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Systematic Approach to Maintenance

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Contents

Foreword

With the exception of the prize-winning paper on Restoration of Load Transfer, included here as a companion piece to a French paper on restoration of load transfer at joints with connectors, the papers in this Record were written by French representatives and offer an overview of the systematic improvement in all aspects of highway maintenance in that country.

Michel Ray made informal presentations on the work during meetings of the committees on Pavement Maintenance and on Maintenance Equipment at the 66th Annual Meeting of the Transportation Research Board. His presentations generated a request that he arrange a comprehensive series of papers for the 67th Annual Meeting. The results of that effort, presented here, should encourage North American authorities to consider changes in their operations.

Authors address the following themes:

- State-of-the art improvements in chip seal processes and equipment that make possible placement of chip seal treatments on portland cement concrete pavements carrying more than 50,000 vehicles per day. U.S. authorities are reluctant to place chip seals on pavements carrying even 5,000 vehicles per day.
- Development of communication among contractors, equipment manufacturers, and state agencies and laboratories through a National Road Equipment Committee. In France, as in North America, innovative equipment for routine maintenance is limited because it represents only a small, scattered market for manufacturers, unlike the market for new, big construction equipment. Cooperation is helping to overcome that problem in France and, perhaps, offering a worldwide market for French manufacturers.
- Offering a formal education program for senior maintenance engineers. This apears to be equivalent to a master's degree program in a U.S. university because it includes attending a road management course for 6 months followed by designing and putting into practice a road maintenance methods and organization modernization project in the engineer's own organization.
- Innovations in equipment that are expected to significantly improve users' and maintenance workers' safety.
- Implementation of a preventive maintenance strategy in 1972. The preferred, and optimal, strategy consists of an initially high investment to provide a pavement design thickness for a life expectancy close to that which is given to a new pavement. Perpetual life is then to be afforded by timely applications of surface dressings and asphalt wearing courses. The authors caution that continuous and excessive budgetary restrictions will undermine the overall credibility of the policy.
- Restoration of skid resistance on portland cement pavements by longitudinal grooving was dropped because of unpleasant effects on motorcyclists. The substitutes include development of cost-effective equipment for transverse grooving and a surface dressing for motorway pavements. An average life of 7 years on truck lanes is attained by preheating of aggregates, dust removal, high-precision binder and chip spreading equipment, finishing by vacuum sweepers before the pavement is reopened to traffic, and highly specialized contractors and crews.

Summary of Road Maintenance in France

JEAN FRANCOIS COSTE

In European terms, France's road network is very dense. It consists of 1700 km of state-run motorways and 4500 km of motorways privately run, as well as 28 000 km of Class A roads and 350 000 km of Class B roads. Since 1980 traffic has increased by at least 4 percent per year nationwide, which has led to increased maintenance and improvement needs. During the same period the budget has stagnated and maintenance personnel have been reduced by from 1 to 1.6 percent per year. The administration has therefore had to rethink its maintenance methods in terms of technology, staffing, and organization. In this paper the present organization and role of the Public Works Administration are traced, the main evolution of road maintenance in France is outlined, and technical reports of other French experts are summarized.

The French road network is one of the densest in Europe with

- 1700 km of state-run motorways,
- 4500 km of privately run motorways,
- 28 000 km of Class A roads,
- 350 000 km of Class B roads, and
- 600 000 km of minor and byroads.

Each network has a main contractor that finances its maintenance and development:

- The state for state-run motorways and Class A roads,
- Motorway companies for privately run motorways,
- 100 County general councils for Class B roads, and
- 36 000 Towns (communes) for minor roads.

OVERALL MAINTENANCE BUDGET

Maintenance of the national network of state-run motorways and Class A roads alone represents an annual cost of around 10 billion francs (about $1.660 billion).

To this figure should be added the salaries of the 50,000 state employees working on network maintenance. This is half of the total personnel, and the annual cost is on the order of 5 billion francs (about $830 million).

Finally, some 60,000 machines and vehicles are involved, and renewal costs are 500 million francs (MF) per year (about $85 million).

The foregoing figures highlight the financial burden that road maintenance represents for France. However, in spite of economic problems, road maintenance cannot be neglected because traffic volumes are on the increase and users are becoming more demanding. The present challenge is therefore important and must inevitably lead to better money management, improved productivity, and modified methods.

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ORGANIZATION OF SERVICES

Central Organization

Two committees are in charge of road maintenance:

- The Directorate of Roads and
- The Directorate for Road Safety and Traffic.

Both of these belong to the French Ministry for Public Works, Housing, Country Planning and Transport.

The Directorate of Roads also manages policy, new engineering structure budgets, and maintenance for the following undertakings:

- Coordinated road strengthening works;
- Maintenance of carriageways already strengthened (routes that undergo preventative maintenance);
- Regular maintenance of carriageways and Class A road ancillaries such as roadsides, plantings, and rest and service areas but excluding traffic signing; and
- Supplying equipment to county depots.

In 1986 the budget for this was on the order of 1.1 billion francs (about $185 million) for coordinated road strengthening, 1.1 billion francs (about $185 million) for the maintenance of strengthened routes, 770 MF (about $130 million) for regular maintenance, and 120 MF (about $20 million) for depots.

The Directorate for Road Safety and Traffic is responsible for

- Maintaining road signs;
- Winter road service; and
- Road equipment management (control systems, variable message signs, traffic diversion signs, etc.).

In 1986 the budget for these activities was

- 50 MF (about $8.4 million) for signing,
- 85 MF (about $14.2 million) for winter road service, and

- 60 MF (about $10 million) for maintenance and management.

To define their policies and improve techniques, these two ministry departments rely on the "technical network" made up of the Service d'Etudes Techniques des Routes et Autoroutes (SETRA) (Roads and Highways Engineering Department) and the Laboratoire Central des Ponts et Chaussées (LCPC) (Public Works Central Research Laboratory). This network is extended to an interregional level by the Public Works Regional Engineering Centers (CETE).

Until the 1960s maintenance was neglected in favor of new works. In 1968 a policy of coordinated road strengthening was instigated to reinforce carriageways of main Class A roads to make them "frostproof." In 1972 a preventative maintenance policy was instituted for new and strengthened roads; resurfacing was to be done according to a defined cycle to prevent degradation and avoid repairs.

Only in 1983 did the Road Maintenance Study Group highlight the need to radically rethink regular road maintenance practices (in order to better understand the costs) and to train personnel in modern maintenance methods. Since then technicians' interest in, and enthusiasm for, maintenance methods has reawakened.

Local Level

Public Works District Direction

At the county level maintenance is coordinated by the department of transportation of the district (DDE), which is responsible to the following main contractors:

- The state for the national network (state-run motorways and Class A roads) and
- The county, represented by the general council, for the county network of minor roads.

Each DDE defines its annual maintenance program within the budgetary limits set by one or the other of the main contractors.

Subdivisions

The DDEs are kept aware of the situation at specific sites by 10 to 20 subdivisions per county. Subdivisions are responsible for supervision of maintenance work for the state and the counties. In addition, they are concerned with communes (10 to 20) and their minor roads in rural areas. Maintenance in towns is normally the responsibility of the town's technical services. Some subdivisions have wider responsibilities and take care of canal and waterway structures.

On average one subdivision manages

- 20 to 50 km of Class A roads,
- 200 to 400 km of Class B roads, and
- 500 to 1000 km of minor roads.

Around large built-up areas, state-run motorways are managed by one or more specialized subdivisions.

A subdivision is usually run by a Public Works Civil Engineer seconded by a Public Works Technical Assistant. About a dozen secretaries, designers, and accountants complete the office staff. Personnel more directly concerned with road maintenance at work sites are

- Two to four site supervisors,
- About a score of skilled workers, and
- A score of works officers.

Almost all of these people used to be paid by the state, but for the past 2 years county general councils have been able to hire staff.

In certain rural areas, subdivisions also manage a number of "commune" officers.

County Depots

There is an equipment depot in the majority of counties. The depot supplies specialized equipment to subdivisions and supervises

- Painting of road markings and
- Surface dressing repairs in some counties.

It also takes care of machinery and vehicle maintenance. County depots are jointly managed by the state and the county.

In accounting terms, a depot is an independent unit in the DDE's budget in the sense that it invoices the services it renders to the subdivision and must balance its books between income from services invoiced and expenses such as equipment amortization and maintenance. The annual budget of a depot is on the order of 40 MF (about $7 million).

Depots are usually run by a Public Works Civil Engineer under the authority of the DDE. Personnel have a special status known as Depot Workers (OPA). A single depot can employ from 50 to 180 workers.

REGULAR MAINTENANCE JOBS

Types of Tasks

Regular road maintenance depends on the kind of area served and the general context (town or country). This makes analysis of the problem difficult. Tasks can, however, be grouped under five main headings:

- Regular carriageway maintenance,
- Maintenance of ancillaries and rest areas,
- Road signing and machinery and vehicle maintenance,
- Winter road service, and
- Regular maintenance of engineering structures.

In 1986 a working group on External Services' Road Maintenance Equipment analyzed the work involved in the first three of these headings and broke it down into 28 different tasks. Specified for each task were

- The type of road in question,
- The DDE department concerned (subdivision or depot),
- Personnel needed,
- Present degree of mechanization of the job,
- Average unit cost,
- Equipment necessary to carry out the task,
- Suitability of equipment allocated to the various tasks and types of present or future improvement, and
- Personnel health and safety problems specific to a given task.

Winter road service also came under special study as did engineering structure maintenance cycles.

Principal Maintenance Techniques in Use

Carriageway Maintenance

Surface Sealing This technique is used to repair road surfaces, mainly with surface dressings that are an emulsion of bitumen and chippings applied by a spreader; this is known as "patching." This method is often used by subdivisions, but it is costly in emulsion and the repaired surface is not compacted. This can lead to "bleeding" or "fatting up" in hot weather.

Reshaping Reshaping is done before surfacing, most frequently using hot or cold macadam spread with a finisher.

Filling Potholes This is usually done by obsolete methods using noncompacted cold macadam, which often leads to repeated visits as the repair deteriorates. There is a lot of room for improvement in this technique.

Dealing with Bleeding The technique used in hot weather is chipping with 4- to 6-mm chippings. Rolling with a smooth-surfaced roller is essential. Sandwiching macadam with chippings also produces good results.

Repairing Trenches Electricity and telephone companies use carriageways as an easy place to dig trenches. This has disastrous results for road surface conditions and leads to tracking or rutting and patch works. Cement-bound granular materials should be used to limit settling. Trenches dug with specialized equipment have clean straight edges and are easier to fill and resurface. A surface sealer applied along the edges of trenches is recommended.

Carriageway Cleaning Cleaning is carried out to remove superfluous chippings after resurfacing or, on fast roads, when snow has melted, to remove the spread gravel. Either a towed or a self-propelled suction sweeper is used.

Replacement of Failed Areas This is not very common, and replacement requires the body of the road to be rebuilt. Because only small areas are involved, compaction is not done thoroughly.

Ancillaries

Mechanical Mowing and Scything of Road Verges This is one of the commonest tasks in spring and summer. The equipment normally used is a rotary mower that cuts the grass and leaves it on the roadside, which sometimes leads to the disadvantage that summer fires spread faster. Average speed is 2 km/hr. This type of machinery is dangerous for the personnel working with it.

Mechanical Brush Clearing The most suitable machine is a rotary cutter attached to a farm tractor. Speed is around 1.5 km/hr.

Pruning and Lopping French roadsides are often planted with plane trees. Low branches are lopped with mechanical saws from telescoping elevator platforms. This work is expensive and sometimes dangerous, especially in heavy traffic.

Maintenance of Grassy Areas Grass on rest areas and grade-separated interchanges is mown with low-speed mowers.

Cleaning Aqueducts In most cases this is done manually so it is very slow and requires intensive manpower.

Ditch Cleaning This is usually done by dredging with a mechanical shovel at a speed of 1 to 1.2 km/day. Chopping systems are also used, but only where the chopped material can be left on neighboring properties; these systems are not suitable where vineyards border the road.

Road Signing

Aside from repairing or replacing damaged road signs, the main job is to clean signs and roadside marker posts. Cleaning is normally done by hand. If signs are movable, the simplest solution is to replace them with clean ones and then clean the dirty ones in the workshop.

Winter Road Service

Preventive Salting This is done to prevent ice formation, or before or after snowfalls. Salting is done from automatic salt spreaders working from lorries.

Salting and Gritting Packed Snow Salting is done as described previously. A technique known as "salt mush," which consists of saturation salting, is being developed. This is efficient at temperatures below −6°C when the salt cannot hydrate fast enough on frozen snow. Gritting is only done locally on secondary roads.

Snow Clearing In mountainous areas special machines (snow cutters and blowers) are used to clear snow. In other areas snow is cleared by lorries with adjustable V-blades in front. These vehicles are often four wheel drive and have strengthened chassis.

Regular Maintenance of Small Structures

Maintenance of small structures is essentially a question of supervision with attention paid to water drainage because proper drainage contributes to long life.

If a structure is made of bricks, plants and bushes whose roots break up the brickwork should be systematically removed.

Carriageway joints should be cleaned to allow them to expand freely.

Personnel and Equipment

Personnel

Road maintenance personnel are organized into three or four brigades per subdivision. Each brigade is responsible for a specific road sector or, sometimes, for greater efficiency, a particular route. A brigade is led by a supervisor or a very skilled worker and consists of five to ten skilled workers and office staff. A brigade's area of operation is a canton.

Equipment

Subdivisions have their own equipment for regular use, and they rent specialized equipment from county depots. Typical equipment owned by a brigade includes

- One tipper lorry, with a payload of 3.5 tons, per 100 km of road,
- One tractor (45 to 75 hp) per 100 km of road,
- One van, and
- One transportable or nontransportable vibrating roller.

Subdivisions in mountainous areas also have

- One lorry with a payload of 9 or 15 tons,
- One loader, and
- One or two transportable salt spreaders.

The county depots rent more specialized equipment to subdivisions. Examples are patching equipment for surface sealing with emulsion and highly productive mowing and brush cutting equipment. Specialized depot teams also carry out most sign painting using painting machinery that automatically doses the paint.

Maintenance Budgets

An average budget can be broken down as follows for both national and county networks:

Unit	*Amount*
Depot	21 MF (about $3.5 million) including amortization of equipment
Subdivisions	52 MF (about $8.7 million) for the national and county networks
DDE	2 MF (about $350,000)
Total:	75 MF (about $12.5 million) per year.

This is 4 million to 7 million francs per subdivision, or 70,000 francs (about $12,000) per kilometer for Class A roads and 15,000 francs (about $2,500) per kilometer for Class B roads.

The budget devoted to roads in communes is quite variable. In rual areas it is on the order of 10 MF (about $1.7 million). The DDEs are not very active in urban areas because maintenance work there is undertaken by the technical services of the communes.

The budget is used as follows:

Use	*Percentage*
Carriageway maintenance	30
Maintenance of ancillaries	20
Winter road service	20
Miscellaneous	30
Total	100

Regular maintenance work is usually carried out under the supervision of subdivisions with the assistance of county depots.

Help from outside firms is used only in special cases, for example equipment rental or specialized jobs such as marking of long stretches of road. However, outside firms are engaged in the majority of cases in which new macadam surfacing is required. Macadam surface renewing is shared equally by outside firms and the county depots. About two-thirds of the budget is devoted to new surfaces.

EVOLUTION OF REGULAR MAINTENANCE

General Evolution

Since 1980 the DDE working environment has been rapidly modified by both institutional and socioeconomic factors.

The institutional evolution is the result of decentralization. The law of March 2, 1982, delegated the state's authority to "Territorial Communities." This law stipulates that "Communes, Counties, and Regions shall be administered by Elected Councils." This law also removed all state administrative supervision of communities as well as specific grants (especially for roads).

Grants have been grouped in the form of one general allocation from the state to the community. This law also excludes all supervision of communes by counties. Administration had previously been very centralized in France, so this law represents a real administrative and cultural revolution.

In each county there are three administrative types of road network—national (Class A), county (Class B), and communal (minor or byroads). The main contractors for these three types of roads are totally independent, but road users have no idea that these "frontiers" exist.

The DDEs that manage the national and county, and sometimes the communal, networks have had to adapt to this situation. In particular, they have now to take into account the more demanding financial management requirements of main contractors. Funds are jealously kept for exclusive use on the networks for which main contractors are responsible.

The socioeconomic evolution can be observed in all developed countries and leads on the one hand to a reduction of economic and resource activities and on the other to public demand for less administration.

The result is a reduction of funds and public investment; major motorway works are contracted to private or mixed companies. Regular maintenance work, however, is not very profitable for business and remains largely a DDE responsibility. DDEs therefore have to meet maintenance needs with less money and fewer personnel.

Existing staff are worried about this evolution taking place around them that they cannot easily understand or follow. Road maintenance officers tend to be unmotivated, which is bad for work quality.

This evolution can also be viewed in terms of the need to invent and develop new techniques and equipment, as well as the need to better organize and train manpower.

Evolution of Techniques and Equipment

The evolution of regular maintenance techniques is closely allied with the development of machines, particularly for maintenance of ancillaries and road signs.

Regular maintenance techniques have not evolved much because they represent only a small, scattered market for manufacturers, unlike the market for new, big investment works. They have been developed mainly in response to administrative encouragement of resurfacing product and machinery manufacturers.

Hot, noncompacted materials of the rolled sulfur asphalt type have been experimented with for surface sealing. This technique is usable for shallow surface repairs, but it is difficult to use and has not yet lived up to its promises. Black binders can also be improved by the addition of polymers of the rubber type, but they are used mainly for large areas of top resurfacing.

It should be noted that hydrocarbon binder emulsions, the breaking point of which can be controlled, have recently been introduced. These emulsions are an improvement on conventional emulsions the breaking point of which depends on ambient hydrometry and the mineralogical characteristics of the aggregate. In time this advantage should encourage the use of emulsions for maintenance.

Many mastics for sealing surface cracks have been developed since 1980. The firms that have developed these products usually also apply them because this is a delicate job that requires surface preparation with heat guns to strip the overburden of bituminous concrete and the use of pretreated industrial microchippings.

For surface sealing, a decisive step forward has been taken with the improvement of spreaders for patching (see paper on Two Major Innovations in this Record by G. Point) and the SECMAIR Company's automatic chip spreader that allows binder quantities to be better dosed (2 kg/m^2 of emulsion instead of 2 to 3 kg/m^2 with traditional spreaders), but, above all, it gives far better returns, multiplying productivity by five. The cost per square meter of surface treated is reduced by 40 to 60 percent. Experience has shown that this machine, which has so far been bought by 40 road enterprises, will bring with it a new maintenance concept that can be called "regular planned maintenance."

The use of aggregate-bitumen combinations appears to be promising for reshaping carriageways. These combinations are made in a central mixing plant by cold mixing graded aggregate 14 mm in diameter with a bitumen emulsion. Such combinations need to be vigorously compacted and the surface needs to be sealed, but this can be done a few months later.

Treatment of bleeding, or fatting up, can be improved by the application of hot chips plus dust, after drying at 160°C.

Trench repairs are made easier by special excavating machines that produce clean-cut edges that are easier to reseal. Certain companies have perfected automatic resealing machines. An example is the J. Lefebvre Company.

Evolution of Maintenance Equipment for Ancillaries

This evolution is characterized by multipurpose equipment. The first such piece of equipment was the multiuse vehicle (MUV) designed by the Société Nicolas. This machine was originally developed for mowing and palletization but has been progressively extended to deal with brushwood clearing, ditch cleaning using cutters, sweeping, and more recently snow clearing with cutters and blades.

Other machines, though less multipurpose, are being developed by a variety of manufacturers. These machines are usually pneumatic extensions to tractors for loading and other tasks.

Evolution of Road Sign Maintenance

Research has been concerned mainly with roadside marker post cleaning. One company has developed an automatic cleaning machine that is still in the experimental prototype stage.

It might be profitable to improve the sticking power of adhesive sign faces so they would resist high-power hose washing, but it appears that nothing has yet been done in this field.

Evolution of Winter Road Service

The only new salting technique that should be developed appears to be "salt mush." A saturated salt solution, prepared just before it is applied, is spread on the road. Salt mush is effective at −6°C because the salt cannot hydrate fast enough in contact with the snow.

For snow clearing, a V-blade attached to the front of a self-propelled vehicle continues to be used. The shape and coating of the blade can be perfected to clear snow faster without its sticking to the blade. Smooth plastic coatings have been developed by a number of manufacturers.

Evolution of Public Works Organization and Management

Since 1986 the whole Public Works Administration has recognized the need for reorganization to meet maintenance requirements, taking into account budgetary restrictions.

Centrally, the partitioning triggered by decentralization has led to funds being directed to the DDEs. The central Roads Management Committee is only concerned with overall budget programming and coordinating innovation by working with the technical network and with businesses.

Locally, the DDEs are making efforts to use good management practices.

Finally, a coordinating body called the Permanent Roads Maintenance Group (GPER) has been set up.

Evolution of Central Organization

At the central level, maintenance funds have thus far been distributed in a very specialized way. Funds destined for national roads and motorways come from three central administration committees, the Roads Committee, the Road Personnel and Safety Committee, and the Traffic Committee. These committees are divided into subcommittees and bureaus. The specializations of these bureaus and the suggestions of the technical services have led to a regrouping of maintenance problems. This maintenance regrouping can be found at the county level. The organization of the DDEs has been strongly influenced by that of the ministry.

There are three necessary elements of network maintenance: manpower, equipment, and funds. The balance among these three is difficult to attain in the present administrative situation. Moreover, this balance also depends on geographic criteria and local priorities that are difficult to appreciate at the central level. It has thus become essential that responsibilities be very seriously accepted at the local level.

Centralized funding is used to achieve this objective. Such centralization cannot, however, be complete and immediate because of the problems involved in rapidly modifying existing structures. However, the Roads Committee is going to regroup funds that have hitherto been allocated to road markings, maintenance of ancillaries, maintenance of main road machinery and equipment, vehicle and fuel purchasing, regular maintenance of engineering structures, and winter road service. It is therefore to be hoped that this measure will encourage managing bodies to make small savings everywhere so that larger local works can be carried out with the resulting savings.

However, the maintenance of roads already strengthened is specialized and must therefore remain centralized to ensure conservation of the national heritage.

At present the DDEs rely on state and county funding. Twenty percent of purchases are made by the state and 80 percent by county general councils. There are therefore as many equipment buyers as there are counties. In this context central committees cannot to any great extent influence the market, nor can they dictate the purchase of any particular type of equipment.

Purchases have, until now, very often been made on the recommendation of depot heads. However, purchasing decisions are strongly influenced by internal organizational considerations that have developed through systems dating back to the 1960s. This reasoning should be dropped in favor of purchases determined by the type and size of the tasks to be accomplished.

The Roads Committee will supply funds to the DDEs for the purchase of modern maintenance equipment. This step should give a shot in the arm to the whole system and help to modernize services.

Relationships with manufacturers take the form of dialogues in which the central administration's primary role is to quantify the tasks to be done and to determine what needs to be done to accomplish each task. The report that is given to manufacturers is only a first stage that must be furthered in all areas in cooperation with the industrialists concerned.

It is necessary to inform external providers as much as possible about specifications and the use of new machinery. Several organizations including the Permanent Roads Maintenance Group (GPER), the Technical Road Study Planning Department (SETRA), and the Central Bridges and Highways Laboratory (LCPC) carry out this information distribution, which is a prerequisite for new maintenance ideas.

Evolution of DDEs

Regular road maintenance has always been left to the initiative of divisional engineers, so maintenance quality depends to a large extent on their conscientiousness. Recently the DDEs have been reorganized to set up maintenance–road management services in charge of coordinating, programming, and ensuring more rational management of road maintenance funds in each county.

Technical and management tools are being developed:

Technical Tools Fast, efficient, road data collecting techniques followed by automatic data processing are being developed. Data banks are also being set up, and the prototype is known as the Roads Data Bank (BDR).

The Roads Data Bank allows each DDE access to data on the national road network that are collected automatically by specialized devices designed to observe the condition of road surfaces and road signing. The INFOROUTE interrogation system allows the BDR to be asked questions such as

- What signing equipment is there on this road section?
- What is the road surface condition at this point?
- What maintenance work has been done on this section since 1983?

At the present time research is being carried out on the use of video disks to image routes. There is an existing prototype designed for engineering structure maintenance.

Management Tools These are bookkeeping tools assembled under the name "CLAIRE." They are designed to

- Increase understanding of the use of funds received from the state and territorial community in order to better control management and maintenance costs and
- Detect differences between targets and results, which should make forecasting easier.

They are intended for subdivisions and should be computerized soon.

The county depots already have computerized state-of-the-art analytical bookkeeping systems for determining prices of equipment and machinery. The most recent version is M R 4 G.

As is the case in other fields, expert systems are springing up. The Technical Road Planning Study Center (CETE) in Aix-en-Provence has developed a system of road maintenance aided by a multiexpert system called ERASME, which is designed for flexible pavements.

Expert systems are of interest not so much because of the results they give, but because they encourage engineers to take into logical account all maintenance parameters.

Permanent Roads Maintenance Group (GPER)

The GPER was set up in October 1986 by the head of the Roads Committee to form a permanent information center to collect information about local experience and advise the various central management directorates: the roads directorates, the road safety and traffic directorates, and the personnel directorates.

This organization completes the road maintenance cycle studies of civil engineers in the field. The recommendations made by this group are sound because they come not only from engineers but also from depot heads, works supervisors, and welfare and safety inspectors. These people are divided into four "workshops" that make up the GPER with its Roads Directorate national secretariat.

- Workshop 1: Techniques and Equipment,
- Workshop 2: Human Resources,
- Workshop 3: Contacts with Main Contractors, and
- Workshop 4: User Relationships.

Each workshop is headed by a county manager.

Evolution of Jobs and Training

Evolution of Jobs

Until the 1950s road maintenance in France was undermechanized and the responsibility of road menders and district (canton) road surveyors. Each road mender was in charge of 3 to 7 km of road known as a "canton road." He was his own boss and did maintenance work himself, or sometimes with temporary help; he cleaned ditches and gutters, trimmed shoulders, and the like. He was well known in his village and his main strength was his muscles.

Between 1954 and 1959 it became clear that increasing mechanization of maintenance machinery such as sweepers, rollers, and patchers made it logical to group road menders into teams. Thus individual responsibility for canton roads gradually disappeared.

The county depots were created in 1967 and have become more and more mechanized as they have acquired tractors, mechanical shovels, self-propelled sweepers, painting machines, and automatic mowers.

Maintenance crafts are diversified and specialized, especially at the depot level; there are vehicle and machinery drivers, radio specialists, and road marker painting teams.

At the subdivision level, on the other hand, skills have not evolved at the same speed and do not really meet today's requirements. Most of the personnel are trained on the job and are still attached to the values that built the reputation of the old-time road menders. What is more, staff numbers continue to fall, and the whole notion of brigades becomes senseless near big agglomerations.

Finally, engineers and senior management have taken note of the need to better coordinate and program maintenance work at the county level. This means that the DDEs need to have real road management policies.

The present changeover period requires up-to-date training in:

- The latest techniques and management methods and
- The use of new techniques and equipment.

Training

Training Senior Managers Since 1987 each engineer responsible for the road maintenance service of a DDE has undergone a road management training course of two 6-month periods:

- The first is at a university and includes four 1- to 2-week modules devoted to road techniques and modern methods of management and organization.
- The second consists of drawing up and putting into practice a "road maintenance methods and organization modernization" project in each DDE and involving all of the personnel in the working groups.

Training Managerial Staff At the regional level there are Permanent Interprofessional Training Centers where specific maintenance training for managers and site supervisors is given. The ministry is also trying to provide more training information. Thus, in February 1987, SETRA published a Practical Guide to Regular Road Maintenance.

Training Workers and Officers The evolution of techniques during an officer's working life leads to the need for retraining during his career, especially as recruiting is reduced and average age increases. The average officer is 40 years old, and it is not easy to change his thinking habits quickly.

A lot remains to be done in the training of road officers. Audiovisual methods are preferred because they diffuse information rapidly. It is also absolutely necessary to modify recruitment methods to take into account the qualifications required.

Infrastructure and Maintenance Concepts

In general, roads used to be simple carriageways bordered by two raised edges and by ditches. Modern roads include

- Central reserves,
- Roadside landscaping,
- Crossroads with planted islands,
- Grade-separated interchanges that are planted, and
- Rest areas.

Traffic and safety management needs have led to the gradual cluttering of roadsides with safety fences, signposts, and lampposts.

Recently equipment such as traffic sensors has been embedded in the roads themselves. All of these objects meet various needs, but they represent obstacles to logical maintenance management and complicate road works.

Rural Roads

Roadsides

The presence of roadside marker posts at the distances presently prescribed leads to new cleaning and maintenance jobs that are difficult to mechanize and slows down the mechanization of verge mowing and ditch cleaning to such an extent that it now appears to be desirable to entirely rethink specifications to take these problems into account.

A comparative study could solve the problem, but certain parameters, such as operators' safety, road users' comfort, and the effect of new ideas, are difficult to estimate.

Safety fences also slow down mechanization of regular maintenance jobs, such as mowing behind, in front of, and under these barriers; ditch cleaning; tree pruning; and maintenance of slopes and banks, not to mention winter road service.

Measures can be taken to alleviate problems before projects are carried out; obstacles can be moved or weakened, ditches and drainpipe openings can be better designed, banks can slope more gently, GS2SO-type safety fences can be used where barriers are necessary, and the ground can be treated to minimize vegetable growth under barriers (noneroding gravel to be cleared yearly by chemical or other means) to avoid manual mowing and cutting with inefficient garden-type mowers and scythes.

Signposts are often positioned for maximum visibility, but road maintenance and safety consequences are rarely taken into account although recent studies have allowed ideal posts to be defined, particularly from the safety standpoint. Overhead and gantry sign installation is even more important because it dictates barrier installations and the use of roadside mowing and ditch-cleaning equipment. Lightposts create the same types of problems as signposts.

Efficient, easy-to-maintain drainage should be studied: roadsides should be leveled to a 2 in 1 nonstabilized slope; water should be directed to avoid gullying; ditches should be designed to be crossable and thus maintainable with present equipment; drain clearance should be limited by suitable installations.

Cuttings and embankment slopes should be designed to take into account the following considerations: soil stability; safety (slope, height, and appearance); and environment (landscaping and its maintenance, depending on the availability of materials, the slope, and the type of vegetation chosen). Mechanical equipment cannot operate on slopes of more than 3 in 1, and available mechanical arms are limited in length. Thus banks near abutments of engineering structures are often difficult to reach and maintain.

Landscaping can lead to serious constraints. For aesthetic reasons and reasons of safety (visibility and fire risk), mowing needs to be done two or three times a year, watering needs to be done regularly, and trees must be treated yearly. Trees must be carefully chosen to have the same growth rate and the same frost and pollution resistance; they must present minimum danger for vehicles. Special maintenance considerations for plantings that present safety problems on Class A roads were specified in Circular No. 80.41 of November 28, 1984.

Central Reserves

A majority of problems with roadsides are also present on central reserves; in some cases they are magnified because of the difficulty of accessing central reserves. It should be noted that

- The original profile of stepped slopes cannot be maintained.
- Mechanical mowing of central reserves is essential for reasons of operator safety. If widths are insufficient for the passage of mechanical mowers, it is better not to sow grass.
- Well-chosen tree plantings can require minimal maintenance, which can be mechanized by using a cutting and pulverizing machine.
- A surfaced central reserve requires at least annual sweeping.
- Maintenance of safety fences on central reserves under urban and suburban heavy-traffic conditions is such that one or two concrete lane separators may be preferable, provided drainage and vegetation problems, including watering and maintenance, are studied at the same time if two lane separators are to be installed.
- The choice of lampposts may be governed by maintenance considerations, provided they meet safety requirements for width and positioning vis-à-vis the barriers; curved channels or even open rectangular gutters can be used on central reserves to direct water.

Highways That Cross Built-Up Areas

Where a rural road crosses villages or small built-up areas, the work done is usually to strengthen or improve existing roads.

Road verges are replaced by pavements that must be surfaced to prevent growth of vegetation. They must also be designed to meet drainage requirements.

When roads cross large built-up areas, consideration must be given to lampposts, restraining devices, dynamic operating equipment, and noise screens.

Grade-Separated Interchanges and Rest and Reception Areas

Design of these features must take short- and medium-term maintenance into account. In certain cases maintenance considerations may influence the design itself. Requirements include

- Limited earth movement.
- Earthworks designed to be planted and maintained mechanically. This means accessible slopes, grouping like beds (grass, trees, etc.), and automatic watering in some regions.
- A minimum of surfaces to be maintained; in some cases the land can revert to agricultural use.

CONCLUSION

In the world of road maintenance, in-depth cooperation is essential, but this is only possible when the institutional, budgetary, organizational, and technical situations are well understood.

The French road maintenance "framework," which is special from several viewpoints, has been described. The special nature of this framework may be responsible for some recent innovations.

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Characterization of Polymer-Modified Binders for Special Surface Dressings

JEAN CLAUDE VANISCOTE AND BERNARD BRULÉ

The Laboratoire Central des Ponts et Chaussées, a French technical administration department, has put forward a laboratory method for characterizing polymer-modified binders for surface dressings such as emulsions and fluxed asphalt cements. This method has been applied to the most commonly used polymer-modified binders in France. In consultation with contractors, nine binders have been selected. For comparison purposes, an unmodified binder has been added to the list for each category. All of the binders on the list underwent all known practicable laboratory tests. This exhaustive characterization had two objectives: to evaluate the degree of modification of each binder compared with the corresponding reference binder and to simplify the characterization methodology by requiring that only tests that indicate significant aspects of modification be run. To complement the laboratory tests, a traffic simulation test was carried out on a circular traffic simulator to make more lifelike usage comparisons. It has been possible to draw up a classification system and threshold limits, below which binders cannot be considered "modified," for certain specifications.

In the 1970s highways of hydraulic concrete began to present maintenance problems, and it was becoming essential to reestablish their surface roughness. Foreseeing that surface dressings using conventional fluxed binders would not be able to withstand the wear produced by heavy traffic, the administration informed petroleum companies and other interested parties of its interest in polymer-modified binders and that it intended to experiment on certain road sections with any binders they might propose. The administration also organized its own research on the addition of thermoplastic polymers to asphalt cements in order to select the best polymer types.

