LOAD TRANSFER RESTORATION AT JOINTS

From the laboratory to the jobsite ...

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Synopsis: For several years, French engineers are developping and qualifying some devices for load transfer restoration at joints to reduce the pumping effects. These maintenance operation is strategically important for French motorway network and some north american networks, which some old jointed concrete pavements are without dowels. Researches about this matter are described. They ended by a co-operation between Central Laboratory of Bridges and Roads (LCPC) and French company Freyssinet International to develop a repair system with metallic connectors. These connectors are in the form of steel cylinders in two half-shells linked together by a steel pin sliding in a horizontal plane. The connectors are sealed by gluing in holes drilled vertically astride the joint between slabs. French Roads Administration, Airport Autority, LCPC and Freyssinet International are looking about construction of special site equipment for a rapid restoration to reduce traffic interruption and repair costs. First prototype and his performances will be showed. Measurements carried out in situ show that connector carries efficantly loads one slab to the other with an excellent resistance to fatigue and corrosion. Relative displacement between two adjacent slabs is substancially reduced, and pumping effects are stopped. Equipments are planning to be able to restore one kilometre of one lane road in a day.

1- Birth of an idea

In 1960, during the launching of the French expressway (autoroute) construction program, concrete pavements were chosen owing to their reputation for long service life without maintenance. Slightly over a decade later, while the backbone of the freeway network (Lille - Paris - Lyons - Marseilles) had just been completed, agencies having jurisdiction for these freeways were alerted by some rare but significant early signs of damage.

1-1- Damages observed

In most cases what was involved was damages encountered by all countries or states having used the "Californian" structure. However, at that time, only California and some other North American states had described them and explained their origin: pumping, slab faulting at joints and damage on longitudinal joints between pavement and shoulder or emergency stopping area [1, 2].

1-2- The idea

After about a year of observation, analysis and consideration, a work group created in 1975 by the main French highway agencies concerned *(Directorate of Roads and the concessionary company Société des Autoroutes Paris Rhin Rhone)*, was convinced that the restoration of the load transfer device, by changing the functioning mode of the pavement, was the basic technique which, with a set of arrangements including waterproofing and edge drainage, could provide true progressive maintenance.

Several countries had techniques for repairing load transfer devices, most often in the prototype phase. All consisted in installing dowels of different types and in varying number, and also involved generally complex concrete machining operations. The anchoring of these new dowels often consumed large amounts of glue and resin mortar. All these embryonic techniques were characterized by their high cost and by the installation speeds which were incompatible with the operation of a freeway handling high traffic levels.

After analyzing this situation, the group was able to define the first conditions to be met by the ideal load transfer restoration method:

- Require little automated machining, and allow fastest possible completion,
- Use little resin for anchoring the surfacing concrete,
- Involve a minimum number of parts in relative motion to avoid or reduce wear or corrosion.

The essential part of the work was done shortly after the key was designed (Figure 1). The initial idea was based on the following conditions:

- Minimum amount of machining and as simple as possible: a vertical hole astride the joint and obtained by percussion drilling from the only side of the pavement which is accessible: the traffic side.
- Little glue, creating a cylindrical device of the same diameter as the hole and whose adherence to the concrete consumes only a film of resin suited to gluing in the presence of water.
- No wear because the device is a pleated tube with a high shearing resistance parallel to its axis and with bellows affording largely sufficient deformability orthogonally in relation to their plane, generally in the elastic domain but also in the plastic domain if necessary.

1-3- The first in-situ tests

Several keying operations were completed on different sections of the concrete pavements on the Paris-Lyons freeway. On two sections, the tests also included four keys per joint. On one section, several joints were keyed respectively with 1, 2, 3, 5 and 6 keys.

With four keys and more, it is observed that deflections are roughly halved and phase shifting is eliminated (Figure 2), showing the short-term effectiveness and the validity of this method.

In-situ fatigue tests carried out with the LCPC heavy vibrator show effective load transfer for about 1.10^6 cycles of loading at 130 kN, which represented 2 years of freeway traffic at that time.

Deformations are reduced and their transmission is perfect: there is no relative displacement of slabs.

1-4- Design

After obtaining encouraging initial results, efforts were turned to the design of all the elements of the method. The design studies covered drilling, gluing and the glue itself, the key and the number of keys, as well as the stress level in the concrete at the gluing interface.

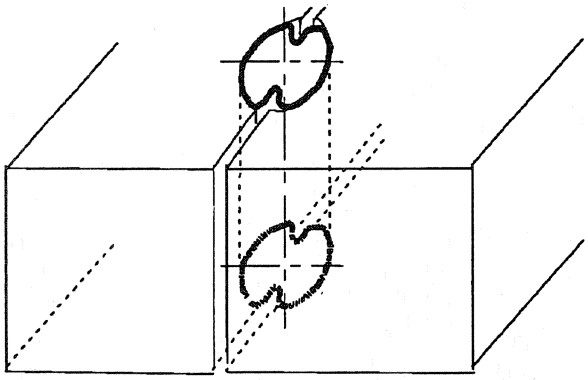




Figure 1- Load tranfer device using a key: the key is made to adhere by gluing and/or prestressing to the edges of the slab. Its shape allows the slabs to expand and contract freely.

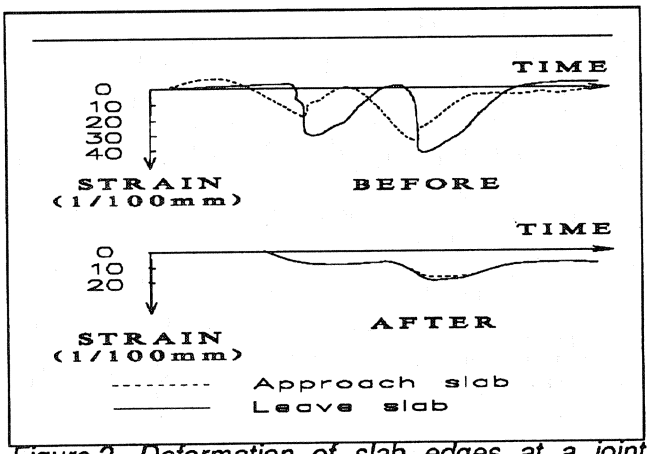


Figure 2- Deformation of slab edges at a joint before and after keying.

1-4-1- Drilling

The diameter of the hole obtained by rotary percussion drilling, as well as the dimensional variations were covered by measurements on a series of drilled holes completed in full scale. The conicity and the surface condition of the concrete in the hole were also examined; the drilling time was evaluated.

These measurements made it possible to confirm the advantages of percussion drilling: sufficient precision (tolerance on diameter required: +0.2 and -1.2 mm), speed, roughness and presence of water, making it very economical, as well as its major limits: need for control of power to avoid conical breaking at base of hole.

1-4-2- Glue

Several tests were run to characterize the glue: pure shearing, traction on specimen, traction on key-concrete gluing and simulation of real loading.

1-4-2-1- Shearing

The shearing of the glue was investigated by pulling on two steel plates which were joined using concrete (Figure 3). For each test, the concrete broke first, as its dimensions were too small in relation to the glued surface. It may thus be said that the shearing strength of the glue is greater than the stress produced by the concrete breaking force, which corresponds to about 2.4 MPa.

