

REHABILITATION OF CONCRETE PAVEMENTS ANTI-SKID PROPERTIES

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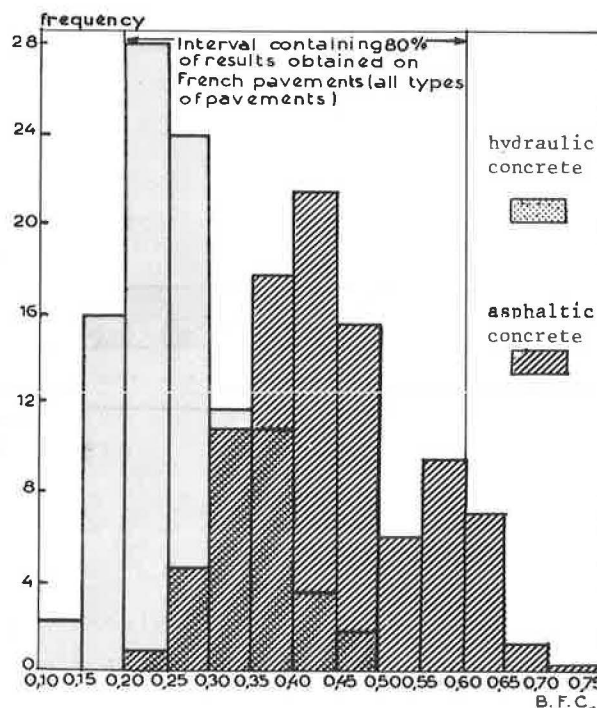
The highways built in France in the 1960-1970 period with a cement concrete pavement have now very low friction coefficients, mainly because they had received only a very unefficient burlap surface treatment. This leads to an abnormal decrease of safety on wet conditions, characterised by a high value of the ratio "number of wet pavement accidents/total number of accidents". A research has been made by L.C.P.C to compare different methods of skid resistance improvement, in order to prepare a program of improvement work on this network. 25 experimental stretches on highways have been made, including transversal (diamond sawing and percussion) and longitudinal (diamond sawing) grooving with different grooving patterns, and surface dressings. The main conclusions are :

1. For longitudinal grooving, narrow and close-set grooves are more efficient than wide and far apart grooves. As for braking force coefficient, longitudinal grooving leads to surfacings equivalent to a poor asphaltic concrete, but as for sideways force coefficient its efficiency is much better. The influence of grooves depth is not high, provided this depth is more than 2 mm.
2. For the same quantity of concrete removed by grooving, the braking force coefficients obtained with longitudinal and transversal grooving are the same, but the sideways force coefficient is much higher with longitudinal grooving.
3. It is possible to use surface dressings on a highly trafficked concrete motorway (40,000 veh/day) with hard stone chippings and a polymer modified asphaltic binder. This process is cheaper than grooving on concretes made with flint aggregates; after four years the skid resistance is still good.

The anti-skid properties of concrete pavements having received a light surface texturing (burlap drag finishing or transverse brooming) are reduced very quickly under the effect of traffic. In France this deterioration in pavement skid resistance has been especially noted during recent years with the growing use of studded tires. On freeways having supported 4 to 5 years of traffic, pavement friction coefficients have taken on low values, especially at

high speed, and are in any case clearly lower than those obtained on the asphaltic pavements of freeways handling similar traffic levels (figure 1)

Figure 1. Braking force coefficient at 80 km/h on hydraulic concrete and asphaltic concrete pavements carrying similar traffic (freeways).



These low friction coefficients have brought about greater wet-pavement accident proneness especially on older concrete pavements. The criterion used in France to assess wet-pavement accident proneness is the ratio of the number of wet-pavement accidents to the total number of accidents. It has been found that this ratio was much higher on the oldest concrete paved freeway sections, the braking force coefficient of which (measured with the L.P.C trailer) at 80 km/h is in the neighborhood of 0.20.

From this arose the awareness that a substantial improvement in rainyweather safety could be achieved on French freeway concrete pavements by utilizing an effective method for rehabilitating their anti-skid properties. Such a treatment would be justified on pavements older than 4 or 5 years which, when originally placed, were given only a light surface treatment, these pavements representing over 300 km (90 percent) of the concrete paved freeways existing in France in 1975.

For this reason, the Laboratoire Central des Ponts et Chaussées (L.C.P.C) has been undertaking since 1972, at the request of the Service d'Etudes Techniques des Routes et Autoroutes (S.E.T.R.A), research aimed at comparing the different methods of rehabilitating the skid resistance properties of concrete pavements in order to determine their optimum utilization conditions in France.

In setting up the research program, use was made of the results obtained in the United States, and in particular in California where a current practice is the longitudinal grooving of pavements by means of diamond saws yielding very fine grooves (2,4 mm wide) with a small pitch (20 mm between groove centers) and a minimum depth of 3.2 mm. Account has also been taken of experiments conducted in England especially in connection with transverse grooving as well as the use of tar-P.V.C surface dressings. However, the conclusions arrived at in these countries are not applicable to conditions in France without further studies. In fact, climatic conditions are very different (in Los Angeles, only 2.5 percent of the traffic occurs on wet pavements - corresponding to at least 0.25 mm of rain in one hour - whereas in France this proportion is doubtless higher). Driving conditions, types of vehicles and especially the types of tires are also different. Limestone aggregates are generally used in California, whereas in France many concrete pavements contain silex aggregates which are more difficult to saw. Finally, California traffic is much lighter and, as it is not exposed to studded tires, is not as hard on roads as French traffic.

Other countries have also used various methods for producing an aggregate mosaic on the concrete pavement surface by removing part of the surface mortar so as to enhance pavement roughness. The following methods may be mentioned.

1. Flame treatment, which breaks up part of the mortar by a sudden thermal shock obtained by means of propane burners.
2. Hydrochloric acid treatment, to break up part of the mortar by spraying diluted acid on the surface and brushing vigorously.
3. Roughening by impact to destroy the surface of the concrete.