Since then, surface dressings have played a greatly increased role, and in France around 350 million square meters of pavements are now treated with surface dressings. The use of polymer-modified binders in special surface dressings has become commonplace where traffic is relatively heavy, and it is estimated that about 10 percent of surface dressings applied in France are special dressings with polymer-modified binders.

With such a large market, each civil engineering company has tried to perfect its "very own" modified binder, and this is why it is now necessary to do laboratory characterization to determine the properties of these special surface dressing binders. The Central Public Works Laboratory, the Laboratoire Central des Ponts et Chaussées (LCPC), has therefore suggested a laboratory characterization method for polymer-modified binder emulsions and polymer-modified fluxed asphalt cements.

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This method has been applied to the most commonly used polymer-modified binders. In consultation with contractors, nine binders were selected—four emulsions and five fluxed asphalt cements. For comparison purposes, an unmodified binder was added to the list for each category.

All of the binders underwent all known practicable laboratory tests. This exhaustive characterization had two objectives: to evaluate the degree of modification of each binder compared with the corresponding reference binder and to simplify the characterization methodology by requiring that only tests that indicate significant aspects of modification be run. To complement the laboratory tests, a traffic simulation test was carried out on a treadwheel to make more lifelike usage comparisons.

A classification system and threshold limits, below which binders cannot be considered "modified," have been drawn up for certain specifications.

CHARACTERIZATION METHODOLOGY

To evaluate binder characteristics and their short-term evolution as thoroughly as possible, their properties have been determined for

- Fluxed or emulsified binders, known here as "as-they-are" binders, and
- Binders from which the essence of the volatile fraction is removed or that result from the breakup of the emulsion, here called "stabilized" binders.

Laboratory characterization was completed by treadwheel simulation. This intermediate step between laboratory and on-site use was applied only to stabilized binders.

In practice a stabilized binder is obtained by oven testing a film 1 mm thick (for fluxed binders) and a thickness corresponding 1 mm of residual binder (for emulsions) at 50°C in ventilated conditions for a fortnight. In the case of emulsions, breaking is obtained by simple water evaporation at 50°C. Table 1 gives the tests carried out on as-they-are binders and stabilized binders. The tests were run in conformity with the French standards (AFNOR), the LCPC working methods, or the test methods described in the Appendix.

TABLE 1 TESTS CARRIED OUT ON AS-THEY-ARE AND STABILIZED, FLUXED, MODIFIED BINDERS

Test	Working Method	As-They-Are Binders	Stabilized Binders
Penetration at 25°C	NFT 66 004		X
Ring-and-ball softening point	NFT 66 008	X	X
Fraass brittle point	M.O. RLB 7 project	X	X
Elongation at −10°C	See Appendix	X	X
Elongation at +20°C	See Appendix		X
VIALIT cohesion	See Appendix	X	X
Treadwheel traffic simulation	See Appendix		X

INTERPRETATION OF TEST RESULTS

The following characteristics will be examined:

- Consistency as noted in penetration, ring-and-ball, and Fraass tests;
- Elongation behavior at constant speed;
- Cohesion noted with VIALIT pendulum ram;
- Adhesion and cohesion measured with a VIALIT plate (only for anhydrous as-they-are binders); and
- Traffic simulator behavior at Total's French research center.

Consistency Characteristics

Under this heading can be grouped measurements of ring-and-ball softening point (RBP), Fraass brittle point, and penetration. The object of modifying binders with polymers is to reduce thermal susceptibility at normal usage temperatures because this leads to reduction of the brittle temperature level and increases the softening temperature level and therefore the plasticity range. In the case of fluxed binders, spraying viscosity temperatures remain compatible with equipment used and aggregate wetting. Comparisons therefore are more important between plasticity ranges that are directly related to the binder's modification level than between the RBP and Fraass values taken separately. Each manufacturer can, for a given plasticity range, favor hot or cold behavior characteristics by the choice of asphalt cement or the amount and nature of fluxing oil, or both. Figure 1 shows the absolute plasticity range stages compared with reference binders (1 and 7) for each binder category (emulsions and fluxed bitumen) for both states (as-they-are and stabilized).

Examination of these results leads to some general comments:

- For as-they-are binders (binders 7 to 12), the plasticity range goes from 45°C for the reference binder 7 up to 64°C for binder 10, in other words a maximum increase of around 20°C. It should be noted that the modified binders 9 and 11 are not different from traditional binders in this respect.
- For stabilized fluxed binders, evaporation of the volatile fraction is accompanied not only by consistency increases but also by an increase in the plasticity range (on average, 10°C); the overall classification order remains virtually the same.

Modified binders can be clearly distinguished by their plasticity ranges.

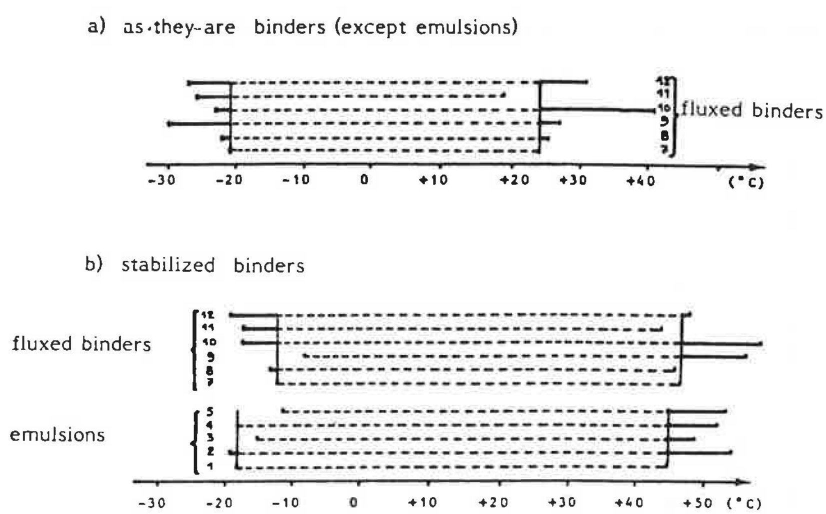

FIGURE 1 Plasticity range: Fraass and ring-and-ball.

Elongation Characteristics

The elongation trial working method is briefly described in the Appendix, and the results are shown in figures.

As-They-Are Binders

For fluxed bitumens, the trial is carried out at −10°C. Figure 2 shows the average curves.

Under these conditions, all of the binders cross the flow threshold. Stress falls more or less quickly—the higher the threshold the faster it falls—and reaches a zero value in the case of reference binder 7. This is characteristic of ductile behavior. For modified binders, stress keeps a value above zero that can increase with lengthening (binder 10). This latter type of curve represents viscoelastic behavior similar to that of an elastomer. It should be remembered that this is the type of behavior sought when binders are modified for surface dressings.

Elongation of Stabilized Binders at 20°C

Curves of the as-they-are binder types at −10°C are shown in Figure 3. A consistency increase due to evaporation of a part of the fluxing oils appears to have compensated for the softening caused by the test temperature. The same general remarks are therefore applicable.

Elongation of Stabilized Binders at −10°C

After evaporation of the volatile fraction (and breaking of the emulsions), the binders have clearly differentiated elongation behavior at −10°C (Figure 4):

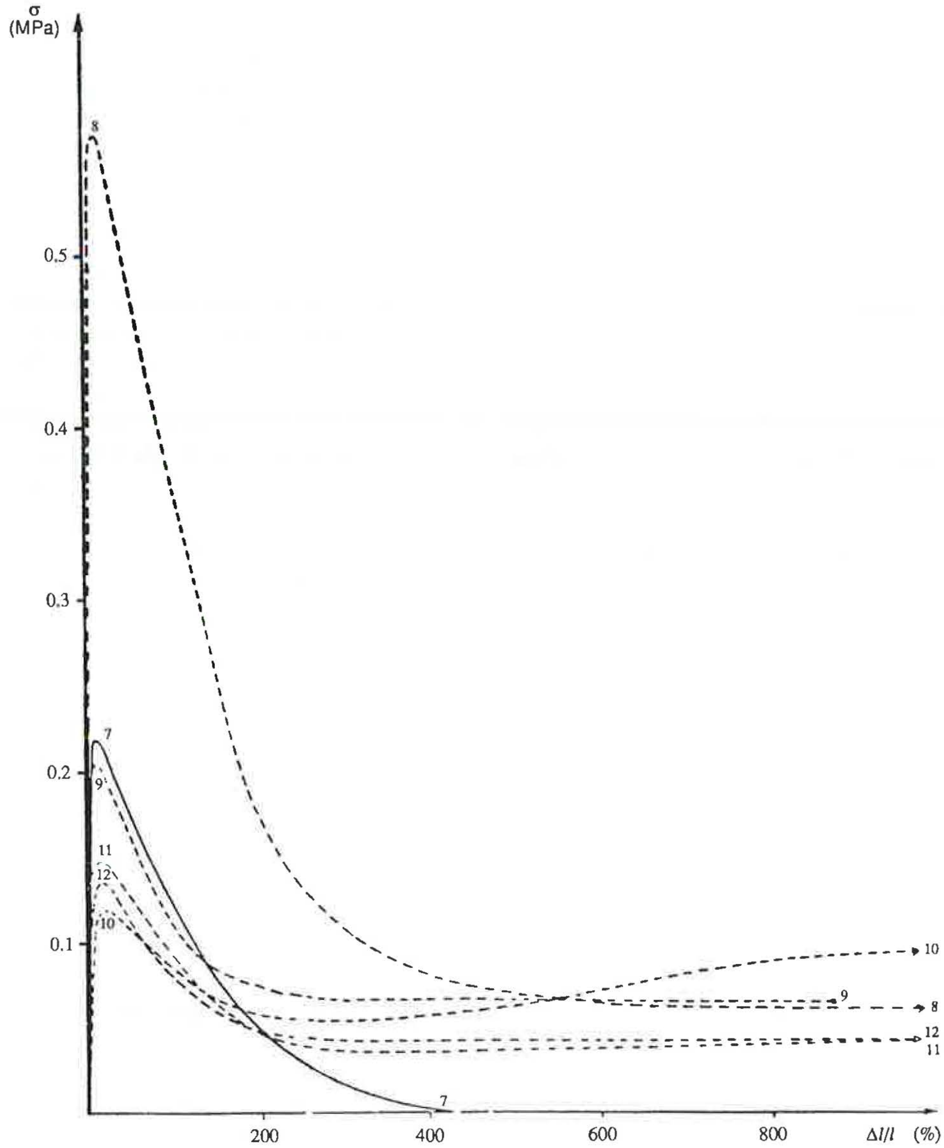

FIGURE 2 Curves of average stress/lengthening at −10°C, 100 mm/min for as-they-are binders (fluxed asphalt cement).

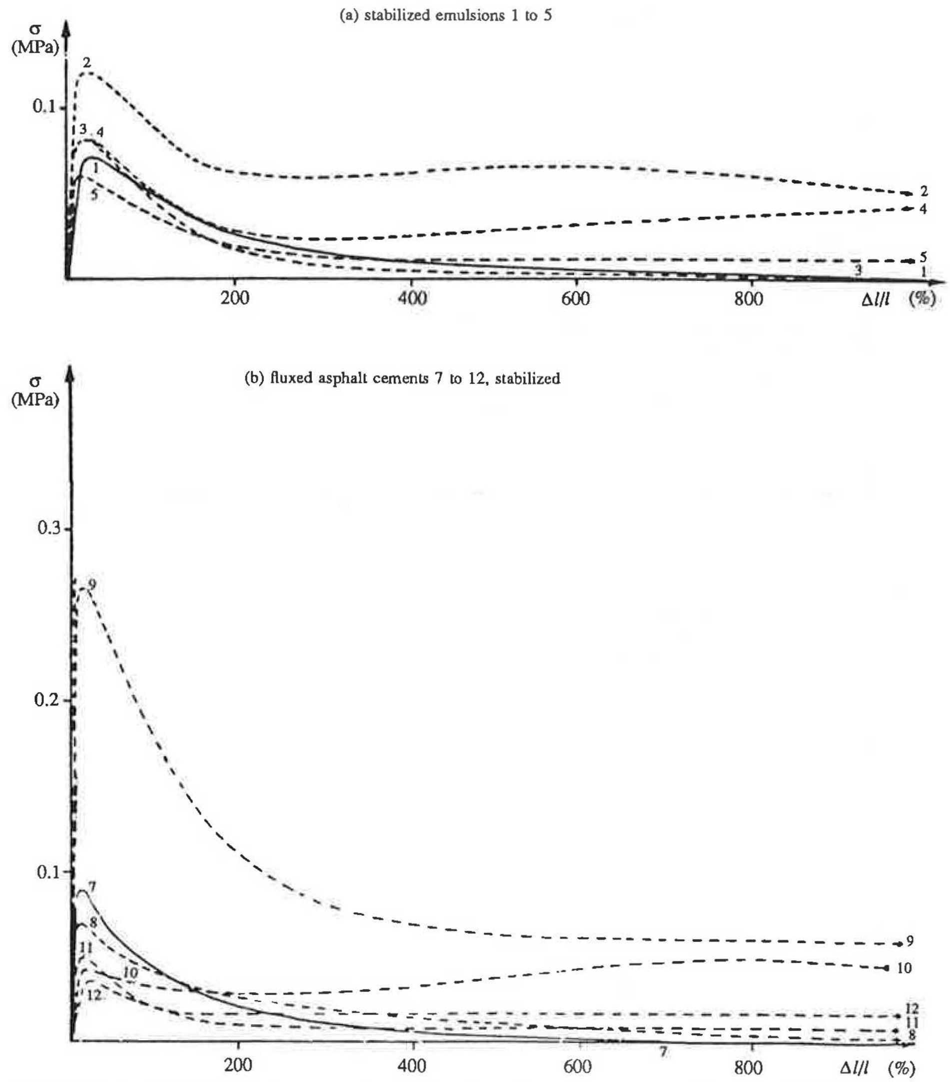

FIGURE 3 Curves of average stress/lengthening under elongation at +20°C, 500 mm/min.

- Only two modified binders (10 and 12) cross the flow threshold at a speed of 100 mm/min;
- Reference binders 1 and 7, and also modified binder 9, are brittle even at a speed of 10 mm/min; and
- All of the other binders (emulsions 2 to 5 and fluxed asphalt cements 8 and 11) cross the flow threshold at an elongation speed of 10 mm/min.

The information obtained from the elongation trials carried out on modified binders in different conditions is fairly homogeneous. The behavior of stabilized binders, which is markedly different at −10°C, is already different at +20°C and shows up in the behavior of as-they-are binders at −10°C. Stabilized binders that are not brittle at −10°C produce considerable break lengthening (more than 800 percent) at 20°C (or at −10°C for as-they-are binders) corresponding to equally great stress compared with the threshold stress level.

Furthermore, 20°C cannot be considered a high working temperature, and it appears that the most interesting information on stabilized binders is obtained at −10°C, which is a low working temperature. The elongation trial could therefore be considered an indication of the degree of modification associated with possibilities of deformation under cold conditions.

Cohesion Using a VIALIT Pendulum Ram

One of the essential reasons for adding polymers to binders for surface dressings is to increase cohesion. The VIALIT pendulum ram is a simple means of evaluating the energy absorbed by the breaking of a binder film (see Appendix). Trials of each binder are carried out at various temperatures and a cohesion/temperature curve is drawn.

All of the cohesion/temperature curves have the same appearance. As the temperature drops from the high working values of 60°C to 70°C, cohesion increases in proportion to increasing viscosity and reaches a maximum value that allows a maximum cohesion temperature to be defined. It then decreases from the viscous state to the brittle state and reaches

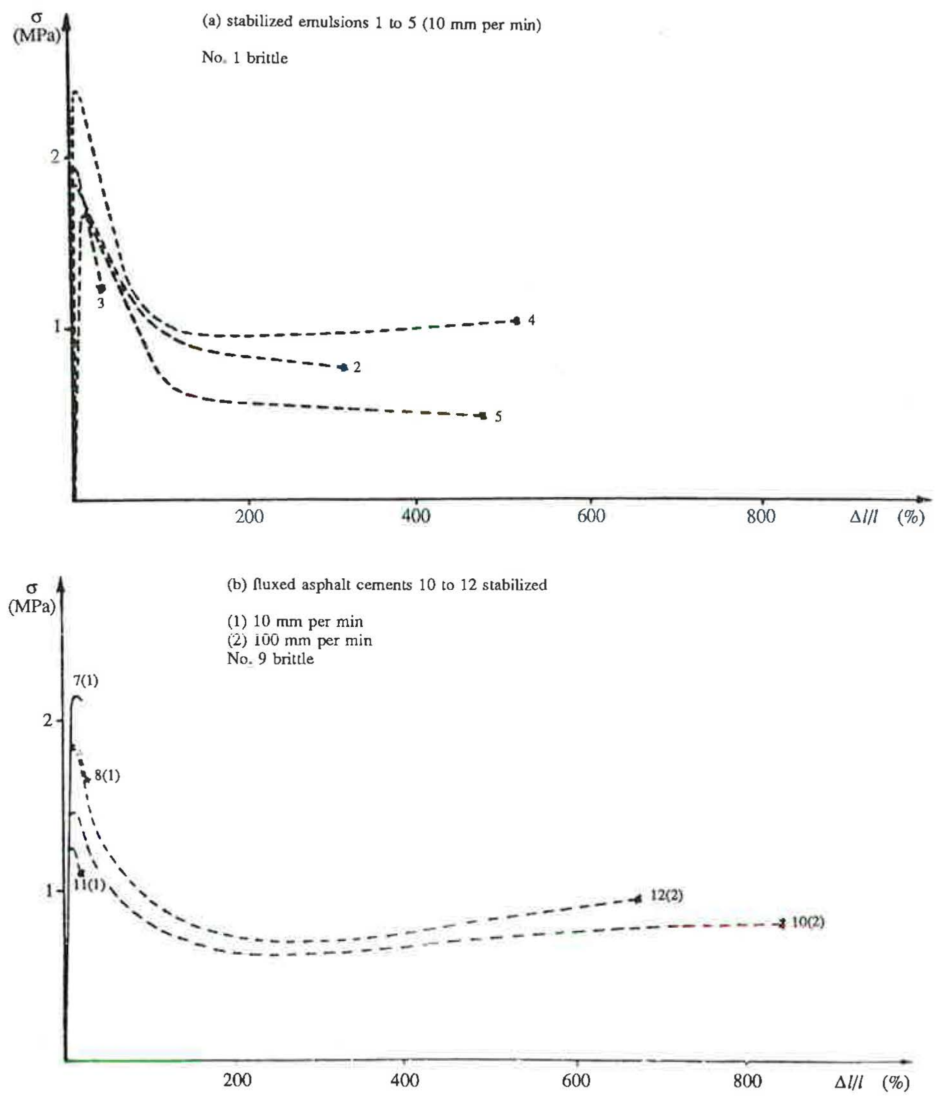

FIGURE 4 Curves of average stress/lengthening under elongation at −10°C.

a low level that is characteristic of a brittle state. Such curves have been established for the anhydrous as-they-are binders and for all of the stabilized binders (Figure 5).

It has been observed that for as-they-are anhydrous binders the introduction of polymers leads to a considerable increase in maximum cohesion that can almost double (binders 10 and 12). The temperature range over which cohesion is increased is also considerably increased, going to as much as 20°C for these binders.

Eliminating the volatile fraction sends the cohesion curve sliding toward the highest temperatures whether or not there is a reduction of maximum cohesion. It should be noted that the maximum cohesion classification order remains unchanged. An examination of stabilized binders resulting from modified binder emulsion breaking leads to observations similar to those made about anhydrous stabilized binders.

It therefore appears that the best modification indicator of both anhydrous and emulsion binders for surface dressings is the value of maximum cohesion measured on the stabilized binder (the value cannot be measured with as-they-are emulsions). The maximum associated cohesion temperature is a reflection more of the product's viscosity than of its degree of modification. It is therefore interesting to know the initial value as well as the variation during evaporation of the volatile fraction of the fluxing oils in the case of anhydrous binders so as to adapt them to the climatic conditions under which they will be used.

Adhesion and Cohesion to the VIALIT Plate

The VIALIT plate test method allows binder/aggregate combination brittleness to be studied under the conditions in which it was created. This test, which was not originally considered as a means of revealing the degree of modification of a binder, has produced sufficiently interesting results for it to be included in this paper. The test consists of making plates of surface dressing (known as VIALIT plates) in a traditional way with dry aggregate and varying the temperature of the ingredients at the moment the aggregate is put into contact with the binder (here, 5°C and 20°C). After compaction, each plate undergoes repeated shocks from the ball starting at +5°C and decreasing by steps of 5°C. The number of chippings remaining on the plate after each series of three shocks and the temperature are noted.

This test was carried out on the six as-they-are anhydrous binders with the three types of reference aggregate generally used for adhesion trials—flint, quartzite, and microdiorite. The results are shown in Figure 6.

Comparison of the left and the right graphs highlights the influence of temperature at the moment chippings are added. Although adhesion created at +5°C may appear to be satisfactory, its fragility is quickly evidenced at a lower stress temperature. This phenomenon is much less pronounced if the chipping temperature is +20°C (see left graphs).

The influence of the type of aggregates used and their cleanliness (even after washing, the microdiorite used was still covered with a clay gangue) is increased under bad damping conditions (5°C) whereas it is much less under better

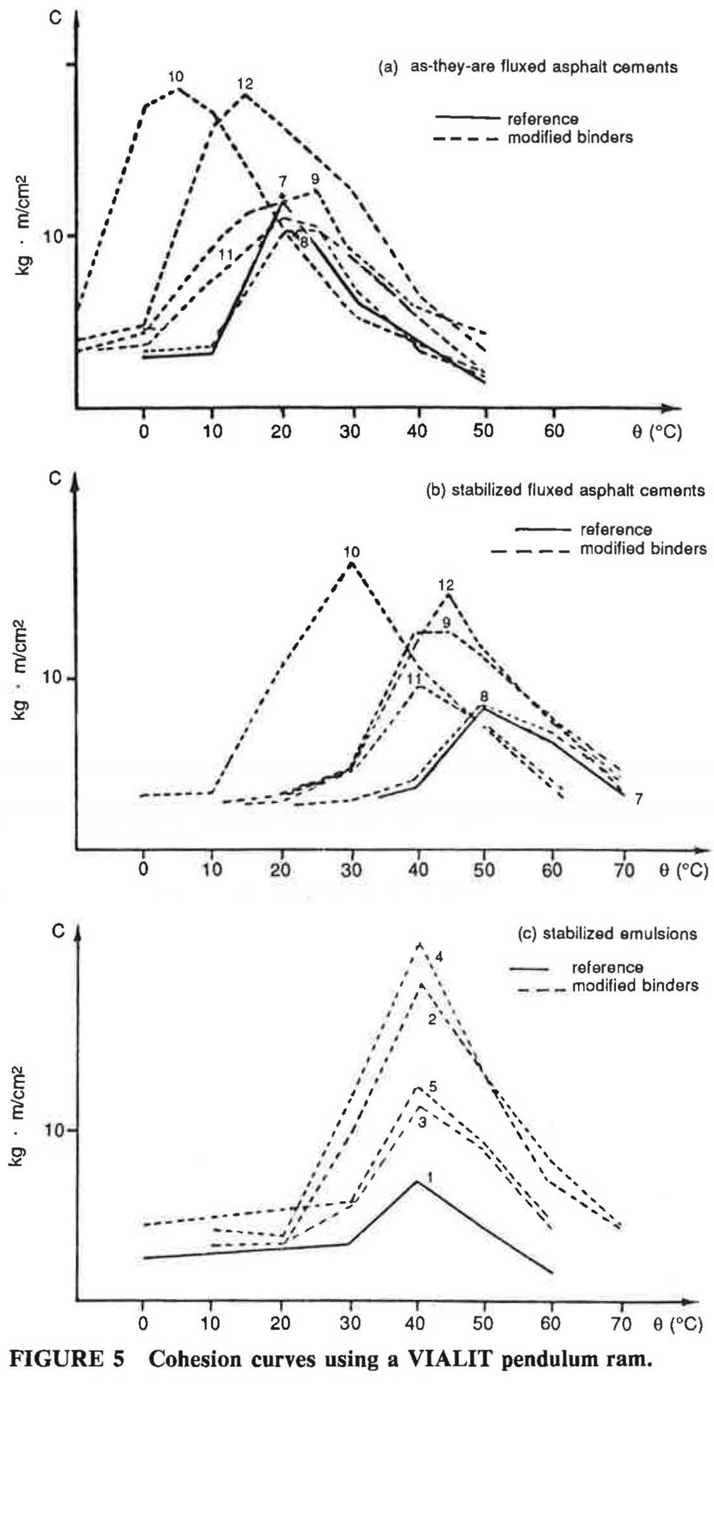

FIGURE 5 Cohesion curves using a VIALIT pendulum ram.

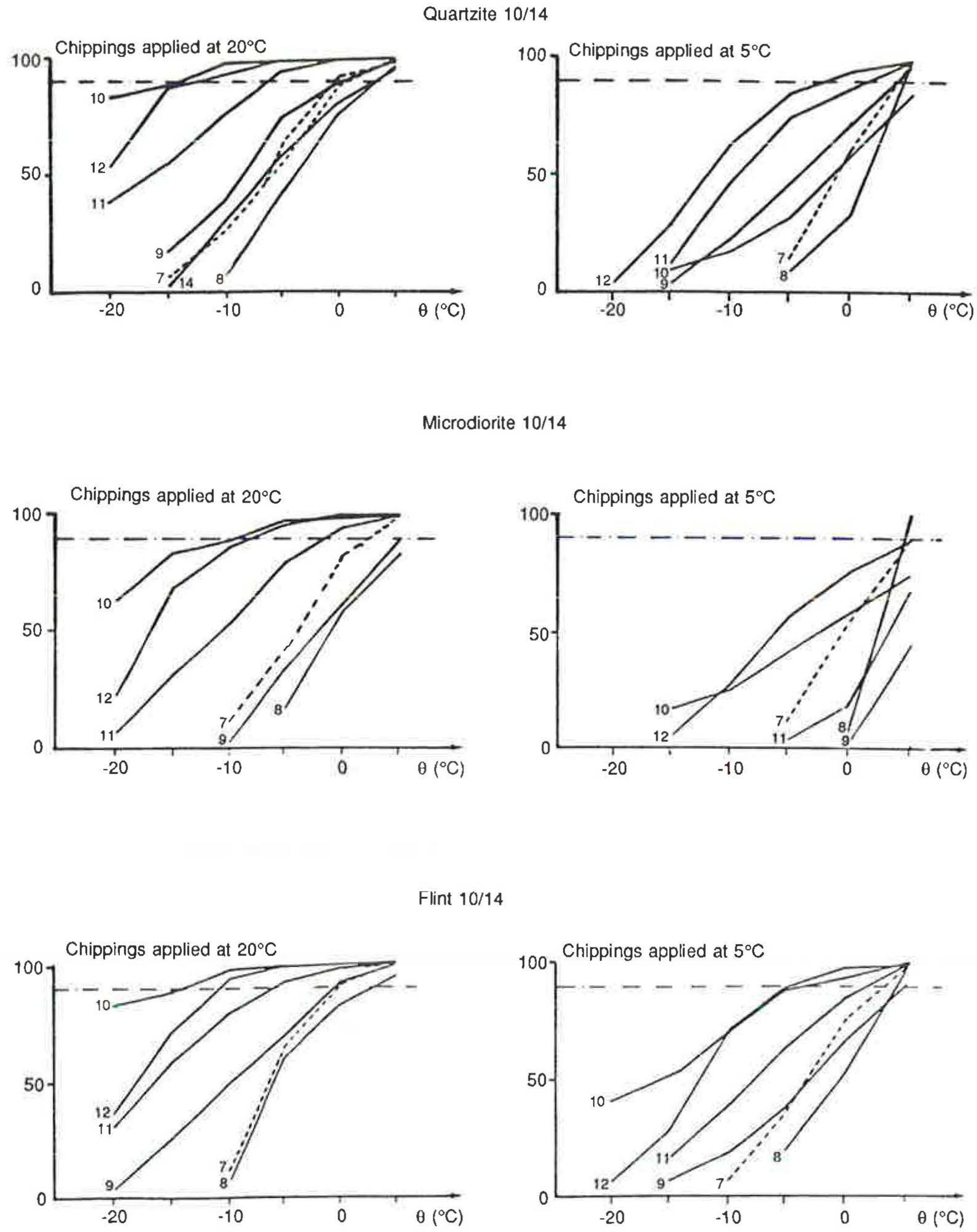

FIGURE 6 VIALIT plate test: percentage of different types of aggregate remaining on plate as temperature is decreased.

conditions (20°C). It is therefore imperative to respect minimum temperatures, not only for modified binders but also for the traditional binder 7. For this reason, comparisons are based on curves established at 20°C.

This trial concerns both binder/aggregate adhesion, which tends to take place at the beginning of the curves at around 50°C, and binder cohesion that takes place at low temperatures. The empirical results are therefore generalized and quite similar to practical usage conditions. The indicator chosen is the temperature that corresponds to 90 percent of the aggregate remaining attached to the plate.

Circular Trials

This test is used to study, at various temperatures, how well chippings attached to a surface dressing remain attached after the repeated passage of a loaded, constantly braking wheel. The quality of the binder content to be studied is estimated by examination of the appearance of the test bar, and the quantity by observing the chippings rejection rate. The working method of this test is described in simplified form in the Appendix. The chippings rejection rate per number of passages of the wheel is shown in Figure 7.

Behavior comparisons on the treadwheel concern only stabilized binders that have been prepared under conditions in which damping is correctly carried out with hot aggregates and support. The choice of the two test temperatures was based on experience in previous studies and confirmed by the first results of the present study.

It was known that

- The variation in the rejection rate due to temperature goes through a minimum,
- The minimum rejection temperature is fairly closely linked to the maximum cohesion temperature measured with a VIALIT pendulum ram, and
- The most significant rejection rate differences are obtained at temperatures quite far from the minimum rejection temperature.

Examination of the results indicates that, indeed, the difference in behavior is much greater at 5°C because rejection rates after 5,000 revolutions go from less than 15 to more than 80 percent. This temperature can therefore be considered sufficiently low for test conditions although it is still far from the extreme temperatures of actual winter service.

The treadwheel trial at 5°C appears to be suitable for indicating the improvement that modified binders can produce in the resistance of chippings to being torn off by traffic at low temperatures. At 35°C the average rejection rate and its generalization are reduced about 5 to 30 percent. At this

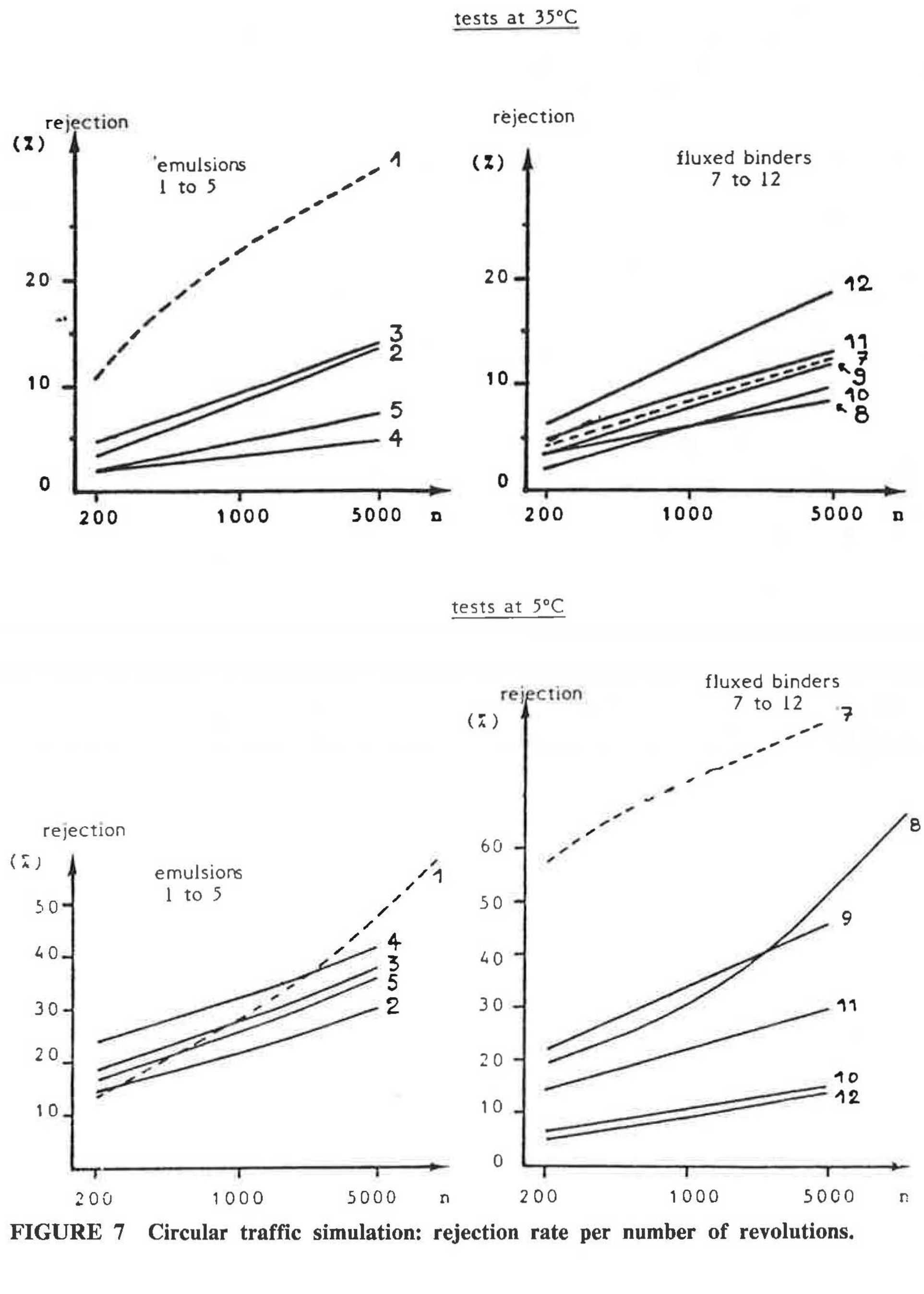

FIGURE 7 Circular traffic simulation: rejection rate per number of revolutions.

temperature, chippings are not rejected by the fracturing of the binder but by a viscous fracture that also leads to chippings being moved, but this is not measured. In addition, the softening of the binder coating triggers the start of tracking and the forcing of chippings into the surface dressing. There is therefore no clear difference between conventional binders and modified binders at this temperature.