This strength is clearly higher than the shearing stresses in the glue as calculated theoretically: less than 1.0 MPa in every case.

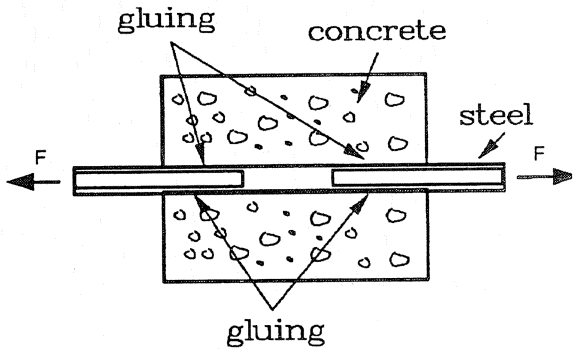


Figure 3- Diagram of specimens for measuring the shearing strength of steel-concrete gluing. In all the tests, the concrete broke and the glue did not shear.

1-4-2-2- Traction

Tensile tests on a specimen of the glue used on the jobsite, molded in the form of dumbbells, made it possible to measure its modulus of elasticity: about 3.5 GPa. This modulus may be regarded as high for a glue; it is generally closer to 1.0 GPa. The glue used is not highly elastic, which is favorable: the key will be stressed and not the glue.

1-4-2-3- Traction on key-concrete gluing

To determine the force required for glue failure, traction experiments were conducted on glued keys. In one of the cases, for a key 4 mm thick, the glue failed with a force lower than that required for obtaining the entire elastic deformation of the key. On the other hand, with a key 1 mm thick, with a maximum elasticity force of less than 5 kN, no failure of the glue was observed (Figure 4).

Limiting the thickness of the key to 2.5 mm, the elastic force should generally be lower than the glue failure force. Even in very cold weather, during which slabs are highly contracted, the key will never reach this limit; it will be in the plasticity mode first.

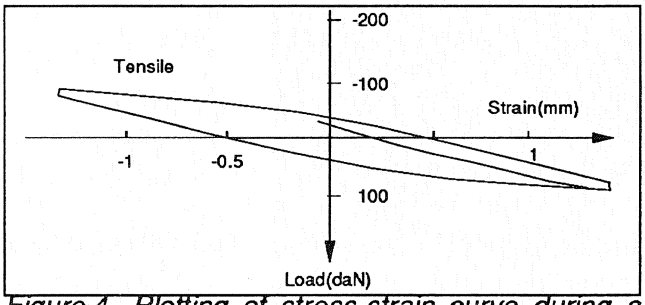


Figure 4- Plotting of stress-strain curve during a key tensile test. The stress is perpendicular to the plane of the bellows; the thickness of the key is 1 mm. The test is discontinued when the strain leaves the elastic domain.

1-4-2-4- Simulation of real loading

The test consists in shearing the glued key in a concrete fixture (Figure 5).

Generally, with a key 4 mm thick and 0.20 m long, there is no failure for a force varying from 40 to 76 kN. There should consequently be no shearing failure in service; the maximum load capable of being withstood by a key upon the passage of a 130-kN axle is about 30 kN (see below).

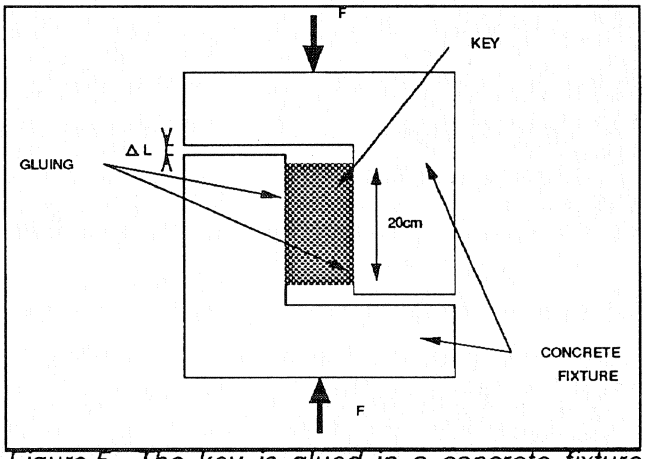


Figure 5- The key is glued in a concrete fixture obtained by casting. By compression, if the setup if sufficiently strong and the key rigid enough, the glue is subjected to shearing stresses.

For this load, deformations in the glue do not exceed 5 to 6.10-2 mm, or 10% of the average deflections observed on an unkeyed pavement after about 10 years of service and exhibiting average performance.

1-4-3- The key

Two types of studies were carried out on the key, for different thicknesses of the bellows sheet metal:

- Elasticity in the orthogonal direction in relation to the plane of the bellows, i.e. possible elastic strains in the key during the expansion-compression cycles of the slabs, and the resultant forces which, transmitted to the concrete, could initiate longitudinal cracking if they are too high.
- Straining of bellows subjected to shearing stress parallel to the faces of the key, similar to the stress resulting from the passage of a load over a joint. The test setup is similar to the one described below, but metallic (Figure 6).

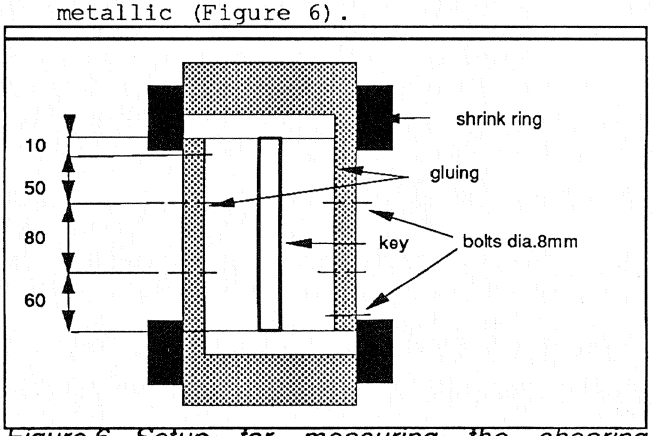


Figure 6- Setup for measuring the shearing behavior of keys in thin sheet metal. To prevent the opening of the setup, the ends are shrink fitted using a ring equipped with a ball-type slider.

The first series of tests (Table 1, Figure 7) showed that it would not be possible to reconcile adequate elastic strain and corrosion protection by an extra thickness of metal. A small thickness of sheet metal was required, compatible with the shearing stress to be transmitted, with suitable corrosion protection. In addition, while compressive stresses appear to be supportable by the concrete, tensile stresses in the event of thermal contraction during a period in which the temperature is lower than that of the

installation period, were considered to be too high for gluing. Several solutions were considered:

- Make the key in stainless steel with compression applied during installation, guaranteeing that there is practically never any tension applied to the gluing. This approach was ruled out for several reasons. It was not possible to find a thickness allowing both sufficient deformability along the direction orthogonal to the plane of the bellows and very small shearing parallel to this plane. Its cost was very high and the stainless steel is more difficult to glue than mild steel.
- Provide corrosion protection using a material that could act as an internal spring. This is the design investigated most thoroughly.

