THE INFLUENCE OF GROOVING OF ROAD PAVEMENTS ON ACCIDENT FREQUENCY

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Frequency of accidents and the percentage of accidents on wet and dry road surface for the years 1966 - 1973 have been analysed on a road of 44 km, comprising few very smooth spots on a total length of about 2 km. Data for analyses were provided by official traffic counts, precipitation measurements of the Swiss Central Meteorological Agency and accident reports of highway police. The 2 km long smooth sections have been grooved twice during the observation period with groove distances of 5,0 and 2,0 m. This road represents a good example for a study on the influence of grooving on accident frequency. Relative values of accident frequency per km and 1 million vehicles were determined in relation to the number of wet and dry days of each year, for the grooved and ungrooved sections. The percentage of accidents on wet surface compared to the total number completes the study. The results show clearly a positive influence of grooving, even with great groove distances, and the effect of a reduction of the water film on skidding properties. A clear-cut information is given particularly by the relation of accidents according to the formula:

$$A_N = \frac{A_w}{A_{w+d}} \quad 100 \quad (\%)$$

Economical aspects of this measure and legal questions about the road owner's responsibility are also considered.

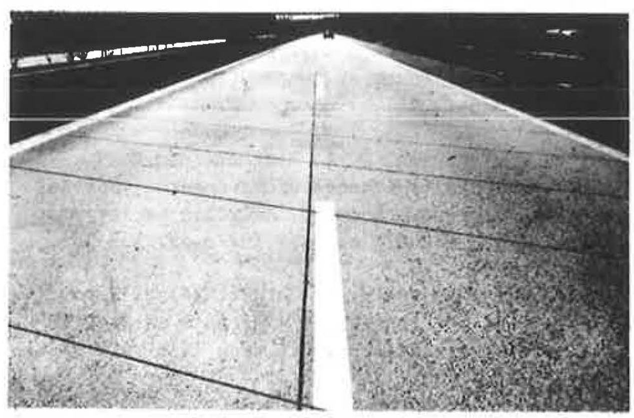
Introduction

In the years 1966 to 1973 police of the Canton Vaud registered an extremely high number of accidents on some particular sections of the National Highway Lausanne - Geneva, km 17 to 39.

Geometric design of the highway was based upon design standards valid at the moment of construction. The road follows the shore of the Lake of Geneva at a certain distance and an altitude varying between 375 and 390 m above sea level. Figure 1 gives a general view of the highway including the grooving of 1970, with groove distances of 2,0 m.

Accidents occurred mostly in particular zones, covering about 5% of the 44 examined kilometers (both directions). A grooving with varying groove distance was therefore ordered for these short sections. The late Prof. Wehner mentioned in his last report (1) good experiences made up to now in America and Belgium with grooving of slippery pavements. However, results of longer observations about the efficiency of such grooves and their condition are still missing. This study can give an answer to both the questions. The condition of the grooves after 7 years of traffic does not present any visible change yet.

Figure 1: General view of the highway (1970) showing the grooving of 1970 with groove dinstances of 2,0 m.



Characteristical Data and Provisions

Weather

Statistical data of the Swiss Central Meteorological Agenci (2) make it possible to determine the number of days with rain in a particular year. Precipitations for this region were calculated from the mean values of 4 meteorological stations nearby. Te assumption was made that only a rain quantity of

1,0 millimeter and more would satisfy the criterion of a wet road pavement. Smaller rain quantities were neglected, assuming that they evaporated in a short time without leaving the road surface in a wet state for a longer period.

Figure 2: Number of wet and dry days for the years 1966 to 1973 (wet when rainfall in 24 hours >1.0mm).

Year	1966	1967	1968	1969	1970	1971	1972	1973
Yearly average								
dry days (365 days)	238.25	246.75	225.25	260.50	236.35	280.25	275.50	277.25
wet days >1.0 mm H_2O	126.75	118.25	140.75	104.50	128.65	84.75	90.50	92.75

Traffic

The highway was opened to traffic at the beginning of the National Exhibition Expo 1964 and had already reached an average daily traffic (ADT) on both directions of 12'696 motor vehicles in 1966. ADT for 1973 amounted to 22'218. We have so total frequencies of 4,64 (1966) to 8,1 (1973) millions of motor vehicles per year on the observed highway section (3).

Figure 3: Annual traffic fequencies for wet and dry days in the years 1966 to 1973 for each direction.