COMPARISON OF BINDER CHARACTERISTICS OF STABILIZED BINDERS MEASURED IN THE LABORATORY AND THEIR BEHAVIOR ON TRAFFIC SIMULATION TRACKS

Stabilized binders are the only ones tested on the traffic simulation track. As has already been mentioned, the traffic simulation track trial was more discriminating at 5°C than at 35°C. Problems such as bleeding failure, viscous displacement, and embedding movements of chippings, which appear at higher temperatures, are difficult to measure with the rejection indicator. The ring-and-ball softening point, which is the only indicator to approach high working condition temperatures, is not related to traffic simulator behavior at 35°C whether the rejection rate or the "degree of blackening" be chosen as indicator.

It would therefore appear that the proposed methodology does not allow behavior problems under real, high-temperature working conditions to be satisfactorily appraised. Comparisons of traffic simulator and laboratory results are therefore limited to cold testing (Fraass and elongation at −10°C), as well as specific indicators of modification characteristics associated with the incorporation of polymers that are independent of the temperature plasticity range and cohesion on the VIALIT pendulum. An arbitrary four-level scale was adopted for each binder to compare laboratory tests with treadwheel tests.

The data in Table 2 indicate that

- A close connection exists between the plasticity range and the maximum cohesion measured by the VIALIT pendulum.
- A satisfactory relationship exists between these two criteria and elongation behavior at −10°C. The difference is never greater than one of the classes defined in Table 3.
- A low Fraass temperature is a necessary condition but is not sufficient to obtain important elongation of the fracture at −10°C. If the Fraass lowering is due to a modification of the binder by the polymers, it is accompanied by an increase in the plasticity range and an increase in lengthening at the fracture point in elongation at −10°C. If, on the other hand, it is simply due to a soft binder, the behavior in traction at −10°C remains mediocre. A bad Fraass always leads to fragile behavior under elongation at −10°C.

That traffic simulator behavior is close to the results of laboratory tests shows that none of them can "forecast" traffic simulator behavior. On the other hand, the "average" calculated randomly (without weighting) over the four laboratory tests is fairly close to the traffic simulator "score." Differences that are smaller than or equal to a "class" for the totality of the stabilized binders can be observed.

It therefore appears that the main indicators of the degree of modification of stabilized binders are

- Plasticity range: the softening temperature must be measured by ring and ball, and the fragility temperature by the Fraass method;
- Fracture lengthening under elongation at −10°C for a speed of 10 mm/min;
- VIALIT maximum cohesion, which completes the information given by the plasticity range; and
- The ratio of the stress at 1000 percent with the stress at the flow threshold under elongation at 20°C and 500 mm/min, which is fairly similar to the information obtained under elongation at −10°C.

TABLE 2 STABILIZED FLUXED ASPHALT CEMENTS AND STABILIZED BINDERS OF MODIFIED-EMULSION ORIGIN: SCALE OF VALUES FOR EACH TRIAL

	0	1 +	2 ++	3 +++
Plasticity range (°C)	60	60 à 65	65 à 70	70
Maximum VIALIT cohesion (kg.m/cm²)	5	5 à 10	10 à 15	15
FRAASS (°C)	5	-5 à-10	-10 à-15	-15
Fracture lengthening at -10°C 10 mm/min (%)	10	10 à 100	100 à 1000	1000
Traffic simulator (+ 5°C) rejection after 5,000 cycles (%)	75	75 à 50	50 à 25	25

TABLE 3 STABILIZED FLUXED ASPHALT CEMENTS AND BINDERS OF MODIFIED-EMULSION ORIGIN: COMPARISON OF LABORATORY TESTS AND TREADWHEEL BEHAVIOR AT 5°C

Binder number	1 (1)	2	3	4	5	7 (1)	8	9	10	11	12
Plasticity range	+	+++	+	+-	+	0	0	+	--+	-	---
Maximum cohesion	+	+++	++	--+	++	+	+	++	---	+-	---
FRAASS	+++	+++	++	-++	+-	++	++	+	+-+	+++	---
Elongation at -10°C	0	+-	+	-+	++	+	+	0	---	+	---
Lab. average	+	++-	+	--	++	+	+	+	---	+-	---
Traffic simulator at 5°C	+	++	++	--	+-	0	+	+-	---	--	---

All of these characteristics measured on stabilized binders can be obtained for all binder types, whether they be fluxed or in emulsion. In the case of fluxed binders, certain characteristics measured on the as-they-are binders are also interesting indicators. It has been noticed that stabilized fluxed binder characteristics (VIALIT maximum cohesion and traction behavior) are related to the characteristics of as-they-are fluxed binders.

SUGGESTED METHODOLOGY FOR CHARACTERIZATION OF MODIFIED BINDERS

The methodology suggested here aims at specifying the degree of modification of a binder compared with a traditional binder, and does not claim to prejudge behavior under road traffic conditions of the surface dressing produced from such modified binders. The surface dressing's formulation parameters, such as viscosity adjustments and dosages to the medium, and traffic and climatic conditions have at least as much influence as the degree of modification of the binder.

Moreover, although the tests carried out in this study allow cold binder behavior to be reasonably well characterized, they are less satisfactory for hot binder behavior. In the absence of more satisfactory tests, a minimum ring-and-ball temperature is recommended to avoid the appearance of "soft binders" that might be induced by the proposed methodology. Table 4 gives the test evaluating degree of binder modification and suggests associated thresholds below which binders should not be considered modified.

CONCLUSION

The French administration has invested heavily in modified binder research for special road surface dressings during the past 15 years. This investment was first and foremost in research on procedures for dealing with the mechanisms that modify traditional binder properties when polymers are incorporated. Second, and this is the object of this paper, it was in characterization of industrial binders in cooperation with the manufacturers concerned.

The present study has attempted to find a way to completely characterize modified binders for surface dressings, and has led to

- Improvements in knowledge of the intrinsic characteristics of each binder through laboratory tests;
- The discovery that a close connection exists between characteristics of binders and their behavior on a circular traffic simulator;

TABLE 4 TESTS SELECTED AND THEIR ASSOCIATED THRESHOLDS

Characteristic	Threshold
As-They-Are Anhydrous Binders	
Plasticity range (°C)	≥ 50
Maximum cohesion (kg·m/cm^2)	≥ 12
Elongation at −10°C (100 mm/min)	
Fracture lengthening (%)	> 1000
Stress ratio at 1000% and at flow threshold	> 0.1
Stabilized Binders	
Plasticity range (°C)	≥ 60
Maximum VIALIT cohesion (kg·m/cm^2)	≥ 10
Elongation at 20°C (500 mm/min)	
Fracture lengthening (%)	> 1000
Stress ratio at 1000% and at flow threshold	> 0.1
Elongation at −10°C (10 mm/min)	
Fracture lengthening (%)	> 100
Ring-and-ball temperature (°C)	≥ 50

- A suggested characterization methodology using only the most useful tests: plasticity range, VIALIT pendulum ram cohesion, and direct elongation at different temperatures; and
- Suggested threshold limits for these characteristics below which the degree of modification of the properties compared with traditional binders can be considered too small.

This paper represents an important step forward in knowledge of modified binders but does not claim to resolve all of the problems; in the future more work should be done, particularly on

- The behavior of modified binders at high operating temperatures (a suitable laboratory test method should also be sought) and
- The relationship between laboratory- and treadwheel-determined characteristics and the behavior of binders under traffic.

APPENDIX: Brief Description of the Trials

Elongation

During an elongation test at constant speed (500, 100, 10, or 1 mm/min), the stress/lengthening variation is measured. The test bars are of the H2 type (Figure A-1) as defined by the French Standard NFT 5134 of December 1981. The initial length used in the calculations is the distance between the jaws, which equals 50 mm.

Test temperatures are −10°C and +20°C for stabilized binders. For fluxed binders only −10°C is usable because their consistency prevents tests at +20°C. For each temperature, the results are given for the maximum speed possible that does not lead to fracturing before the flow threshold is reached. For example, a result expressed at −10°C and 10 mm/min means that the binder is brittle at this temperature for the next higher traction speed of 100 mm/min.

Each result is presented as pairs of average values (stress and lengthening) measured at the flow threshold and at the fracture point and an average curve produced from at least five repetitions.

VIALIT Cohesion

The principle of the test (Figure A-2) is to measure the energy absorbed by the fracturing of a binder film under a given impact. The binder to be tested is used to stick a grooved-surface steel cube to a grooved-surface steel stand. The cube has two 1-mm shims that allow a binder plate to be made up that is 1 mm thick with a 1 cm^2 section.

The cube undergoes the shock of the pendulum ram, and the binder holding the cube breaks across its thickness. A graduated dial equipped with a nonreturn needle measures the maximum swing of the ram by steps.

This test is carried out twice: the first time, the cube is stuck to its stand by the binder; the second time, the cube is not stuck to the stand. A conversion table allows the energy for each angle to be calculated.

Cohesion is equal to the difference between the energy necessary to knock off the cube stuck on with the binder and that necessary to knock off the unstuck cube.

Tests were carried out at temperatures between −30°C and +60°C for each binder. The cohesiveness curves were then drawn relative to temperature.

VIALIT Adhesion

This test is based on the principle described in the preproject Overall Adhesion Test of a VIALIT Plate of March 1973. It consists of making surface dressing plates (VIALIT plates) by using traditional methods with dry aggregates and varying the temperature of the components when they are put into contact with the binder and aggregates (here, 5°C and 20°C). After compaction, each plate undergoes a series of shocks from the ball at decreasing temperatures (starting at 5°C and decreasing by steps of 5°C). The number of chippings re-

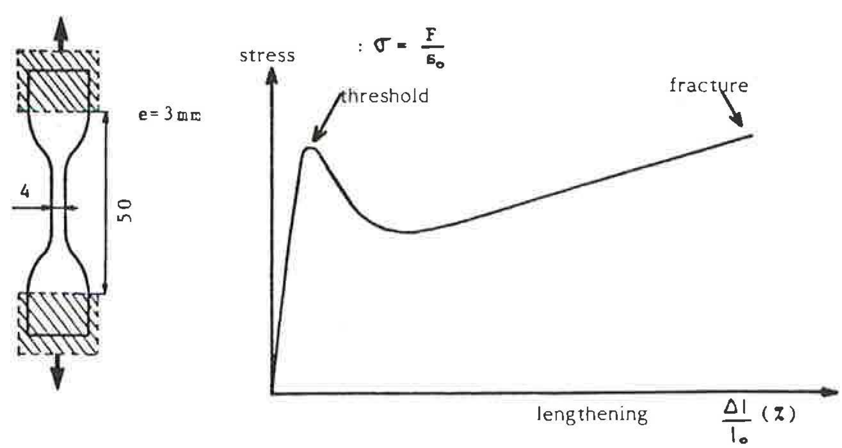

FIGURE A-1 H2 test bar and typical traction curve.

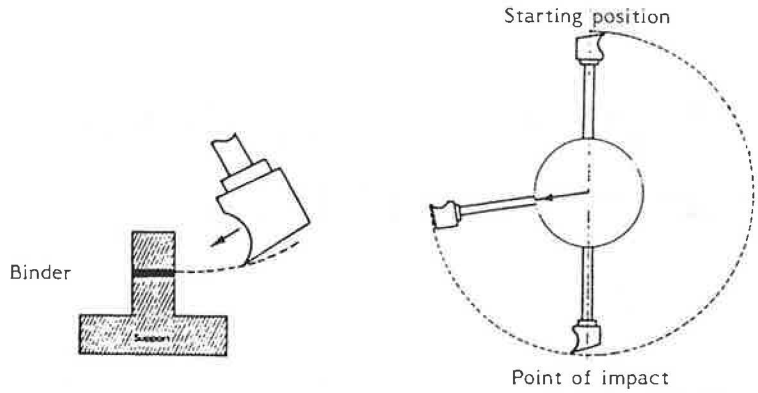

FIGURE A-2 VIALIT pendulum ram.

maining on the plate is noted after each series of three impacts, as is the temperature. The results are presented as a variation graph that shows the cumulative number of chippings remaining and the temperature.

Circular Traffic Simulator (by Total, France)

This test aims at an overall estimate of the qualities of a modified or unmodified binder for surface dressings by studying chippings' resistance to being torn off the test surface dressing at different temperatures under conditions similar to those of real life.

A loaded and constantly braking wheel turns on a test bar of surface dressing made using the binder to be studied. At each test temperature, the binder's holding power is estimated qualitatively by examining the test bar's appearance and quantitatively by measuring the chippings rejection rate.

The trial test bar consists of a 0/10 bituminous concrete support (40/50 bitumen, compaction level above 95, 6 cm thick) covered with a 6/10 single layer of surface dressing produced with the binder to be tested at a rate of 1.5 kg/m^2. The binder to be tested is heated to test temperature (in this case 5°C and 35°C). A probe placed on the binder to be tested gives the exact temperature of the surface dressing, and a second probe gives the inside temperature.

Test conditions for each temperature were as follows:

Parameter	*Value*
Wheel speed	12 km/hr
Load	300 kg
Tire pressure	2.5 × 105
Braking torque	3 m · daN

During the test, which lasts 5,000 cycles, rotation is interrupted at least four times (e.g., at 300, 600, 1000, and 2000 turns), and the torn-off chippings are vacuumed up and weighed. The results are given in graph form showing the rejection rate and the number (n) of revolutions of the treadwheel ($0 < n < 5000$).

Publication of this paper sponsored by Committee on Pavement Maintenance.

French Strategy for Preventive Road Maintenance: Why and How?

Gilbert Batac and Michel Ray

The French national road network, which is 28 000 km long, is subject to heavy traffic, sometimes under difficult climatic conditions. An ambitious policy for rehabilitating this network has been in effect since 1969, and since 1972 a preventive maintenance strategy has been applied. In this paper are described the reasons that led to that choice of strategy, and figures drawn from 15 years of experience are supplied. The preventive maintenance system includes a rigorous follow-up study of pavement behavior based on data obtained with powerful measuring devices. The Road Data Bank collects and processes the data, and information is made available in a technical guide to ensure coherent implementation of the selected strategy.

The preventive maintenance system used in France provides a very good service level, regardless of climatic conditions. It is important that the capital investment that this road network represents be protected by maintaining the network to meet users' requirements. The financial effort agreed to is small compared with the savings it produces—particularly in terms of vehicle operating costs and, to a certain extent, journey times. The documents used to prepare this paper can be made available to all persons interested in the subject.

WHY?

French Main Roads—A Dense and Busy Network

France has a network of 28 000 km of national roads across her 550 000 km^2 (212,300 mi^2). These roads accommodate an average of 7,800 vehicles per day of which 13 percent are heavy goods vehicles (HGVs); in this context an HGV is a vehicle with a payload of 5 tons or more.

Renovation and Preventive Maintenance Policy

In 1969 France began reconditioning the national road network at an average rate of 1000 km per year. From a technical point of view, this program (known as "coordinated reinforcing") consisted of putting down a road base and a wearing course.

So far 2.2 billion francs (about $350 million) has been spent on coordinated reinforcing, and about 6000 km remain to be treated.

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Beginning in 1972 (3 years after the start of the program), a preventive maintenance policy was adopted. This policy represents the second step, fully in stride with the first one, that consists of the complete renovation of the network to adapt its structure to both traffic and climate.

A volunteerist policy provided for ambitious new targets. Three closely linked objectives are associated with this preventive maintenance policy:

- To provide the country with a consistent traffic flow level, regardless of climatic conditions;
- To provide, at all times, a consistent and unchanging quality of service to users, bearing in mind users' ever growing safety and comfort requirements; and
- To adapt road structures to foreseeable traffic conditions.

Roads awaiting rehabilitation are subject to an upgrading maintenance policy the aim of which is simply to limit degradation while ensuring necessary repairs to maintain traffic flow.

It was not easy to get the preventive maintenance policy accepted as reasonable because maintenance of rehabilitated roads costs about twice as much as maintenance of the same roads before rehabilitation. Rehabilitation had adapted pavements to the new requirements, especially by making them frost resistant. The higher maintenance costs were therefore consistent with the objective of maintaining capital investment value and with the desire to avoid damage by severe winters or heavy vehicles. Preventive maintenance should prevent ever having to invest in a second rehabilitation program.

Those responsible for roads, as well as locally elected officers, who could have had the impression that money was being spent on roads in seemingly good condition and that nonrehabilitated roads were being left to deteriorate, had to be convinced. The basic principle of preventive maintenance implies spending money before the quality of pavements deteriorates seriously or irrevocably, and so the concept of carrying out work on apparently good pavements must be accepted. Moreover, in the early 1970s the temptation to divide funds and maintenance more "equitably" between rehabilitated and nonrehabilitated roads was great.

If the preventive maintenance policy finally prevailed it was because it was the logical extension of a credible combined rehabilitation policy; users of nonrehabilitated roads simply had to be patient, and, in any case, the Directorate of Roads aimed to complete reinforcement of the 28 000 km of national roads by the early 1980s. Despite the considerable time taken for combined rehabilitation, the target was maintained.

STRATEGIES

There is no single strategy for renovating and maintaining a road network. Various strategies can be imagined for upgrading and maintaining underdesigned or damaged pavements such as those in France in the late 1960s. The following four strategies have undergone detailed comparative studies.

Strategy 1: Localized Repairs Without Structural Strengthening

This strategy consists of allowing deterioration of the pavement to continue while searching, whenever possible, to avoid acceleration (punctual repair is carried out on deteriorations when they appear and surface dressing may be done for protection against water infiltration).

This is a strategy of submission, not direction. Most often it is the result of abusive budgetary restrictions, and it is no doubt an exaggeration to consider it a real strategy.

This strategy provides a low level of service; the evenness obtained is mediocre and ephemeral. It gives no improvement to the structure, and the probability of blocking traffic during a thaw is in no way reduced.

This strategy is rather restrictive for the manager because it requires uninterrupted surveillance of the network along with rapid, frequent, and nonprogrammable intervention because potholes or other deteriorations of similar nature must be repaired as soon as they appear.

A large work force and adapted equipment are required, and it is difficult to optimize all of these factors. In reality, this strategy should be applied only to a very secondary network with little traffic.

Strategy 2: Progressive Redressing

This strategy consists of applying relatively thick asphaltic concrete wearing courses (approximately 10 cm) at regular intervals (about 5 years in cases of average traffic) with bank supports and improvement of the drainage system if necessary.

Localized interventions might still be necessary in order to repair deteriorations that might follow a severe winter.

This strategy has several drawbacks:

- The laminated structure of the pavement prevents adequate behavior of the assembly;
- The structure remains underdesigned and therefore fragile; during a severe winter it may be necessary to restrict heavy-vehicle traffic during thaws; and
- Repeated interventions on traveled carriageways cause considerable nuisance for users.

This strategy leads to the exclusive use of asphaltic materials, and asphalt produced from petroleum is costly.

Nevertheless, there are some advantages:

- The initial investment is relatively moderate, which, at a given budgetary level, makes possible more rapid renewal of the network and good homogeneity;
- Except during severe winters, the level of service remains adequate; and
- The techniques used are highly flexible in both program and execution.

This type of strategy therefore appears to be well adapted for networks with moderate or average traffic in areas where the climate is generally not severe.

Strategy 3: Strengthening Followed by Preventive Maintenance

This strategy requires a large initial investment for a pavement design thickness that will provide a service life similar to that which is given to a new pavement vis-à-vis both traffic and frost. This is the strategy that has been applied to the national road network since 1969. It should be stressed that a quarter of this network carries more than 750 HGVs a day.

To maintain the capital investment, this strategy envisages follow-up structural strengthening so that the surface qualities (evenness, roughness, waterproofing) remain at a high level and that, at the same time, compensation is made for the accumulated fatigue of the road base.

Maintenance work is therefore mainly surface dressing or laying an asphalt wearing course of variable thickness. It is thus possible, if maintenance interventions are carried out in time, to give the pavement an almost infinite service life.

However, this strategy requires a very high initial investment, and it is illusory to envisage the general strengthening of an entire network within a short time; the manager is obliged to concentrate the investment effort on those parts of the network that are considered top priority, and consequently he must delay intervention on the remainder of the network (i.e., adopt Strategy 1, a strictly curative strategy, for the latter network).

Any continuous and excessive budgetary restrictions can undermine the overall credibility of such a strategy because they delay the renovation of a part of the network that is deteriorating acceleratingly.

Strategy 4: Strengthening Followed by Curative Maintenance

This strategy is a combination of Strategies 1 and 3. It consists of strengthening the existing pavement (as in Strategy 3) and then ensuring maintenance by patching and dressing (as in Strategy 1). When a break in the pavement occurs, new strengthening is required and the cycle is repeated.

The level of service, good at the beginning, deteriorates in time (this is contrary to the user's wishes); it remains superior,

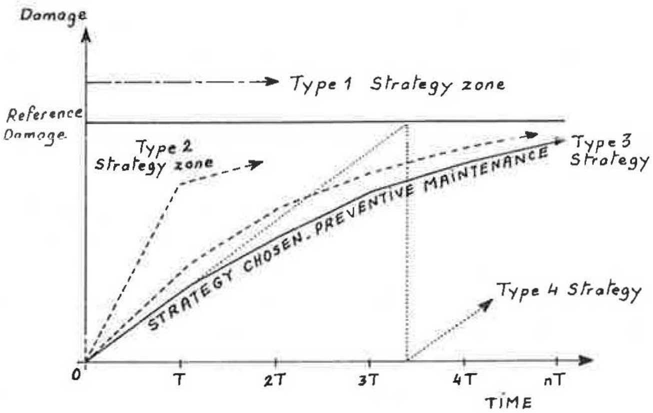

FIGURE 1 Fatigue damage by strategy.

however, to the level obtained with Strategy 1, particularly at the beginning of the cycle.

As is the case with Strategy 3, a very high initial investment is necessary. The present strategy is nevertheless still more sensitive to budgetary fluctuations because an extreme limit is awaited before strengthening action is taken.

Indeed, everything takes place as if a massive investment were made and the capital were left to progressively consume itself; it is then reconstituted as the end of the term.

Recapitulation and Conclusions

Figure 1 shows the evolution in time of fatigue damage sustained by a pavement. For this analysis, "pure" strategies are used; however, various combinations can be found in reality, particularly after a delay in the execution of certain maintenance operations.

The first horizontal line represents reference damage, that is, the accumulated damage sustained by the pavement at the end of its design life in the absence of all structural maintenance. Consequently, as long as the reference damage line has not been reached, fatigue breaking of the pavement should not occur.

The interval of time between two interventions (in the case of Strategies 2 and 3) is equal to T.

The relative position of the strategies studied can be described as follows:

- Strategy 1 is always found above the breaking threshold, which is to say that the capital of fatigue is consumed from the beginning.
- Strategy 3 is represented by a converging series (given an hypothesis of damage additivity), the curve of which is asymptotic at the reference damage line. This means that routine maintenance interventions (T, . . ., N T) confer a practically infinite service life on the pavement.
- Strategy 4 implies that new strengthening will be done as soon as damage reaches the reference damage line.
- The area situated between the Strategy 3 curve and the reference damage line is the domain of Strategy 2, which is qualified as "progressive" in opposition to Strategy 3; the design thickness, which is initially much thinner (resulting in a larger damage curve slope), must later be compensated for by heavier maintenance interventions if the break threshold is not to be exceeded.

France has selected, for its national roads, a rehabilitation strategy followed by preventive maintenance to provide all users with a high level of service everywhere and under all climatic conditions (this is essential). After this was decided upon, large investments were agreed to as well.

HOW?

Regardless of its organization, a system of road maintenance management must

- Gather all information on the condition of the pavement;
- Define the work requirements and their classification in priority order; and
- Provide the engineers with a wide range of well-adapted, well-known, and reliable techniques.

The first task that people in charge of maintenance must assume is to appraise the road sections under their charge. For this, they have at their disposal data, measured or observed, that they must interpret and examine to determine rules for action. Two approaches are possible: (a) development and use of an overall indicator and (b) "serviceability index" or a parameter-by-parameter analysis.

Analysis of Parameters

Since 1972 present serviceability index (PSI) methods have been found to lack the qualities required of an ideal system for selecting stretches of road to be maintained in priority order. A parameter-based approach allows the required selectivity to be attained and, at the same time, takes advantage of modern auscultation methods and leaves the way open to future progress. This approach consists of fixing warning and intervention thresholds for each parameter (bearing capacity, evenness, skid resistance, surface deterioration, etc.) based on foreseeable consequences such as safety and comfort of users and the structure itself (wearing course regularity, conservation of the structure, etc.).

Technical Guide to Preventive Maintenance

The *Technical Guide to Preventive Maintenance*, which was published in 1979 and is used today in all maintenance departments, is based on this concept. It should be noted that this guide has been in continuous use for nearly a decade by 1,300 subdivisions of a hundred or so public works district directorates. Even though true "pavement management systems" are now available in France and include the laws of deterioration evolution for pavements, the wide use and value of this guide should be stressed. It is the tool that allows coherent implementation of the chosen strategy.

This guide, designed for prime contractors, was written to answer three key questions:

- When and where should maintenance be done?
- What job is to be carried out?
- What is the degree of urgency of the proposed work?

The answers are not simple and the proposed approach, although constituting a remarkable advance in a domain that has been neglected and devalued, offers only provisional solutions, which are, however, precious to decision makers.

To define maintenance requirements, the guide retains three successive approaches, which are relatively independent of each other and cover the main maintenance objectives:

- Conserve and adapt the structure;
- Conserve general safety and comfort; and
- Conserve the intrinsic surficial qualities of the pavements.

For each of these objectives, the pavement condition is characterized by a series of quantified condition indicators: deflection, evenness, roughness, and apparent strains (the list of the indicators obviously differs with respect to the objective considered). These indicators are generally accompanied by two or three degrees of gravity in comparison with reference values.

If he knows the value of the condition indicators, and the various data on the structure or previous works as well as the road environment, the engineer in charge of maintenance can diagnose pavement conditions. In practice, he marks the sections that raise problems (this is the summary diagnosis) and then searches for the cause of the detected faults and attempts to predict their evolution (this is the detailed diagnosis). When the diagnosis has been made, homogeneous sections are defined from the point of view of their condition (identical indicators and degrees of gravity) under each of the three approaches mentioned previously.

Because of the intervention thresholds provided by the maintenance regulations, it is now possible to define elementary work sections. These thresholds constitute "quality standards" that link the quantitative condition indicators to the various possible maintenance jobs.

The final works program is obtained by making a synthesis of the defined elementary works. The works retained are then classified according to their priority by means of a system of notation that is based on the nature and gravity of the detected defects. In certain cases, a laboratory study is necessary to define the content of the works.

Table 1 gives the Technical Guide method for the "conserving the structure" objective in the case of untreated subbases. It gives warning and intervention threshold values and

TABLE 1 WARNING AND INTERVENTION THRESHOLDS

Condition Indicator	Parameter	Degree of Gravity	
		Level 2	Level 1
Deflection	Deflection to $\frac{1}{100}$ mm depending on traffic		
	T0	35–50	Values greater than Level 2 maximum
	T1	50–75	
	T2	75–100	
	T3	100–150	
Structural Deterioration			
Roadside defects (subsidence, ridges)	Percentage of pavement length affected	5%–10%	Values greater than Level 2 maximum
Depressions and potholes (appearing or filled)	No. per 200-m section	2–4	Values greater than Level 2 maximum
Large-scale rutting	Average depth	15–20 mm	
	Percentage of length rutted	> 30%	20 mm over more than 30% of length
Crazing	Percentage of surface crazed	2%–5%	Values greater than Level 2 maximum
Longitudinal cracks in wheelpaths	Percentage of length cracked	5%–10%	Values greater than Level 2 maximum
Roughness	Irregular roughness	Considerable reduction in value (2 points minimum) between two successive measurements may indicate structural deterioration	

TABLE 2 DEFINITION AND CLASSIFICATION OF WORKS BY PRIORITY (*Guide technique de l'entretien préventif*, SETRA-LCPC, 1979)

	Deflection		
Structural Deterioration	Level 1	Level 2	Less Than Level 2
Structural deterioration			
Level 1	Priority 1	Priority 1	Priority 2
Level 2	Priority 1	Priority 2	Surveillance[a]
Likely to become generalized	Priority 2	Surveillance[a]	
Absent	Backup study[b]	Surveillance[a]	

[a] Special surveillance of the section and detailed inspections and additional measurements if required. Local repairs if necessary.
[b] To define the types of works to be planned and their urgency.

definition of the required works based on these thresholds. Classification of works by priority is given in Table 2.

Traffic Group T1 is calculated from the mean daily traffic of HGVs on the most used lane of the road. T0 corresponds to between 750 and 2,000 HGVs per day. T1 corresponds to between 300 and 750 HGVs per day. T2 corresponds to between 150 and 300 HGVs per day. T3 corresponds to between 50 and 150 HGVs per day.

If, on a road with an untreated subbase that has 600 HGVs per day (T1), there is a deflection of 70/100 mm (Degree of Gravity 2) and crazing of 6 percent of the pavement (Level 1 deterioration), then the necessary maintenance works are of Priority 1.

Maintenance Management System

The maintenance management system throughout the national network is based on strict surveillance of pavement behavior and condition. This follow-up is carried out by highly efficient auscultation equipment that complements a systematic, well-classified visual examination:

- The Lacroix deflectograph, developed in France, measures the deflection under a wheel loaded at 6.5 tons and traveling at a speed of 4 km/hr (there is a measuring point every 3.7 m). A new version of the apparatus, called "long chassis," allows detection of small variations in deflections on semirigid pavements.
- A section length analyzer, developed in France, allows simultaneous measurement of evenness in the two tire tracks at a speed of 72 km/hr. It makes it possible to obtain a technical mark for evenness between 0 and 10 for each 200-m section of road and for three ranges of wavelength.
- The SCRIM, developed in Great Britain, measures the transverse friction coefficient (one value every 20 m) at a speed of 60 km/hr with the aid of a measuring wheel inclined at 20 degrees with respect to the traffic direction. Since 1986 the SCRIM has been equipped with a Rugolaser that measures sand height, which is representative of macrorugosity.
- The GERPHO, which is a continuous-stream camera mounted on a vehicle, makes it possible to film surface deterioration at a speed of 50 km/hr. The films are examined in a semiautomatic manner with the aid of a reading board. The GERPHO is especially useful on heavily trafficked roads, mainly freeways, visual inspections of which are dangerous for personnel. It is particularly adapted to close follow-up inspection of concrete slabs, where the same types of deterioration are found along the entire route. The GERPHO could in no case take the place of a visual inspection on foot, but it can be used as a support tool for detecting sections that must be examined in more detail.

From the beginning, continuous rutting measurements have been unnecessary because in France the quality of bituminous mixes is such that widespread deterioration of this type does not occur, in spite of some very hot summers and the 13-ton legal axle weight.

The *Guide technique de l'entretien préventif* (Technical Guide to Preventive Maintenance) specifies the average frequency of passage of measurement devices, and each year the Roads Department establishes a program for the main road network.

The year after a new or strengthened pavement is placed in service, what is called a "zero point" is determined by allowing all of the apparatus to pass over the pavement.

Thereafter, roughness is measured every 2 years and evenness and deflection every 4 years. The GERPHO is not yet programmed systematically (except by most of the freeway management firms). If required, more frequent measurements are carried out on certain sections in case of either difficult diagnosis or rapid evolution.

Apparent deterioration of and strains on the pavement wearing course are marked during detailed visual inspections at least once a year and, if possible, twice a year. Carried out entirely or partly on foot, these inspections are written up in a report in which figure the deteriorations and strains, quantified and localized on the ground.

This method of pavement condition follow-up is one of the fundamental axes of the technical guide; the guide also includes a catalogue of deteriorations with definitions and photographs that make it possible for all of the services to use a common language and to greatly reduce possible differences in notation used by the various teams. Specific training is desirable for the agents responsible for visual inspections.

Road Data Bank

The Road Data Bank can be defined as an assembly of data-processing files that are coherent among themselves (particularly in terms of the location and definition of information), accessible to numerous users, able to be modified with respect to the evolution of their needs, and continuously updated.

A catalogue of information has been produced that specifies definitions and data collecting and updating methods for each type of data used. Seven types of data have been listed:

1. Basic information about nomenclature and administrative classification;
2. Geometric characteristics such as horizontal alignment, longitudinal section, and width;
3. General road equipment and appurtenances;
4. Road pavement structures and works including course types and thicknesses, binder types, and grading;
5. Road pavement auscultation data (skid resistance, evenness, deflection);
6. Traffic; and
7. Accidents.

Two devices for collecting data automatically have been developed:

- The Cameroute takes photographs every 10 m at a speed of 50 km/hr. It allows longitudinal and transverse distances to be measured and qualitative data on traffic signing, trees, barriers, and the like to be collected. The results are compiled manually.
- The Gyros is a gyroscopic device that allows bend radii and slopes to be calculated.

The data on the pavement structures and works are transcribed manually in letters on appropriate slips, according to a simple and rapid procedure.

It is also necessary to emphasize that the results obtained by the high-output measurement devices are integrated into the roads data bank.

One of the main products of the data bank is the Pavement Itinerary Sketch (PIS), which has been specially designed for use with the *Technical Guide to Preventive Maintenance.* The synthesis PIS shown in Figure 2 is an example of results of measurement by high-output devices and visual inspections (for a road section 10 km long) as well as information on the structure (nature and thickness of the layers, dates of measurements etc.). The PIS is used in establishing a pavement status diagnosis according to the Technical Guide.

Preventive Maintenance Strategy

The secondary network in France is made up of 347 000 km of district roads that carry an average of 1,200 vehicles per day. This average, however, hides considerable fluctuations.

On larger district roads, the local authorities generally operate under a policy inspired by that of the national network. On district roads with less traffic, curative maintenance, often using surface dressings and patching, is presently used.

In all cases, however, the strategies are based on systematic surveillance of the network. There is also a clear preference for a preventive maintenance policy for heavily trafficked motorways. The procedures used on both the privately and state operated motorways have their roots more or less in the Technical Guide.

RESULTS OF PREVENTIVE MAINTENANCE POLICY

Preventive maintenance provides a consistent, long-lasting high level of service for users. Since 1980, the *Technical Guide to Preventive Maintenance* has been applied to the national road networks in all French districts. By setting up "quality standards" and maintenance rules, the Guide has led to long-lasting roads and a consistent, quantified, high level of service.