These methods have apparently not been very efficient or long-lasting and certain are liable to weaken the concrete surface.

French experience with concrete pavement grooving prior to 1972 was gained essentially on airfield runways. Because of the large width of runways (45 m and sometimes wider) and the very small cross slope (1 percent maximum, as against 2 to 2.5 percent for a highway), the accelerated drying of the pavement takes on primary importance, so that transverse grooving is essential. In general, as in other countries, runway grooves are 6 mm wide, 3 mm deep and from 25 to 40 mm between centers. However, the Aeroport de Paris prefers much wider grooves (10 mm) in order to facilitate the removal of tire rubber deposits, and much lar-

ger spacing (100 mm pitch) for reasons of economy.

However, it became clearly apparent that the problem of runways was very different from that of freeways. Besides the width and the cross slope of the pavements, tire-pavement contact conditions are very different. On runways, much higher speeds are encountered, as well as higher contact pressure and larger contact areas. Aircraft tires moreover have deep longitudinal treads, and devices are used to prevent wheel locking, whereas vehicle tires can be smooth and wheel locking can occur. Surface wear and polishing is also less of a problem on runways than on highways. Finally, working conditions for grooving operations are quite different. It was thus evident that the types of grooving suited to runways stood only a meager chance of being adaptable to highways.

At most, use could be made of braking force coefficient measurements carried out on runways under usual highway test conditions. These results indicated that new transverse grooves 6 mm wide, 3 mm deep and with a spacing of 30 mm were very effective (the braking force coefficient rising from 0.12 to 0.35 at 120 km/h).

Tar-vinyl surface dressings were also used in France on concrete pavements but for traffic much lighter than freeway traffic.

Research Program On The Rehabilitation of Freeway Concrete Pavement Anti-Skid Properties

Based upon our knowledge and the particular requirements of our freeway network, it was possible to set the research objectives to be striven for in France with regard to methods for rehabilitating the skid resistance properties of concrete pavements.

These goals are as follows :

1. Comparing the different possible methods and determining their fields of utilization.
2. Setting, for each method worthy of interest, its optimum conditions (arrangement and dimensions of grooves, formulation of surface dressings).
3. Evaluation their effectiveness.

The methods to be adopted must exhibit a sufficiently lasting effectiveness, with an acceptable cost, must involve work not hindering traffic excessively (traffic flow and safety), without any drawback to their application, must conserve the other surface properties of the concrete (evenness, rolling noise) and, finally, must allow a new rehabilitation of anti-skid properties when the effect to the treatment has become insufficient.

A preliminary problem to be solved was whether on the French network, it was desirable to look for rehabilitation methods applicable only to short stretches of highways where a clearly higher wet-pavement accident rate was observed (in this case, it was necessary to look for very effective methods from the viewpoint of water drainage but involving a rather high cost) or whether it would be preferable to define methods capable of being applied to all concrete pavements over their entire length (in this case, only low-cost and fast-application methods were considered, even if their effectiveness was not so high).

A first study of this problem, dealing with personal injury accidents over a 3-year period, made it possible to point out zones of which the cumulated

length represented 8 to 10 percent of the total length to be considered road, in which the ratio of the number of wet-pavement accidents to the total number of accidents was clearly higher than along the rest of the road. Over 40 percent of wet-pavement accidents occurred on these sections. A second study, dealing with material and personal injury accidents over the next two years on the same road, appears to confirm only certain wet-pavement accident prone areas previously found.

Among the wet-pavement accident prone areas which appear to remain constant in the studies conducted during different periods, most are zones with long ramps or depressions, or banked corner transition zones located on a flat pavement. The skid-resistance properties of these zones are poor, without however being lower than elsewhere in every case. The difficulty of interpreting these results calls for great caution. There are, however zones in which skidding accidents occur and in which pavement surface water drainage is not as effective as elsewhere. But, there are a majority of accidents which are distributed in a random manner and, while the treatment of skid-accident prone areas must be given priority, it is also necessary to find methods of rehabilitating the anti-skid properties over the entire length of a road.

Considering the results of a study of the literature, it was decided to concentrate research on two methods : grooving and surface dressing.

A program of experimental road sections was therefore worked out, including a rather large number (25) of short sections (100 to 300 meters) for the different rehabilitation methods to be compared. The criterion used for comparing the effectiveness of the different methods was the improvement in friction coefficients. The effect of increasing rainy-weather safety was investigated only subsequently, on longer sections prepared with the best methods found during the first phase of the study. These accidents studies require long enough observations and are consequently not yet completed.

Rehabilitation of Anti-skid Properties By Grooving

Principle of action

The methods of rehabilitating the anti-skid properties of pavements by grooving are aimed at modifying the pavement surface water flow conditions. At least as regards certain groove arrangements, their principle of action is twofold.

1. They accelerate the drying of the pavement surface, with the water filling the grooves and flowing out faster in the grooves than on the pavement surface. Consequently, the pavement remains wet shorter and, for a given rain, the thickness of the water film is less. This may be referred to as a "preventive" effect. Obviously, this effect will be in direct relation with the distance of the grooves from the line of greatest slope of the pavement, and with the pavement water runoff conditions.
2. They facilitate the ejection of water from under the tire preventing the appearance of a continuous water film between the tire and pavement, or in any case clearly reducing its thickness.

The grooves act as an auxiliary to the tire treads. In contrast with the preceding principle of action, this may be referred to as a "instant" effect.

For this latter effect, it is seen that orientation of the grooves has a secondary influence but that, by contrast, the groove surface falling within the imprint of a tire is predominant. Finally, it is possible that the sharp edges of grooves, when they exist, facilitate the breaking of the water film under the tire : the orientation of grooves in relation to the considered braking force direction doubtless intervenes in the latter effect.

Different types of grooving

If we disregard the grooves made along two perpendicular lines at an inclination of 45 degrees to the centerline of the pavement, which have been tested on experimental road sections in England, two types of grooving exist and are favored by engineers.

