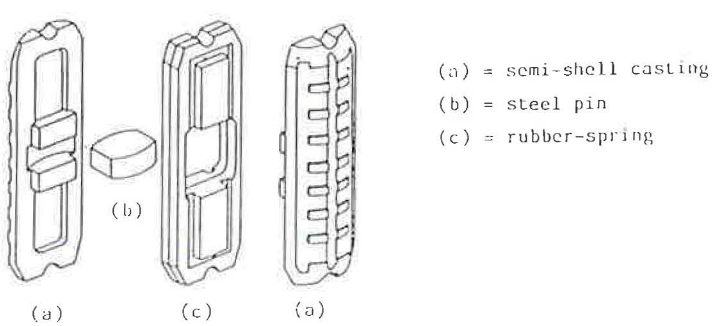


FIGURE 7 Exploded view of connector.

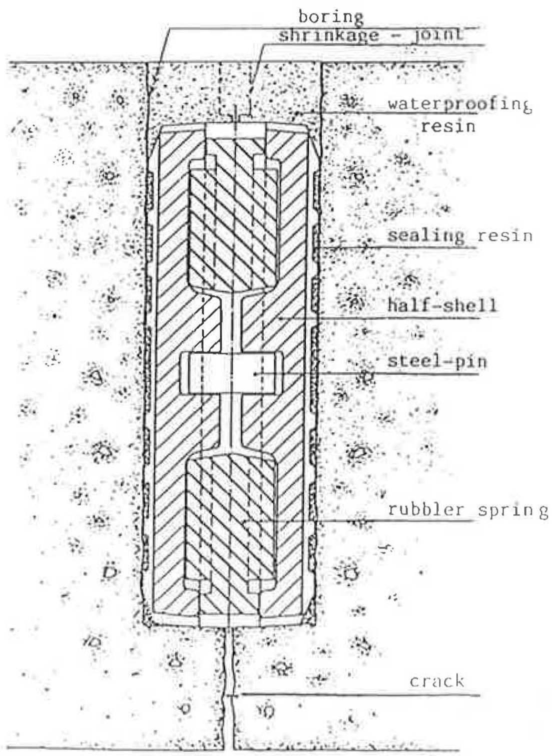


FIGURE 8 Cross section of connector.

at 0.5 m, in each transversal joint, are used for an airport runway 22.5 m wide (Figure 9).

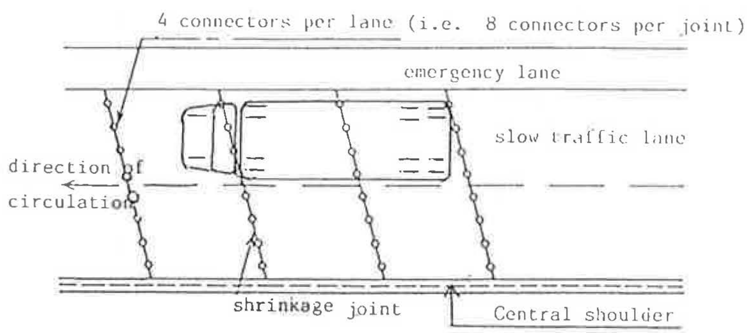
RESULTS OF TESTS ON CONNECTORS

Connectors for use on roads have been developed to withstand the passage of convoys of heavy vehicles by transmitting the vertical forces, which are due to 13-t axle weights, to four individual units without causing vertical movements in excess of 0.2 mm. Airport connectors are intended for much larger loads—13 t per connector—placed every 0.5 m, and the permissible vertical movements are less than 0.5 mm. It should be noted that the frequency of loading is infinitely greater for road connectors than for airport connectors.

Freyssinet International, in conjunction with the LCPC, has carried out numerous laboratory tests.

Fatigue Test of Connectors

Results are given in Table 5 and shown in Figure 10.



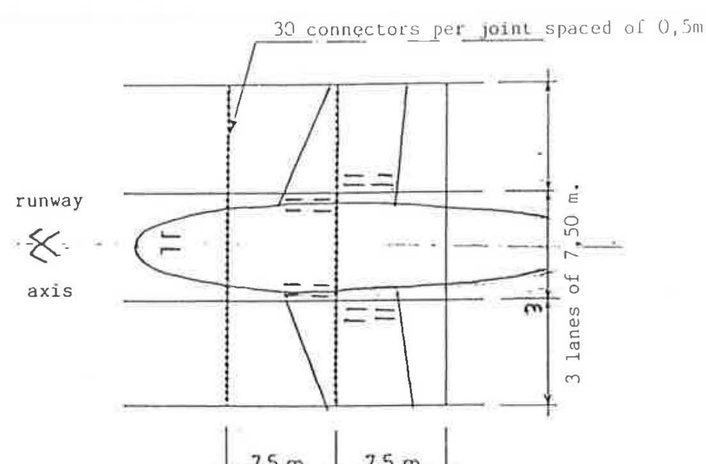


FIGURE 9 Principle of connector implementation for two-lane highway (top) and airport runway (bottom).