Because the principle of this policy is to not intervene systematically or periodically, but according to an evaluation of real needs, the funds devoted to the maintenance of the national network can vary appreciably from region to region for a given year, or from year to year for a given region. In 1987, for example, the funds allocated per kilometer varied from 24,300 francs (about $4,050) in the Mediterranean region to 41,100 francs (about $6,850) in the South West region (the Paris region is not in this range because its highly urban nature leads to higher costs). Generally speaking, roads for which maintenance costs are lower are either those that have recently been rehabilitated or those that were rehabilitated a long time ago and have already received a thick maintenance layer. From year to year in a given region, preventive maintenance funds (per road kilometer) can vary by a factor of two and even three.

This clearly shows that merely allocating maintenance funds according to the mileage of roads would not ensure a consistent level of service.

From 1981 to 1987 the network covered by preventive maintenance has grown from 17 000 to 22 000 km (including state-operated motorways). During the same period the percentage of surfaces on which preventive maintenance works have been carried out has developed as follows:

Year	*Percentage*
1981	6.5
1982	6.6
1983	6.8
1984	5.9
1985	6.8
1986	8.2
1987	9.3

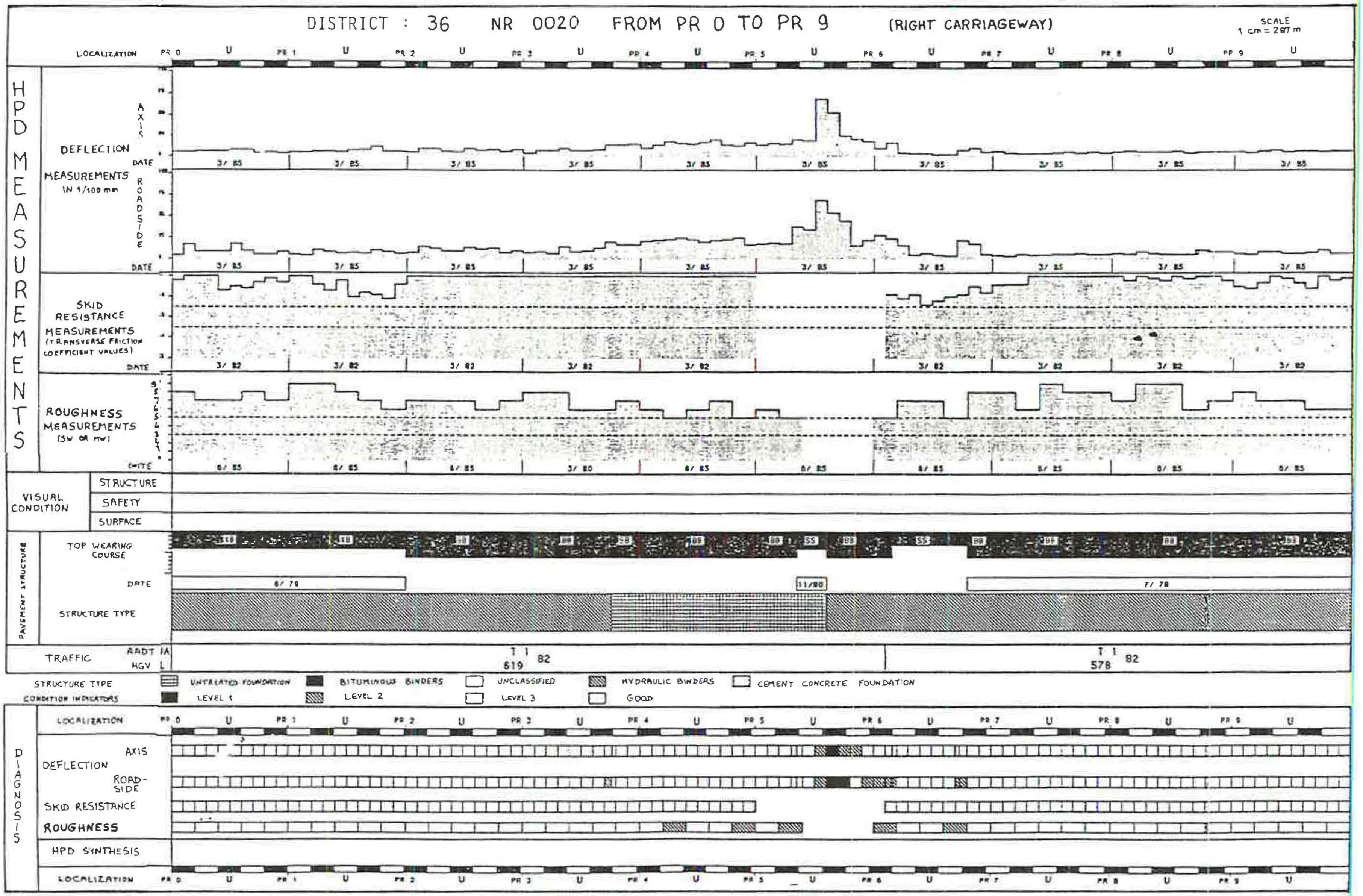

FIGURE 2 Example PIS; the diagnosis box contains a synthesis of comparisons with the Guide's threshold values.

This evolution was possible because the budget, which had gone up only slightly from 1982 to 1984, was considerably increased in 1986 and 1987.

This can also be explained by the evolution in the techniques used, more precisely by the use of techniques with a low cost–to–surface-treated ratio; more than 50 percent of the surfaces treated in 1987 were re-covered with a surface dressing or bituminous concrete less than 4 cm thick (compared with 33 percent in 1982). In 1987, 17 percent of surfaces treated received a layer of bituminous concrete more than 5 cm thick (compared with 33 percent in 1982).

Long-Term Funding

To be believable, a preventive maintenance policy requires adequate long-term funding. How the *Technical Guide to Preventive Maintenance* works and how it led to priority classification (Priority 1 or Priority 2) was described earlier. In practice, the overall demand volume for works, and consequently the necessary funding, can vary considerably upward, after hard winters, for example, or downward as a result of the use of "delaying" techniques such as surface dressings. Funding can also be modified by budgetary reallotments or limitations.

For these reasons funds devoted to preventive maintenance are not always sufficient; if the allocated funds are divided by the funds required to carry out the Priority 1 works [i.e., the most urgent ones (× 100)], it can be seen that this value has been 80 on average for 8 years (1980–1987), whereas a rate of 100 is usually considered normal. Fortunately, such budgetary limits do not cast doubt on the overall preventive maintenance policy; because the implemented strategy is relatively far from the reference damage (Figure 1), it is possible to accept a little delay in necessary maintenance. Vigilance should, however, be the watchword. Even small delays have repercussions in the future; if, for example, necessary structural work is put off for 2 years the thickness of the later works will have to be increased by 50 percent. In the worst cases, too long a delay means that there will have to be a radical change of strategy from rehabilitation to simple maintenance.

One major difficulty of a preventive maintenance policy is that users, and so also public powers, have difficulty realizing what is at stake because pavements always appear to be in good condition.

Progressive Construction

In some cases a policy of progressive construction can be better than preventive maintenance. Three real-life cases will be used to illustrate the advantages and disadvantages of these two kinds of strategy—the "Progressive Construction" strategy and the "Structure Catalogue" (French reference document for design of new pavements on national roads) strategy. Economic results will be given for both overall construction and maintenance, and comparisons will be made for 10- and 25-year periods. This case study is taken from the conference on La Route et l'Energie that was held in Paris in 1981.

Strategy 1: Progressive Construction

The progressive construction case is based on an actual case that is analyzed from various points of view including traffic, structure, materials, and maintenance carried out. A plausible scenario can thus be extrapolated over the first 25 years: The initial works are those that have actually been carried out, and the following ones are the result of a calculation based on average hypotheses drawn from available information. Works that will really be carried out in the future could be different depending on unknown factors (quality of materials and implementation quality).

Strategy 2: Structure Catalogue

This strategy is of the Catalogue type with slag-treated gravel base and subgrade. Average maintenance sequences were defined to take into account the increased traffic rates that differ noticeably from those defined in the Catalogue.

Costs, expressed as relative values, are actualized costs under 1981 economic conditions. Thicknesses are expressed in centimeters.

Example 1 This example, selected from the national network, corresponds to a flexible structure made of untreated gravel on medium-quality subgrade. When this road was opened in 1966, traffic was very light (60 HGVs/day), but it grew at an annual geometric rate of 12 percent. The structure had to be rehabilitated (Table 3).

The progressive strategy requires rehabilitation after 14 years and is the most cost-effective; it makes it possible to save 18 percent over 10 years and 10 percent over 25 years compared with the Catalogue strategy.

Example 2 This example is of a motorway that had a light bituminous coating on an exceptionally good base of natural, clean, very thick, well-graded aggregate.

Traffic was always heavy (300 HGVs at the opening in 1965) and had a high growth rate (14 percent geometric per year). In calculating future growth, a lower rate was used to take into account transfer of traffic to the adjoining lane. These circumstances of exceptionally good base plus high traffic flow growth very much favor progressive work (Table 4).

The progressive strategy produces a saving of 21 percent over 10 years and 19 percent over 25 years compared with the Catalogue strategy.

Example 3 This example was also chosen on a motorway that had a bituminous treated gravel structure. General features here were less favorable to progressive working because the soil was only mediocre, although the traffic growth rate

TABLE 3 EXAMPLE 1

	Strategy 2 (carried out)	Strategy 3 (Catalogue) using slag treated gravel
Construction	40 NTG + 9 BC	38 SG + 6 BC
Maintenance	5 BC at 5 years *	5 BC at 5 years
	4 BC at 9 years *	4.8 BC at 14 years
	8 BC + 12 BG at 14 years *	5.6 BC at 21 years
	4.8 BC at 22 years	5.6 BC at 28 years
	5.6 BC at 30 years	

* these interventions were actually carried out.
BC = Bituminous concrete ; SG = Slag treated gravel ; BG = Bituminous treated gravel ; NTG = Non treated gravel.

Analysis after 10 years

	Strategy 2	Strategy 3
Construction cost	0.74	1.1
Updated construction + maintenance cost	1.0	1.22

Analysis after 25 years

	Strategy 2	Strategy 3
Construction cost	0.64	0.95
Updated construction + maintenance cost	1.0	1.11

was less than in the other cases (9 percent). At the opening in late 1972 there were about 220 HGVs per day (Table 5).

The traffic flow growth rate is less than in the other cases, although it is higher than the average for national roads.

The progressive strategy makes possible savings of 8 percent over 10 years and 4 percent over 25 years compared with the Catalogue strategy.

Conclusions Drawn from Examples

It can be seen from this synthetic study that the advantages of a progressive construction method compared with a Catalogue strategy take on even more importance when

- The subsoil has good carrying qualities,
- Initial traffic flow is low,
- HGV traffic growth is high,
- The updating rate is high, and
- Bituminous mixtures are inexpensive.

However, a progressive strategy has two disadvantages:

- More materials, and therefore more energy, are used in the long term. This high energy consumption is further increased by the use of techniques that require bitumen.
- Delays in applying scheduled maintenance courses are less well tolerated.

Moreover, in all cases, progressive construction of structures implies frost damage checking, and some French regions are subject to such deep frosts that the progressive method is ruled out. Thus it can be said that the rigorous climate of many French regions and main-road traffic characteristics (high initial level followed by relatively slow growth) discourage the choice of a progressive strategy. On the basis of all of the elements described, the strengthening (or Catalogue) strategy with preventive maintenance was chosen as the most suitable for France.

Frost Protection

The immediate and lasting frost protection given by a rehabilitation strategy followed by preventive maintenance leads to considerable economic savings.

One of the main advantages of the strategy applied to the French national network is that it has enabled pavements to resist extreme climatic conditions, in particular freeze-thaw cycles, without damage.

Combined rehabilitations were described earlier, and it was mentioned that around 6000 km remain to be treated. This means that HGV traffic has to be limited over part of these roads under thaw conditions.

The extreme conditions of the winter of 1984–1985 underscored this Achilles' heel. Weight limits during the thaw had to be imposed for 2 or 3 weeks on national roads that

TABLE 4 EXAMPLE 2

	Strategy 2 (carried out)	Strategy 3 (Catalogue) using slag treated gravel
Construction	20 BC	38 SG + 8 BC
Maintenance	5 BC at 4 years * 4 BC at 15 years * 12 BC at 21 years * 4 BC at 29 years	4.8 BC at 8 years then, 5.6 BC each year

* these interventions were actually carried out.
BC = Bituminous concrete ; SG = Slag treated gravel ; BG = Bituminous treated gravel.

Analysis after 10 years

	Strategy 2	Strategy 3
Construction cost	0.83	1.16
Updated construction + maintenance cost	1.0	1.27

Analysis after 25 years

	Strategy 2	Strategy 3
Construction cost	0.77	1.06
Updated construction + maintenance cost	1.0	1.23

had not yet been rehabilitated, as well as on the majority of secondary roads. Losses due to reduced turnover and increased costs resulting from reorganized journeys, production, and sales have been estimated at 30 billion francs (around $5 billion).

These losses and additional costs were not incurred only on national roads; secondary roads also play a vital role in end-of-trip deliveries. Nor were these losses a complete write-off for the country. Many of those responsible for road management have no doubt compared this figure with the 2 billion or so francs ($330 million) devoted annually to renovation and preventive maintenance of the national main road network and noted the difference of scale.

The winter of 1984–1985 also demonstrated very clearly the excellent reaction to continuous heavy traffic of the 20 000 km of roads that had received preventive maintenance. It is likely that waterproof qualities of pavements, partially resulting from preventive maintenance, played an important role.

High Levels of Service

High levels of service result in considerable savings by reducing users' costs. The strategy of rehabilitation followed by preventive maintenance also leads to reduced costs for road users, the first of which are the operating costs of vehicles that are especially sensitive to pavement roughness.

In spite of the importance of cost variations that depend on pavement qualities, no precisely quantified figures are available in France. A simple simulation carried out with the World Bank Highway Design and Maintenance Standards (HDM) model nevertheless gives an idea of the scale involved. This simulation estimates the difference between operating costs on a good, even surface and a bad surface at 0.1 franc (or $0.017) per vehicle kilometer. The two evenness values were chosen in the French context and are representative of a newly rehabilitated pavement, or one maintained by preventive maintenance techniques, and a nonrehabilitated pavement subject to curative maintenance.

This difference in operating costs does not tell the whole tale, but extrapolating over the entire national road network of 28 000 km, given traffic flow of 7,800 vehicles daily, gives a yearly total of 8 billion francs ($1.333 billion).

This result should be considered only an indication, but it is likely that savings resulting from reduced vehicle operating costs are approximately 5 times greater than the investment difference between a policy of renovation followed by preventive maintenance and one of curative maintenance.

This review should be completed by adding the time gained

TABLE 5 EXAMPLE 3

	Strategy 2 (carried out)	Strategy 3 (Catalogue) using slag treated gravel
Construction	27 BG + 6 BC	47 SG + 8 BC
Maintenance	7.8 BC every 8 years	4.8 BC at 8 and 16 years 5.6 BC at 24 and 32 years

BC = Bituminous concrete ; SG = Slag treated gravel ; BG = Bituminous treated gravel.

Analysis after 10 years

	Strategy 2	Strategy 3
Construction cost	0.85	1.0
Updated construction + maintenance cost	1.0	1.09

Analysis after 25 years

	Strategy 2	Strategy 3
Construction cost	0.79	.92
Updated construction + maintenance cost	1.0	1.04

by users. It appears that the level of service provided by preventive maintenance with strengthening is around a significant 10 percent higher than that provided by curative treatment without strengthening, with more or less the same safety levels.

Structural Behavior

Structural behavior results contribute to the evaluation of the French preventive maintenance strategy. These results, established in 1985, were based on statistical analysis of the maintenance carried out since about 1972 and were presented to the 65th Annual Meeting of the Transportation Research Board in 1986.

More than half the preventive maintenance network, in other words 11 000 km of main road network sections, was studied. Three-quarters of these roads were rehabilitated, and the other quarter was new roads.

The main maintenance lessons learned from this study are discussed in the following subsections.

First Maintenance

For all structural types, the first preventive maintenance intervention takes place on average 9 years after the road is opened. The average time is 9 to 10 years for rehabilitated roads and 8 to 9 years for new roads.

These average figures hide considerable variations:

- No maintenance has been carried out on about 5 percent of 16-year-old roads.
- Some sections require early maintenance or two successive interventions. Between 2.5 and 3 percent of stretches are maintained after 3 years or have two interventions in 10 years. These types of problems are studied, and the results are used to modify future design and construction.

The nature and cost of maintenance works vary. The following cost scale has been drawn up for five types of jobs:

Index	*Job*
1	Surface dressing
2.5	3- or 4-cm bituminous concrete
5	5- to 8-cm bituminous concrete
7	9- to 14-cm bituminous concrete
10	Structural rehabilitation (base and wearing courses)

By applying these indices to the percentages of length on which the various types of tasks have been done, it is possible to obtain an average weighted cost index (AWCI) for the maintenance of each structure.

The value of this weighted index is 3.8 for all structures combined, from 4 to 5 for new roads, and from 3 to 4 for rehabilitated roads. Thanks to the *Technical Guide to Preventive Maintenance*, which gives well-calculated service levels, maintenance decisions are triggered at the right time. This allows relative judgments to be established for various pavements (flexible, semirigid, etc.).

The more HGV traffic there is, the more involved is maintenance, but the analysis shows a ratio factor between these two criteria.

Second Maintenance

Structural behavior results are continuously studied; during the past few years new data, particularly on the second maintenance intervention, have been collected. Figure 3 shows, for all structures, according to their age, the percentage of road stretches that have received first maintenance (solid line) and the percentage of stretches that have received second maintenance (broken line).

At present only the beginning of second maintenance (less than 10 percent of the total length) can be observed between 6 and 12 years. Although this graph's slope variation is less than that of first maintenance, this tendency is still to be confirmed.

In the short term the objective of the permanent monitoring of structural behavior is to contribute to practical preventive maintenance evaluation.

WORK IN PROGRESS

Quantified Service Level Follow-Up

Among the objectives of the preventive maintenance policy practiced on the French national road network is that of

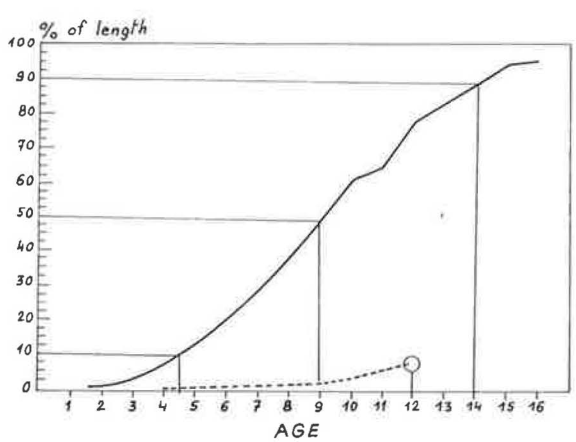

FIGURE 3 Percentage of road stretches that have received first maintenance (solid line) and second maintenance (broken line).

maintaining a high level of service to the user. This is why a synthetic system was set up to follow up on level of service. Two priority indicators were selected—one related to journey time and the other to pavement condition.

Journey Time Indicator

A method of measuring journey times over a network divided into sections was set up and a working method devised for the measuring teams. Data collection started in 1987.

Pavement Condition Indicator

This is an indicator of both usage wear quality and asset quality. Unlike the journey time indicator, which requires measurements taken on many network sections, it is based on a sample. Sampling methods are currently being set up, and data collection and processing have already started. This indicator should be operational in 1988.

Benefits Derived from Experimental Data

In a country in which all rehabilitated national roads are maintained preventively it is difficult to find an adequate statistical basis for reckoning what a curative maintenance system would cost, but the choice of maintenance policy is directly influenced by the rate of degradation near the end of a structure's life.

Experimental data dictated the fundamental choice of a preventive maintenance policy in the late 1960s and the choices of quantified thresholds in the *Technical Guide to Preventive Maintenance* in 1979. First, a limited number of data were examined closely because there were not many sections that had both suitable structures and a sufficiently long maintenance period for observation.

Initial approximate estimates of pavement degradation evolution laws proved to be reasonably, and sometimes very, accurate. Since that time,

- The Laboratoire Central des Ponts et Chaussées has used a fatigue treadmill to calculate degradation evolution toward the end of the life of roads. The results appear to confirm the first choices, especially for semirigid structures the total fatigue potential of which is used up by dense heavy-vehicle traffic that causes rapid deterioration.
- A few isolated roads that had not received preventive maintenance in time required more costly maintenance or even rehabilitation at a cost considerably higher than that of the preventive alternative.

These considerations, along with a variety of other factors such as the desire of users to have a long-term high service level, have tended to confirm the French engineers and decision makers in their choice of preventive maintenance, which is especially important when the roads in question are subject to heavy traffic.

Recent World Bank analytical documents, although not applicable in the same context, contain solid economic analyses that indicate that delaying road maintenance for too long causes loss of invested capital and increased users costs.

The exchange between countries of information on experimental laws of pavement deterioration evolution, with or without preventive maintenance, is a key factor in determining maintenance policies.

CONCLUSIONS

Having undertaken the renovation of her national roads, France implemented a strategy of preventive maintenance for the network in 1972. This program is today applied to 21 000 km of roads.

Given the density of HGV traffic and the sometimes very severe winters, this strategy is the most effective if a high, consistent level of service is to be ensured both in time and in space.

Control of the preventive maintenance program depends on strict follow-up evaluations of pavement condition, a computerized data bank, and the *Technical Guide to Preventive Maintenance* that allows priorities to be determined.

A preventive maintenance program offers relative flexibility, but takes time and requires long-term funding.

Rehabilitation and preventive maintenance provide frost protection and so produce considerable savings. The vulnerability of the secondary network and a small part of the main network led to turnover losses and additional costs estimated at more than 30 billion francs ($5 billion) in the exceptionally hard winter of 1984–1985.

The average preventive maintenance cost for French national roads is around 36,000 francs per kilometer per year (about $9,600/mi per year). This figure should be compared with the savings of about 300,000 francs per km ($80,000/mi), for the average French traffic volume of 7,800 vehicles per day, attributable to the difference between vehicle operating costs on national roads subject to preventive maintenance and secondary roads under curative maintenance.

The French preventive maintenance program has, for 15 years, represented an important means of developing innovations and contributing to road maintenance techniques.

Statistical analysis of preventive maintenance works over 13 years and 11 000 km has highlighted the good condition of the main road network, thus showing how adequate were the decisions made for the special problems of the country.

The French preventive maintenance policy should be followed in the future with the same determination as in the past. Present results are favorable but provisional and will be enriched by results from studies (such as permanent structure behavior figures) now taking place and the setting up of a service level follow-up system.

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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.

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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.

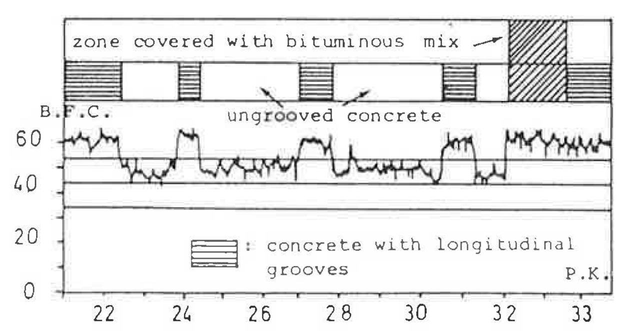


FIGURE 1 Coefficient of transverse friction measured by SCRIM.

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.

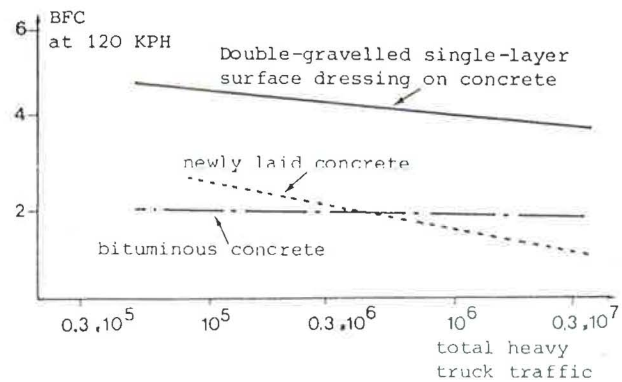


FIGURE 2 Braking force coefficient versus total heavy-truck traffic.

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.

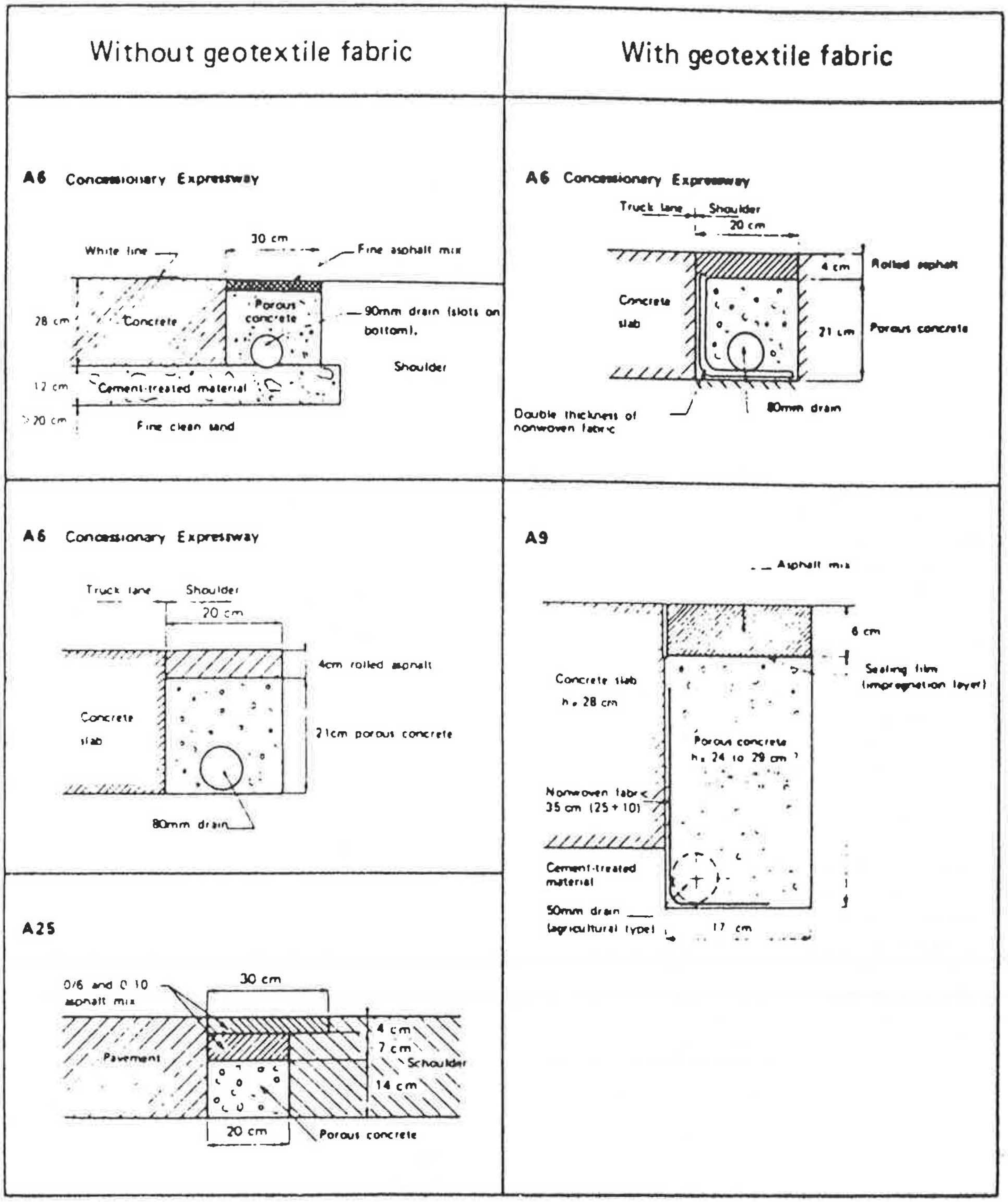


FIGURE 3 Solutions to water trap on old pavements: shallow pervious trenches with and without geotextile (A6, A25, and A9 expressways in France).

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

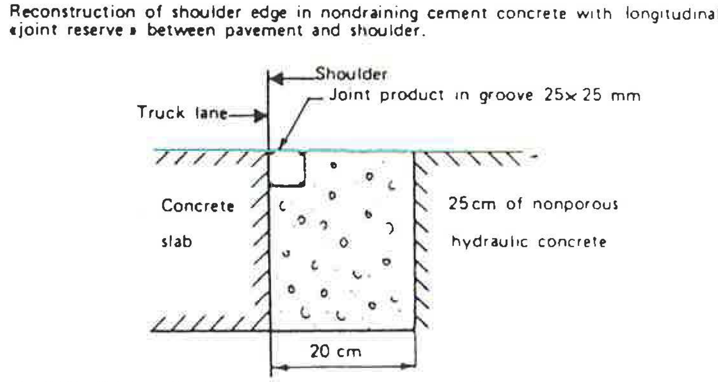


FIGURE 4 Shallow impervious trench (A6 expressway in France).

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).

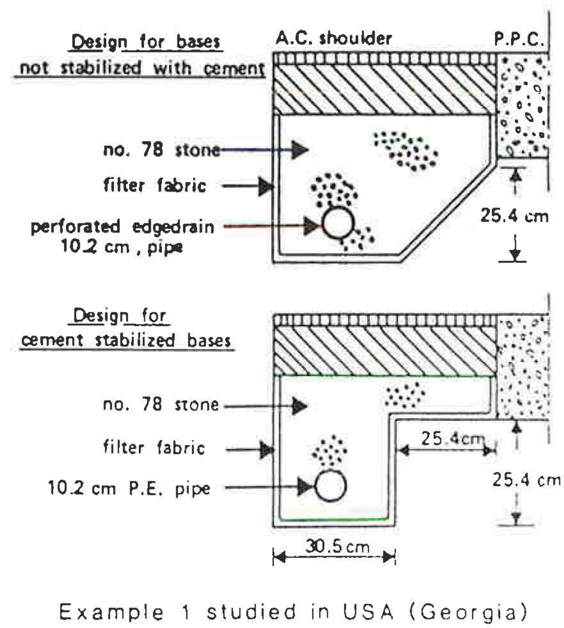
This ties in with notions about filter materials and stability criteria with respect to environments (soils to be drained and orifices receiving drainage pipes).

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.



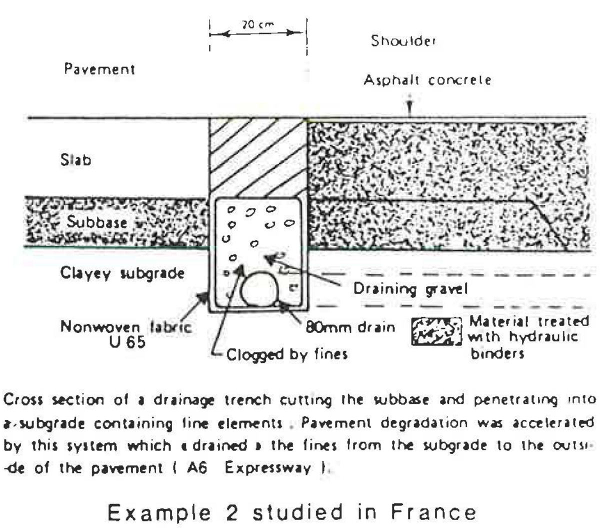


FIGURE 5 Dangerous drainage structures on old pavements: deep drain cutting the subbase.

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.

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.

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.

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

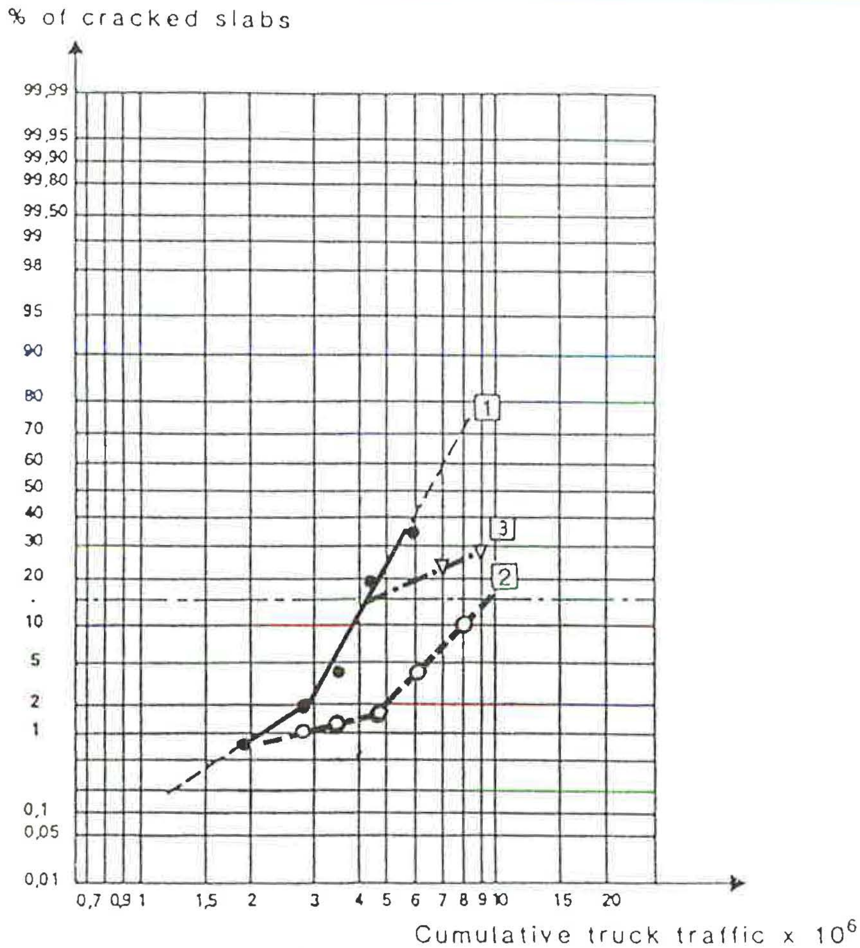


FIGURE 6 Curves of slab cracking as a function of cumulative truck traffic.