1. Longitudinal grooving.
2. Transverse grooving.

It is also possible to classify grooving techniques according to their working methods :

1. Diamond blade grooving. What is involved here is a virtual sawing of the concrete, but to a depth of only a few millimeters. The grooves thus formed have clean borders and sharp edges when the grooves is new, and the walls of the groove are perfectly smooth (unless the sawing produces concrete spalling, which occurs with certain aggregates - silix - poorly suited blades or in the case of grooves which are too deep in relation to their spacing).
2. Impact grooving. In this process, the grooves are obtained by breaking up the concrete under impact. This result is obtained either by means of small compressed-air hammers (KLARCRETE process) or rotating beams (ERRUT process, Cement and Concrete Association).

In both cases, the hammers or beams are fitted with tungsten carbide inserts. The grooves obtained have fairly irregular borders, rounded edges, and walls exhibiting roughness.

In fact, if we confine ourselves to processes which can be implemented on a large scale on free-ways with equipment presently available on the market, and involving an acceptable hindrance to traffic, there are only two valid techniques :

1. Longitudinal grooving with diamond-studded blades, for which operational machines of American manufacture exist (Catgroover, Hatcher, etc...).
2. Transverse grooving by impact of rotating beams, performed with an English prototype machine (ERRUT - CCA) or with other machines.

Finding optimum grooving arrangements Results obtained by L.C.P.C

Several tens of experimental road sections were constructed in 1972 and 1973 in order to determine optimum grooving arrangements for transverse as well as longitudinal grooves. It should first be pointed out that the different types of grooves were compared from the viewpoint of an improvement in the anti-skid characteristics measured either by means of the L.P.C trailer or the C.E.B.T.P (Centre Expérimental de Recherches et d'Etudes du Bâtiment et des Travaux Publics) "stradographe". These two apparatus wet the pavement immediately ahead of the measuring wheel. The result is that the different processes are compared only from the viewpoint of the "instant" effect of ejecting the water from under

the tire, and not at all from the viewpoint of the "preventive" drying of the pavement.

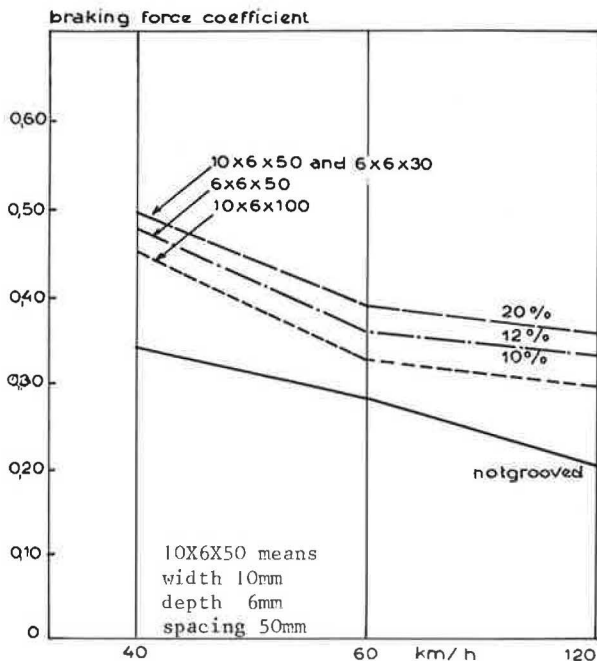
Transverse grooving

Grooving with diamond saw. Although transverse grooving is presently not achievable on a large scale on freeways except in the form of impact grooving, most of the experimental road sections have been set up on the basis of convenience with diamond-studded blades.

Four experimental road sections were constructed on the French Autoroute (freeway) A6 near Paris (in the Seine et Marne Department) on a fairly old (1963) silico-limestone aggregate concrete (the aggregate being a natural mix of silex and limestone aggregates). However, as the surface wearing led to an exposure of the aggregate, the pavement exhibits a certain macroroughness, so that the skid properties, in particular at high speed (braking force coefficient of 0.29 at 80 km/h), are slightly higher than the average of these old freeway concrete pavements.

It is noted (figure 2) that transverse grooving clearly improves the braking force coefficient whatever the speed and in proportion to the concrete area removed. As a first approximation, it moreover appears that the effectiveness is the same irrespective of the manner in which this surface is removed: narrow and closely spaced grooves, wide and highly spaced grooves (in the field investigated, i.e. with pitches not exceeding 100 mm).

Figure 2. Braking force coefficient as a function of speed for different types of diamond transverse grooves on silico-limestone aggregate concrete.



Note : % = percentage of concrete surface removed

A large part of the improvement is obtained as soon as the groove surface reaches 12 percent of the total surface. It increases to a lesser degree for higher removed surface proportions.

Transverse grooving also clearly improves the sideways friction coefficient (with a slip angle of 3 degrees) but the maximum improvement is reached as soon as the surface of the grooves reaches 12 percent of the total surface, and then no longer increases.

It is possible to conclude, for diamond transverse grooving, that the grooves must remove at least 12 percent of the concrete surface. This result can be obtained, for example, by using grooves 6 mm wide, spaced 50 mm between centers. On a worn concrete, with a braking force coefficient from 0.20 to 0.25 at 80 km/h, and from 0.10 to 0.15 at 120 km/h, this treatment will lead to a braking force coefficient of 0.35 at 80 km/h and from 0.25 to 0.27 at 120 km/h. The skid-resistance properties thus obtained are suitable, while remaining lower than the average of French pavements (and also lower than the average of asphaltic concrete pavements on freeways, which exhibited a braking force coefficient of 0.45 at 80 km 80 km/h in 1972).

To obtain significantly higher anti-skid properties after treatment, it would be necessary to substantially increase the proportion of the removed concrete surface, by tending toward the proportion of 30 percent recommended by British engineers in 1963 since the effectiveness of the treatment increases only slowly when more than 12 percent of the surface is removed. However, the cost of treatment, if it is performed by diamond sawing, would become prohibitive.