Average thickness mm	Average elastic strain mm	Average elastic stress dN
4	0.8	3190
3.5	0.86	1870
3.3	1.12	2220
2.3	0.99	1090
2	0.97	1000
1.5	1.29	492
1.2	1.35	456
1	1.35	420
1	1.50	201

Table 1- Stress perpendicular to bellows and elastic strain of key as a function of its thickness. The different thicknesses were obtained by machining the bellows of a key with a thickness of

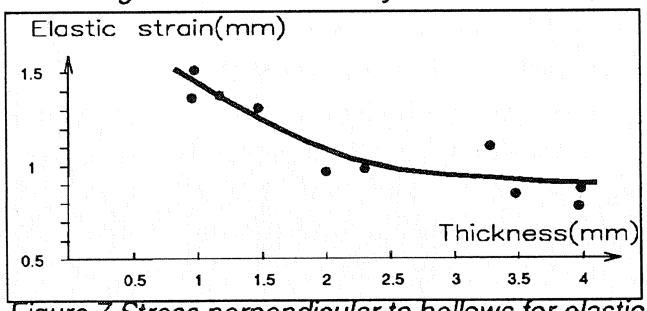


Figure 7 Stress perpendicular to bellows for elastic deformation of key as a function of its thickness.

The second series gave the first indications of the major difficulty encountere in this research and which was confirmed by in-situ tests described later. If, for small stresses, the key acts as expected, with small strains by shearing a thin blade parallel to its plane, before the load reaches 30 kN -- level determined by the study described below or measured on a real pavement later -- the blade will buckle and the bellows will warp. Deformations become large and incompatible with the deflections one is attempting to reduce (Figure 8).

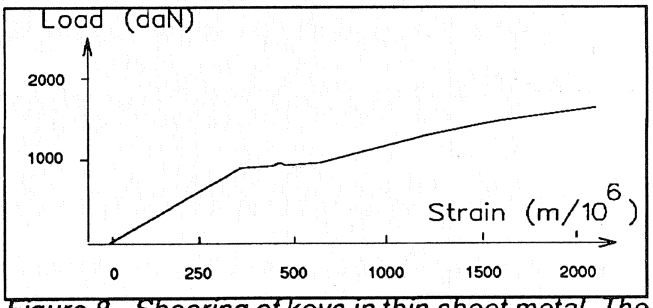


Figure 8- Shearing of keys in thin sheet metal. The stress-strain curve shows a plateau due to the buckling of the bellows. Total deformation is greater than the deflections to be reduced. At the same time it is noted that the bellows are no longer sheared.

1-4-4- Number of keys

Two verifications were carried out on this subject:

- An estimate of the stresses transmitted by two or four keys per truck lane (one or two in each truck wheel track). This estimate was based upon the Pickett and Ray charts [3] calculating the theoretical pressure in the impressions of the keys on the slab edge making it possible to even out the deflection with and without keys. This estimate led to about 30 kN for the most heavily loaded key on the road (standard axle of 130 kN) and about 110 kN on an airport runway upon the passage of a Boeing 747. In the first case, there are four keys per lane; in the second there is one key every 0.5 m.
- estimate of the maximum stress at the concrete-key interface obtained by means of a finite-element calculation program (Figure 9). Setting aside considerations regarding the elastic deformation capacity, the stresses developed in the concrete at the key contact during compression are proportional to the force involved, i.e. proportional to the rigidity of

the key which depends directly on the thickness of the bellows sheet metal (Figure 7). Compressive stresses are always lower than 12 MPa. On the other hand, tensile stresses may reach 2 MPa for the thickest keys. This stress, which is added to the tensile stresses due to loading and to temperature gradients, can initiate an unstable longitudinal crack propagating as the thermal cycles and loads are accumulated.

This key, abusively set to be prestressed, consisted of a deformed tube identical to the initial model with a thickness of 1.5 mm, in which a synthetic rubber block was vulcanized. A metal piece forced into a recess significantly smaller than it made it possible to "prestress" the key once again in its hole (Figure 10).

The difficulty in providing a sufficient force during the slab contraction periods without the force being excessive during expansion, as well as the risk of the key creeping out the hole as shown by fatigue tests, led to a gluing-prestressing compromise. This design formed the subject of experimentation on a road in service (see below).

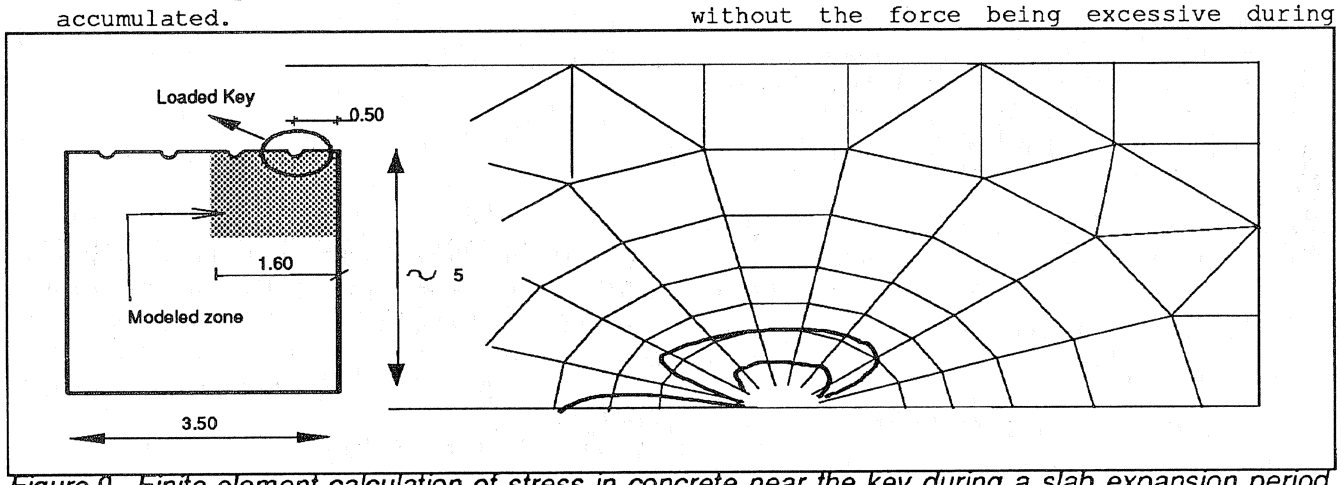


Figure 9- Finite-element calculation of stress in concrete near the key during a slab expansion period. Grid used and iso-stress curves.

1-5- Approaches considered

The first tests demonstrated the value of keying but were unsuccessful owing to the excessive rigidity of the key with respect to stresses perpendicular to the plane of the bellows, leading to tensile failure of the gluing during slab contraction periods.

An analysis at that time led to the design of a complex key, combining a metallic part whose function is to transmit the shearing stress and a spring whose function is to keep the glue under compression under all circumstances and in particular whatever the thermal conditions at the time of key installation.

Very rapidly, using this approach, there was the temptation to eliminate the gluing, a long and costly operation which is the fragile element of the method and the main risk of failure. It in fact appeared possible to increase the capacity of the associated spring to apply a sufficient force so that the shearing stress is transmitted to the metallic element by rubbing on the concrete.