- 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

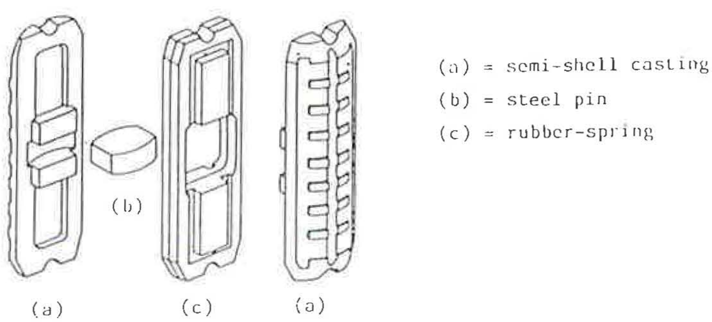


FIGURE 7 Exploded view of connector.

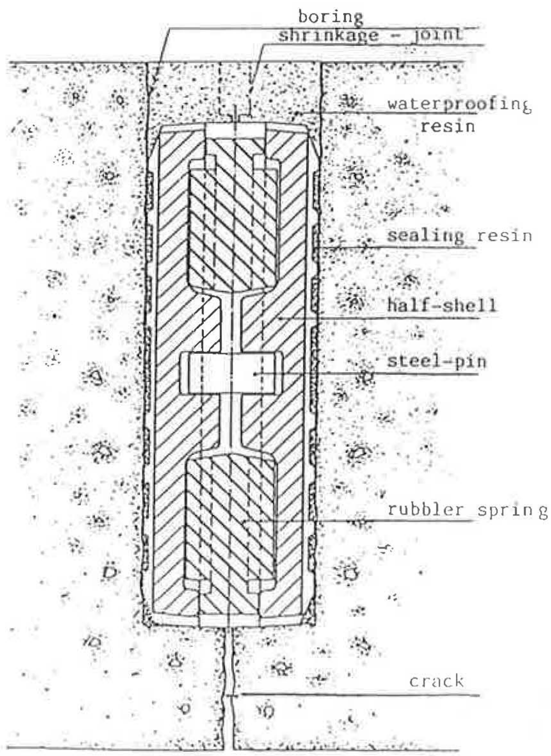


FIGURE 8 Cross section of connector.

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

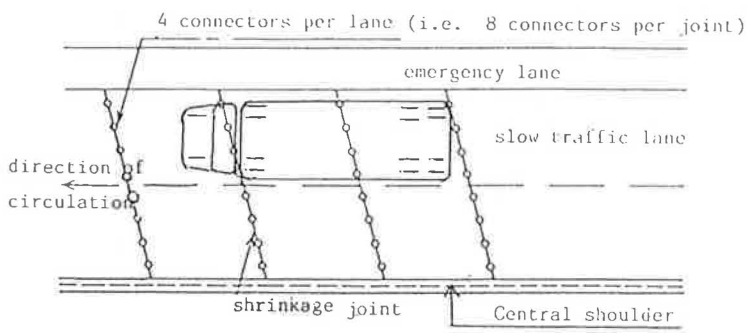
RESULTS OF TESTS ON CONNECTORS

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.



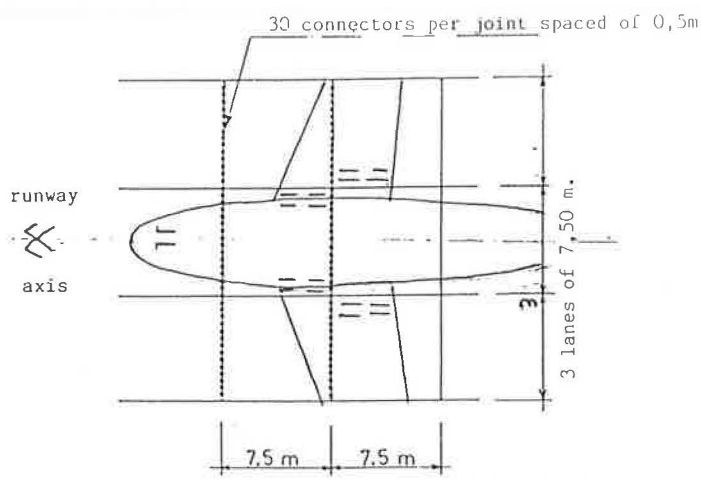


FIGURE 9 Principle of connector implementation for two-lane highway (top) and airport runway (bottom).

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

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

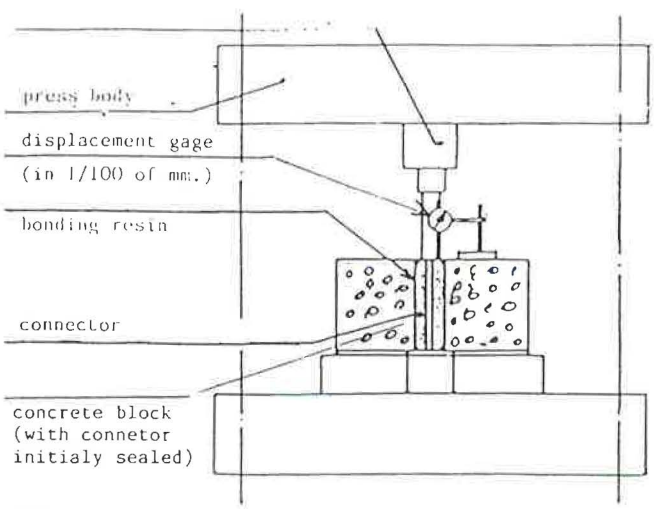


FIGURE 10 Fatigue test of connector bonding.

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.

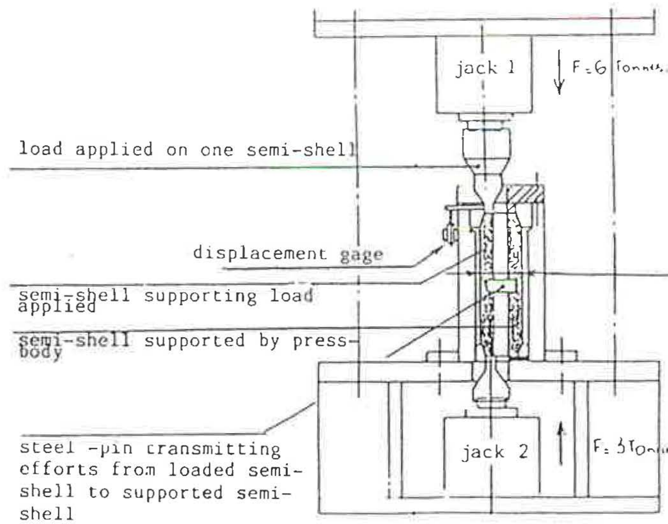


FIGURE 11 Fatigue test of connector with alternate loads.

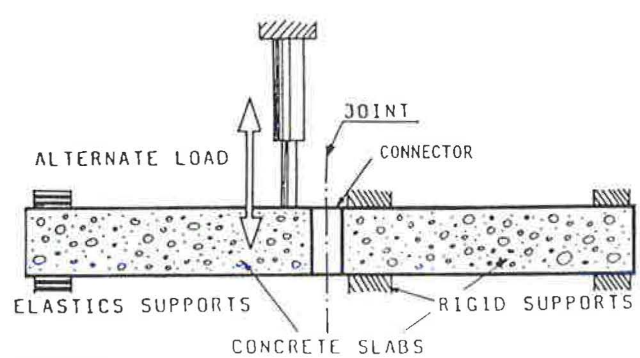


FIGURE 12 Dynamic fatigue test of connector.

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.

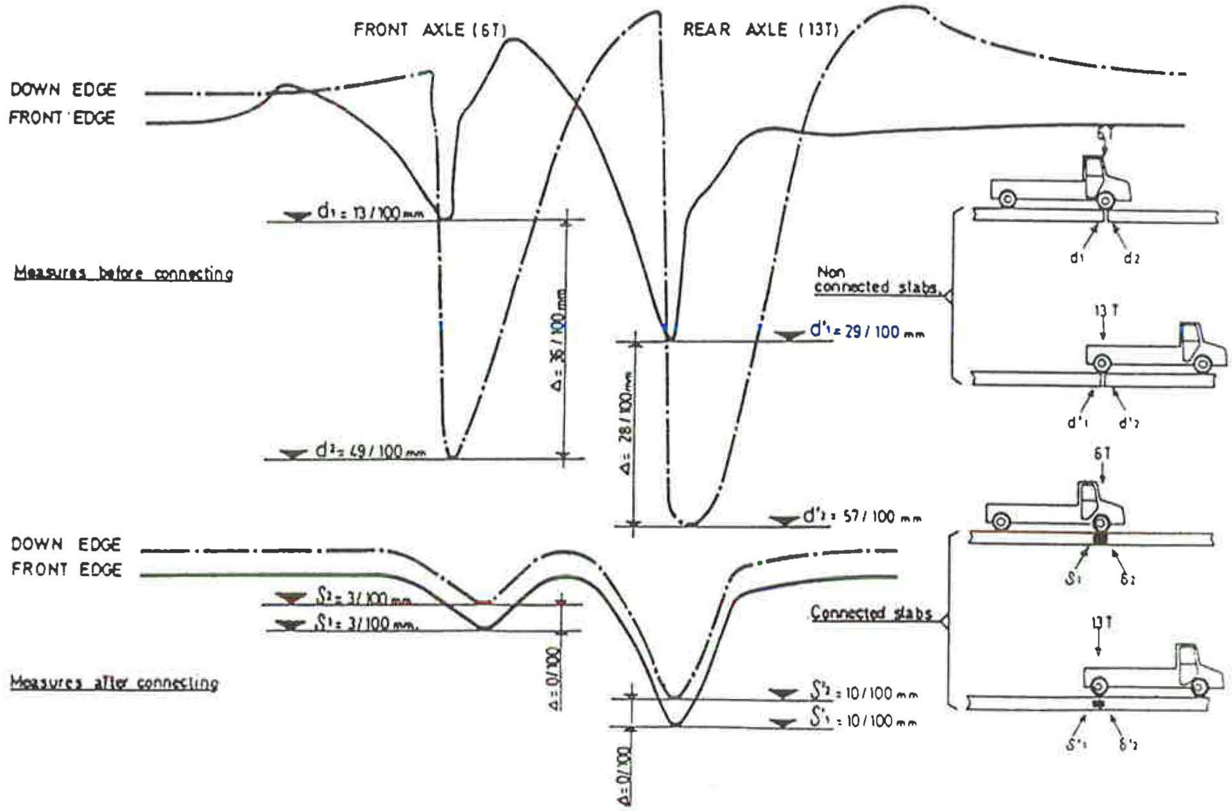


FIGURE 13 Typical diagram of behavior of adjacent slab edges before and after connecting (horizontal axes of references have been shifted for clarity).

- 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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Restoration of Joint Load Transfer

MICHAEL J. REITER, MICHAEL I. DARTER, AND SAMUEL H. CARPENTER

Load transfer at joints and cracks in concrete pavements greatly affects faulting, cracking, and spalling. The restoration of load transfer has been attempted recently by several highway agencies. The results of field performance studies of 369 restored joints and cracks located in 9 states are presented. Four retrofit load transfer devices were evaluated: round steel dowels, double-vee shear devices (without precompression or grooving), figure-eight devices, and minature I-beam devices. Extensive field and office data were collected and analyzed. Models were developed to predict the relative performance of the devices. Results indicate that the round steel dowel bar did the best job of reducing faulting, and it showed no device or matrix failure. Additional research is under way to provide improved performance data. A recommended retrofit dowel design for joints and cracks is provided.

Many jointed concrete pavements have been constructed with no mechanical load transfer devices across joints (e.g., no dowels), and significant faulting has occurred on some of these pavements. Many others have dowels, but they have become loose and faulting has developed. In addition, many transverse cracks have become working cracks and developed faulting and spalling due to poor load transfer.

In an effort to extend the life of in-service concrete pavements that exhibit poor load transfer, highway agencies have begun to use various devices to restore joint or crack load transfer to an acceptable level to prevent further faulting and spalling and reduce deflections and pumping. Even if asphalt concrete overlays are placed, poor load transfer leads to rapid deterioration of transverse joint reflection cracks.

This study deals with the field performance of four load transfer restoration devices. The effectiveness of these devices has been evaluated in terms of the amount of faulting associated with the rehabilitated joints and cracks, and failure of the device or bonding matrix.

The overall goal of this study is to improve the design and construction of load transfer restoration devices. Four load transfer devices are evaluated:

- Retrofit conventional round steel dowels placed in slots (*1, 2*);
- Double-vee shear devices marketed by Dayton Superior Corporation (*1, 2*);
- Figure-eight devices, used in a Georgia project, that were originally experimented with in France (*3*); and
- Miniature I-beam devices used in New York (*4*).

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DATA BASE AND DATA COLLECTION

The load transfer restoration data base incorporates design, construction, and performance variables for 13 uniform sections. These variables are in addition to the original pavement design, traffic, and climatic variables summarized by Reiter et al. (*5*). Figure 1 shows these load transfer restoration variables. In addition to monitoring the performance of the device itself, some measure of joint and sealant distress was also recorded. Also, faulting measurements were taken at 369 restored joints or cracks, and device performance ratings were taken on 1,525 individual devices.

General Description of Project

Thirteen uniform sections were located in nine states: Colorado, Georgia, Illinois, Louisiana, New York, Ohio, Oklahoma, Pennsylvania, and Virginia. These uniform sections were broken into 20 sample units that were up to 1,000 ft (305 m) long, where possible (Figure 2).

Load Transfer Restoration Design Variation

Load transfer restoration devices were placed and evaluated at five different locations in the pavement:

- Regular contraction joints at 15- to 100-ft (4.6- to 30.5-m) joint spacings (predominant location),
- Full-depth repair approach joints,
- Full-depth repair leave joints,
- Pressure relief joints, and
- Transverse cracks.

The devices were mainly placed in the outer traffic lane; however, some were installed in the inner traffic lane as well. From one to eight devices were installed at any given joint or crack. The restoration projects had been in service from 1 to 9 years at the time of the survey.

Traffic and Climatic Variation

The devices have withstood from 0.3 million to 5.9 million 18-kip (80-kN) equivalent single axle loads (ESALs) while in service. Annual loadings ranged from 0.3 million to 2.0 million ESALs. The projects were located in several climatic regions as shown in Figure 3 (*6*).

LOAD TRANSFER RESTORATION

DATABASE DESIGN VARIABLES

- Project Identification Number and Sample Unit.
- Load Transfer Device Type.
- Frequency of Installation.
- Lane Restored by Load Transfer.
- Number and Location of Devices along Joint/Crack.
- Diameter and Length of Retrofit Dowel Bars.
- Backfill Material and Bonding Agent for Slot or Core Hole.

DATABASE PERFORMANCE VARIABLES

Overall Distress
- Project Identification Number.
- Sample Unit Number, Length, and Present Serviceability Rating.
- Foundation of Sample Unit (cut,fill,at grade).
- Condition of Drainage Ditches and Subsurface Drainage.
- Joint/Crack Station.
- Transverse Joint Type or Crack.
- Load Transfer Device Type.
- Lane Restored by Load Transfer.
- Number of Devices along Joint/Crack.
- Device Performance:
    - no failure.
    - material failure.
    - device failure.
    - debonding on approach side.
    - debonding on leave side.
    - debonding on both sides.

Joint Distress
- Transverse Joint Spalling on Approach and/or Leave Side.
- Corner Spalling on Approach and/or Leave Side.
- Corner Breaks on Approach and/or Leave Side.
- Pumping.
- Joint/Crack Faulting.
- Joint/Crack Width.
- Durability Cracking.
- Reactive Aggregate.

Sealant Condition
- Sealant Absent.
- Cohesion Failure.
- Adhesion Failure.
- Sealant Extrusion.
- Sealant Oxidation.
- Incompressibles in Joint.

FIGURE 1 Load transfer restoration data base design variables.

Performance Variation

Faulting measurements ranged from flat to 0.36 in. (0.91 cm), and the majority of the joints had less than 0.07 in. (0.18 cm) of faulting at the time of the survey. All of the projects that involved load transfer restoration had been diamond ground the same year. At any joint, anywhere from zero to eight devices were in good condition (i.e., showed no visible signs of failure) at the time of the survey.

DATA COLLECTION

The data base is comprehensive; it contains as many projects as were available or could be included with available resources. This was done to provide a wide range of data to facilitate analysis of performance and development of performance models. The projects included in the data base are believed to be most of the highway pavements that have undergone load transfer restoration in the United States. These pavements were surveyed between June 1985 and July 1986.

There were five basic data sets that were deemed necessary for the development of life prediction models and for analysis to aid in the development and improvement of design and construction procedures:

- Field condition data;
- Original pavement structural design and construction and subgrade soil classification;
- Rehabilitation design factors;

FIGURE 2 Location of load transfer restoration sample units by state.

PRECIPITATION

TEMPERATURE	WET	WET -DRY	DRY
FREEZE	5	0	1
FREEZE -THAW	2	2	0
NO FREEZE	3	0	0
TOTAL	10	2	1

NOTE: A total of 13 uniform sections were evaluated through condition surveys.

FIGURE 3 Climatic zone factorial for load transfer restoration, uniform sections.

- Historical traffic volumes, classifications, and accumulated 18-kip (80-kN) ESALs; and
- Environmental data.

The data sources and procedures used in the collection of each are described elsewhere (*5*).

FIELD PERFORMANCE AND EVALUATION

Field Performance

The performance of individual load transfer restoration devices was evaluated only in terms of visual characteristics. As a result, none of the load transfer devices were rated as having a "device failure" because the devices themselves cannot be seen. Some of the devices may well have failed; however, these failures are probably manifested by the other failure modes. It is interesting to note that the retrofit dowel

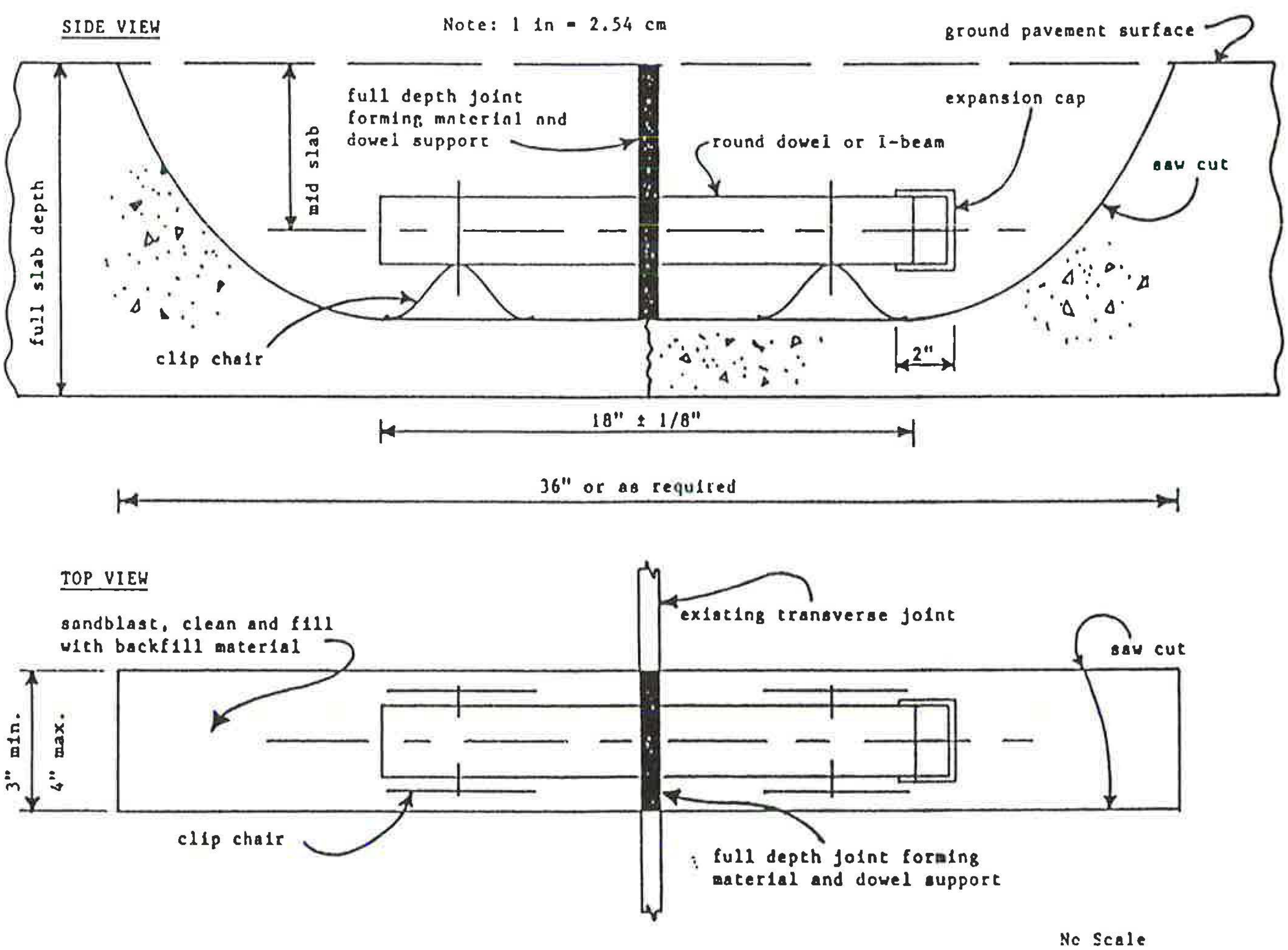


FIGURE 4 Diagram of retrofit dowel or I-beam device and installation.

bars and the miniature I-beam devices have similar performance characteristics. The same can be said of the double-vee shear and figure-eight devices. This is probably because both pairs of devices rely on similar mechanisms for load transfer restoration. It should be noted that some of these devices and their representative construction procedures have been modified and, it is hoped, improved since these installations. For example, the double-vee shear device construction procedure now recommends grooving the core walls and recompressing the load transfer device itself to improve performance; all of the shear devices in this study were uncompressed and ungrooved. The Florida Interstate 10 experimental study is evaluating the effectiveness of these construction modifications (*7*).

Retrofit Dowel Bar Performance

The performance of the retrofit round steel dowel bars, as shown in Figure 4, was measured in terms of two criteria:

- Faulting readings at 72 joints and
- Visual evaluations of 515 devices.

The mean faulting reading of the 72 joints restored with retrofit dowel bars was 0.04 in. (0.10 cm). This faulting occurred after an average of 2.62 million ESALs had loaded the pavements during an average 3.8 years of service. This mean faulting lies well below the failure criteria for faulting of 0.13 in. (0.33 cm), the point at which faulting affects rideability significantly (*8*).

Of the 515 retrofit dowel bar load transfer devices inspected, 507, or better than 98 percent, were in good condition (Figure 5). The most prominent mode of failure identified was material failure (1 percent or five devices) wherein the backfill matrix had been cracked or become loose and dislodged by traffic. Less than 1 percent of the joints were debonded on the approach, leave or approach, or leave side. None of the joints restored with retrofit dowel bars exhibited device failure or multiple modes of failure. Multiple modes of failure refers to the existence of two or more of the failure mechanisms given in Table 1 at any one device. The one

TABLE 1 PERFORMANCE SUMMARY FOR ALL DEVICES EVALUATED

	Dowel Bars	Double Vees	Figure Eights	I-Beams
Number of Devices	515	810	36	164
	Percentages			
Good Condition	98	72	75	99
Debonding Approach	<1	6	8	0
Debonding Leave	<1	4	6	0
Material Failure	1	9	8	1
Device Failure	0	0	0	0
Debonding Approach and Leave	<1	13	6	0
Multiple Modes of Failure	0	4	3	0
Average Faulting, ins.	0.04	0.07	0.08	0.13

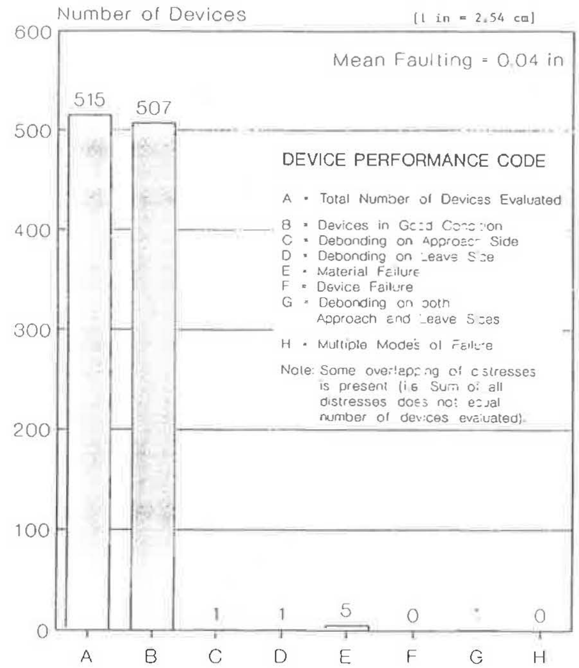


FIGURE 5 Distribution of retrofit dowel performance.

exception to this is debonding at both the approach and leave sides of the same device. This was not recorded as a multiple mode of failure. Similarly, if a joint exhibited debonding on both the approach and leave sides of the same device, this was recorded in one category and not reflected under the individual failure modes of debonding approach side and debonding leave side so as to not record the failure twice.

Double-Vee Shear Device Performance

The performance of the double-vee shear devices (Figure 6) was measured in terms of two criteria:

- Faulting readings at 260 joints and cracks and
- Visual evaluations of 810 devices.

The mean faulting reading of the 260 joints restored with shear devices was 0.07 in. (0.18 cm). This faulting occurred after an average of 2.55 million ESALs had loaded the pavement during 2.5 years of service, on average. This mean faulting is approximately one-half of the failure criteria for faulting of 0.13 in. (0.33 cm), the point at which faulting affects ridability significantly (*8*).

Of the 810 uncompressed, ungrooved shear load transfer devices inspected, 583, or 72 percent, were in good condition (Figure 7). The most prominent mode of failure identified was debonding on both the approach and leave sides of the same device, which was found on 108, or 13 percent, of the devices. As was stated previously, this failure mode was recorded separately from the individual modes of debonding failure. Again, the Florida study is evaluating the use of device precompression and core wall grooving as remedies to this debonding mode of failure. None of the joints restored with

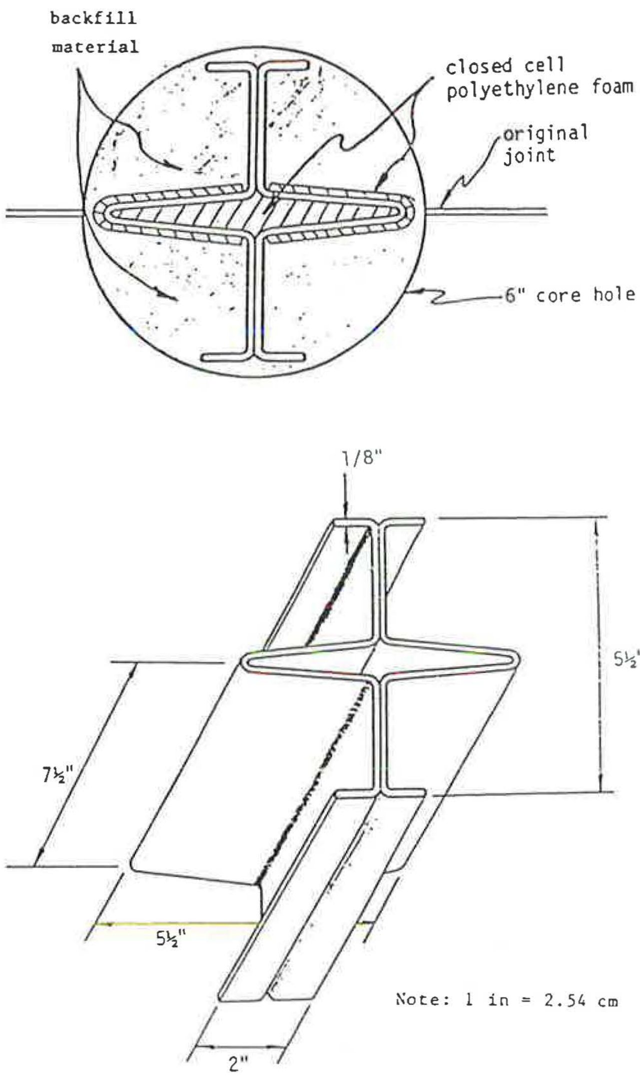


FIGURE 6 Diagram of double-vee shear device and installation.

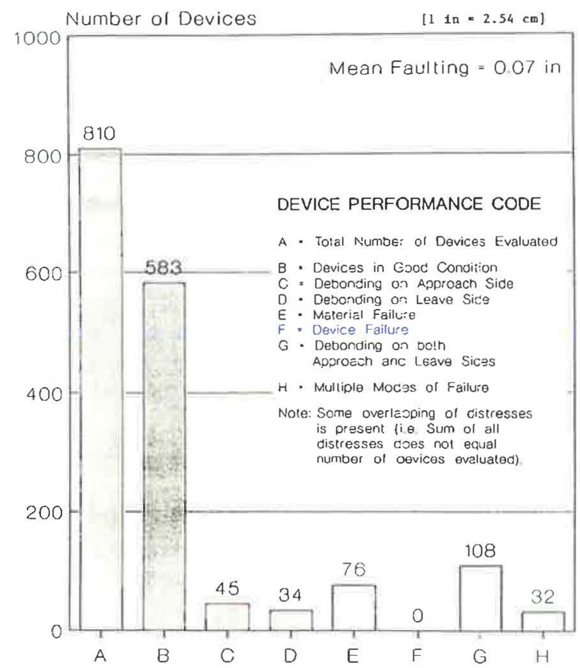


FIGURE 7 Distribution of double-vee shear device performance.

shear devices exhibited device failure. Multiple modes of failure were identified at 4 percent of the devices.

Miniature I-Beam Device Performance

The performance of the miniature I-beam devices, as shown in Figure 4, was measured in terms of two criteria:

- Faulting readings at 23 joints and
- Visual evaluations of 164 devices.

The mean faulting reading of the 23 joints restored with miniature I-beams was 0.13 in. (0.33 cm). This faulting occurred after an average of 4.01 million ESALs had loaded the pavement during 2.0 years of service, on average. This mean faulting is equal to the failure criteria for faulting of 0.13 in. (0.33 cm), the point at which faulting affects rideability significantly (*8*).

Of the 164 I-beam load transfer devices inspected, 162, or better than 98 percent, were in good condition (Figure 8). The most prominent mode of failure identified was material failure (about 1 percent or two devices) wherein the backfill matrix had been cracked or become loose and dislodged by traffic. None of the devices were debonded on the approach, leave, or both approach and leave sides. Also, none of the joints restored with I-beams exhibited device failure or multiple modes of failure.

Figure-Eight Device Performance

The performance of the figure-eight devices (Figure 9) was measured in terms of two criteria:

- Faulting readings at 8 joints and
- Visual evaluations of 36 devices.

The mean faulting reading of the 8 joints restored with figure-eight devices was 0.08 in. (0.20 cm). This faulting occurred after an average of 5.45 million ESALs had loaded the pavement during 9.0 years of service, on average. This mean faulting is approximately two-thirds of the failure criteria for

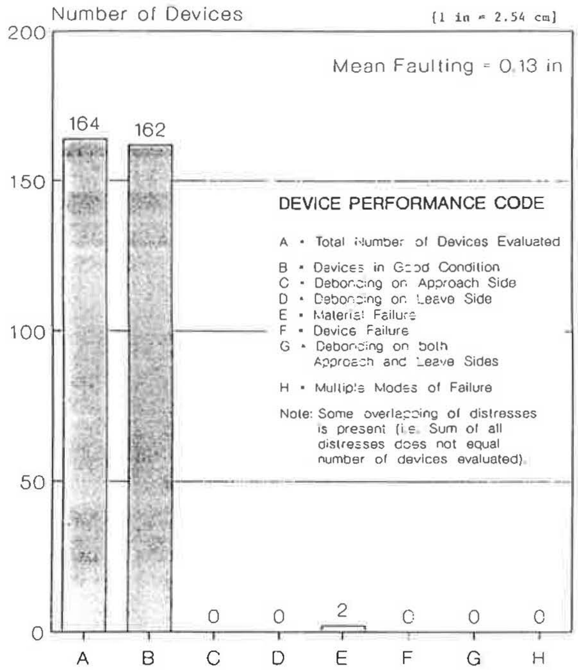


FIGURE 8 Distribution of I-beam device performance.

faulting of 0.13 in. (0.33 cm), the point at which faulting affects rideability significantly (*8*).

Of the 36 figure-eight load transfer devices inspected, 27, or 75 percent, were in good condition (Figure 10). The most prominent failure modes identified were debonding on the approach side and material failure. Both of these failure modes occurred at 8 percent of the devices. None of the joints restored with figure-eight devices exhibited device failure. Multiple modes of failure were identified at approximately 3 percent of the devices.

Performance Summary

Table 1 gives the four load transfer devices evaluated in this study along with their respective modes of failure. If a device had more than one failure mode, each failure mode was recorded separately. This resulted in a cumulative percentage greater than 100 percent. The entry entitled "multiple modes of failure" was established to help determine if any of the devices had deteriorated drastically and to provide a possible indication of the extent of device failure present (the devices themselves cannot be seen).

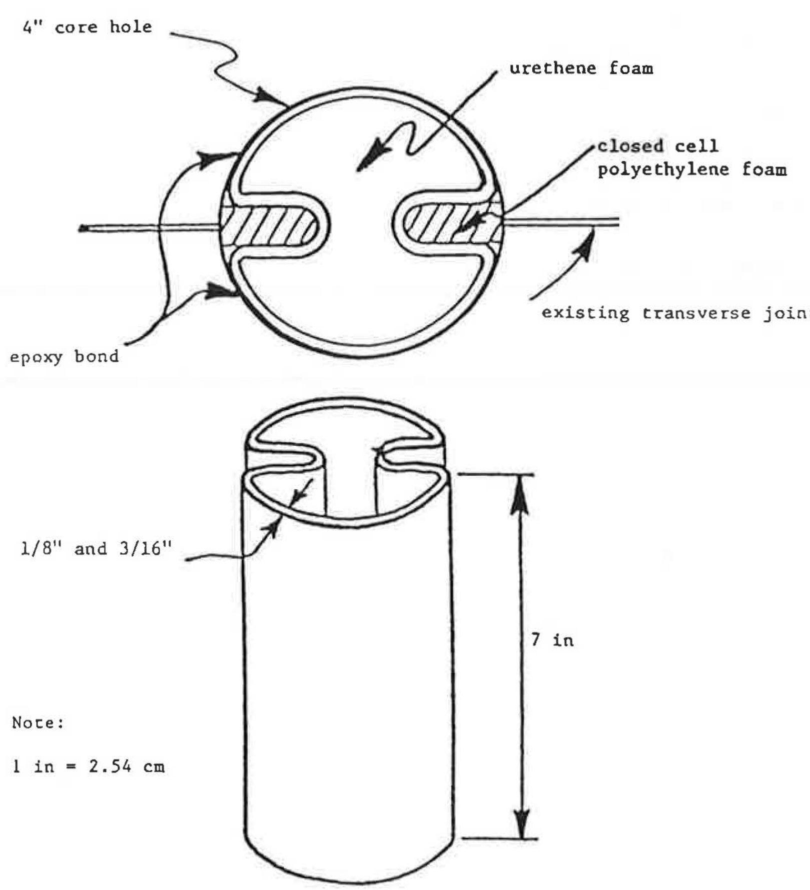


FIGURE 9 Diagram of figure-eight device and installation.