Year	1966	1967	1968	1969	1970	1971	1972	1973
Annual average in millions of vehicles								
Dry days	1.52	1.67	1.73	2.20	2.17	2.74	2.88	3.02
Wet days	0.85	0.80	1.08	0.88	1.18	0.83	0.92	1.03
Total traffic	2.32	2.47	2.79	3.08	3.34	3.56	3.80	4.05

Surface Conditions

At five locations of the highway, on both traffic directions, a much higher concentration of accidents than on the rest of the road was noticed quite early. The observation of a waterfilm covering the road surface immediately after beginning of the rain and staying for a longer time led to the conclusion, that too slow surface drainage could be the cause of this concentration of accidents.

Transverse grooving of these short sections was therefore executed at the end of 1967 and in 1970. The first grooves were cut into the surface with a distance of 5,0 m in 1967. In 1970, after the good experiences of the first years, additional grooves were cut between the existing ones with distances of about 2,0 m.

Those five different sections in both directional roadways were grooved, with a total summed up length of 1,91 km. The residual length of the highway, 42,09 km, remained in the original condition.

All the grooved sections are indicated in the following table.

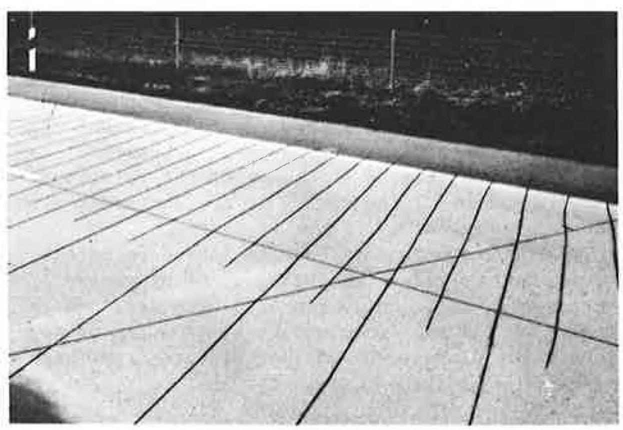
Grooving on the National Highway Lausanne - Geneva

Direction: Geneva	length of Section	grooving type 1967	1970
km 28'350-28'880	530 m	1790 meters 5,0 m distance	1910 meters 2,0 m distance
km 31'020-31'380	360 m		
km 36'100-36'500	400 m		
	1'290 m		
Direction: Lausanne			
km 28'380-28'880	500 m		
km 30'360-30'480	120 m		
	620 m		

grooved pavement=1,91km; ungrooved pavement=42,09km

Actual condition of the grooves is shown in Figure 4, including additional grooves with distances of 0,25 m executed in 1973. The grooves have a width of 6 mm and a depth varying between 6 and 15 mm. The grooves are deeper at the edge side according to a greater amount of water. They are cut in an angle of 10 - 20^{o} to the line of maximum slope, so that they have a greater angle with transversal joints, a shorter drainage distance and better efficiency in spite of relatively great distances between the grooves.

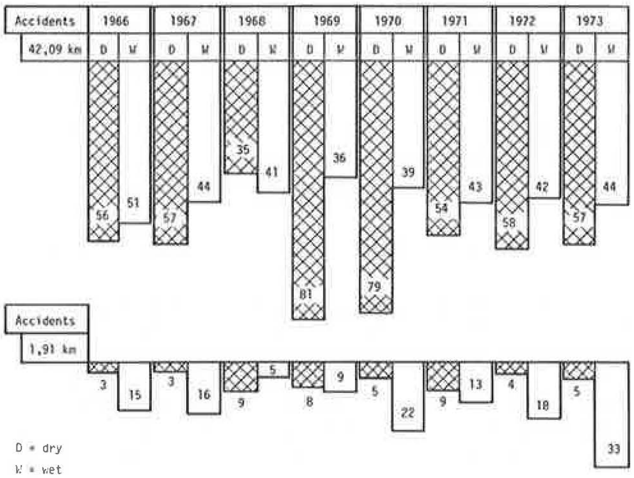
Figure 4: Condition of the grooves after 1973. Additional grooves with distances down to 25 cm were cut after 1973. The position of the grooves in relation to transversal joints can be seen clearly on the picture.



Accident Data

The number of accidents was taken from highway police reports (4) of the years 1966 - 1973. Analyses of these data (Figure 5), particularly of those accidents which occurred on grooved sections, made it possible to draw conclusions on the efficiency of grooving of wet pavements for the traffic intensity existing under these conditions. Relative data (Figure 6) were used for a better comparison of values independently of yearly growing traffic frequencies. These relative data are the number of accidents per km and per 1 million vehicles on wet surface, related to sections with grooved and ungrooved surface.

Figure 5: Number of accidents on wet and dry pavement surfacees for the ungrooved and grooved sections in the years 1966 to 1973.