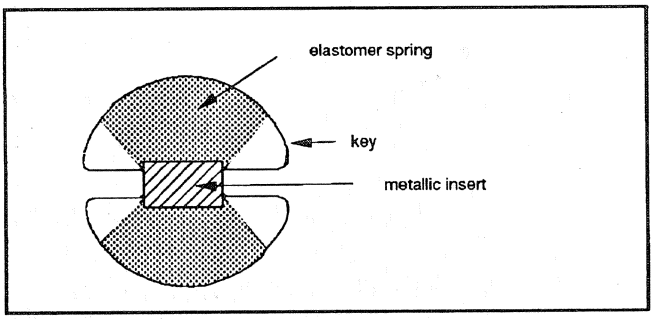


Figure 10- Section of key with elastomer spring. The prestressing force is obtained by forcing a metallic piece into recess(es) provided in the elastomer. The insert has a volume significantly larger than the recess.

Two other "models" were analyzed:

- A key in several parts. The shearing stress is transmitted by one or more pins located in two metal halves. The spring function is performed by a stack of dished washers. This design was not adopted because it was difficult to provide a small clearance during the service period (reducing wear and crushing) and also provide corrosion protection.
- A key consisting of a block of synthetic material whose modulus would have been highly variable with the stress application rate: small when deformation is slow (thermal contraction and expansion) and, on the contrary, very high when deformation is applied rapidly (passage of an axle). Such materials exist; some elastomers act in this manner. However, within the range of low-cost industrial products, predictable strains upon the passage of an axle were much higher than deflections.

1-6- Instrumentation and measurements in situ

Qualification tests for the glued and "prestressed" key, the solution finally adopted, continued.

Several joints were keyed with different glues so as to check the performance under real service conditions. The keys used were instrumented in order to measure any residual deflection as well as deformations in the bellows upon the passage of loads.

Residual deflection was measured by displacement transducers on a fixture installed on a slab adjacent to the keyed joint (Figure 11).

The deformation of the sheared bellows was measured by means of strain gages glued on one of the folds of the bellows (Figure 12).

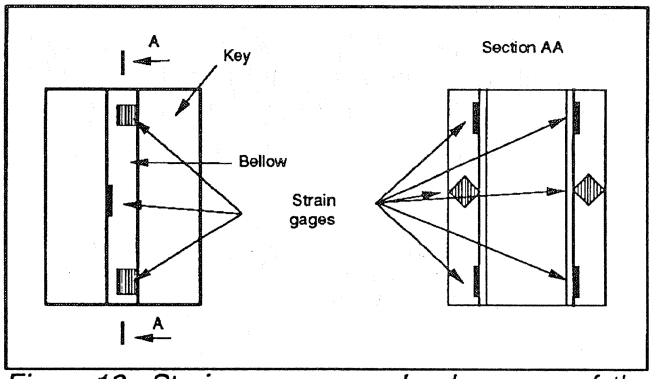


Figure 12- Strain gages are glued on one of the flat parts of the bellows. Two orthogonal gages are placed at 45 degrees in relation to the vertical direction of the stress causing the shearing.

1-7- Temporary impossibility

This experimentation yielded significant information, most of which was negative.

Glue tests allowed the selection of formulas making it possible, at least in the short term, to glue the key to the concrete in the presence of water and with an unfavorable ambient temperature.

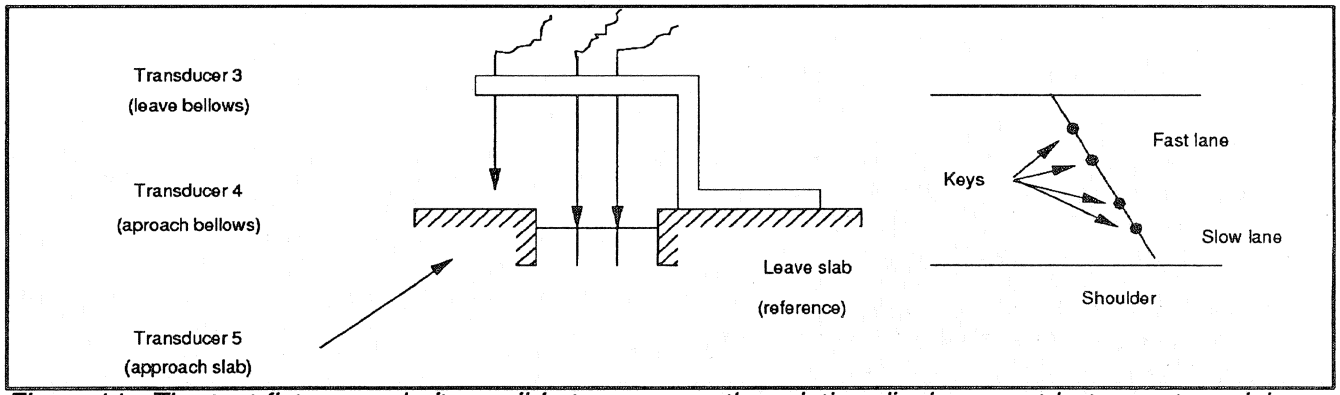


Figure 11- The test fixture made it possible to measure the relative displacement between two slabs on either side of a joint. It also allowed the measurement of the relative displacements of two folds of the bellows in relation to the slab on which the fixture was set up.

Measurements of residual deflection and shear strain were consistent and confirmed the measurements performed in the laboratory:

- Residual deflection reached 0.3 to 0.4 mm at the passage of a 130 kN axle; the displacement was continuous along the bellows, and this deflection could not be explained by any separation (Figure 13).
- The bellows was practically not subjected to shearing (Figure 14).

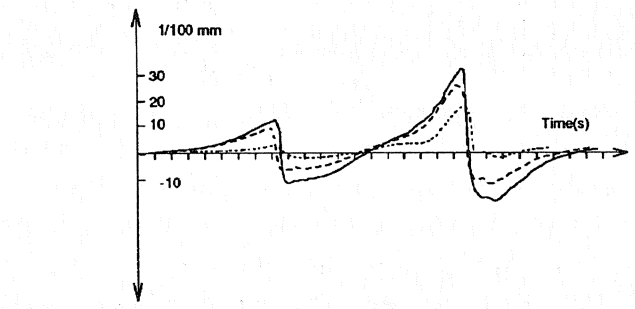


Figure 13- Plotting of residual deflection upon the passage of a load. The measurement is carried out with the setup of Figure 11, It is noted that displacement is proportional to the distance from the measurement to the point on one of the two slabs: there is thus no separation, but indeed deformation of the bellows.

It was necessary to face the facts: the flexibility of the key perpendicular to the plane of the bellows was certainly sufficient. However, as it was obtained by using a small sheet metal thickness, it favored buckling or warping of the bellows. Once warped, the bellows unfolded practically without any stress, and the deformation was incompatible with the limitation of deflection to less than 0.1 mm.

Cursory research into the stability conditions of the bellows showed that the shape of the bellows had to approximate a cylinder as much as possible in order to optimize elasticity, and that the two edges of the bellows had to be very rigid and remain parallel if the shearing stress was to be transmitted. These conditions could have been met by a significant thickness of the key in only the gluing zone (Figure 15).

No industrial solution was envisioned for the practical design of such a key, not even for some limited prototypes to check stability conditions.