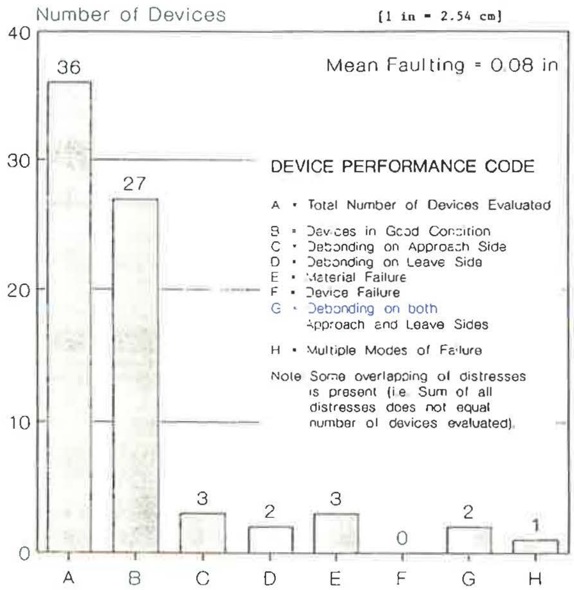


FIGURE 10 Distribution of figure-eight device performance.

PERFORMANCE MODELS

Model Development

A predictive model for faulting, after load transfer restoration, was needed to determine the effectiveness of the devices and for estimating future faulting. Regression analysis of the load transfer restoration data base was accomplished using the SHAZAM and SPSS (Statistics Package for the Social Sciences) statistical packages (*9, 10*). The initial analysis included all variables in the data base that were potentially meaningful for the performance of restored joints and cracks. The analysis resulted in the development of a performance model for joint and crack faulting.

Faulting Model

The model for the prediction of future joint or crack faulting from the time of load transfer restoration is given hereafter. It should be stressed that this model was derived from a data base in which all of the projects had diamond grinding performed at the joints or over the entire project length in the same year as load transfer was restored. To develop the model, all of the projects in the grinding data base and the load transfer data base were used.

Joint Faulting

$$FAULT = -5.62\,(ESAL + AGE)^{0.540}\,[5.85\,(DRAIN + SUB + 1)^{0.0529} - 3.8 \times 10^{-9}\,(FI/100)^{6.29} + 0.48\,(THICK + PCCSH)^{0.335} + 0.1554\,BASE - 7.163\,JSPAGE^{0.0137} + 0.136\,DOWEL + 0.003\,SHEAR - 0.027\,FIG8 - 0.316\,IBEAM]/100$$

where

- *FAULT* = mean faulting of the restored, ground joints or cracks (inches);
- *ESAL* = equivalent 18-kip (80-kN) single axle loads accumulated on the restored, ground joints or cracks (millions);
- *AGE* = age of the restored, ground joints or cracks (years);
- *DRAIN* = 0 if subdrainage is present currently (whether installed initially or incorporated in the rehabilitation) and 1 if no subdrainage is present;
- *SUB* = 0 if subgrade is a fine-grained soil and 1 if subgrade is a coarse-grained soil;
- *FI* = mean freezing index (degree days below freezing);
- *THICK* = thickness of the in-place concrete slab (inches);
- *PCCSH* = 0 if concrete shoulders are not present and 1 if concrete shoulders are present;
- *BASE* = 0 if granular base type and 1 if stabilized base type (asphalt, cement);
- *JSPAGE* = contraction joint spacing (feet);
- *DOWEL* = 0 if retrofit dowels are not used to restore load transfer and 1 if retrofit dowels are used to restore load transfer;
- *SHEAR* = 0 if double-vee shear devices (uncompressed, ungrooved) are not used to restore load transfer and 1 if double-vee shear devices (uncompressed, ungrooved) are used to restore load transfer;
- *FIG*8 = 0 if figure-eight devices are not used to restore load transfer and 1 if figure-eight devices are used to restore load transfer; and
- *IBEAM* = 0 if I-beam devices are not used to restore load transfer and 1 if I-beam devices are used to restore load transfer.

R^2 = 0.30
SEE = 0.04 in. (0.10 cm)
n = 114 ground sections without load transfer restoration plus 368 load transfer joints

Range of Applicability of Equation

- *ESAL*: The accumulated ESALs ranged from a minimum of 0.225 million in Minnesota to a maximum of 7.812 million in South Carolina; most projects had accumulated fewer than 3.0 million ESALs.

- *AGE*: The range of project ages varied from a low of 1 year in Arizona, Illinois, Iowa, Louisiana, Pennsylvania, South Carolina, and Virginia to a high of 9 years in Georgia and South Carolina; most projects were less than 5 years old.
- *FI*: The freezing index ranged from a minimum of 0 in 9 southern states to a maximum of 1750 in Minnesota; a majority of the projects were exposed to a freezing index between 0 and 250 freezing degree days.
- *THICK*: The range in pavement thickness varied from a low of 7 in. (17.8 cm) in Minnesota to a high of 12 in. (30.5 cm) in Arizona; most projects had a 9- or 10-in. (22.9- or 25.4-cm) thick pavement.
- *JSPAGE*: The contraction joint spacing ranged from 15 ft (4.6 m) in Arizona, Arkansas, California, Minnesota, and Oklahoma to 100 ft (30.5 m) in Illinois; most projects were built with a joint spacing between 15 and 30 ft (4.6 to 9.1 m).

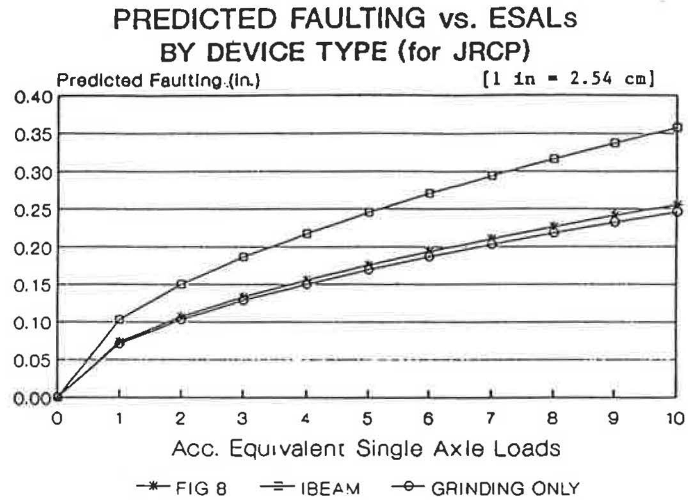
Note that all of the pavements incorporated into the regression analysis of load transfer restoration had also undergone diamond grinding of the entire pavement surface or localized grinding at the restored transverse joints.

A sensitivity plot is shown in Figure 11 for jointed reinforced concrete pavement (JRCP). The inputs for the pavement design variables were selected from a list of standard inputs considered representative of current trends in design parameters (*7*).

Faulting of both the jointed plain and jointed reinforced pavements increased rapidly initially and then leveled off as the pavements accumulated more loadings. This type of curve has been found for all types of new and restored pavements as well as full-depth repairs (*11*). The figure contains five curves for

- Retrofit dowels,
- Double-vee shear devices,
- Figure-eight devices,
- Miniature I-beam devices, and
- No devices (diamond grinding alone).

The plot shows that the retrofit dowel bars reduce faulting significantly from that obtained with grinding alone. The double-vee shear devices and figure-eight devices have practically no effect, and the I-beam devices appear to increase faulting. This increase, however, must not be taken literally because there is no physical reason for this result. It should only be concluded that the device has no effect on faulting according to the available data. These results are in response to the coefficients that were derived from the regression analysis. Similar results are shown in Figure 12 for JPCP, but without the I-beams because these devices were used only on JRCP. If 0.13 in. (0.33 cm) and 0.26 in. (0.66 cm) are used as faulting criteria for JPCP and JRCP, respectively, the following allowable loadings result from this model:



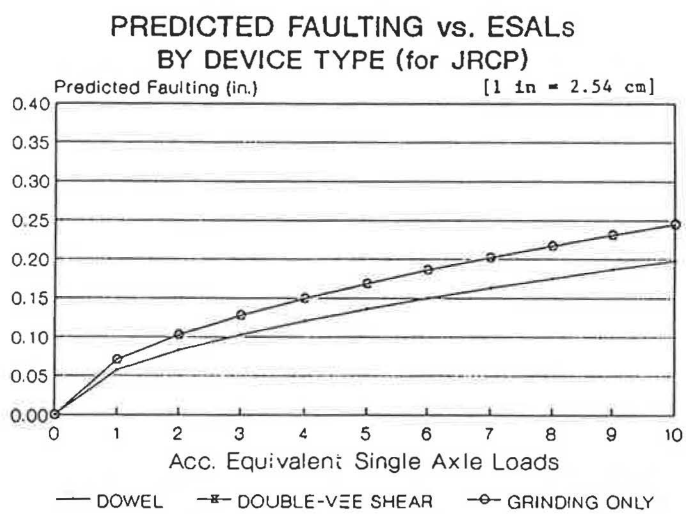
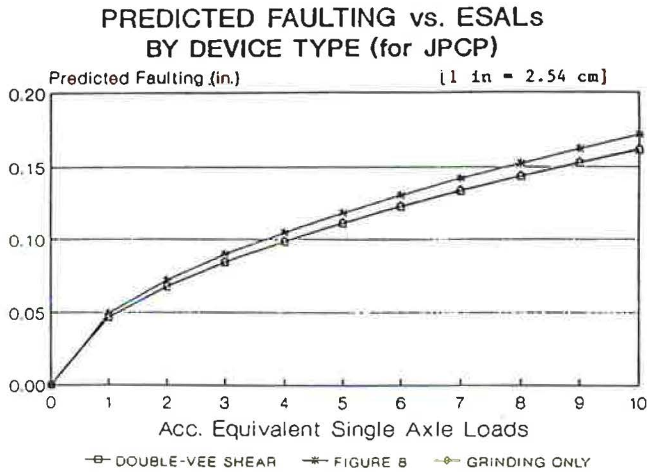


FIGURE 11 Sensitivity plot depicting model-predicted faulting vs. accumulated 18-kip (80-kN) ESALs for JRCP.

Restoration Device	*JPCP Allowable*	*JRCP Loadings*
Retrofit Dowels	16.0	10.0
Diamond Grinding Alone	8.8	6.9

Loadings are in millions of 18-kip (80-kN) ESALs (*8*)

The extension of life obtained with retrofit dowels is significant (almost double). Diamond grinding addresses only the symptoms of pavement deterioration (excessive faulting) without addressing the source of the deterioration, which may require load transfer restoration, subdrainage, and the like. If diamond grinding is used as a temporary repair strategy, it has been shown that faulting will develop at a rate greater than that of initial new pavement faulting (*7*). Load transfer restoration appears to be an effective means of extending the life of a restoration project.



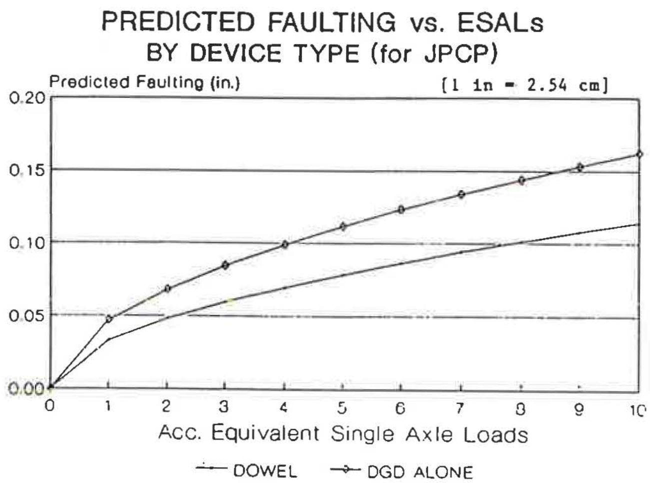


FIGURE 12 Sensitivity plot depicting model-predicted faulting vs. accumulated 18-kip (80-kN) ESALs for JPCP.

It is important to note that the projects in which double-vee devices were used did not include grooving of the core walls or precompression of the devices. These two modifications may or may not have a significant effect on performance of these devices and are currently under study at a Florida experimental section on I-10 near Tallahassee.

DESIGN AND CONSTRUCTION GUIDELINES

Guidelines were originally prepared under NCHRP Project 1-21 and published in NCHRP Report 281 (*2*). Further updates resulted from the research conducted under this study and are published elsewhere (*7*).

Restoration of load transfer across a transverse joint or crack can be used to retard further deterioration. Poor load transfer leads to joint or crack deterioration, including pumping, faulting, corner breaks, and spalling. Overlays placed over joints or cracks that have poor load transfer will soon develop reflective cracks that will spall and deteriorate into potholes.

Load transfer restoration is recommended for all transverse faulted joints or cracks that exhibit poor deflection load transfer of approximately 0 to 50 percent when measured early in the morning or in cool weather. Heavy load deflection devices that resemble regular traffic loads should be used for measurement. These recommendations are for jointed concrete pavements with or without asphalt overlays (*2*).

If deflection measurements are impossible, an indicator of poor load transfer is faulting of the joint or crack. Any joint with 0.10 in. (0.25 cm) of faulting or more will likely have poor load transfer.

Gulden and Brown (*1*) conclude that the following criteria must be met for a load transfer restoration system to provide long-term performance:

- The patching material and device must have sufficient strength to carry the required load.
- Sufficient bond must be achieved between the device and the patching material to carry the required load.
- Sufficient bond must be achieved between the patching material and the existing concrete to carry the required load.
- The device must be able to accommodate movement due to thermal movement of the concrete slabs.
- The bond between the device and the patching material must be sufficient to withstand the forces due to thermal expansion of the concrete slabs.
- The patching materials must have little or no shrinkage during curing. Shrinkage of the patching material can cause weakening or failure of the bond with the existing concrete.
- The patching material must develop strength rapidly so that traffic can be allowed on the slabs in a reasonable length of time (3 to 4 hr).

Results of tests conducted in Georgia, Florida, and other states show that the retrofit dowel bars can meet these requirements. Dowels, when properly constructed, were found to greatly improve existing load transfer (and reduce deflection) and to permit horizontal movement (or opening and closing) of joints (*1, 2*).

The number, diameter, and spacing of dowel devices must be determined. An analysis was conducted by Tayabji and Colley that determined that stresses and deflections for six dowels spaced nonuniformly in a joint (three in each wheelpath) were similar to stresses and deflections obtained for a joint with 12 uniformly spaced dowels (*12*). Placing retrofit dowels in the wheelpaths should provide similar performance and be more cost-effective.

The number, spacing, and diameter of the dowels will determine the amount of future faulting of the transverse joints. Several different retrofit dowel load transfer restoration designs were evaluated during this study. Table 2 gives these design variations and pertinent pavement factors.

Results from NCHRP Project 1-19 showed the significant impact dowel diameter has on faulting. Larger-diameter dowels slow down the development of faulting in new pavements.

TABLE 2 DESIGN VARIATIONS AND PERTINENT FACTORS

Devices in Wheelpath		Dowel Spacing	Mean Fault	Dowel Diameter	Accumulated ESALs	Joint Spacing
Outer	Inner	(in.)	(in.)	(in.)	(millions)	(ft)
4	4	15	0.04	1.25	5.45	30.0
3	3	12	0.09	1.25	1.49	15.0
3	2	18	0.03	1.25	5.45	30.0
4	0	18	0.01	1.25	5.45	30.0

NOTE: Faulting values pertain to the outer lane only, measured 1 ft in from the lane edge. 1 in. = 2.54 cm; 1 ft = 0.3048 m.

The larger dowels also showed less loss of load transfer in the Illinois I-70 full-depth repair study (*7*). Figures 13 and 14 compare joint faulting of new JPC and JRC pavements built with dowels of various diameters with joint faulting of similar rehabilitated pavements (either diamond griding alone or diamond grinding along with retrofit dowel load transfer restoration). These figures indicate that retrofit dowels reduce faulting; however, they do not do so to the same level as they do in newly constructed pavements. This probably occurs because the aggregate interlock is much less for an older pavement than for new construction.

The development of a mechanistic, empirical retrofit dowel design procedure is currently under investigation using the results from the Florida test site in addition to data from other states. The best recommendations that can be provided at this time follow:

1. Use dowel bars with diameters of at least 1.25 in. (3.2 cm) and preferably 1.50 in. (3.8 cm). For more heavily trafficked pavements that sustain 0.5 million ESALs per year in the outer lane, the 1.50-in. (3.8-cm) diameter bars should be used. The length of the bars should be 18 in. (46 cm).
2. Use three or four dowels placed in each wheelpath at 12-in. (30.5-cm) spacings.
3. The outermost dowel in the outer wheelpath should be located 12 in. (30.5 cm) from the outer lane edge.
4. Care must be taken to avoid any existing dowels in the pavement.

A recommended layout is shown in Figure 15 for retrofit dowel design.

Patch material used with load transfer devices is a critical factor in performance, particularly with shear devices. Sufficient bond must be established between the device and the patching material as well as between the existing concrete and the patching material to carry the applied loads and movement from thermal changes. Patching material must also develop strength rapidly to accommodate traffic and thermal stresses soon after placement.

Polymer concretes and high early strength portland cement concrete have been used in most installations to date. Polymer concrete material properties, fine aggregate gradation, and mix designs should be specified by the agency. A high early strength concrete mixture in conjunction with an epoxy applied to the existing slab was used successfully in Georgia (*1*). Aggregate gradation should meet the fine aggregate requirements of ASTM C33, Standard Specification for Concrete Aggregates. This allows the polymer concrete to easily

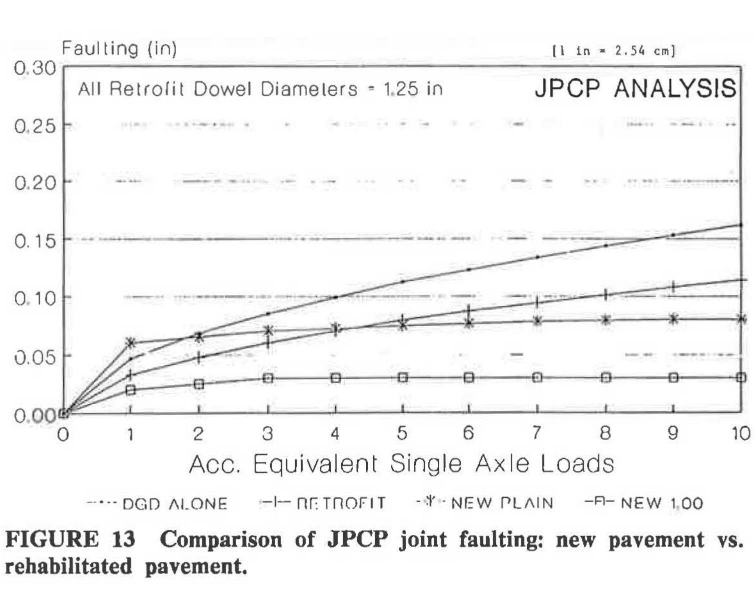


FIGURE 13 Comparison of JPCP joint faulting: new pavement vs. rehabilitated pavement.

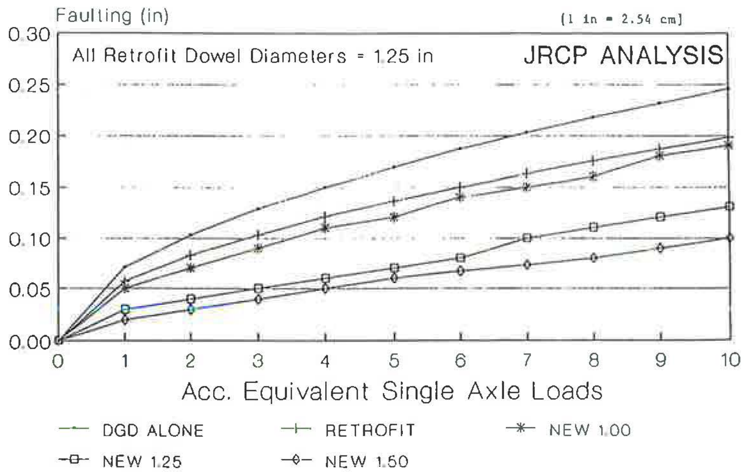


FIGURE 14 Comparison of JRCP joint faulting: new pavement vs. rehabilitated pavement.

fill the space. The mix design should allow the fine aggregate to be easily and completely coated.

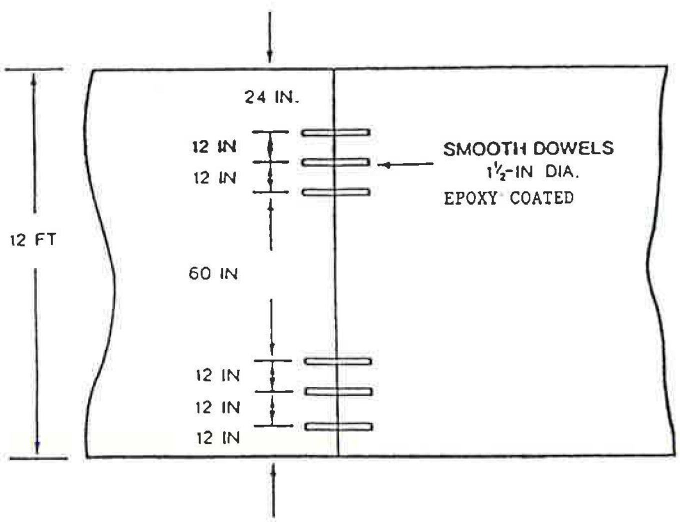
On the Florida test section a heavy-duty patch material (Trade name HD-50, manufactured by Dayton Superior Corporation) was successfully used for both the retrofit dowels and the double-vee shear devices. In addition, a $\frac{3}{8}$-in (0.95-cm) top sized pea gravel extender was used for the dowels.

When dowels installed in slots are used, expansion caps should be specified. Coated dowels should be 18 in. (35.6 to 45.7 cm) long and of sufficient diameter to reduce faulting to an acceptable level, described in the section on design.

Slots for dowels should first be cut with multiple-blade saws (a ganged sawing assembly will allow for a more uniform and efficient sawing operation). The "fins" have a life expectancy of about 1 week, depending on width, before they break down and the open slot becomes a hazard to traffic (*13*).

Lightweight pneumatic hammers are then used to remove the concrete with minimal damage to the surrounding concrete. Sandblasting of the slots followed by airblasting to provide final cleaning should be performed.

Slots should be cut so that the dowels are allowed to rest



Note: For very heavy traffic, 4 dowels may be necessary in each wheelpath.

1 in = 2.54 cm
1 ft = 0.3048 m

FIGURE 15 Recommended retrofit dowel design for heavy traffic.

horizontally and perpendicular to the joint or crack at mid-depth of the slab. Each dowel should be placed on a support chair to allow the patch material to surround the dowel.

Dowels must be provided with filler board or styrofoam material at midlength to prevent the intrusion of patch material into the existing joint or crack and to form the joint in the kerf. To fill varying joint or crack widths over the project, multiple thin sheets of filler can be used. To keep joints or cracks free of material it is important to have a tight-fitting filler that matches the existing contraction joint width. Details of dowel placement are shown in Figure 4.

CONCLUSIONS AND RECOMMENDATIONS

1. This research study revealed that retrofit dowel bars did the best job of reducing faulting. The double-vee shear device (without precompression or grooving of the core walls), the figure-eight shear device, and the retrofit miniature I-beam device did not reduce faulting to any greater degree than did diamond grinding alone. All of the projects considered here had diamond grinding conducted as part of their rehabilitation strategies. The initial faulting, therefore, was zero in all cases, and direct comparison of the devices could be made. Device faulting performance is summarized in Table 3. The results of this analysis reflect a wide range of both project and rehabilitation design, in-service life, traffic loading, and climatic variables.

2. Faulting analysis of load transfer–restored and control joints clearly showed the benefit of some types of load transfer restoration as a rehabilitation technique for restricting the development of joint or crack faulting. As expected, load transfer efficiency at the Florida test site was greatly increased and deflections reduced through the use of load transfer restoration devices.

3. The most promising method of restoring load transfer to existing transverse joints and cracks is retrofit dowels. Results from test sites in Georgia and Florida, as well as from field tests, show that retrofit dowels can reliably reduce faulting. These dowels, when properly installed, were found to greatly improve the existing load transfer (and reduce deflections) and to permit horizontal joint movement (or opening and closing).

4. The retrofit dowels were more effective and reliable than the other load transfer devices. However, the contractor in Florida indicated that, as expected, the dowels were more difficult to install properly than were the double-vee shear devices (even when the shear devices required core wall grooving and precompression). Equipment manufacturers are currently developing more efficient means of cutting the slots and removing the concrete "fins."

5. The device performance evaluation indicated that the critical factor for any of the devices was the performance of the backfill material. Backfill material failure was either the most prominent or second most prominent failure mode for all of the four load transfer devices evaluated. This was evident even on the retrofit dowel bars and miniature I-beams, less than 2 percent of which exhibited any failure mode.

TABLE 3 DEVICE FAULTING PERFORMANCE

Device Type	Mean Fault		Mean ESALs	Mean Age
	in.	cm	(millions)	(years)
Retrofit dowels	0.04	0.10	2.6	3.8
Double-vee	0.07	0.18	2.6	2.5
Figure-eight	0.08	0.20	5.5	9.0
I-beam	0.13	0.33	4.0	2.0

6. The successful performance of load transfer restoration is controlled, as are so many other rehabilitation techniques, by the ability to identify and address the source of the deterioration. These distress mechanisms must be addressed and any deficiencies corrected before load transfer restoration. Typical rehabilitation work associated with load transfer restoration can require (a) localized subsealing to provide uniform slab support to compensate for a pumped subbase, (b) retrofit subdrainage to provide a positive way for infiltrated free water to more rapidly leave the pavement structure, (c) diamond grinding of the restored joints or the entire pavement to reestablish a smooth riding surface, and (d) joint resealing. Diamond grinding and joint resealing are done after the load transfer devices have been installed.

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New Developments in Road Maintenance Equipment: Chip Seals and Current Maintenance

M. Behr and R. Baroux

In this paper are presented the state of the art of chip sealing equipment in France (asphalt distributors and chip spreaders) and the methods and tools that have been developed and used during the last 15 years to improve this equipment. Equipment test benches appear to improve quality control of the equipment. Success to date is due to coordinated action of equipment manufacturers, road contractors, and the administration. An automatic patching machine or flexible compound spreader that incorporates technologies of asphalt distributors, chip spreaders, and compactors is discussed briefly.

Maintenance of the road network is essential for the economy and requires a large investment. In France, 450 million square meters of chip seals are placed each year; these seals represent three-fourths of road asphalt consumption. Patching with asphaltic emulsion uses 300 million tons of emulsion a year. The equipment used for chip seals (asphalt distributors, chip spreaders) has been improved during the last 15 years, and innovations in equipment for maintenance are now developing. The characteristics and capacities of the most representative equipment are discussed.

CHIP SEALS

Design, adjustment, and method of operating equipment are major factors in quality control. That is why the French administration has developed evaluation tools for use on chip sealing equipment. Constant communication with contractors and equipment manufacturers makes it possible to improve and optimize design and operation of equipment. To maintain these links, a National Road Equipment Committee was created in 1973 to bring together contractors, manufacturers, and the administration. That committee has issued acceptance rules for equipment and has defined the work program of equipment test stations. The rules, programs, and stations deal with all kinds of road construction equipment, but only chip seals and current maintenance are discussed here.

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Asphalt Distributors

Technology

Approximately 1,200 asphalt distributors are working in France; two-thirds of them are less than 10 years old or have been improved with recently designed parts. Most of them use an asphalt dosing pump bound to the speed of the vehicle through hydrostatic transmission. The spray bars are fitted with middle pressure jets (100 to 200 kPa). Pneumatic outfits are also sometimes used. Features of the asphalt distributors include

- Transverse displacement and lifting of the bar to travel position by pressure cylinders and
- Traditional fittings changed for pneumatically controlled valves.

During the last 15 years, the multijet spray bars have gone through the following evolutionary stages:

- 1974–1975: position of the nozzles designated,
- 1976–1977: improvement of the pipe of the spray bar,
- 1978: beginning of the use of electronics and automation of asphalt distributors (Figures 1 and 2), and
- 1982: process control managed by microprocessor.

Present asphalt distributor technology appears to be optimal for traditional chip seals. However, new chip seal techniques require new equipment to spread high-viscosity asphalt binder (> 1500 cSt). Even though these high-viscosity binders represent only 2 percent of all spread asphalt binders, 50 percent of the asphalt distributors are outfitted at the beginning to allow the spreading of binders the viscosity of which is between 200 and 2500 cSt. This is the result of the contractors' decision to invest in tools that will allow technological evolution (at present 90 percent of asphalt distributors are used with traditional binders). Improvements of the equipment include

- Reinforced thermal insulation and thermofluid heating (now with regulation of the burner),
- Increase in the diameter of pipes upstream of the pump, and
- Use of larger pumps.

FIGURE 1 Modern asphalt distributor, for all asphalt binders, outfitted with electronic drives to provide uniform distribution of material.

Innovation in chip sealing techniques requires new equipment. For instance, two techniques for using foamed asphalt are being developed; one uses a mixture of asphalt, foaming additives, and water; the other uses a mixture of asphalt, foaming additives, and water in an air flow through a grid.

Automation

Electronics for asphalt distributors with "automatic proportioning" allow calculation and on-line regulation of the rpm of the pump depending on the speed of the vehicle, the density of the binder at the spreading temperature, and the number of open nozzles.

Microprocessor units have been developed to improve reliability and ease of command. Use parameters are displayed by the operator either with an input keyboard or from the microprocessor memory. Pump rpm, running speed, and temperature data are collected from sensors and processed by the calculator. To ensure that the correct running speed is input, one of the French manufacturers of asphalt distributors uses a radar placed between the axles under the truck chassis (Figure 3).

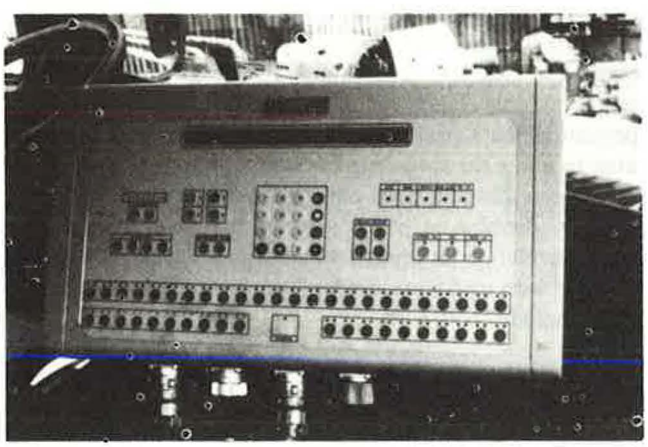

FIGURE 2 Cab control desk of automatic asphalt distributor.

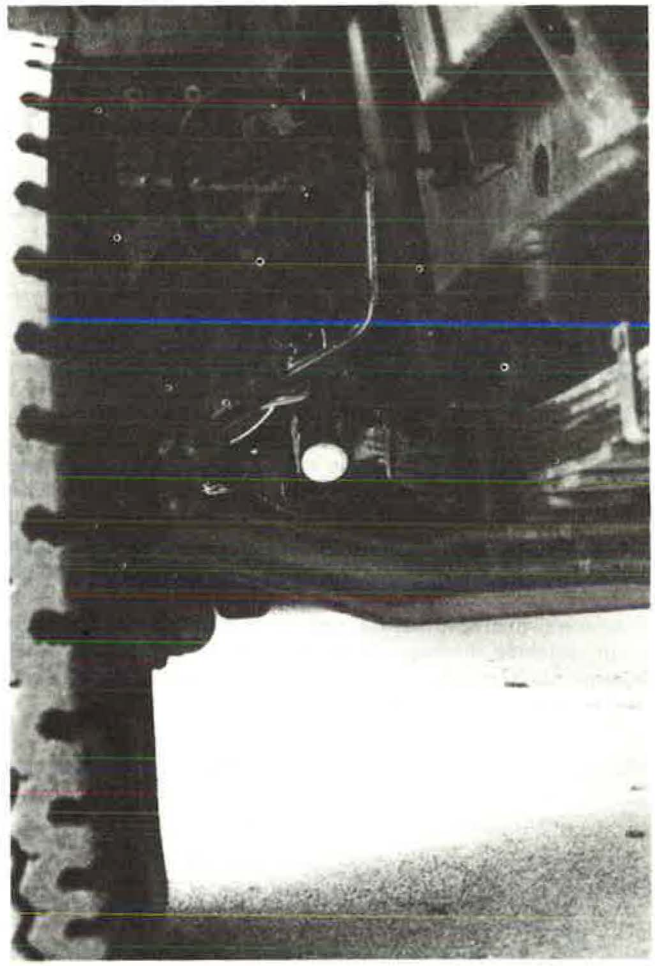

FIGURE 3 Döpler radar for measuring running speed.

Optimal Operating Conditions

The test bench of the Road Equipment Test Station has permitted study of the operation of asphalt distributors and quantification of improvements. The results of the tests have shown the necessity of

- Redetermining and maintaining the position of the nozzles and
- Maintaining correct spray bar height so that the output of the nozzles overlaps on the road during spreading.

It has also been determined that an optimal value of the pump rpm can be identified by using asphalt jets of steady geometry. This is shown in Figure 4; the pump rpm depends on the number of working nozzles.