Other Parameters

Among the factors which cannot be evaluated, we have the influence of traffic intensity, growing yearly with the rate of about 10%, on psychological driver behaviour and a subconscious but unjustified feeling of safety when driving at high speeds, due to different and effective improvements of traffic safety. Both factors can lead to an accident, but they cannot be connected with the alignement of the road or its surface.

After so many years it is also impossible to control whether dust and sand have been deposited in the grooves and how much. This would mean a reduction of drainage quantity towards the pavement edge and ponding on the surface in case of overflow. This could possibly be the cause of the relatively small reduction of the number of accidents after the second grooving of 1970.

These unknown factors have an influence on the results and may reduce the validity of otherwise clear facts. It is however possible to draw general conclusions on the consequences of grooving of sections particularly exposed to accidents from these results.

Skidding Conditions of the Surface

Measurements of skid resistance of the surface were effectuated with a Skiddometer trailer by the Institut for Road Construction and Underground Structures of the Federal Institute of Technology in Zürich (ISETH). Average friction coefficients measured in 1972 on wet surface with blocked wheel and with a slip ratio of 16% are shown below (5).

Direction Geneva, slow lane

Speed	km	μ (average value) blocked wheel	μ (average value) slip 16%
80	18 - 38	26,2 (35)	46,9 (70)*
100	20 - 38	25,2 (30)	45,8 (65)

Direction Lausanne, fast lane

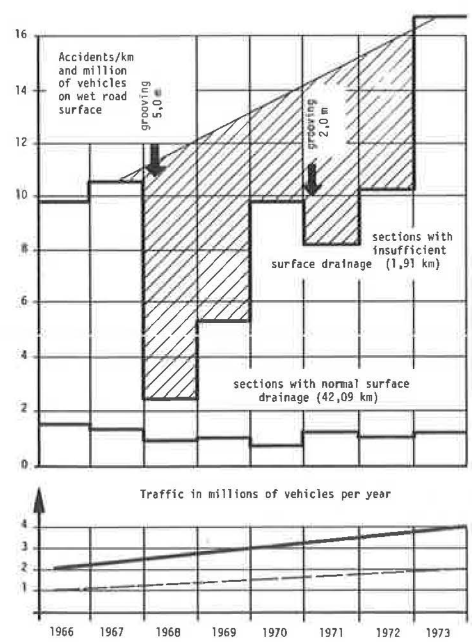
80	21 - 38	30,5 (35)	53,7 (70)
100	20 - 38	21,8 (30)	48,8 (65)

(..)* : minimal values from experience.

These μ-values are also very low on the grooved sections, and are clearly under the limits set by experience.

A slippery pavement gets a considerable friction reduction when the surface is just wet or covered with a thin film of water. Slipperiness is therefore of the greatest importance as a cause of accidents, and measurement of skid resistance is an important additional criterion as grooving, even with great groove distances, improves drainage of the surface without raising the skid resistance of the surface between grooves. As such it helps to definetely lower the danger of accidents.

Figure 6: Evolution of accidents on wet road surface 1967/73 Highway Lausanne - Geneva (km 17 - 39).



Results

General Presentation

The results of the study are given in Figure 6. The lower curve shows the growth of annual traffic in millions of motor vehicles.

The curve in the middle shows the number of accidents on wet surface per kilometer and million of vehicles for the road length of 42,09 ungrooved kilometers.

The upper curve shows the number of accidents on wet surface per kilometer and million vehicles for those sections with a total summned up length of 1,91 km, which were grooved the first time in 1967 and the second time in 1970.

These sections had not yet been grooved in 1966 and 1967, and the high values of the number of accidents shows the high degree of accident possibility. This value was almost lowered to the level of the number of accidents of the remaining 42,09 km after the first grooving (1968). The fact of a new increase of the number of accidents in the following years leads to the conclusion of a sinking drainage efficiency of the grooves. This behaviour occurred also after the second grooving of 1970.

The number of accidents of 1973 corresponds to a value which could have been expected under the assumption that the drainage effect of the grooves had ceased. This means, in other terms, that water drainage was insufficient or none, so that a reduction of the water-film thickness could not occurr. This condition is comparable to that of a surface without grooves. The increase in percentage of the number of accidents between 1966 and 1973 corresponds to the increase of traffic volume during the same period. This observation could be used later (see: Economical Aspects) for a general calculation on economical aspects of a grooving although not always having the maximum efficiency.

Figure 6 shows a clear decrease of the number of accidents after grooving of the surface. This decrease is stronger after the first grooving than after the second. It is essential to notice, that it is not sufficient just to groove surfaces with bad drainage conditions, but that the grooves must also provide shorter drainage distances in addition to a better and faster drainage. This can be done, as it was the case here, by cutting the grooves in a particular angle to the line of maximum slope. This circumstance made it possible to obtain an efficient drainage even with a great groove distance of 5,0 m (first grooving 1967). The second grooving of 1970 with distances of 2,0 m had then an additional effect.