TABLE 5 GAP FATIGUE TEST RESULTS

Load (kN)	Frequency (Hz)	No. of Cycles	Vertical Displacements (10^{-2} mm)
36	3.0	1,000,000	6
60	2.1	1,500,000	14
90	2.1	300,000	16

Fatigue Test of Gluing

The test apparatus shown in Figure 11 makes it possible to observe the performance of the gluing of the connector to the concrete at the joint (Table 6). A piston that applies increasing force acts on the glued connector. The relative dowel-concrete movement is measured, and the test is carried out until failure of the fixing.

Watertightness Test

This test is carried out to check the functioning of the mechanical key under various climatic conditions.

Dynamic Test

Tests under alternating loads are being conducted in the LCPC at Nantes; Figure 12 shows how two concrete slabs simulate a transverse joint in plain concrete pavement without dowels. A connector is placed in this joint as previously described. One slab is immobilized, and the other is alternately loaded to produce the same stresses that would be produced by a truck axle crossing a transverse joint. Table 6 gives the first results of these tests.

It is assumed that the fatigue diagram equation is

$$\frac{\sigma_i}{\sigma_1} = A(Ni)^{-b}$$

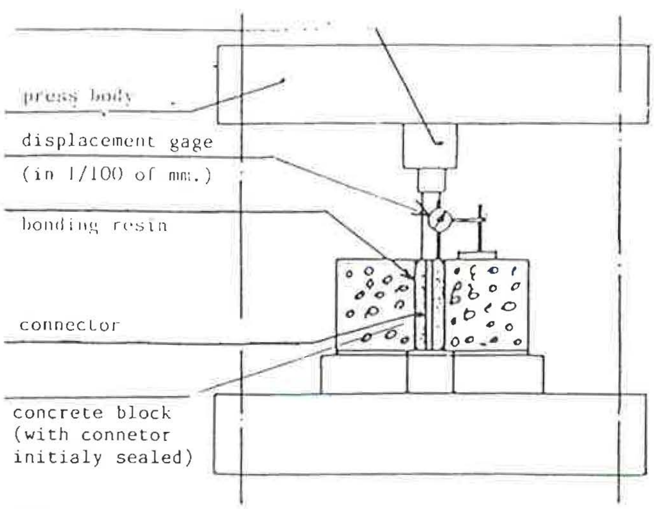


FIGURE 10 Fatigue test of connector bonding.

TABLE 6 DYNAMIC TEST RESULTS

Load (kN)	Frequency (Hz)	No. of Cycles	Vertical Movement (10^{-2} mm)
100[a]	15	Variable up to 2.5×10^6	3.5 avg
15 to 45	15	From 1.5×10^6 to 1.7×10^6	From 10 to 40[b]

[a] Test of gluing between connector and concrete; load was simultaneously applied on the two shells (Figure 11).
[b] At the end of the dynamic test of the whole device (Figure 12).

where

A = constant value;
Ni = number of loads (or stress) applied, the value of which is σ_i;
1 = load (or stress) of one cycle (static breaking value);
b = slope of fatigue diagram; and
Sb and S = standard deviation of b and σ_1, respectively.

Values of σ_1 and b can be determined in order to make the results of this test coherent with those specific to connector concrete gluing.

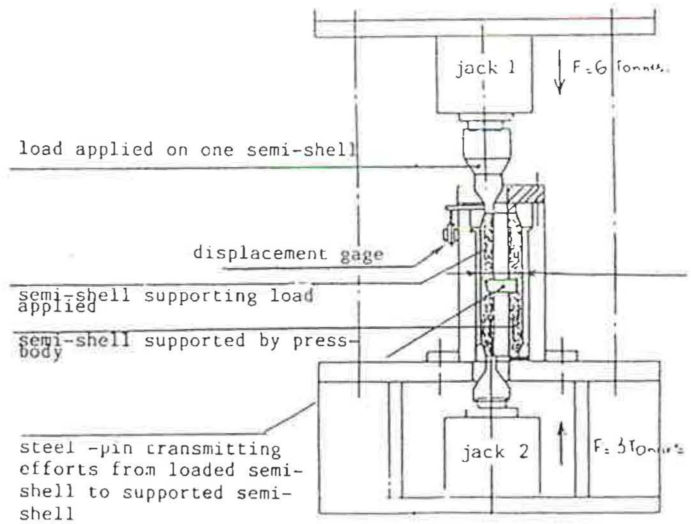


FIGURE 11 Fatigue test of connector with alternate loads.