Impact grooving. Experimental test sections were set up using prototype machine ERRUT-CCA, on limestone and silico-limestone aggregate concrete. In this process, the grooves are irregularly spaced, in order to avoid a sharp tire noise. The groove walls are not so smooth than with diamond grooving. The results obtained are given in table

SPEED km/h	BRAKING FORCE COEFFICIENT		SIDEWAY FRICTION COEFFICIENT	
	before grooving	after grooving	before grooving	after grooving
40	0.40-0.45	0.40-0.55		
80	0.20-0.25	0.35-0.43	0.25-0.40	0.45-0.50
120	0.10-0.15	0.25-0.30	0.20-0.30	0.40-0.50

Longitudinal grooving

Fifteen experimental road sections with longitudinal grooving made with the diamond-studded blade were set up in 1973 on the French freeway A6 on different types of concrete. Most of the experimental sections involved a concrete with hard aggregates (porphyritic). The concrete had a low roughness and low anti-skid properties (braking force coefficient of 0.23 at 80 km/h, the not highly polishable stones not being apparent).

A few experimental test sections were set up on two other concretes in order to confirm the findings a low-roughness limestone aggregate concrete of which the polishable stones are apparent (braking force coefficient of 0.22 at 80 km/h); a silico-limestone aggregate concrete of which the slightly

exposed stones are apparent and which thus exhibits a low, but non negligible macroroughness. Its anti-skid characteristics are slightly better (braking force coefficient of 0.29 at 80 km/h). These three concretes are proportioned with 300-330 kg/cu.m of Portland cement. They were placed using a slipform paver and were burlap drag finished. The experimental road sections, in general 100 meters long, were set up using the Catgroover machine which is one of the two machines of American make presently capable of working in France.

This machine grooves the pavement by means of a rotary cutting head with a transverse axis 150 cm wide, equipped with diamond disks of 35 cm diameter driven by a 350 HP motor running at 1800 rpm. The water necessary for the cooling and the lubrication of the blades and laden with cuttings, is pumped, separated from the cuttings by settling and filtering, and then recycled. This is performed by a tractor/motor-pump/tank unit following the grooving machine.

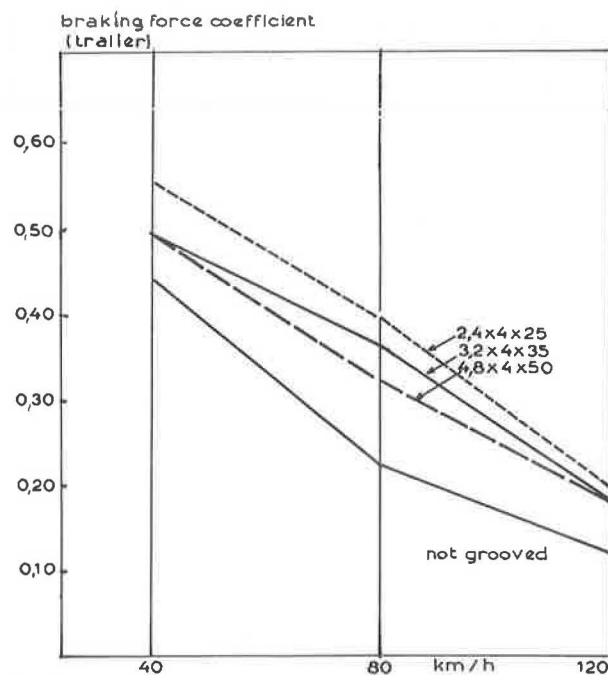
The anti-skid properties on the different test sections were determined shortly after the construction of the sections by means of the L.P.C trailer, for the braking force coefficient, and by means of the C.E.B.T.P "stradographe" for the braking force coefficient and the sideways friction coefficient.

Results

Influence of grooving arrangements.

1. For the same proportion of the concrete surface removed by the grooves, the arrangement of the grooves is significant: it is found that, in order to obtain the best effectiveness, it is better to use fine and closely-spaced grooves rather than wide grooves with large spacing. This results was obtained for the braking force coefficient (figure 3) as well as for the sideways friction coefficient (figure 4).

Figure 3. Influence of groove spacing and width on braking force coefficient for the same removed concrete surface equal to about 10% (constant depth).



Porphyritic concrete - Longitudinal grooving

One is moreover led to choose fine and closely-spaced grooves for another reason; the effect of longitudinal grooving on the driving comfort of motorcyclists.

In fact, the reactions of motorcycle users riding on the experimental road sections very quickly confirmed the observations made in the United States indicating that motorcyclists complained of a feeling of uneasiness on grooved pavements, even when the pavement is, dry, but especially when the pavement is wet.

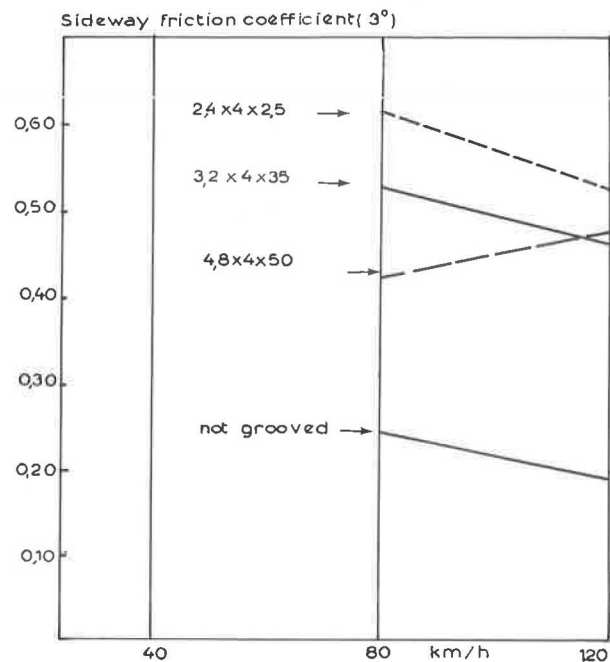
This probably can be explained by an engagement of the grooves in the tire which appears more with tires having longitudinal treads, such as the type used on motorcycles.