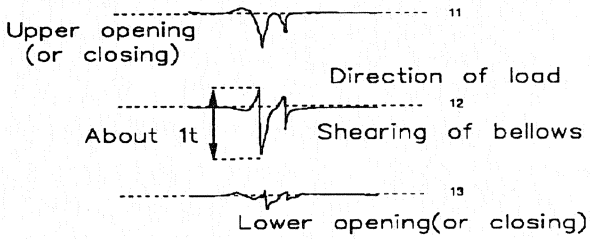


Figure 14- Plotting of shearing strain of bellows. The measurement is carried out by means of strain gages placed as shown in Figure 12. The shearing strain of the blade constituting the bellows corresponds to a force smaller than the one the key should take up. The key consequently is not subjected to shearing as it should be. In addition, variations in the curvature of the bottom of the bellows also do not correspond to the expected deformation of the key. In fact, the key should act as a hinge: opening downward and closing upward upon the passage of the load. These deformations can be explained only by the warping of the bellows which then unfolds, with the generatrix at the bottom of the bellows no longer remaining parallel to those of the edges.

1-8- Death of the key, birth of the connector

Time passed and the pavements in service continued to deteriorate, often slower than what had been expected in 1975, and the need for a load transfer restoration method was still indicated by the most recent analyses [4, 5].

Early in 1983, it was decided to separate the problems:

- Pursue the investigations in the area of the tubular key whose development was found to be more difficult than predicted.

- Initiate the development of equipment for high-output installation with a multi-section key , whose development was quite simple and whose performance was probably sufficient.

Since most of the goals and data relative to the problem had not changed, the new method for restoring load transfer devices resumed many provisions of the preceding one.

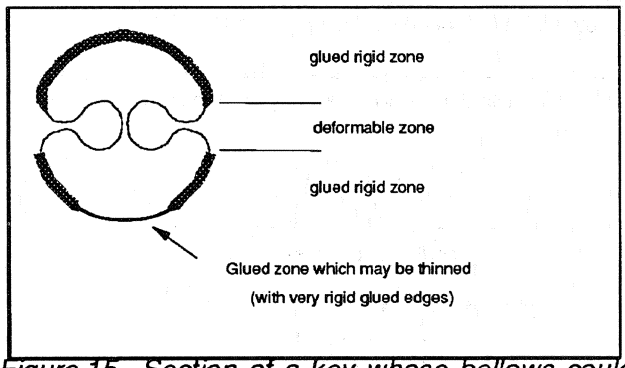


Figure 15- Section of a key whose bellows could be stable during shearing. The great increase in thickness would have the twofold advantage of preventing changes in the generatrices of the bellows and the initiation of separation when the bellows are under tension.

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 (AdP), Freyssinet International designed and developed a repair system meeting the following criteria, very similar to those proposed some years ago:

- Transfer of load from one slab to another provited entirely by the repair work. For example, four units of 30 kN each per road lane of 3.5 m with (for a standard axle load of 130 kN).
- Reduction of the faulting from several millimeters to several tenths of a millimeter.
- Execution of repair work in any weather and preferably in winter, to take advantage of maximum slab shrinkage.
- Rapid construction to reduce traffic interruption.
- Reduced repair costs, compared to other methods.

1-8-1- Principle of the LCPC 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 connectors sealing with them to take up the shear forces due to the passage of vehicles by preventing vertical movements while allowing longitudinal movements created by thermal changes.

The connector consists of:

- two hollowed out symmetrical semi-shell castings (part (a) of Figure 16),
- a flat, thick metal plate sliding freely within the housing formed by the half shells (part (b) of Figure 16),
- - an elastomer lining placed between the two half shells, making it possible to ensure watertightness and to retain the grease within the cells of the shells. This also provides a minimum permanent keying force (part (c) of Figure 16),
- - the dowels are retained in the holes by gluing.

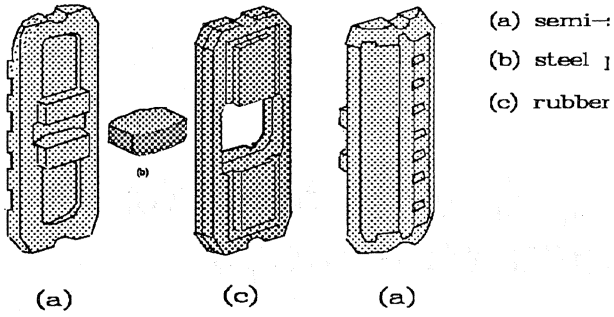


Figure 16- Exploded view of connector parts

1-8-2- Placing the connectors

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

1) Simultaneous drilling of 4 holes on the axis of the shrinkage joint,

2) Simultaneous placing at the bottom of each hole of pre-determined quantities of sealing resin followed by insertion of the connectors,

3) Completion of upper watertight seal by the placing of a flexible bituminous product.

For a dual lane highway, four connectors are placed on the truck lane (130 kN standard axle load) and 30 connectors spaced of 0.5 m, in each transversal joint, for an airport runway of 22.5 m width (Figure 17).

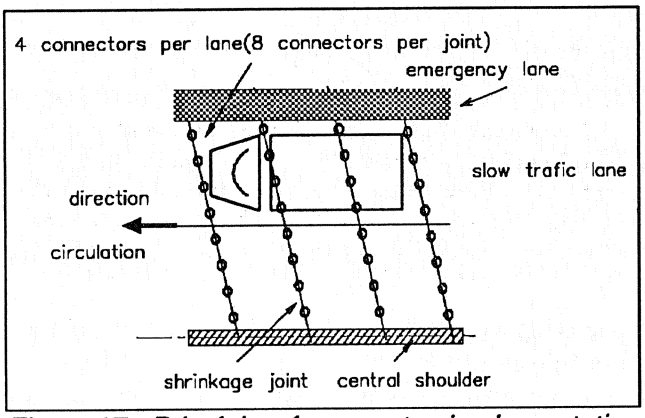


Figure 17- Principle of connector implementation. Right: for airport runway; left: for two-lane highway (130 kN standard axle load).

2- A step towards industrialization

Connectors for use on roads have been developed to withstand the passage of convoys of road haulage vehicles by transmitting the vertical forces due to the axle weights to four individual units, without causing vertical movements into excess of 0.2 mm.

2-1- Fatigue behavior of gluing

The test described in Figure 18 makes it possible to observe the performance of the gluing of the connector to the concrete at the joint (Table 2). A piston acts on the glued connector applying increasing forces. The relative dowel-concrete movement is measured and the test is carried out until the failure of the fixing.

2-2- Fatigue behavior of connector

Dynamic tests of the whole system, under alternating loads, have been conducted in the LCPC at Nantes (Figure 19). Table 2 shows the results of these tests.

Assuming the fatigue diagram equation to be as follows:

$$\sigma_i/\sigma_1 = A(N_i)^{-b} \quad (1)$$

(same equation as for most road materials) one can determine values of σ_1 and b in order to make the results of this test consistent with those specific to connector concrete gluing.

Load (kN)	Frequency (Hz)	Number of cycles	Deflect. (10^{-2} mm)
100*	15	Variable, up 2.5×10^{-4}	Average 3.5
15 to 45	15	From 1.5×10^{-6} to 1.7×10^{-6}	From 10 to 40**

*Table 2- Dynamic test results-*test of connector-concrete gluing - load was simultaneously applied on the two shells (Figure 18) ** after dynamic testing of whole device (Figure 19)*

For instance, one can adjust values of σ_1 and b considering that either the variability of the slope of the fatigue diagram (case a) or the variability of static breaking values (case b) give an explanation to the scattering of results:

1 -See below, for meaning of symbols.