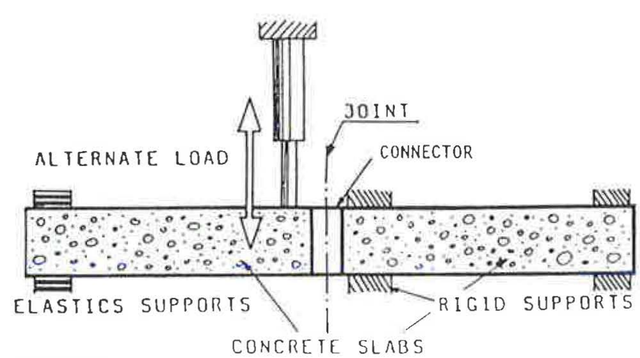


FIGURE 12 Dynamic fatigue test of connector.

Until there are results from the tests now being performed, this calculation requires numerous hypotheses. For instance, the values of σ_1 and b can be adjusted so that either variability of the slope of the fatigue diagram (Hypothesis A) or variability of static breaking values (Hypothesis B) explains the dispersion of results. Hypothesis A is that the fatigue diagram equation is

$$\frac{\sigma_i}{\sigma_1} = A(Ni)^{-(b+x \cdot Sb)}$$

Hypothesis B is that the the fatigue diagram equation is

$$\frac{\sigma_i}{\sigma_1 + xS\sigma} = A(Ni)^{-b}$$

The values given in Table 7 are obtained if A is set equal to one.

The relation between laboratory fatigue test results and in situ values has to be established.

TABLE 7 VALUES OBTAINED WHEN $A = 1$

	Hypothesis A	Hypothesis B
Testing of Connector-Concrete Gluing Only		
Test 1		
1 =	10 t	12 t
b =	1/20.1	1/16
Test 2		
1 =	10 t	10.6 t
b =	1/17.3	1/16
Testing of Whole Device		
Test 1		
1 =	10 t	9 t
b =	1/14	1/16
Test 2		
1 =	10 t	9.7 t
b =	1/15.4	1/16

EXPERIMENTAL SITES

To date, Freyssinet International has installed several thousand dowels on roads and airport runways, among which the following may be mentioned:

- The A6 Motorway (Pouilly-Avallon-Nemours),
- The A43 Motorway (Dullin Tunnel),
- The A8 Motorway (Antibes Toll Road),
- The A10 Motorway (C6),
- The A4 Motorway,
- The A6 Motorway (south of Paris), and
- Charles de Gaulle Airport at Roissy.

Certain motorway areas and airport taxi tracks have been used as test sites for checking the actual performance of the connectors under traffic. These checks have been carried out by the Regional Laboratory of the Ponts et Chaussées at Autun and the Laboratory of Eastern Paris at Trappes.

The same measurement principle was applied both before the dowels were placed and after varying periods in use. Comparison of the measurements, for the majority of the joints, revealed that

- Vertical movement is limited to a very low value and
- Interlocking of the slabs is perfect, which indicates most satisfactory performance.

For example, the following results have been obtained:

- A6 Motorway: in the Nemours area 178 of 190 joints checked in the central lane had step values of less than 0.05 mm. In the Avallon area 153 of 155 joints checked in the truck lane had step values of less than 0.05 mm.
- A10 Motorway: For the 53 joints checked in the truck lane, measurements were, on average, reduced by 50 percent; the percentage of nonlocked joints was zero, whereas it was 42 percent before work was carried out (Table 8 and Figure 13).

TABLE 8 HIGHWAY A10—EXAMPLES OF RECORDS BEFORE AND AFTER CONNECTING FOR TREATED SECTION AND REFERENCE SECTION (average values)

	Connected Section (average value from 53 joints recorded)		Reference Section Without Connectors (31 joints)	
	Displacement[a] (10^{-2} m)	Noninterlocking Joints (%)	Displacement[a] (10^{-2} m)	Noninterlocking Joints (%)
Measures of reference before connecting	13.6	42	13.6	36
Measures after connecting (external temperature 7°C, temperature gradient 0°C)	8	0	13.1	36
Measures after connecting (external temperature 7.5°C, temperature gradient 1°C)	6.3	0	12.2	36

[a] Average values of displacements before and after connecting.