These asphalt distributors can be used in accordance with the fixed regulations for chip seal work:

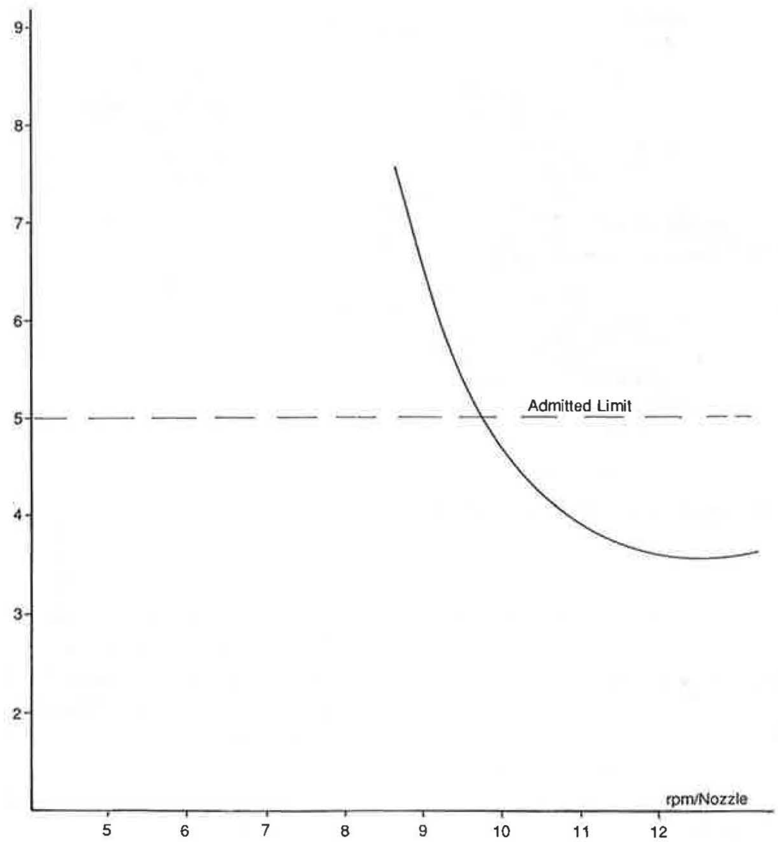

FIGURE 4 Regularity as the ratio CV = (dosage standard deviation)/(dosage mean value) in reference to pump rpm/working nozzle.

- Transverse regularity of dosing with a coefficient of variation of less than 5 percent and
- Actual dosage within 5 percent of the predicted value.

Evaluation and control tools permit a drift to be measured and corrected.

Evaluation Tools

There are three types of evaluation tools: a test bench for spray bars and two methods of controlling the regularity of spreading. One method uses radioactive tracers, the other sampling in couples or boxes. Continuous data collection during operation of an asphalt distributor allows continuous control of the equipment.

Spray Bar Test Bench The testing bench for spray bars in the Road Equipment Test Station of Blois (Figure 5) is used before field operation to check the operation of asphalt distributors either at the design stage or during operational checkout of new equipment. It is also used for periodic control tests of working asphalt distributors. In 1984, 115 pieces of equipment were tested; in 1985, 104 were tested; and, in 1986, 127 were tested.

The test bench is composed of a pit in which is placed a large storage tank that contains oil with a heating capability similar to that of asphalt. Above the tank, 35 weighing receivers are placed. A bypass device is located between the grid and the tested spray bar and allows the bypassing of the test product either directly in the storage tank or in the 35 weighing receivers. Spray bar height is determined by the distance between the nozzles and the division grid.

A sample is taken during a predetermined time, and comparison of the quantities of product received in the 35 weighing boxes (the width of one box is 10 cm) gives an evaluation of the transverse spraying regularity of the tested bar.

Tests are run using an oil the temperature of which is adjusted to obtain a viscosity that is the same as that of the binders during spreading (100 cSt).

Each year, 120 spray bars are tested. These tests are quite useful and necessary for maintaining the quality of chip seals. More than 50 percent of the equipment tested needs an adjustment or maintenance of the spray bar (shift of nozzles, adjustment of valves, etc.) to give it a coefficient of variation of less than 5 percent; in some cases, adjustment of the automatic components is necessary.

Printing of Asphalt Binder with a Radioactive Tracer This nondestructive method is used to test the quality of an asphalt distributor under real operating conditions.

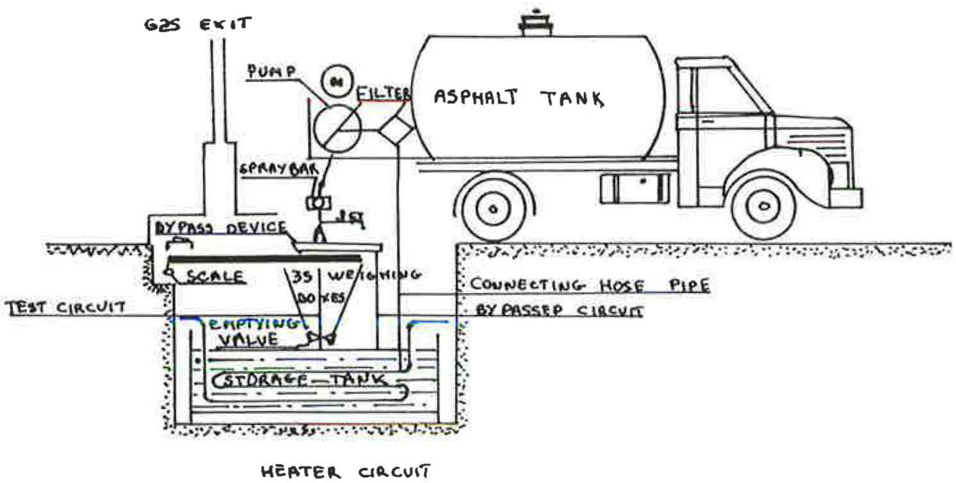

FIGURE 5 Spray bar test bench: schematic diagram of a test.

Asphalt is marked with a gamma-emitting radioactive tracer, indium 113, that has a short half-life (1.5 hr). After the tracer and binder are mixed, the marked asphalt is spread and gritted.

A collimated detector (Figure 6) is moved over a chip-sealed section of road. The detector delivers a counting rate that is proportional to the asphalt dosage per surface unit.

Data are collected each 8 cm by a microcomputer. For each section, the asphalt mean dosage per surface unit and the ratio of the standard deviation to the dosage mean value (transverse regularity) are calculated.

The rapidity of the method makes it possible to test two asphalt distributors per day and to immediately correct spreading faults of all types of equipment and binders.

Local Control of Asphalt Dosage and Regularity with Transverse Sampling Bars and Boxes This destructive method is often used on a test section at the beginning of a chip seal campaign. A metallic bar outfitted with 40 to 80 couples (50 × 100 mm) of synthetic material is placed in a transverse section of the road. The couples are filled with asphalt during spreading and weighed.

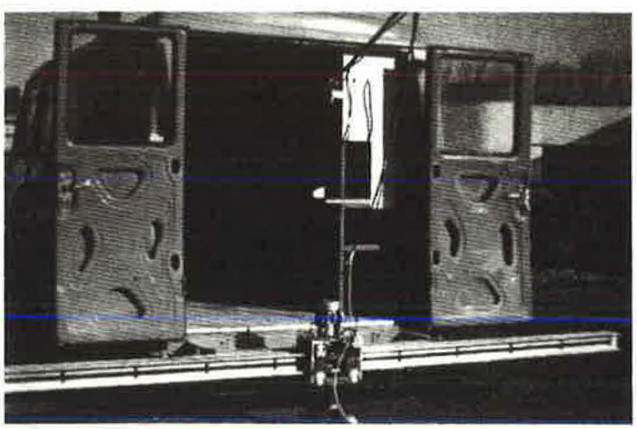

FIGURE 6 Collimated detector mounted on a rail.

This method gives a picture of a transverse section at a fixed time and allows calculation of a regularity coefficient as the ratio of the standard deviation to the mean value of the asphalt dosage of the different couples. Because of outflow from the couples, it is not possible to determine the mean value of the dosage. A good regularity coefficient is less than 10 percent, and it has been verified that the sampling bar value of 10 percent is in agreement with the value of 5 percent at the spray bar test bench in Blois.

Boxes that measure 400 × 500 mm are used to determine the mean value of dosage and, if necessary, to modify the calibration of the asphalt distributor.

These methods are long, boring, and destructive, but they give a good evaluation of the regularity of spreading.

Control with a Data Collection System Attached to the Asphalt Distributor This method affords continuous control of asphalt distributor operation and makes it possible to determine

- The mean value of the spread asphalt dosage per surface unit and
- The lengthwise regularity of asphalt spreading.

It has also been used to qualify the validity of interlocking systems and displays of automatically controlled asphalt distributors. Data-oriented sensors are used to collect the values of the following parameters: truck running speed, pressure in the bars, bar height, and number of open nozzles. These data are processed by a microprocessor unit.

Chip Spreaders

Types of Equipment

There are three types of chip-spreading equipment:

- Built-in-bottom gritter: A chip spreader attachment is fixed at the back of the truck body in place of the tailgate. The spreader can be fitted with enlarging tools to increase the chipping width, but this type of spreader always needs two passes whereas the asphalt distributor needs only one. This type of chip spreader is the most often used because rear-dump trucks are used for hauling agricultural products or materials when they are not being used for ship sealing. This equipment can also be easily moved because its width is less than the road clearance.
- Truck-pushed chip spreader: This equipment is self-contained but not self-propelled. It is composed of a chip distribution hopper and a device that couples the hopper with the truck axles, the motion of which is used to run the hopper. Chipping in traffic with this equipment is not easy, and many problems occur during coupling with the truck and operation. Chip seal degradation can also be caused by slippage of the carrying wheels. Because the hopper is wider (3 m) than the road clearance, this chip spreader must be pulled sideways from site to site. For these reasons, development of this kind of spreader has been limited.
- Self-propelled chip spreader: The working principle of this specialized self-propelled equipment is similar to that of the asphalt finisher. The chip spreader pulls the truck with an automatic coupling device. The rear wheels of the spreader run outside of the front wheel track, which prevents rutting. The driver's cab is placed either in front in the middle of the chipping hopper or on the left just before the rear hopper. The width of the "chipping front hopper" can vary between 2.30 and 4.30 m. This equipment can perform one-pass chipping of a width that is equal to that of the asphalt spreader. However, moving this equipment from one site to another presents problems due to the "over road clearance" hopper. Traffic on other lanes is generally disturbed because of the width of the hoppers. This type of spreader allows high daily productivity. A self-propelled spreader outfitted with extendable hoppers (Figure 7) has been developed recently. This chip spreader can work on secondary roads and in traffic.

Two types of built-in-bottom gritters can be defined: the hopper gritter with feed roll and the gravity flow gritter:

- Feed roll: The roll is hydrostatically driven, and the speed of the roll is adjusted to the running speed of the truck. A dosing blade or individual hopper gates are adjusted to a fixed opening. The chip dosage on the road is theoretically constant when the opening of the gate or gates and the ratio of roll rotation speed to truck running speed are properly selected.
- Gravity flow: The output of chips is fixed by the opening of a dosing gate and the nature (essentially the granularity) of the chips. The running speed of the spreader must be kept constant to obtain uniform chip coverage.

Gravity flow can be disturbed by the tipping of the truck body and the vibrations of the vehicle caused by roughness of a road. To avoid these disturbances, one French manufacturer has introduced storage bins at the end of the truck body and before the design gate, which is located in the bottom part (Figure 8). The bins ensure lead regularity for the chipping flow, which takes place in a portioned enlarging device.

FIGURE 7 Self-propelled chip spreader with extendable hopper.

Equipment Capacity

Until the last 3 years, chip spreader technology could not benefit from the results of a test bench. Table 1 gives results obtained on site test sections using sampling boxes 20 × 50 cm. The figures in the table indicate the necessity of improving the quality of chip spreaders to obtain better control of that stage of chip seal works.

Ongoing research programs that use the chip spreader test bench at the Road Equipment Testing Station are intended to improve the capacities of built-in bottom gritters by de-

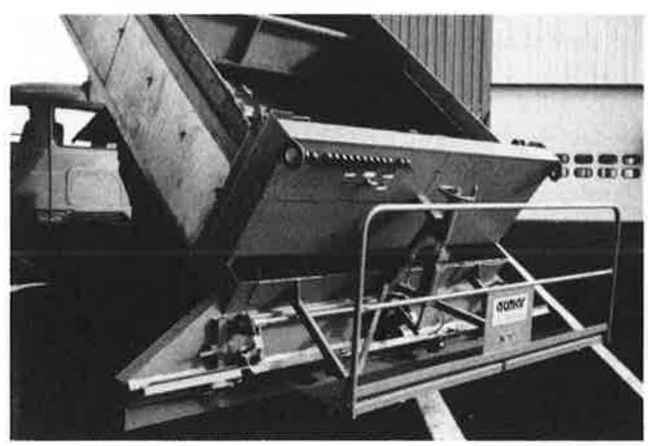

FIGURE 8 Gravity flow system with storage bins.

TABLE 1 RESULTS USING 20- BY 50-CM SAMPLING BOXES

ChipSpreader Type	Compliance with the mean dosage	Lenghtwise Variation	Transverse Variation
Built in bottom type gritter	Bad - (depending of the tipping of the truck body)	5 % (if good roughness of the road)	10 to 20 %
Self-propelled chipspreader	Good - Easy to obtain	6 à 9 %	6 to 9 %
Truck pushed chipspreader	Bad - Difficult to obtain	Depending of the mechanical drive between wheels and feed roll	8 to 12 %

creasing their regularity coefficient to the range of 5 to 10 percent.

Evaluation and Research Tools—Chip Spreader Test Bench

Because of the potential for significant payoffs (economies in aggregates consumption and fewer rejects), it was decided in 1983 to build a test bench at the Road Equipment Test Station of Blois (Figure 9). The chip spreader test is run without moving the equipment, and chip spreading is continuous, as shown in Figure 10.

The mean value of chip dosage is measured with a continuous conveyor scale placed on one of the conveyor belts. The regularity of a curtain of chips no more than 4 m wide is analyzed with an optical device: the chips fall near a source of light, and a video-numeric sensor fitted with 2,048 cells remotely detects occlusion of the light caused by the falling chips. Data transfer is by optical fibers to a microcomputer. Software arranges the 2,048 cells of data on 128 counting and measuring paths.

Screen analysis is done by sampling the 128 measuring paths. Total sampling time is about 5 sec and represents a road spreading length of about 5 m at a running speed of 3.6 km/hr.

Different ways of arranging the 2,048 cells with the 128 measuring paths permit the following limit analysis:

- A curtain 4 m wide with a 3.2-cm sampling pitch and
- Local detection of a curtain the maximum width of which is 25.6 cm with a 2-mm sampling pitch.

The operational checkout of this bench was completed in October 1984, and it appears to be giving rise to innovative ideas for improving chip spreaders.

Ongoing Research with the Chip Spreader Test Bench

Two examples are given of ongoing research programs.

Study of Feed Roll Devices A study of feed rolls has indicated several problems (Figures 11 and 12), and the aim of that study is to design withdrawing feed rolls that would cause the output of chips to be proportionate to the speed of rotation of the roll over a large range of operating conditions.

Study of an Aggregate Flowmeter For all types of equipment, it is difficult to rapidly calibrate output. Research is now under way on the design of an aggregate flowmeter that would use an optical device placed on the chip spreader near where the chips fall. Information from this sensor could be used to determine the opening of the tailgate.

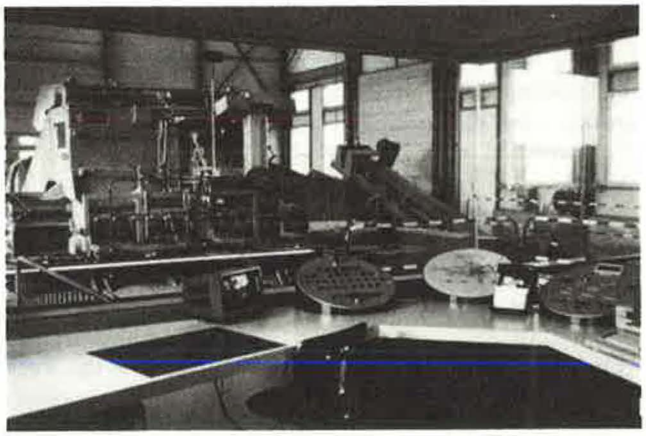

FIGURE 9 Chip spreader test bench, light source, and control desk.

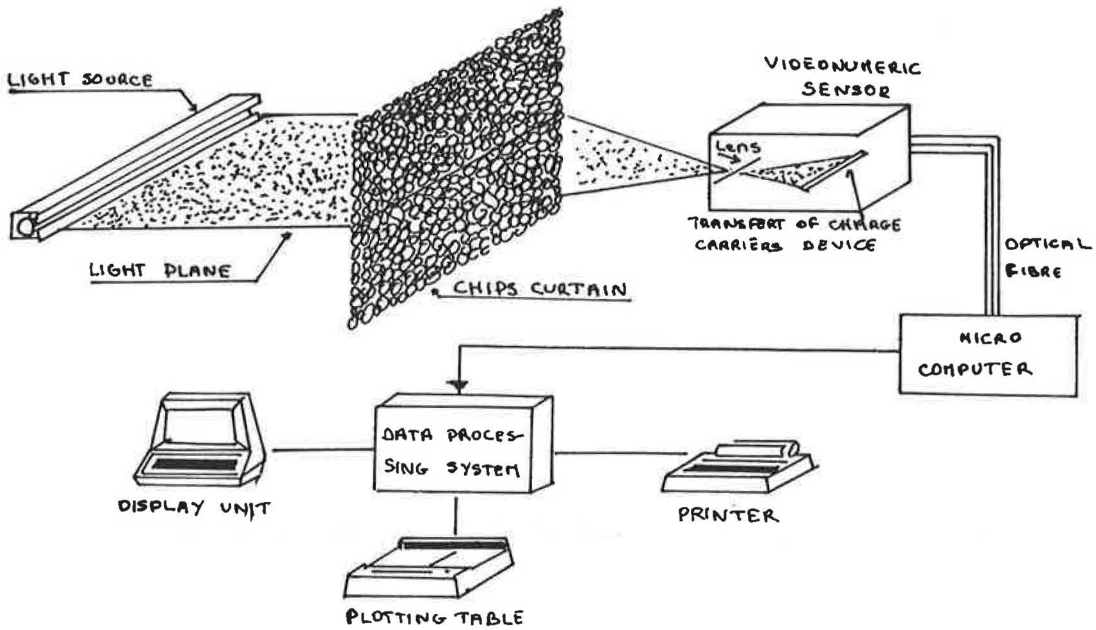

FIGURE 10 Chip spreader test bench: principle of measuring device.

CURRENT MAINTENANCE

A value analysis study was done in 1983 at the request of the Road Innovation Council Committee (see Paper by M. Point in this Record). Since 1986, a Road Maintenance Group has been created to ensure technical coherence and exchange of information among the different administrative districts.

One of the most innovative pieces of equipment that have been developed by a French manufacturer is a flexible compound spreader also known as automatic patching equipment (Figure 13) (Point A Temps Automatique or PATA).

The flexible compound spreader is designed to apply "partial chip seals." The spreader is used for current maintenance such as road sealing to cure highly cracked surfaces in order to avoid the appearance of potholes or deformations.

The flexible compound spreader is also used in scheduled current maintenance as defined by the French Road Current Maintenance Guide. It is not used for emergency repairs.

In addition, it can be used to chip seal larger surfaces such as carparks, town places, and school courts. It can also be used to seal local leveling if the surface treated daily is sufficiently large.

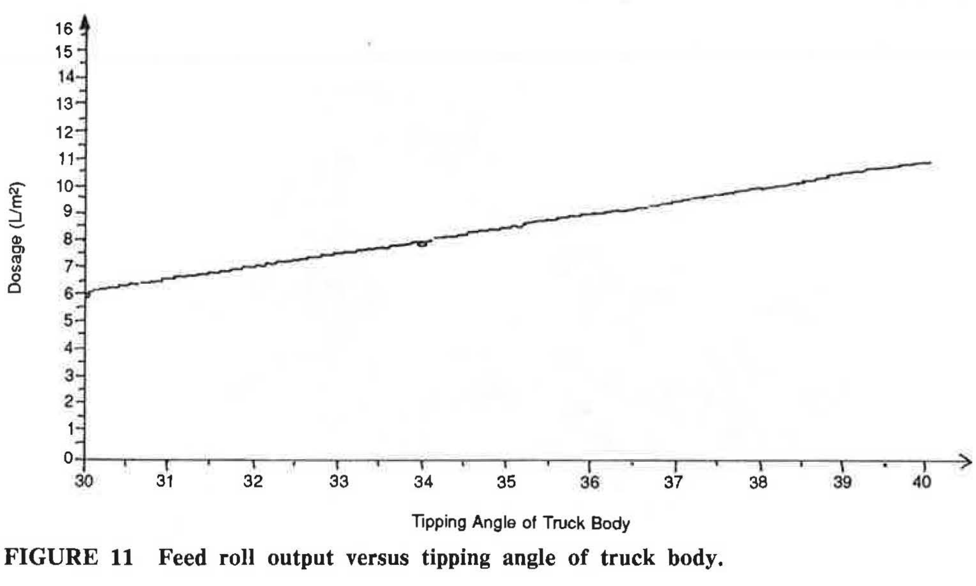

FIGURE 11 Feed roll output versus tipping angle of truck body.

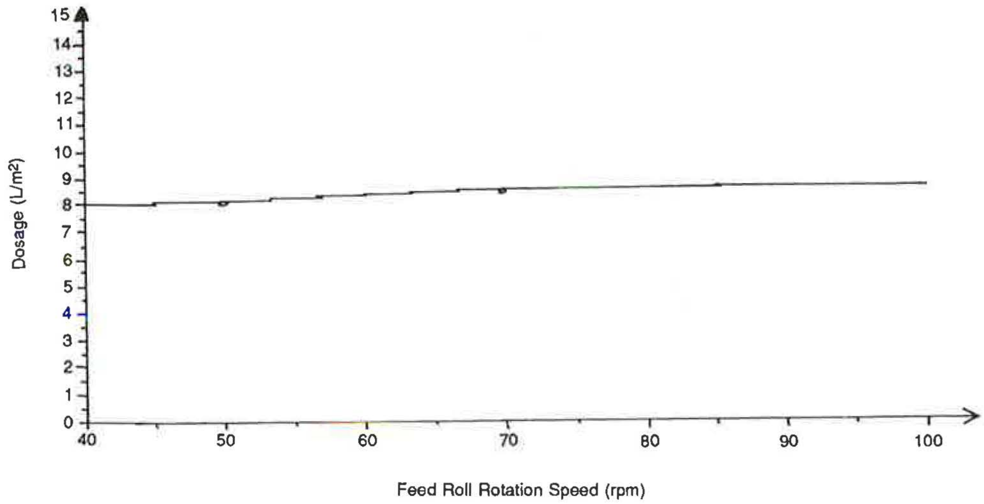

FIGURE 12 Linearity indicating insensitivity of aggregate output to feed roll rotation speed.

The technology of the flexible compound spreader resembles that of asphalt distributors, chip spreaders, and compactors. The following components are used:

- An asphalt emulsion tank,
- A spray bar,
- A multiple-tailgate chip spreader, and
- A compacting set of pneumatic tires.

All of these parts are mounted on a truck.

The flexible compound spreader works in reverse, and the running speed of the truck determines the emulsion dosage (if pressure in the bar and bar height are constant). Two operators are necessary; the one in the rear determines the individual pairs of tailgate nozzles that need to be open, depending on the width and length of the repair.

It was estimated that by the end of 1987 about 200 flexible compound spreaders would be at work in France, and that 30 of them would be owned by administrative districts. Other spreaders (170) were to have been purchased by contractors or town associations.

The first prototype spreader was demonstrated in 1985; since then, the technology of the equipment has evolved as the result of site tests and other research. For example,

- The flexible compound spreader can now spread hot binders as well as emulsion by using a dosing pump to create bar pressure.
- Three improvements to the spray bar have been developed: (a) duplicate arrangement of the spray bar, which allows the nozzles to overlap; (b) transverse displacement of the bar in relation to the road crossfall, which ensures perfect coverage of the spread binder by chips; and (c) automatic adjustment of the height of the bar to ensure that it is parallel to the road surface.

Use of this equipment has led to better quality patching (better compliance with the fixed binder and chip dosage and

FIGURE 13 Flexible compound spreader.

systematic compaction of repairs), to big pay-offs due to its large capacity (as much as 9 tons of emulsion per day or five times more than that of traditional patching equipment), and to decreased costs (repair cost per square meter is 40 to 60 percent less than that associated with traditional equipment). Furthermore, security of operators is improved because nobody is working on the road and only two operators are necessary to control the equipment.

CONCLUSIONS

Since the 1970s the French highway administration has followed a policy of chip seal quality and has developed the necessary tools to control quality and improve chip seal engineering.

It became apparent that the quality of equipment was a determining factor of chip seal quality. Therefore road equipment test stations have been built. A spray bar test bench was installed at the Blois station in 1973 and a chip spreader test bench in 1983. Each year 120 asphalt distributors that belong to contractors and district equipment centers are tested; more than 50 percent of these distributors need adjustment or other maintenance. These benches are also used in working with manufacturers to improve the design and technology of the equipment.

Constant communication among contractors, equipment manufacturers, and the administration (state agencies and laboratories) has been maintained through a National Road Equipment Committee. The work of that committee has contributed to the quality control of chip seals.

Many improvements of chip seal equipment and techniques have been realized in the last 15 years:

- Optimal design of spray bars,
- Automation of asphalt distributors,
- Better quality control, and
- Improvement of chip spreaders (e.g., extendable-width self-propelled equipment).

Improvements to chip seal equipment have led to new patching equipment, such as the flexible compound spreader and automated patching equipment.

The technology of asphalt distributors appears to be optimal; however, chip spreader technology must still be improved. The chip spreader test bench at the road equipment test station in Blois facilitates working with contractors and equipment manufacturers.

Publication of this paper sponsored by Committee on Maintenance Equipment.

Two Major Innovations in Current Maintenance: The Multipurpose Vehicle and the Integrated Surface Patcher

G. Point

Since 1987, a systematic approach to determining what major innovations are needed in maintenance equipment and a value engineering analysis have led to the development of two new units, the multipurpose vehicle and the integrated surface patcher, that represent important advances in routine maintenance equipment. In this paper the development of these two new machines is traced and their performance after 2 or 3 years of field service is assessed.

A working group presided over by J. F. Coste classified the various fields of research into three categories:

1. Main works including improving ways of doing tasks that are often done manually. The objective is to save more than 100 million francs (MF) (about $16,700,000) nationally.
2. Secondary works include tasks the present improvement of which is difficult or the cost of which is less. Savings here should be between 20 MF and 100 MF (about $3,500,000 to $16,700,000).
3. Minor works represent savings of less than 20 MF (about $3,500,000).

Research and improvement policies have so far taken into account:

- The desire to automate,
- Quality improvement needs,
- Comfort improvement needs,
- Ergonomics,
- The search for multitask equipment, and
- Radio telephone equipment improvements.

Table 1 gives a summary of economic and technological tasks. It can be seen that the main lines of action concern

- Repairs to carriageway surfaces using bitumen emulsion;
- Grass and brush clearing of roadsides, banks, ditches, and central reserves;
- Digging and permanent maintenance of ditches; and
- Deep-level repairs to hot- and cold-surfaced carriageways.

DDE de la Charente, Avenue de la Gare, BP 6, 16400 La Couronne, France.

ORGANIZATIONAL ATTITUDE

There is a generally favorable attitude toward the modernization of road maintenance equipment. This is not just a question of fragile enthusiasm born of the excellent atmosphere, peace, and good relationships that have prevailed in each of the working groups. Every officer knows that innovation is part of his working life even if it leads to far-reaching changes in the organization of his work.

To confirm this de facto situation, two concrete examples of new equipment, the respective conception of which took quite different paths, will be discussed.

MULTIPURPOSE VEHICLE

This design first saw the light of day in the District Public Works Management Committee of the Charente District (Working Group DDE 16). The multipurpose vehicle (MPV) is in use today as the result of the following events:

1. 1983: Working Group DDE 16 Study of Mowing Equipment,
2. End of 1983: Conversations with manufacturers based on DDE 16 specification lists,
3. January 1984: Responses from industry,
4. February 1984: The manufacturer's choice and view of the project,
5. February to May 1984: Continuing discussions between the manufacturer and DDE 16 officers,
6. June 7, 1984: Presentation of the prototype to the Public Works Vehicle Congress,
7. July to October 1984: Trials and national presentation of the prototype,
8. November 1984 to April 1985: Modifications by the manufacturer following trials and presentation in other districts,
9. May to September 1985: DDE 16 mowing campaign, and
10. September 1985: Preproduction version of MPV with various accessories.

Some of these phases are described in greater detail in the following subsections.

TABLE 1 ECONOMIC AND TECHNOLOGICAL TASKS

	Work Cost for Main and District Roads (MF)	Improvements Required			Ongoing Improvements	Research and Improvement Methods
		Work Quality	Production	Safety and Comfort		
Main Works						
Surface repairs with emulsion	1400	***	***	**	Automatic patching	Automation
Mowing and bush clearing	700	*	***	***	Highly productive equipment	New equipment
Ditch cleaning	250	***	**	*	None	Current treatments
Deep surface repairs—hot and cold	300	*	***	***	Insulated containers	Improvement of compacting and cutting
Secondary Works						
Special road marking	150	*	***	***	None	Automation
Verge trimming	80	**	***	*	None	Special equipment to be designed
Aqueduct and trench cleaning	70	***	**	***	None	New equipment to be designed
Sweeping	50	***	*	***	None	Equipment halfway between general and specific
Tree pruning and gantry sign cleaning	100	**	**	***	None	Equipment for working at heights
Road marking (traffic lanes and roadsides)	200	*	**	***	Equipment now being tested	Automatic markers Premarking
Reshaping with aggregate and bitumen mixture	100	***	***	*	None	On-site mixing equipment
Minor Works						
Surface repairs with hot materials	*	***	*	**	Trials now taking place	Equipment and materials to be defined
Road marker cleaning	30	*	***	**	Improvements under way	Automation

NOTE: *** = needs urgent improvement;
** = needs moderate improvement; and
* = needs little improvement.

1983 Working Group DDE 16 Study of Mowing Equipment

Very aware of economic factors, as well as the financial aid granted by the Charente District, the DDE 16 decided to study mowing equipment design and use. The working group was made up of

- Equipment users,
- The head of equipment maintenance, and
- Training personnel.

The working group was chaired by the department head and studied

- Mowing quality,
- Road users' safety and locally elected representatives' comments,
- The performances of brushwood clearing and rotary mower equipment powered by farm-type tractors,
- Equipment and labor costs,
- Personnel safety problems,
- Drivers' comfort, and
- Equipment maintenance problems.

The conclusion of this working group was to reconsider the intrinsic properties of farm-type machinery in order to

- Improve the ergonomics of the driver's cab,
- Increase hourly production,
- Ensure road user safety during and after road works, and
- Intervene more quickly and simultaneously throughout the national and district road network.

Conversations with Manufacturers

Tractor and grass-cutting equipment manufacturers were consulted about the specifications drawn up by the working group. To these specifications were added two other requirements:

FIGURE 1 Multipurpose vehicle.

- The cutter should be placed at the front of the vehicle and
- The mowing speed should be more than 5 km/hr.

Manufacturers' responses were of two sorts:

1. The status quo: considerable improvement made to existing equipment, but not enough to meet the specifications and
2. Innovation: creation of new equipment by just one company, the Société Nicolas.

These results led the DDE 16 to choose the Société Nicolas' truly innovative ideas.

Presentation of Prototype

The prototype was presented with its main feature, the "Rotomower" (Figures 1 and 2). Other features included

- Air-cooled 120-hp Deutz engine;
- Overall length, 5.45 m;
- Overall width (Figure 3), 2.10 m;
- Wheelbase, 3.20 m;
- Height, 3.10 m;
- Dead load without tools, 6.50 tonnes;
- Authorized gross weight (with tools, platform and load), 13.50 tonnes;
- Towing weight (including 2 tonnes towed), 15.50 tonnes;
- Working speed between 0 and 20 km/hr;
- Maximum speed, 35 km/hr;
- Variable (300-mm) height hydraulic suspension allowing automatic loading and unloading;
- Hydraulically assisted steering;
- Hardened-steel one-piece welded chassis;
- Tires, F 22.5 pilot XL tubeless;
- Hydraulic drum brakes on four wheels;
- 300-L fuel tank (= 1 normal working week);
- Seven hydraulic connectors front and rear; and
- Three connecting points in front.

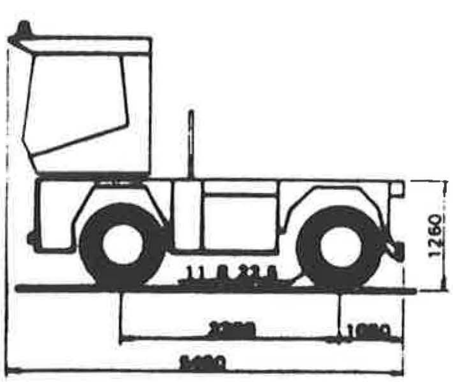

FIGURE 2 Position on road.

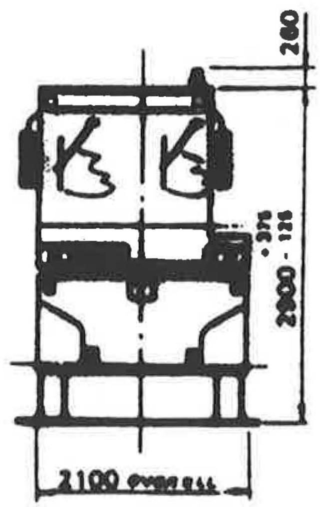

FIGURE 3 Overall width.

The official French classification is Service des Mines: Engin T.P. The prototype is two wheel drive. A four-wheel-drive version is also possible.

Cutting Tool

The Rotomower is attached to the front of the MPV (Figure 4) thus forming a single unit. In two passes it can cut a width of about 2.5 m.