- Case a, the fatigue diagram equation is such that: $\sigma_i/\sigma_1 = A\ (N_i)^{-(b + x.S_b)}$.

- Case b, the fatigue diagram equation is such that: $\sigma_i/\sigma_1 + x.S_\sigma = A\ (N_i)^{-b}$ under repeated loading.

One obtains values shown in Table 3 considering, for the time being, that A is equal to one (Figure 20).

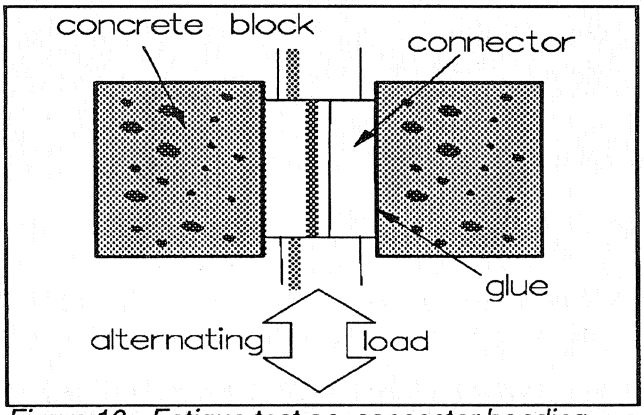


Figure 18- Fatigue test on connector bonding.

Relations between laboratory fatigue test results and in-situ values have to be established.

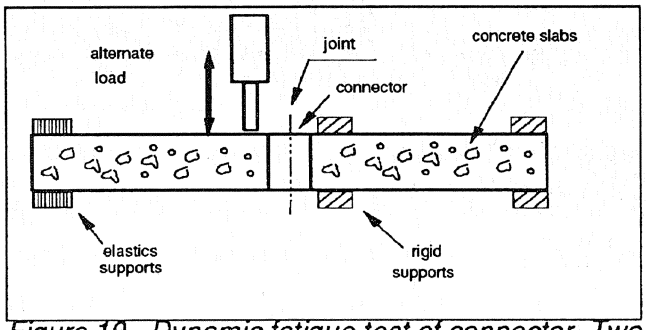


Figure 19- Dynamic fatigue test of connector. Two concrete slabs simulate a transverse joint of plain concrete pavement without dowels. A connector is placed in this joint according to the above description. One slab is held immobilized; the second is alternately loaded to produce the same stresses as a truck axle crossing a transverse joint.

2-3- Crushing under repeated loading

Two fatigue tests on connectors (improving of gap) with alternate loading were conducted:

- one semi-dynamic test directly on the connector (Figure 21 and Table 4);
- fatigue testing of whole device, during which the gap was measured (Figure 22).

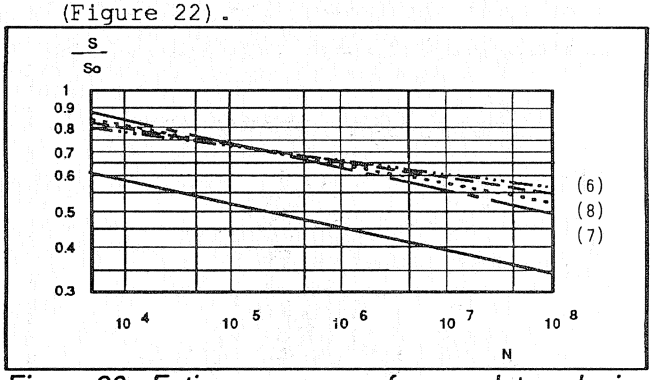


Figure 20- Fatigue curve of complete device compared with published fatigue curves for concrete. The normal working load of the connector is less than 0.4 of its failure load.

2-4- Experimental jobsites

To date, Freyssinet International has installed several thousand dowels on different pavements: roads and airport runways.

		Case a	Case b
Testing of connector concrete gluing only			
Test 1	σ_1 =	100 kN	120 kN
	b =	1/20.1	1/16
Test 2	σ_1 =	100 kN	106 kN
	b =	1/17.3	1/16
Testing of whole device			
Test 1	σ_1 =	100 kN	120 kN
	b =	1/14	1/16
Test 2	σ_1 =	100 kN	97 kN
	b =	1/15.4	1/16

Table 3- Interpretation of dynamic fatigue test on gluing of concrete- connector and of whole device.

Certain freeway areas and airport taxiways have been used as test areas to check the actual performance of the connectors under traffic. For example, for the Roissy test some connectors include two kinds of gages:

- Displacement gages in a connector without its internal key: this device measures the deflection of a joint with and without connectors under aircraft traffic (Figure 23),

- Extensiometer gages glued in a hole drilled in the internal key for shear force measurement; this device measures stresses transmitted from one slab to another by moving aircraft (Figure 24).

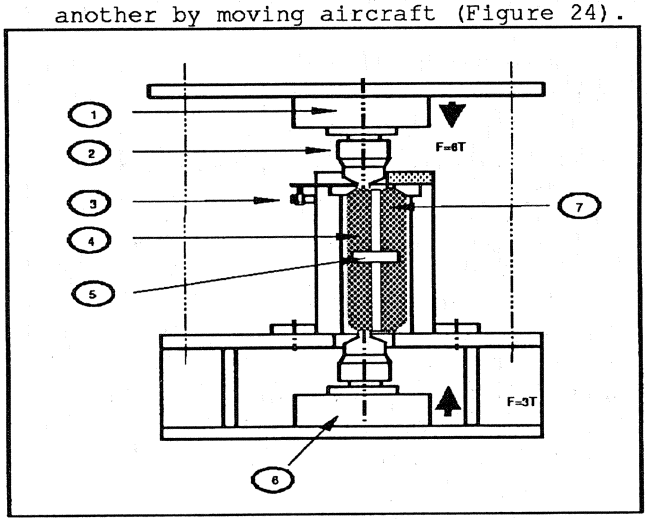


Figure 21- Connector fatigue test with alternate stresses.

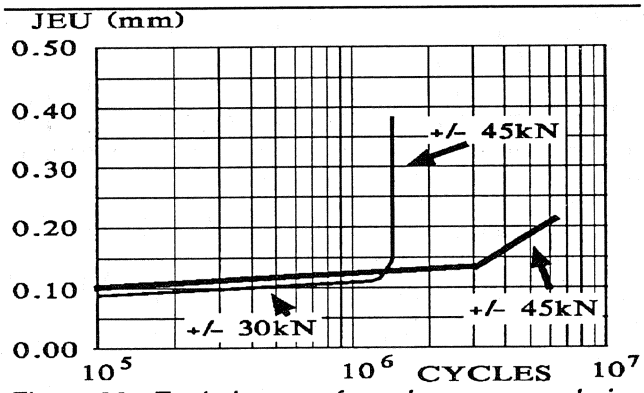


Figure 22- Evolution of clearance during connector fatigue tests.

The same measurement principle was used before and after dowel placement after varying periods in service. A comparison of measurements revealed the following for most of the joints:

- limitation of vertical movement to a very low value,
- perfect interlocking of slabs, with very satisfactory performance.