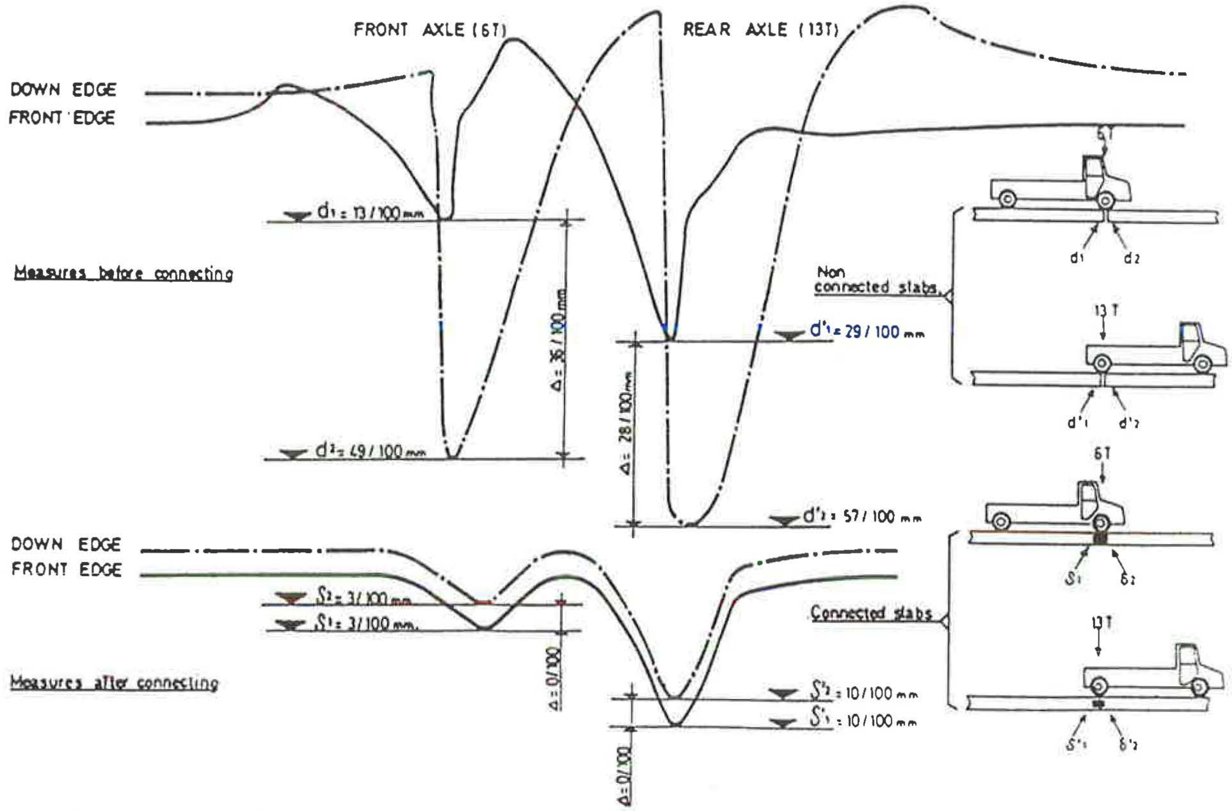


FIGURE 13 Typical diagram of behavior of adjacent slab edges before and after connecting (horizontal axes of references have been shifted for clarity).

- Charles de Gaulle Airport at Roissy: The vertical displacements of three joints tested on the taxiway were 0.03 mm after 1 year as opposed to 0.50 mm before the work was done.

CONCLUSIONS

The surface dressing developed for maintenance of concrete pavement surface roughness reduces the number and gravity of accidents as much as 65 percent on wet pavements and 78 percent on icy pavements.

Shallow drainage trenches immediately produce hydraulic efficacy and positive structural effects depending on the state of degradation of the pavement. However, it is difficult to show the latter effect.

At present, measurements carried out in situ show that the Freyssinet International connector carries loads efficiently from one slab to the other and has excellent resistance to fatigue and corrosion. Relative displacements between two adjacent slabs are substantially reduced, and pumping effects are stopped. The resistance of connectors to corrosion is quite satisfactory; moreover, a test sample that was exposed in a very aggressive atmosphere during a long period of time did not show any evidence of corrosion.

Installing connectors is quite easy even though particular care must be taken to locate the hole to be bored astride the slab joint to be repaired. Installation using existing placement equipment on a heavy movable support should allow the treatment of approximately 1 km of road per day.

Because of the particular design of the connector, which totally fills the hole bored for it, there is no risk of breaking or cracking of any added material.

Similar connectors, with the same diameters but different lengths, are used for both roads and airport runways and can be placed with the same equipment. A comparable model, specialized for industrial slabbings, is under development.

The reinforcement of damaged concrete roads with connectors is cost saving because of the simple design of parts used and the way they are placed.

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