If the proportion of the concrete surface removed by the grooves is increased, the effectiveness of the grooving tends to increase but, as a result of the preceding remark, it is more efficient to achieve this by reducing the spacing between grooves and by conserving their width rather than by increasing the groove width and conserving their spacing. This is true as regards the braking force coefficient (figure 5) as well as the sideways friction coefficient (figure 6). The same result has been found with limestone aggregate concrete.

It is however not possible to remove more than 10 to 12 percent of the concrete surface (with grooves 2.4 mm wide and spaced from 20 to 25 mm). In fact, when groove spacing becomes smaller than 3 times groove depth, the risk of damaging the concrete (by the falling off of concrete in places between two grooves) becomes high with certain types of concrete (silex aggregate).

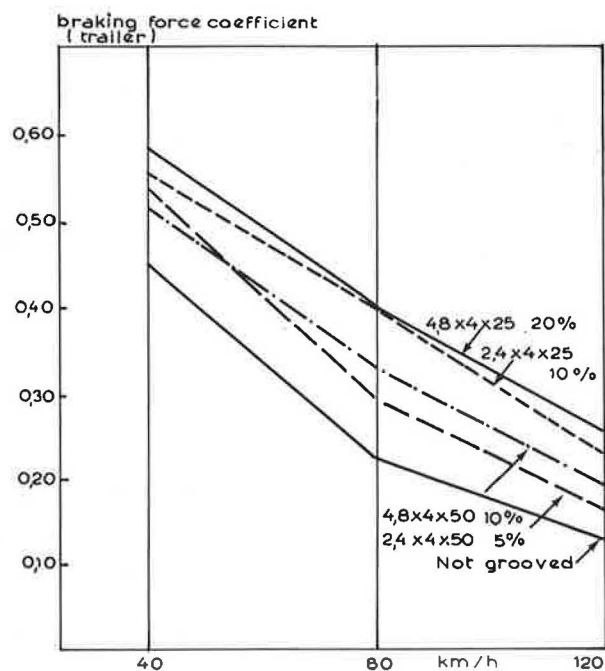
Influence of groove depth. The effectiveness of narrow and closely spaced grooves (2.4mm width and 25 mm spacing) called for by the preceding

Figure 4. Influence of groove spacing and width on sideways friction coefficient for the same removed concrete surface equal to about 10% (constant depth).



Porphyritic concrete - Longitudinal grooving

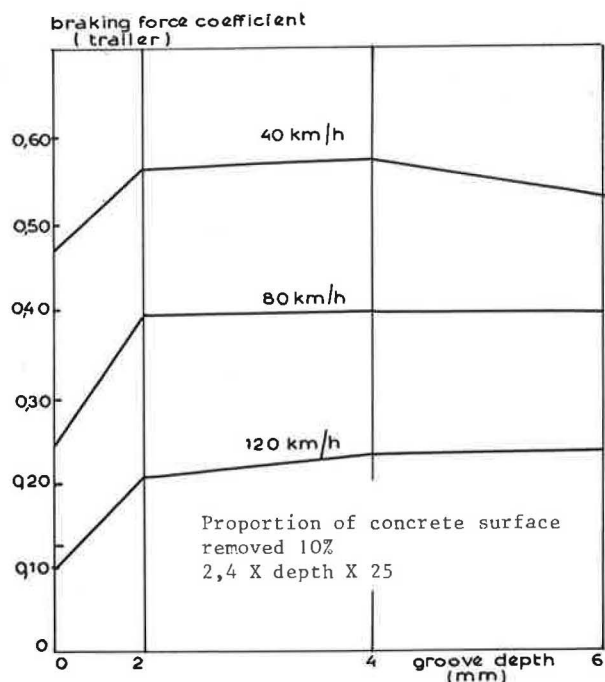
Figure 5. Influence of proportion of concrete removed (at constant depth) on the braking force coefficient.



Porphyritic concrete - Longitudinal grooving

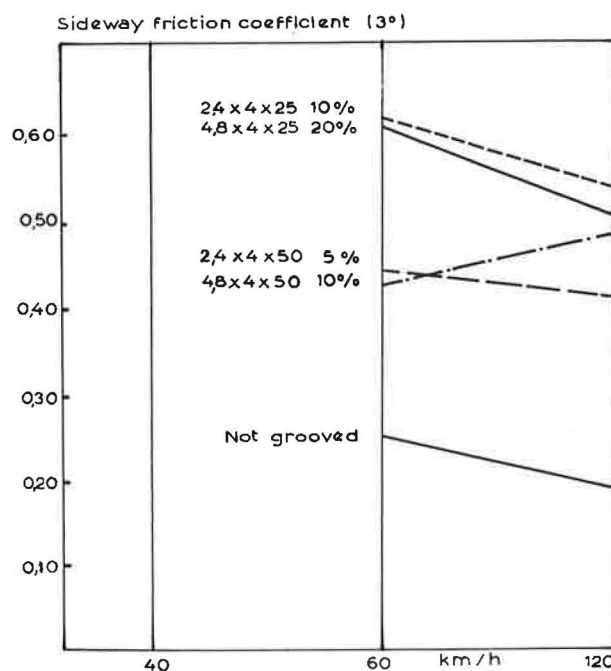
observations, varies very little with their depth, i.e. within the 2-6mm range (these are average depths obtained in the case of these experimental road sections on concrete which was not greatly deformed and, hence, with groove depths not varying greatly).

Figure 7. Influence of groove depth on braking force coefficient.