For example, the following results were obtained:

- A6 freeway - Nemours area (middle lane): out of 190 joints checked, 178 had deflection values below 0.05 mm.
- A6 freeway - Avallon area (truck lane): out of 155 joints checked, 153 had values below 0.05 mm.

Load (kN)	Frequency (Hz)	Number of cycles	Deflect. (10-2 mm)
36	3.0	1 000 000	6
60	2.1	1 500 000	14
90	2.1	300 000	16

Table 4- Gap fatigue test results.

- A10 freeway (truck lane): on the 53 joints checked, deflection was reduced by 50% on average; no nonlocked joints were observed at all, whereas there were 42% before the work was carried out.
- Charles de Gaulle Airport at Roissy - (Taxiway): on the three joints tested, deflection was 0.03 mm after one year, compared with 0.05 mm before the work was carried out.

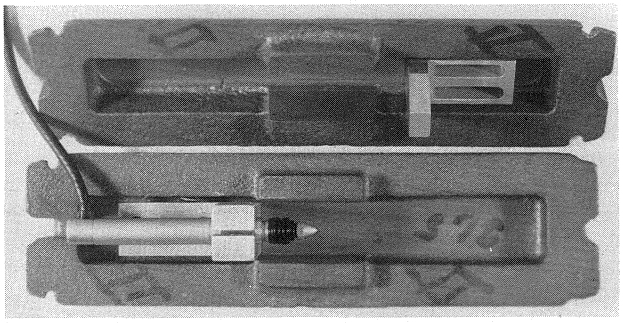


Figure 23- Connector equipped with displacement gages.

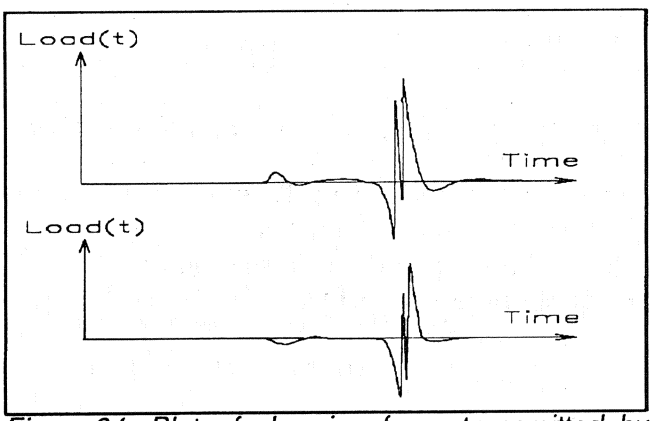


Figure 24- Plot of shearing force transmitted by connectors upon the passage of a Boeing 747.

At present, measurements carried out in-situ show that the Freyssinet International connector transfers loads efficiently from one slab to the other with excellent fatigue and corrosion resistance.

Its mechanical properties are such that deflections are substantially reduced and slab pumping eliminated.

Connector corrosion resistance is very satisfactory: moreover, a test sample exposed to a very aggressive atmosphere for a long period of time did not show any signs of corrosion.

2-5- Connector placement machine

The requirements of different agencies are very different. While it is possible to work conveniently on a lane or on the entire pavement for a period of about a week on intercity freeways, such is not the case on radial highways or freeways leaving major urban centers, which may be worked on only at night and for limited periods.

The placement machine must be able to operate either on roads or airport runways.

In order for the installation of connectors on concrete pavements to be compatible with competing systems, the machine must be capable of completing 1 km per day (or per night), i.e. placing 800 connectors (average joint spacing is taken equal to 5 m).

Assuming the possibility of working at night for 8.5 hours (from 9:30 p.m. to 6:00 a.m. the next day) and allowing for a resin polymerization time of 2 hours before opening to traffic (hence anchoring the last connector after 6.5 hours of actual work), it is necessary to have a machine capable of placing 800 connectors (or 200 stations of 4 connectors) in 6.5 hours.

2-5-1- Description of placement operation in basic steps

The placement of a connector involves the following phases:

- Positioning of drilling tools over joint to be treated.
- Careful drilling of hole (slow pilot drill, final drilling so as not to shatter the bottom of the hole). Vacuum removal of dust throughout drilling operation.
- Forceful blowout of hole.
- Preparation (proportioning/mixing) of resin and injection at bottom of hole.
- Placement of connector (by transverse compression and thrust).
- Holding connector forcefully at bottom of hole to allow resin to rise around connector.
- Completion of top plug in elastomer bitumen.

Owing to the required outputs, it is more realistic to consider equipment consisting of two machines:

- A drilling unit,
- An insertion unit.

2-5-2- Drilling unit

The drilling unit is based upon the use of hydraulic hammers. The use of hydraulics affords flexibility, safety and utilization reliability.

The use of air, on the other hand, though simpler and more economical, lacks the required precision (Figure 25).

To optimize the possibilities of hydraulic hammers, the four holes of a given station will be completed in pairs, as drilling speeds will allow this.

All the equipment is set up permanently on a removable plate clamped on the chassis of the truck.

2-5-3- Insertion unit

The two main functions performed by the insertion unit are:

- preparation (proportioning/mixing) and injection of resin;

- insertion of connectors.

The resin is prepared by a pumping, proportioning and static mixing system capable of operating with very viscous and heavily "laden" fluids.

Connectors are inserted by means of equipment consisting of jacks mounted on a swivelling dual beam and which compress and drive the connectors (just as a cork is inserted into a bottle).