Wide-View Tiltable Cab

Mowing equipment should be designed to limit noise and heat in the cab, to avoid rocking, and to provide good visibility. The driver's seat in the MPV is in a roomy wide-view cab with the following features:

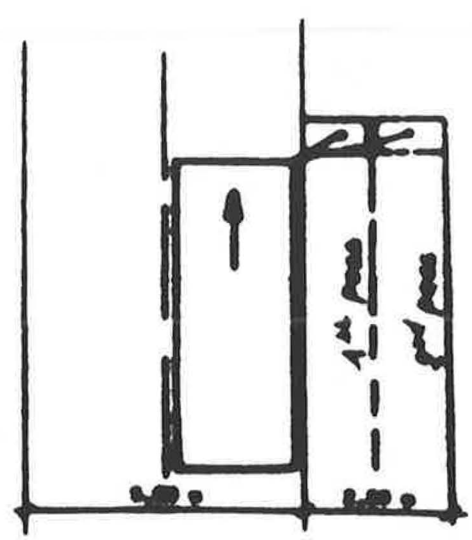

FIGURE 4 Cutting tool.

- The driver's seat is on the right and is accessible from the rear kerbside footplate. Visibility is excellent in front, to the sides, and upward on the right side.
- The seat is adjustable for height, inclination, and fore and aft position. Its suspension is also adjustable, and its arms are retractable and adjustable to provide correct elbow and body support for the driver.
- Lifting the left-hand seat arm activates a cutout switch that stops the Rotomower by cutting the vehicle drive.
- All controls are within easy reach of the driver's hands and feet. Each seat arm has three double-effect hydraulic levers.
- Numerous well-positioned screens and warning lights keep the driver constantly informed.
- The sound level inside the cab is less than 80 decibels.
- Windows exposed to flying objects are made of Lexan.
- Incoming air is filtered and cooled to the desired temperature even in extremely hot weather.
- There is a refrigerated box for food and drinks.
- Other conveniences include a window sunscreen, a clothes locker, and a small folding table.

Connecting System for the Rotomower

Tools can quickly be attached to the front of the MPV (Figure 5) thanks to its suspension and the "Nicolas" interface.

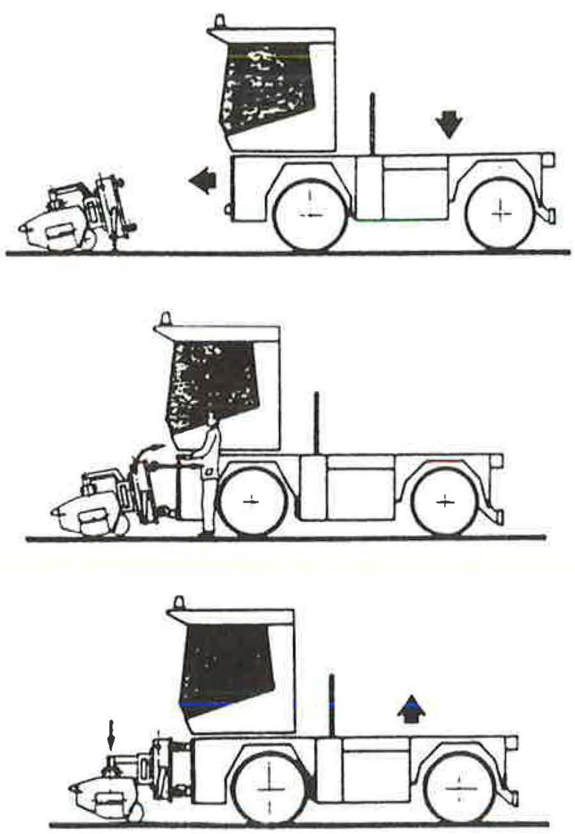

FIGURE 5 Front-attaching system.

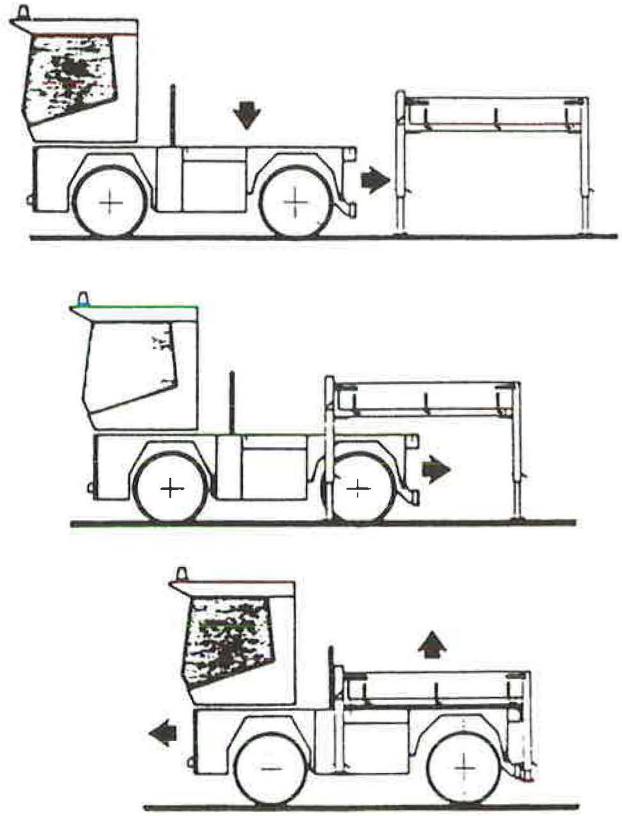

FIGURE 6 Palletization system.

Pallet System

The variable-height suspension system facilitates palletization, thus making the MPV a very fast automatic pallet loading and unloading carrier (Figure 6). Tools or other loads can be carried on pallets.

Trials of the Prototype

The test period was between July and November 1986. During this time,

- Performance was tested and compared with specifications;
- The behavior and reliability of hydraulic parts were studied;
- Cab ergonomics were compared with conventional arrangements, and the various cab features were evaluated;
- The prototype was driven by people of very different backgrounds, including executives, local counselors, mechanics, and managers;
- The prototype was demonstrated to decision makers in various districts, and the development path followed by DDE 16, economic importance, and safety problems were explained; and
- Mowing costs were evaluated.

Other functions and features were discussed as well:

- Sowing,
- Ditch digging,
- Elevator cabin,
- Snow cutter,
- Road marker cleaning,
- Sweeping,
- Surface cutter,
- Loader,
- Salt truck, and
- Painting.

Preproduction Series

During prototype trials the machine met specification requirements. The manufacturer also analyzed and took into account many of the suggestions and criticisms made. This type of testing and the resulting suggestions proved to be a source of interest and encouragement for the manufacturer as he developed a truly new prototype in this hitherto conventional area.

This process took about a year and the preproduction MPV series was launched in 1986.

Evolution of the MPV

Between 1984 and 1986 nine units were produced. These units had three additional accessories: a coring machine, a brushwood clearer, and a vehicle-carrying platform.

Coring Machine

The main technical specifications for this machine, made by the Société Cerimon at Moncoutant in France (79320), are

- The coring machine is attached to the front of the MPV,
- It consists of a hydraulically commanded sliding arm,
- The cutter is driven by a hydraulic motor with an intermediate reducer,
- The cutter has tungsten carbide tips and interchangeable blades,
- It can eject and pile regularly to one side,
- It weighs 1700 kg,
- Cutter rating is 90 hp,
- Maximum distance from MPV to ditch is 4 m, and
- Working rate is between 300 and 500 m/hr.

Brushwood Clearer

The brushwood clearer fits perfectly to the front of the MPV and is used for mowing banks and trimming hedges. Obstacles are automatically avoided by a floating head system. The driver can see the work area clearly through side and top windows. The horizontal part is 4.6 m long, and the rotor power is 60 hp.

Vehicle-Transporting Platform

By using an electric winch, vehicles can be hoisted up aluminum ramps onto the platform for transport. Drivers can thus easily be relieved and the MPV used by two drivers from 6 a.m. to 9.30 p.m.

In 1987 15 units with the following improvements should be in use:

- Power increased to 160 hp,
- Suspension improvements,
- Tubular chassis,
- Tool-attaching system redesigned,
- Mowing height adjustable from the cab, and
- Breakdown localization system installed in the cab.

First Results

Three years after delivery of the prototype, some preliminary results can be examined. Initial results that stem from working experience with the first six attachments show that mowing is economically viable with equipment costing 1.2 million French francs (about $200,000). Practical experience also shows that the MPV was not really used to its full potential, because only a few were equipped with tools other than mowers. Other cases include

- Brushwood cutting in the Vendée District,
- Ditch cleaning in the Charente District,
- Road marker cleaning in the Mayenne District, and
- Snow clearing in the Loir-et-Cher District.

The cost of mowing roadsides with the MPV varied between 4 and 7 centimes per linear meter (less than 1 U.S. cent to about 1.2 U.S. cents). These costs can be compared with those of conventional equipment, which are on the order of 10 to 15 centimes. These figures include driver, amortization, maintenance, and operating cost.

It should be noted that this subject is quite controversial; although the costs of using the MPV are known, the same is not true of traditional equipment. It is safe to say though that the MPV reduces mowing costs by 30 to 50 percent.

It is clear that this equipment has not yet reached its final evolution, and it is probable that in 1987 the MPV will be virtually perfected. On the other hand, more tools remain to be improved or designed.

Comments

Negative Factors

- MPVs are difficult to set up, and in-depth studies are needed to avoid time wasted in traveling.

- Initial investment: how can this system be integrated into existing program renewal requirements?
- Cost: a two-wheel drive 160-hp MPV, a Rotomower, a brushwood cutter, a coring machine, and a vehicle-loading platform cost 1.6 MF (about $270,000).

Positive Factors

- Ergonomics and comfort: possibility of having a tea break during a continuous 7-hr day.
- Safety: improved productivity due to good visibility, control layout, and vehicle appearance.
- Road users' safety: faster working reduces accident risks.
- Good public image reported by local counselors as the result of work on specific routes.
- Personnel: job interest for driving and maintenance staff; increased productivity alleviates staffing reductions.
- Management: reduction of costs; multiple uses ensure profitability if market share is reduced.

Looking Ahead

After 2½ years, the basic principles of the MPV—its hydrostatic transmission and advanced ergonomics—have proved their worth.

On the other hand, this new approach has also demonstrated the necessity of an overall plan and precise usage definition, hence its polyvalence. It now appears that the underlying principle should be used for mowing, brush clearance, and ditch cleaning. Further study is needed to determine the role of the MPV in winter work and other tasks.

Further efforts are needed to optimize and improve the present MPV. It appears to be necessary to rethink certain tools; for example, easier width adaptation may be more desirable than maximum speed for the mower. A definite policy needs to be developed in cooperation with the company that is developing the MPV.

INTEGRATED SURFACE PATCHER

Bitumen emulsion surfacing is another costly part of standard road maintenance. To maintain carriageways at a suitable service level, it is often necessary to deal with local problems by a stopgap measure or by preparing a surface support for another type of technique. This requires that there be on site

- Materials,
- Binders,
- Spreading equipment, and
- Energy supply for compaction.

Patching

Low-cost cold binding materials that are easy to use and stock and can be used under many geographic and climatic conditions are widely used in road works.

Thus patching techniques were born. Binders can be stored in drums, aggregates can be kept near or on site, and spreading and compaction (when done) can be done manually using a tamper or a small roller.

Continuing technological developments have made it possible to perfect pressurized containers that allow the emulsion to be sprayed and containers for transporting and loading chippings as they are spread manually.

These last two pieces of equipment can be made as a single unit to be towed, carried, or self-driven. Compaction particularly favors the breakdown of the emulsion and has traditionally been done by vibrating rollers or by compacting with tires.

Patching Problems

Existing machinery requires the presence of many people:

- One driver per vehicle,
- One spraying man,
- At least two people to spread and smooth the chippings, and
- One person for compaction.

Thus it can be seen that a team consists of at least four people working directly at road level. This presents many safety problems for both road users and personnel.

Because spreading is manual, quantities applied depend on acquired skills, which can lead to bleeding due to too much binding agent or considerable aggregate wastage.

Compaction is not part of the overall operation and so is not generally very well done because there are

- Transport and equipment-moving problems and
- Coordination and productivity level differences that lead to cumulative backlogs that result in reduced production.

Automatic Patching

Traditional patching problems of quantity, compaction, and safety, plus the growing need to maintain and preserve the national road network and constantly rising costs, have led to the notion of consolidating these various activities. This decision is borne out by a value analysis carried out by the French Ministry of Housing, Town Planning and Transport (MULT) of "minor maintenance of highways."

The patching equipment described here (Figure 7) is made by the SECMAR Company and is a prototype that will be studied; evaluation reports will be produced by users (DDE 32 group) as well as the technical services of the ministry.

The unit consists of

- A carrier (GR 190) of 19 tonnes gross weight with rear-wheel steering and spreading from the rear;
- Storage facilities: a 3-m^3 emulsion tank (Figure 8) and a 4-m^3 aggregate container (Figure 9);

FIGURE 7 Automatic patching unit.

FIGURE 9 The 4-m^3 tipper with built-in tailboard spreader.

- A built-in spreader, working from the tipper tailboard, that has a pneumatic chip spreader with 10 flaps and a 10-nozzle pressurized bar (Figure 10); and
- A compaction unit consisting of the rear wheels of the vehicle plus three pairs of tires mounted on an axle and operated by three hydraulic rams through a load distributor (Figure 11).

Energy requirements are supplied by

- A compressor to pressurize the emulsion tank and operate the chip-spreading flaps;
- The truck's hydraulic system that is used (with an additional motor) to operate the tipping mechanism, the operator's platform level, the compacting wheels' axle, and the truck's rear steering system; and
- The truck's electrical system that is used to operate the valve controls.

Hot Resurfacing Repairs

The tipper body is replaced by an insulated container with a distributor chute. The available emulsion can be used for tack coats, and the power available can be used to prepare the area to be repaired (surface cutting, blowing, etc.).

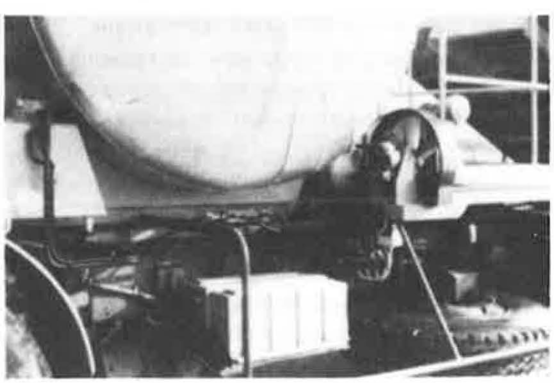

FIGURE 8 The 3-m^3 emulsion tank and compressor.

Repairs Using Continuous Treated or Nontreated Granular Materials

The rear gate to which spreading equipment is attached can be rapidly removed and replaced by a twin chute after a longitudinal separator has been fitted inside the tipper unit. This unit is therefore suitable for deep repairs using aggregate-bitumen mix, cement-bound granular materials, untreated well-graded aggregate, and the like and for sealing wearing courses with granulates.

Results After 2 Years of Operation

Fields of Application

The present design of the Integrated Surface Patcher allows only single-layer sealing coats that consist of a binding base

FIGURE 10 Spreader.

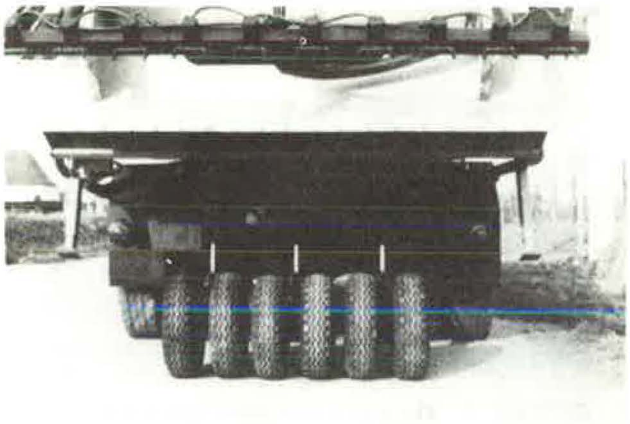

FIGURE 11 Compaction unit.

and a chippings base. It is primarily intended for carriageway surface sealing and not for reshaping or pothole filling.

The patcher carries out "partial surface dressing." This type of repair is used to seal carriageways where surfaces are damaged so as to avoid pothole formation or surface deformations. This equipment is therefore quite suitable in cases in which it is possible to consider and define well in advance the work to be done. The patcher should therefore be used for planned routine maintenance. It should be emphasized that this equipment should not be used for emergency stopgap repairs.

In addition to the uses already described, the Integrated Surface Patcher can also be used for small areas such as carparks, squares, and school playgrounds. It can also seal localized reshaped surfaces provided the area to be treated per day is large enough. For these special uses it may be necessary to use a roller with tires or even a smooth metal roller to finish compaction.

Operation

The Integrated Surface Patcher is a conventional patcher inasmuch as chippings are fed into containers under the operator's control stand from a distributor, and there is a spreading spray.

Manually Started Automatic Patching

The rear stand is fitted with a control panel to carry out the following maneuvers:

- Adjusting bar levels;
- Putting additional compacting wheels in use (or not); and
- Simultaneously spreading binders and chippings, flap by flap.

The patcher needs a team of three:

- One in the vehicle cab to control steady forward movement,
- One on the rear stand to steer the unit, and
- One at the control panel to regulate spreading dosages by 25-cm steps.

Compaction takes place during the first spreading pass and again during a return of the vehicle.

Automatic Patching with Automatic Start

If a line is painted on the road to indicate the beginning and end of the area to be covered, this line can be detected by a battery of optical readers, placed about 1 m above ground level in front of the spreaders as they advance, that open and close the spreaders automatically.

Preliminary Economic Studies

It can be shown that, in the case of superficial surface repairs before coating, savings are on the order of 40 percent both in value and labor time.

This type of equipment can ensure the degree of efficiency demanded nowadays for repairing particular surface conditions, without in any way detracting from the work done by existing enterprises.

State of Present Development

Technical Progress

Since the prototype was demonstrated in June 1985, many modifications have been carried out by the SECMAR Company, the only firm to manufacture this type of machine at present. In order of importance, the main modifications are

- Equipment size: A majority of Integrated Surface Patchers are now fitted to 26-tonne vehicles instead of the 19 tonners used for the prototype. Size should, however, be adapted to each context, and there is now a prototype patcher called Reparetout ("Fixall") that weighs around 5 tonnes.
- System for loading chippings: The manufacturer has developed a lifting arm system to load the tipper. This system appears to be a satisfactory addition to the basic unit and solves the problem of loading chippings, which leads to greater independence.
- Type of binding materials used: Recent Integrated Surface Patcher models can use hot binders or bitumen emulsions equally well. Spreading under air pressure could be replaced by a mixed system of dosage pump pressurizing.
- Spreading bar: Three modifications have been adopted: the bar has been doubled, lateral movements are controllable, and height is automatically adjusted. These modifications contribute to increased work quality.

- Storage tank: The Integrated Surface Patcher can now tow a storage tank of binding materials, thus increasing its daily work capacity and productivity.

Marketing Progress

The first prototype used by the Public Works Management Committee (DDE) in the district of the Gers was operational in June 1985. In 1986 about 50 Integrated Surface Patchers were sold, but only 3 to DDEs. By the end of 1987 there should be around 200 in operation of which 30 will be in public works services.

At present, the majority of Integrated Surface Patchers operates in the West of France, but their use is becoming generalized. It is thought that the Integrated Surface Patcher fills a gap in the market and that its development will continue. This is the result of an excellent adaptation to meet an existing, but hitherto unsatisfied, need.

Use

Approval of the quality of work produced by the Integrated Surface Patcher is virtually unanimous. The machine's cleanliness and improved safety are also appreciated.

The Integrated Surface Patcher can be used either directly by a DDE or through a contractor. If the DDE is directly responsible for the work, a team of specialists is necessary. In either case, road repairs must be carried out at precisely the required site, and there are three ways to ensure this:

1. Mark on the carriageway the areas to be repaired. This is a costly solution but has the advantage of reliability because planning is separated from execution.
2. Allocate to the team a subdivisional officer who is familiar with the road to be repaired; this increases labor costs by 50 percent.
3. Pay for road works in two steps: (a) a daily equipment charge and (b) a charge for materials used (emulsions and chippings).

These recommendations are intended to achieve close cooperation throughout the country in order to unite productivity, quality, and on-the-spot knowledge.

Comments

Positive Points

- Ergonomics and safety: personnel do not work on the carriageway.
- Technical factors: precise binding material and aggregate dosages are used; repairs are systematically compacted.
- Economic factors: high productivity; only two officers are required instead of the usual five; costs are reduced 40 to 60 percent per square meter.

Negative Points

- Planned road repairs: It is necessary to study routes to avoid wasting time.
- Not very suitable for cleaning jobs.
- Large investment: The cost is between 700,000 and 1,200,000 French francs (about $120,000 to $240,000) depending on the specifications chosen.

CONCLUSION

1. The systematic approach adopted by a task force, which included representatives of all administration levels and evaluated each maintenance task and the needs for major equipment innovations, was necessary and has led to a positive balance.
2. The value engineering analysis method has been useful for questioning some habits and has led to the specifications for new equipment.
3. The rapid development of the Integrated Surface Patcher, and its high efficiency in terms of cost and personnel needed, confirms the idea that "these devices may revolutionize routine highway maintenance."
4. The multipurpose vehicle appears to be an important step toward the modernization of routine maintenance; greatly increased productivity, better safety for manpower and road users, and new possibilities for maintenance organization are the three main points that arise after more than 2 years of field use.

LOOKING TO THE FUTURE

"All things on Earth are in perpetual flux" (Heraclitus).

The road network represents an important part of the French national heritage. The perpetuation of this heritage requires the mobilization of energies to ensure design quality and roads maintained in good working order.

The in-depth actions carried out during the past 5 years by the Roads Management have created a general awareness that modernization of road maintenance equipment is one of the major preoccupations not only of decision makers but also of cadres and officers. This cultural evolution is all the more encouraging and enriching because it is backed by a strong desire on the part of manufacturers to stride resolutely along the modernization path.

The way is thus wide open to the year 2000 for forward-looking enterprises to use technologies the social uses of which must be rigorously based on three principles: humanism, innovation, and economic productivity.

Publication of this paper sponsored by Committee on Maintenance Equipment.

Some Equipment Innovations To Improve Safety of Highway Users and Maintenance Workers

G. POINT

Among the many innovations developed in France in the field of road maintenance, three in particular may significantly improve users' and maintenance workers' safety: (a) the cone dispenser, which automatically and rapidly sets up and removes one or two rows of warning cones; (b) the mobile lane separator, which can place road marker blocks that are similar to the New Jersey type of barrier at either 12 or 30 km/hr; and (c) the G810 road surface marking lorry for road surface line painting using several new techniques that improve productivity as well as personnel and traffic safety. These machines and their advantages are discussed.

Three kinds of equipment for road maintenance are discussed in this paper.

CONE DISPENSER

With constantly growing volume of road traffic and the increasing number of maintenance operations, safety levels must be increased. Road maintenance implies millions of warning cones that have to be put in place and removed manually. This operation can now be handled automatically, thanks to a French industrialist's invention.

Description

The cone dispenser comprises a unit with 10 vertical cylindrical magazines in which as many as 230 cones 75 cm high can be carried. This unit is mounted on a chassis.

The cone dispenser can:

- Place cones to the right or left of the unit (Figure 1),
- Collect the cones (Figure 2), and
- Collect cones from one side while it is laying them on the other.

Thus a lane can be displaced laterally from 0.5 to 3.5 m. The driver can program all of these operations himself. Working speed is 15 km/hr.

DDE de la Charente, Avenue de la Gare, B.P. 6, 16400 La Couronne, France.

Driver-Controlled Applications

- Cones can be placed at the required distance on either side of the vehicle.
- Cones, even overturned ones, can be collected from either side of the vehicle.
- Cones can be picked up from one side and simultaneously moved up to 3.5 m away on the other side.
- A traffic lane can be designated by setting down two lines of cones separated by a preprogrammed distance.

The standard cone dispenser only operates moving forward, but an optional version is available for working in reverse.

Recommended Vehicle

The recommended vehicle has a gross laden weight of 4.5 tonnes and a wheelbase of 3.2 m.

Conclusion

The Société d'Etudes Pétrolières (Petroleum Studies Company) presented this machinery at the Fifth International ATEC Congress in June 1986. It provides considerably improved safety for personnel doing road work and road users

FIGURE 1 Cone dispenser placing cones; their spacing is adjustable.

FIGURE 2 Experimental cone dispenser picking up cones.

because warning cones can be used more frequently and more accurately.

FIGURE 3 Mobile lane separator laying first line of blocks in place.

MOBILE LANE SEPARATOR

Traditional temporary road marking methods have not kept up with increased traffic conditions and do not ensure the safety of personnel doing road work or road users. As a result of a number of fatal accidents involving vehicles crossing road marking systems and losing control, a study was carried out to find a solution that would ensure

- Simple, efficient marking;
- Swift setting up; and
- Rapid shifting of the cones or other markers to change traffic flow directions depending on traffic density.

The Technique Spéciale de Sécurité Company (TSS) has developed a new lane separator system.

Description

The basic system consists of a series of concrete blocks that are interconnected by an articulated arm around a vertical axis. Underneath is a passageway with rollers.

Concrete Blocks

The concrete blocks are 1 m long and 80 cm high. Their base width is 60 cm, and they weigh 670 kg (1,477 lb).

Working Principle

The machine picks up the blocks on one side and puts them down on the other side. The vehicle always works protected by its own road marking blocks. The first block is laid in place (Figure 3), and then the machine is brought in front of the first block and the required width is adjusted "crabwise." The machine goes forward, and the blocks picked up slide across the rollers under the machine (Figure 4). The blocks are then put down on the other side of the machine; setting up is thus immediate. Vehicle speed is 30 km/hr for low blocks and 12 km/hr for high ones. The machine leaves when the transposition is finished.

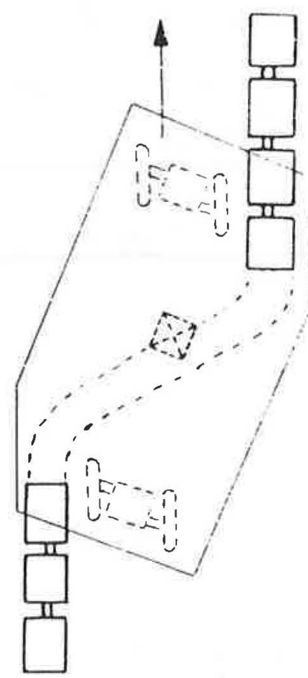

FIGURE 4 Schematic of operation of mobile lane separator.

FIGURE 5 Mobile lane separator.

Equipment

The machine (Figures 5–7) is 9 m long and 2.5 m wide and weighs 6 tonnes. It has a 200-hp diesel engine and a complete hydraulic system. Side travel capacity is 2.1 to 5 m. The machine is self-adjusting, self-driven, and totally reversible. Transposition is performed by sliding the concrete blocks along a roller system.

Application

Where at certain times of the day traffic is heavier in one direction than the other, the number of lanes available to priority traffic can be increased in a few minutes by shifting the separating elements over one lane (Figures 8 and 9). At each end a traffic guidance device, with or without remote control, allows traffic flow to be directed.

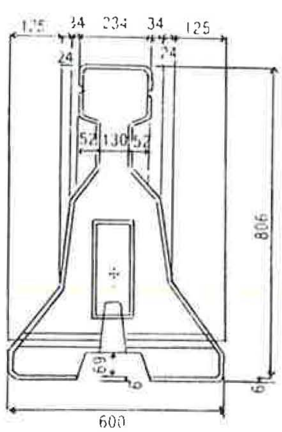

FIGURE 6 Series 800: concrete or metal; Series 500 has a similat profile except it is 50 cm high and 50 cm long.

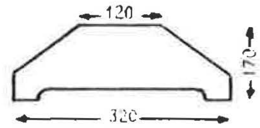

FIGURE 7 Series 200: metal.

Conclusion

This equipment is now in continuous use. Lane changing takes place with no problems in the middle of heavy traffic.

In addition to applications that have now become standard during road works, the following areas could also benefit from use of this equipment in the future:

- Irregular traffic flow spots,
- Temporary traffic increases on weekends or in holiday periods, and
- Planning and design.

ROAD SURFACE MARKING LORRY—G810

The quality of road surface markings depends to a large extent on application conditions, and even more on mastering the use of correct quantities of paint. The safety of road workers and users during line painting is less than it should be.

Studies carried out by the Laboratoire Central des Ponts et Chaussées have shown that widely differing quantities of paint are applied without the driver's realizing what is happening, and research has been undertaken to find different methods and designs, and the Greggory Company has designed the G810 road surface marking lorry.

Technology

Marking Process

The paint spraying system is of the hydraulic airless type, has been patented by Greggory, and has the following advantages:

- Dosage is constantly regulated regardless of temperature,
- There is no need for discs to determine line width, and
- Daily cleaning of the tubes is not necessary.

Traditional methods are not capable of painting two lines simultaneously with different dosages.

Definition of Systems Installed

Airless Pump The airless pump system has two high-pressure pumps the flows of which can be directed toward the

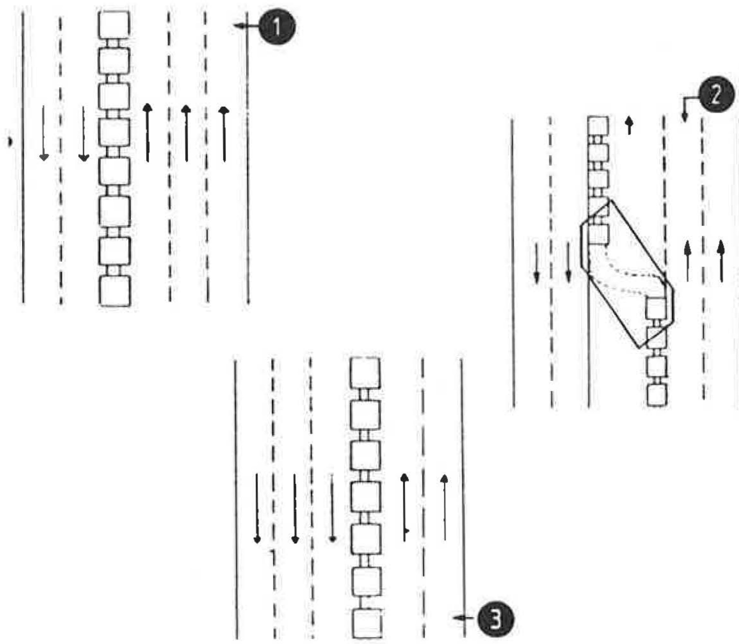

FIGURE 8 Schematic of use to separate traffic: 1, light traffic–heavy traffic during morning rush hour; 2, blocks moved during slack periods; 3, heavy traffic–light traffic during evening rush hour.

centerline of the road or along the roadside, depending on requirements. The output of one pump is 12.5 L/min; the other is a double pump that has an output of 25 L/min.

Marking Guns Marking guns of the airless type are set up for use on roadsides and centerlines. In roadside use three permanently placed paint spray guns give widths of 15 to 18 cm and 22.5 cm. There are also two beading spray guns. The spray guns can be selected from the cabin. Any other desired width can be produced with the 22.5-cm gun. In centerline use three groups of spray guns allow double lines to be painted in one pass.

Power Unit The paint pumps are driven by hydraulic motors the flow and pressure of which are controlled by a hydraulic unit. The hydraulic pump required for the whole unit produces 105 L/min at 110 bars and operates by direct drive from the truck engine.

FIGURE 9 Paris exit of Autoroute A1, July–August 1984.

Air Compressor A 300-cm^3 capacity cylindrical air compressor is driven by the truck engine and does various jobs:

- It controls vehicle braking and the attachment controls with a pressure of 12 bars and
- It controls pistol pressure (5 bars) and glass bead pulverization (2 bars).

The secondary circuit is connected to the attachment outlet.

Power Control System The equipment is entirely hydraulic. A specially designed hydraulic unit includes all of the checking, adjusting, and control systems for moving, guiding, and filling the paint trolleys.

Electronic Control System A rack is installed inside the cab to be used as a control panel to perform relay, calculation, and management operations. The electronic control system is divided into two separate parts; one controls right-hand marking and the other left-hand marking. This arrangement has two major advantages:

- Simplicity of system design and
- In the case of a breakdown, the vehicle is not entirely immobilized because one half is still usable.

When the machine is working, all operations, including speed changes, road surface signs, double lining, arrow spacing, and additional layers, are controlled from the control panel.

Each system includes an industrial-type robot and a printer. The system receives data from a radar device under the vehicle.

Spray Gun Trolleys All of the spray guns are fitted preadjusted and are manually adjustable on two paint trolleys to right and left. These trolleys slide, without play, perpendicularly to the median axis of the vehicle. Paint trolley outward movement is 1.2 m.

Camera Guidance Given the high speed of painting (up to 22 km/hr), a mechanical guide would not be sufficiently accurate and would also lead to excessive eye strain. On this vehicle two matrix cameras are fitted to each of the two trolleys. Their images are shown on screens in the cab.

Dosage Control System The control rack provides the operator a permanent visual check of dosage for each side. The automatic system has warning lights to indicate

Situation	*Indication*
More than maximum dosage	Red lamp
Less than minimum dosage	Orange lamp
Correct dosage	Green lamp
Breakdown	All three lamps on

By using a switch on the control panel the operator can manually correct flow. Actual dosage is shown every 15 sec and is based on the average of instantaneous dosages measured at the processor speed during the opening of the spray gun excluding its reaction time and that of the hydraulic system.

Daily Distance Data A printout can be produced at any time by pressing a single key; the printout gives, for example, the distance since last reinitialization at the start of the job or that covered during the day.

Carrying Vehicle The problem of sideways movements is solved by using a four-wheel-steering vehicle. A standard all-purpose, multifunction Brimont type ETR 206 S vehicle is used.

Conclusions

The technical performance of this system gives better productivity than that of traditional machines, and, at the same time, it gives the staff safe working conditions without interfering with traffic.

GENERAL CONCLUSIONS

In each of the three parts of this paper conclusions have been drawn about particular applications and uses. These three cases are only examples from a wide range of new ideas for meeting maintenance requirements.

In a more general sense it can be said that users' needs will require more and more innovations that, like the ones discussed here, reduce the time spent actually on the road for any given job or feature automation, or both. Such innovations will lead to increased safety for maintenance workers and motorists.

Publication of this paper sponsored by Committee on Maintenance Equipment.