Porphyritic concrete - Longitudinal grooving

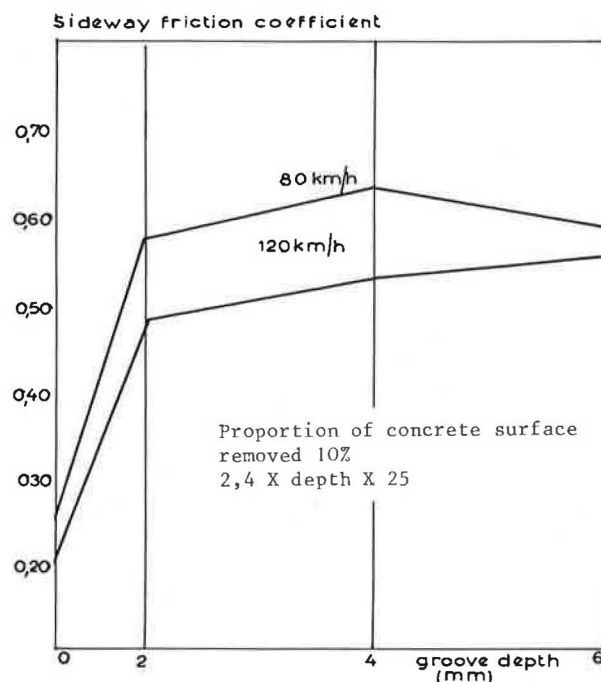
Figure 6. Influence of proportion of concrete surface removed (constant depth) on sideways friction coefficient (3°).



Porphyritic concrete - Longitudinal grooving

However, the unfavorable effect of a decrease in depth is felt more at high speed (120 km/h) than at medium speed (80 km/h) (figures 7 et 8). Below a depth of 2 mm, the effectiveness of the grooving decrease very quickly

Figure 8. Influence of groove depth on sideways friction coefficient (3°).



Porphyritic concrete - Longitudinal grooving

These results are obviously of great importance with respect to the selection of the average depth of grooves to be made and also for estimating the durability of these grooves (these two elements of course being closely related).

It can be set, for instance, that the grooving is no longer efficient when, on more of 10% of the pavement surface, the depth of the grooves is less than 1.5 mm. The histogram of figures 9 shows that, in the case of a pavement exhibiting a poor or bad evenness, there may be a difference of 2 mm between the groove depth reached on 90 percent of the concrete surface and the average groove depth.

Figure 9. Histogram of groove depth - Concrete with poor evenness (1960) - Hatcher machine.

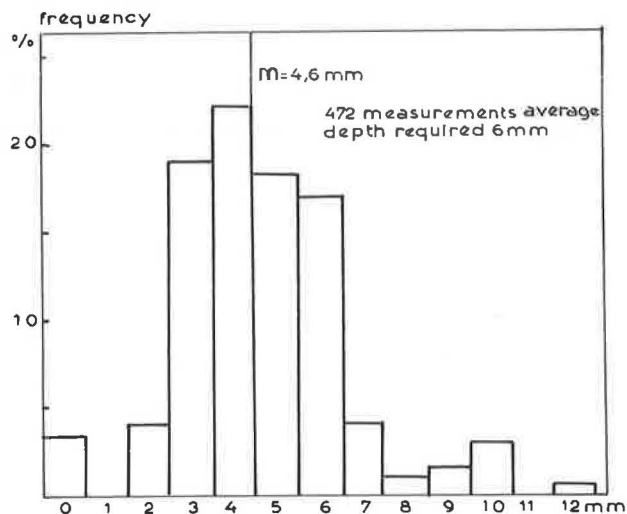
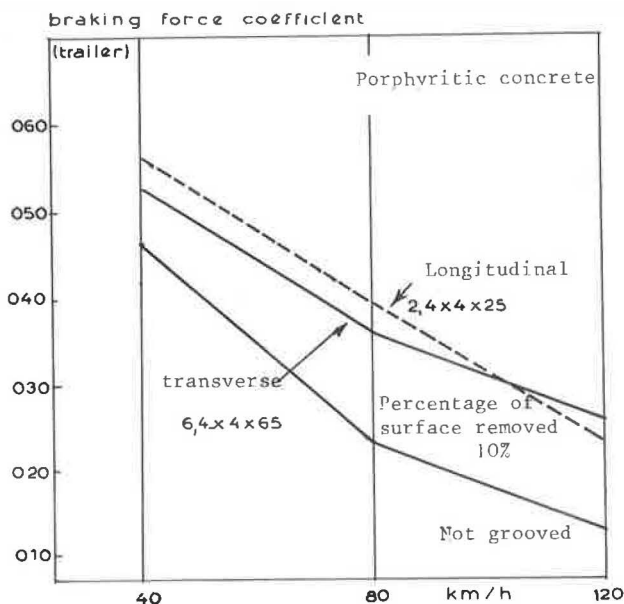


Figure 10. Comparison of longitudinal grooving and transverse grooving with the same amount of concrete removed, for the braking force coefficient.



The annual wear of concrete measured on French freeways is, as an average, 0,5 mm (most of measured wear being between 0.3 and 0.6 mm per year).

It appears reasonable to adopt an average depth of 6 mm. On a pavement exhibiting a poor or bad evenness, the groove depth will be more than 4 mm on 90 percent of the concrete surface; this will lead to a groove service life of 4 to 8 years depending of rate of wear. On concrete exhibiting a better evenness service life of 6 to 10 years is likely.

It may thus be concluded that, for longitudinal grooving, it is necessary to use grooves 2.4 mm wide having an average depth of 6 mm and a spacing of 25 mm between centers.