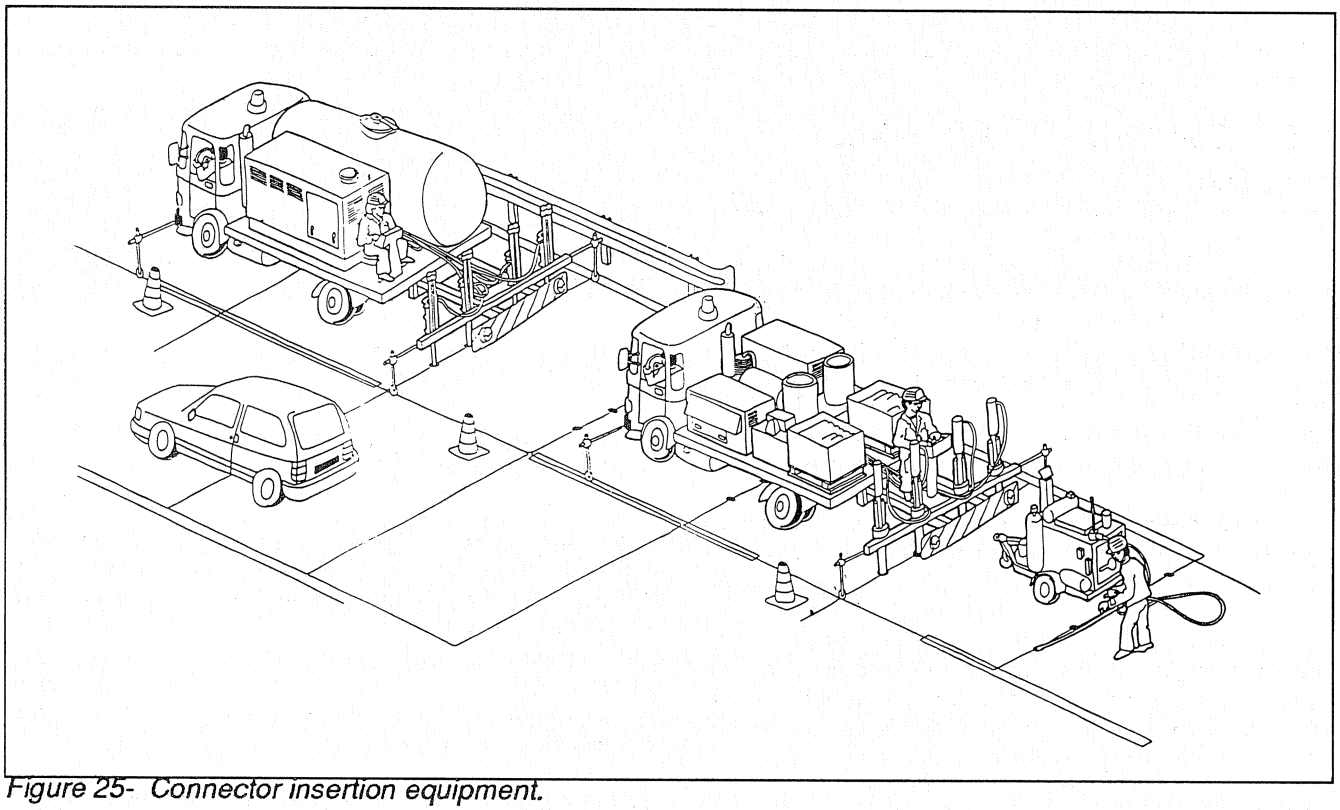


Figure 25- Connector insertion equipment.

3- Restoration of load transfer device and maintenance strategy

3-1- Choice of placement time

3-1-1- Effect of connector installation

To illustrate the value of maintenance by keying, we have simulated the evolution of cracking in a real pavement in which the load transfer device was restored after 11 and 13 years of service and compared it with the real evolution.

For this purpose, use was made of the PREDICT program made available to the LCPC by courtesy of M.I. Darter. This program uses the laws governing the deterioration of concrete pavements established by means of COPES [9]. These laws are adjusted for the time being on the behavior of pavements in different states of the US. It was not possible to use them directly for French pavements.

The application of COPES to French pavements is being considered within the framework of the work of the PIARC Concrete Roads Committee. The results will not be known for several years.

We were also unable to find a provisional correspondence for each type of deterioration whose evolution is simulated by PREDICT. We have thus confined ourselves to the simulation of cracking, regarding as a doweled structure the pavement on which the load transfer device has been restored.

First of all, a realistic correspondence was sought using the crack evolution curves as a function of cumulative truck traffic on several French freeway sections. As cracks are deteriorations related to loading intensity and frequency, it was

only to the amount of traffic that a multiplying coefficient was added, the other values of the PREDICT parameters being as close as possible to the real values. The value of the coefficient obtained is close to the values frequently proposed for the conversion of traffic with different types of load spectra on concrete pavements: 10^{11}.

The results obtained show that the use of connectors allows 8 to 9 years of additional traffic before reaching the cracking threshold requiring extensive pavement maintenance (Figure 26).

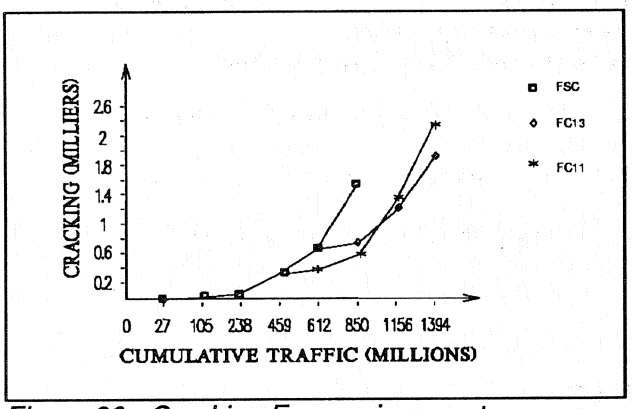


Figure 26- Cracking Economic aspects

3-1-2- Economic aspects

An initial study, carried out to estimate the economic rate of return of building a connector insertion plant as described above, made use of three concrete pavement maintenance models, which were already used for different studies and are realistic (Figure 27).

A comparison is made of the discounted cost, for the year of connector installation, of maintenance over 25 years according to the indicated scenarios. The following results are obtained:

- Placement of connectors, waterproofing and surface dressing: 0.85 MF/km,
- Waterproofing, surface dressing and reconstruction after 25 years: 0.96 MF/km,
- Waterproofing, surface dressing and overlaying with asphaltic concrete after 10 years: 2.1 MF/km.

3-2- Integration within a system for maintaining the service level

For most agencies, maintaining the level of service to users is the prime consideration. This is an especially important factor in France where most of superhighways are toll facilities.

Structural maintenance techniques such as connectors must be integrated within a global policy aimed essentially at improving the comfort and safety of users.

It is for this reason that we have undertaken two types of experimentation with the objective of making operational such possibilities as thin bonded concrete overlays and porous concrete wearing courses. It will thus be possible to provided freeway and concrete highway authorities with a technique for restoring the evenness and skid resistance properties of pavements, offering advantages similar to those of free-draining bituminous mixes.

Model A	Treatment	J	ES	Cl+J	J	ES	J	ES	J	J	ES
Year	0	5	8	10	15	16	20	24	25	30	32 35
Model B	Treatment	J	ES	J	J	ES	J	Re	J	ES	J
Year	0	5	8	10	15	16	20	24	25	30	32 35
In this model, it is assumed that broken slabs are repaired until reconstruction.											
Model C	Treatment	J	ES	AR + BB12	60%BB6+ 40%BB8			60%Rs+ 40%BB6		40%Rs+ 60%BB6	
Year	0	5	8	10	15	16	20	24	25	30	32 35

Figure 27- Maintenance scenarious for economic comparison.J: Repair of joints, C1: Keying, ES: Surface dressing, Re: Repair of truck lane, Rs: Repaving (thermoregeneration)-(45 F/m2 or 38 F/m2 without VAT), BBi: Asphaltic concrete, i = thickness in cm, AR: Reflective cracking control.

This will make it possible to apply a restoration system consistent with comfort and safety requirements to which agencies are attaching increasing importance.

4- Conclusion

Connector placement is very easy. Particular care must however be taken concerning the location of holes to be drilled astride the slab joint.

The installation of existing placement equipment on a heavy movable support should allow the completion of approximately one kilometer per day.

Due to the particular design of the connector, which completely fills the hole drilled for its placement, there is no risk of breaking or cracking any added material. Similar connectors of the same diameter, but of different length are used either for roads or for airports, and can be placed with the same equipment. A comparable model designed specially for industrial slabs is under development.

The restoration of damaged concrete pavements by the use of connectors is a cost-effective procedure: due to the very simple design of the parts used and the way they are placed.

SYMBOLS:

A: constant value.

N_i: number applications of load (or stress) of which the value is σ_i.
$-\sigma_1$: load (or stress) for one cycle - static breaking value.
-b: slope of fatigue diagram

S_b, S_σ : standard deviation of b or σ_1.

7 MPa = 1 000 psi, 10 kN = 2.2 kips

1 i = 25.4 mm = 2.54 cm, 1 f = 0.308 m.

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