As an average, on worn concrete pavements of French freeways, this treatment has improved friction coefficients as shown in table

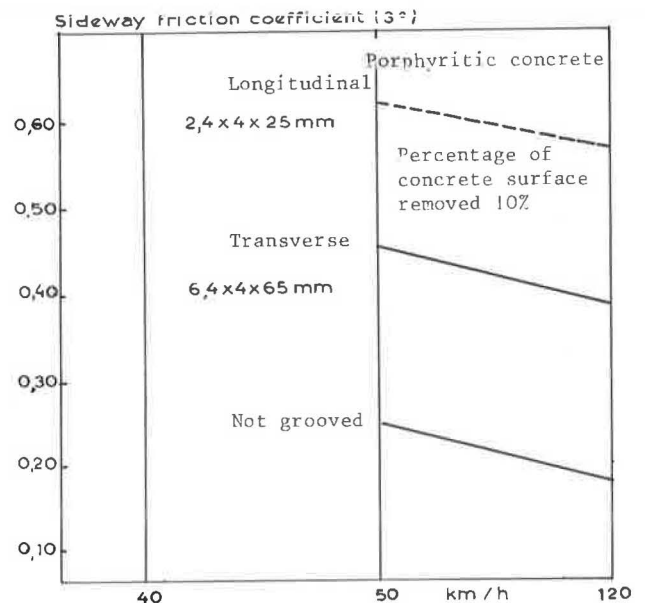
SPEED km/h	BRAKING FORCE COEFFICIENT		SIDEWAY FRICTION COEFFICIENT	
	before grooving	after grooving	before grooving	after grooving
40	0.40-0.45	0.45-0.55		
80	0.20-0.25	0.30-0.40	0.25-0.40	0.50-0.60
120	0.10-0.15	0.20-0.25	0.20-0.30	0.45-0.55

The figures in table result from measures on 30 km of grooved concrete motorways near Paris. These skid resistance characteristics are suitable, while remaining lower than the average of asphaltic concrete pavements on freeways.

Comparison of transverse grooving and longitudinal grooving. (figures 10, 11).

The experimental test sections allow us, first of all, to compare the two treatment modes from the viewpoint of "instant" effectiveness, corresponding to the acceleration of water drainage in the

Figure 11. Comparison of transverse grooving and longitudinal grooving with the same amount of removed concrete for the sideways friction coefficient (3°)



tire-pavement contact area.

It is noted that, for the same amount of concrete removed (10 percent), longitudinal grooving and transverse grooving, using a diamond saw, have a roughly equivalent effectiveness in improving the braking force coefficient. Longitudinal grooving is slightly more effective at 40 and 80 km/h, and slightly less effective at 120 km/h (figure 10). On the other hand, to improve the sideways friction coefficient, longitudinal grooving is much more effective than transverse grooving (figure 11).

And, it would appear that the improvement in the lateral stability of vehicles, in particular in curve sections, is at least as important as the reduction in the braking distance.

However, a comparison of "instant" action is not enough, and it is also necessary to take account of the "preventive" action relative to drainage.

On straight stretches (flat or slightly sloping road), it is certain that transverse grooving plays a "preventive" role with respect to drainage which is not played by longitudinal grooving. The period during which a film of water will exist on a transversely grooved pavement will be shorter than on a longitudinally grooved pavement.

The only valid comparison of the effectiveness of the two processes would be their effect on wet-pavement accidents. The small length of pavement on which transverse impact grooving has been made in our country does not allow such a comparison.

Rehabilitation Of Anti-Skid Properties by Surface Dressing. (Surface treatment).

In this process, surface dressing gives the pavement surface the macroroughness and the microroughness it lacks.

The fact that this surface dressing must be carried out on a freeway, and on a hydraulic concrete slab substrate, calls for the use of carefully selected aggregates, binders and application techniques.

Owing to the high traffic volumes on the freeways to be treated, chippings must have a very high resistance to attrition and to polishing. Since the chippings are placed on a very rigid substrate, they are liable to be crushed by the heavy traffic and must consequently have a high resistance to fragmentation. To enable the resumption of traffic after a very short period of time on the dressed surface, after sweeping and vacuum removal of loose chippings which represent a danger to windshields, the binder used must be very viscous and must very quickly reach its final properties.

The surface dressing methods must also be carefully planned because the work has to be carried out on busy highways. Of particular importance are the choice of materials (spreading of binder and chippings, sweeping and suction), the sequencing of the different work phases and the methods used for controlling the flow of traffic. A discussion thereof is not within the scope of this paper.

On the other hand, a concrete pavement constitutes a very uniform support in which chippings are not liable to become embedded, which is favorable to the service life of the dressing as shown by a comparison of the behavior of surface dressings on a

hydraulic concrete support and on an asphaltic concrete support.

For the study of this method of rehabilitating the anti-skid properties of concrete pavements, use was made of the findings of research conducted in France during the past 5 years for improving the technique of surface dressings, in particular in order to allow their use on heavy-traffic roads. This research suggested that, for a concrete-paved freeway, the surface dressing should be as follows :

1. It should consist of two layers of binder and two layers of chippings or a single layer of binder and two layers of chippings.

2. Chippings, of very hard and nonpolishable rock, must be of large particle size because their mechanical strength is higher and the obtained macroroughness is higher; the largest chippings size must be 10/14 mm.

3. The binder must be a fluxed asphalt or a tar, modified by polymer addition.

Three experimental test sections, each 400 m long, were set up in 1972 on the French freeway A.13 west of Paris, which handles 35,000 vehicles per day at the chosen location (of which 13 percent are trucks of over 5 tons useful load). These test sections were made as follows :

1. One layer of binder and two layers of chippings; the binder is a fluxed asphalt modified by the addition of 10 percent of thioelastomer, the first layer of chippings has a 10/14 mm grading, the second a 4/6 mm grading.

2. Two layers of binder and two layers of chippings, using the same binder, but the first chippings layer has a 4/6 mm grading in this case and the second a 10/14 mm grading. This unusual arrangement is designed to have the first layer of small 4/6 mm chippings play an insulating rôle, preventing the large 10/14 mm chippings from being in direct contact with the very hard concrete substrate.

3. Same mixture as above, but with a tar-P.V.C binder.

The chippings used are from one of the hardest natural rocks found in France (Los Angeles Coefficient 10, Polished Stone Value 0,50).

After 4 1/2 years of traffic, the three experimental road sections are still in excellent condition. Figure 12 shows the evolution of the braking force coefficient during the first 3 1/2 years.

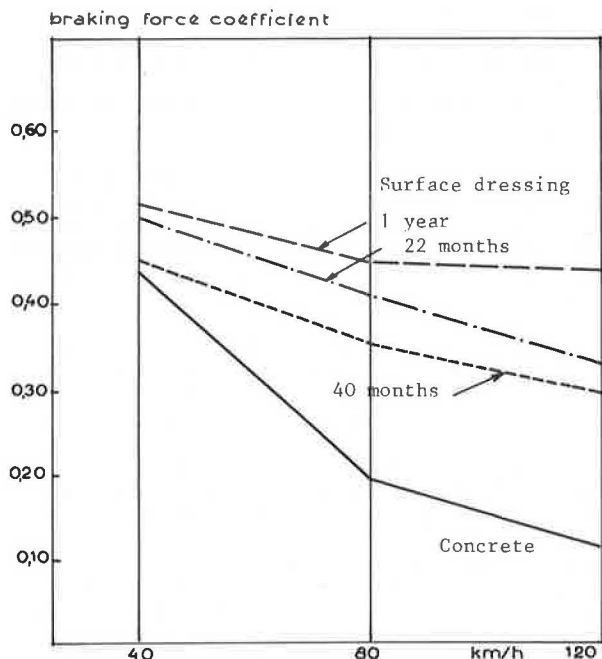
Immediately after laying, friction coefficients are obviously much higher than for any grooving methods.

After 3 1/2 years of traffic, the braking force coefficient at low speed (40 km/h) are low, because of the polishing action of intense and heavy traffic. At 80 km/h the braking force coefficient is of the same order as those of grooved pavements. At 120 km/h, the braking force coefficient is much higher (0.36) than those obtained with longitudinal grooving, which gives a maximum of 0.25. This good result is due to the fact that the macroroughness of the dressing remains high, although it has greatly decreased since laying. These results have allowed surface dressing to be chosen for rehabilitation of anti-skid properties of all the concrete sections of Paris-Lyon motorways, on which more than 200 km of lanes have been dressed since 1974.

The durability of a surface dressing on a concrete freeway is still difficult to predict at the present time. The experience acquired appears to indicate that such a dressing should normally be able to last at least 5 years.

Surface dressings of this type have the drawback of constituting a rather noisy wearing course.

Figure 12. Evolution of braking force coefficient under the effect of traffic. Surface dressing with one layer of asphalt binder and two layers of aggregate of 4/6 - 10/14 mm grading. French freeway A.13 35,000 vehicles per day.



Comparison of Different Processes - Respective Fields of Application

The only three processes presently capable of being applied practically on a freeway are :

1. Longitudinal grooving with diamond blade
2. Transverse grooving by impact
3. Surface dressing.

The problem is to determine the best field of utilization for each of these processes under conditions specific to France.

Each process has a certain number of drawbacks or limitations which rule it out for certain pavements.

Diamond longitudinal grooving

This process has the drawback of being excessively costly on concrete which contains a high proportion of siliceous aggregate, which is rather frequent in France especially on the old freeways. The cost of grooving in this case reaches 15 to 18 F/sq. m (instead of 6 to 7 F/sq. m for the other types of aggregate) owing to the very rapid wear of the saw blades regardless of the care taken in selecting the composition of the cutting parts of the blades.

The use of diamond longitudinal grooving will thus be avoided on siliceous aggregate concrete pavements unless the use of the other two processes is also impossible for other reasons.

In addition, the inconvenience involved for high speed motorcycles, while acceptable in urban areas where rather low speed limits may be set for motorcycles (80 km/h for example) without too much difficulty, is much less acceptable in the open country where long distances are involved and where a such a speed limit would be difficult to impose.

Transverse impact grooving

The use of this process appears to be ruled out in two cases.

1. For pavements having transverse joints which are oblique (and not perpendicular) to the centerline of the road. In fact, the transverse grooves and the oblique joints form very narrow and pointed concrete areas at their intersection where the impact grooving tool could damage the apex. Oblique joints are thus considerably damaged by this type of grooving. And, all concrete pavements in France placed since 1962 by slipform pavers have oblique joints.

2. In urban areas sensitive to traffic noise, it is better to avoid the further increase in the noise level caused by this grooving method.

Surface dressing

The use of this process appears to be ruled out in two cases :

1. For pavements handling more than 35,000 or 45,000 vehicles per day. No experimental data on the use of surface dressings for such traffic are available. The consequences of a failure during the placing of a dressing would become catastrophic and, in any case, it may be feared that the durability of the dressing will be insufficient.

2. In urban areas sensitive to traffic noise, for the same reason indicated with respect to impact grooving.

The cost of each process is also to be taken into account :

1. For diamond grooving : 6 to 7 F/sq. m for aggregates other than siliceous, for an expected durability of 8 to 10 years;
2. For impact grooving : 7 F/sq. m whatever the type of aggregate, for the same expected durability;
3. For surface dressings : 5 F/sq. m for a durability of at least 5 years.

Finally, the effectiveness of the processes is also an important factor. In this regard, the effectiveness of longitudinal grooving in improving the sideways friction coefficient is advantageous for urban roads having small radii of curvature. On the other hand, the effectiveness of surface dressing for high speed traffic is advantageous for freeways in the open country.

The following table may be drawn up to indicate the solutions which appear best suited to the different cases encountered.

Open Country	LOW WEAR RATE CONCRETE PAVEMENT	SURFACE DRESSING or IMPACT	
	HIGH WEAR RATE CONCRETE PAVEMENT	SURFACE DRESSING	
Urban	SECTION SENSITIVE TO TRAFFIC NOISE	LONGITUDINAL DIAMOND	
Areas	SECTION NO SENSITIVE TO TRAFFIC NOISE	OTHER THAN SILEX	IMPACT or LONGITUDINAL DIAMOND
		SILEX AGGREGATE	IMPACT

At the end of 1976, rehabilitation works made on French concrete freeways were as follows.

1. Open country freeways : more than 300 km of lanes with surface dressing, less than 20 km of lanes with longitudinal grooving.

2. Urban freeways : 150 km of lanes with longitudinal grooving, 20 km of lanes with transverse impact grooving.

The effectiveness on reduction of wet-pavement accidents has been very satisfactory, mainly for surface dressing.

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