Accidents on Wet Surface

Interesting results (in percentages) can be obtained by dividing the number of accidents on wet surface (separately for the grooved sections) by the total number of accidents, that is on wet and dry surface, according to the formula:

$$A_N = \frac{\text{Accidents (wet)}}{\text{Accidents (wet + dry)}} \; 100\ (\%) = \frac{A_W}{A_W + A_d} \; 100 (\%)$$

This relative value permits a comparison of road section with a great variation of the total number of accidents (Figure 7) (6).

The range of values for the ungrooved sections is around 45%. This value does not indicate any particular danger with wet surface, without considering general skidding properties of the road. Accidents on wet surface go indeed generally up to 50%, according to slope, yearly rain intensities and random effects.

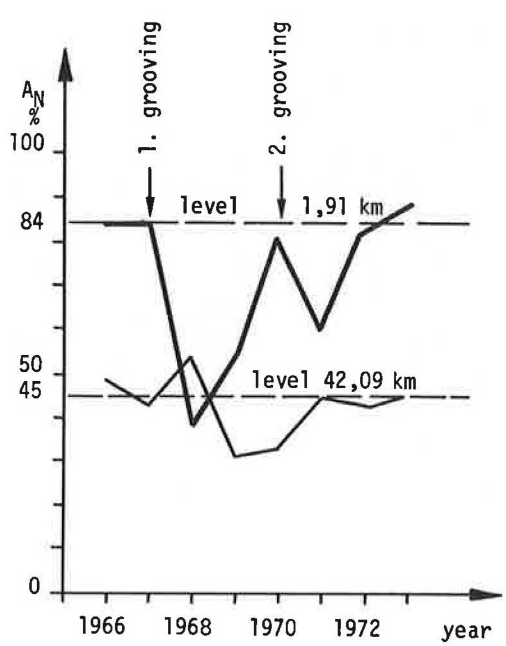
There is on the contrary a great percentage, around 84%, of accidents on wet surface for the grooved sections before grooving was done (1966/1967). These sections had therefore to be judged as highly exposed to accidents and were in a great need of a better drainage. The effect of grooving - a reduction of the water-film - can be seen very clearly in the lower values of the years 1968/1969 and 1971. Grooving can thus reduce the thickness of the waterfilm, but without ever attaining a complete break-through of this film.

It is however difficult to find an axplanation for the reduced long term success of the first grooving (the level of accidents in 1970 was almost the same as before the grooving) and for the efficiency of only one year of the second grooving. The only supposition is a negative influence of dust and dirt filling the grooves.

A graph by Wehner (6) can be used to point out the importance of the average values of Figure 7. It shows the percentage of accidents on wet surface as a function of friction coefficient for 80 road sections in the Federal Republic of Germany.

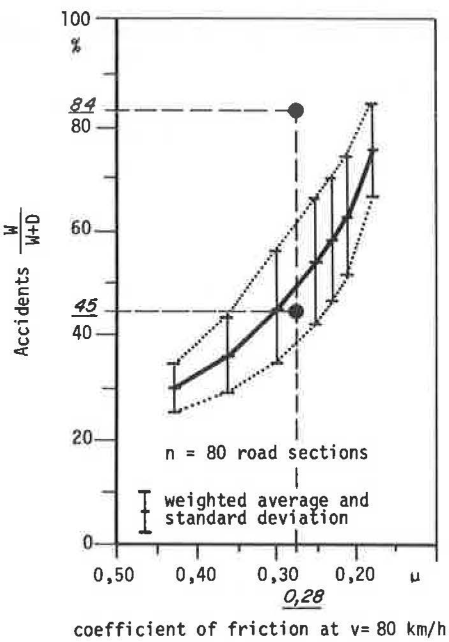
Figure 7: Percentage of accidents $A_N = \frac{A_W}{A_W + A_d} = 100(\%)$ for the grooved and ungrooved sections.
Results in the upper table are given both in absolute values and percentages. (D = dry; W = wet)

Year	1966		1967		1968		1969		1970		1971		1972		1973	
Accidents	D	W	D	W	D	W	D	W	D	W	D	W	D	W	D	W
	59	67	60	60	44	46	89	45	84	61	63	56	62	60	62	77
$A_N = \frac{A_W}{A_W + A_D}$ 42,09	51/107	%/48	44/101	%/43	41/76	%/54	36/117	%/31	39/48	%/33	43/97	%/44	42/100	%/42	44/101	%/44
$A_N = \frac{A_W}{A_W + A_D}$ 1,91	15/18	%/84	16/19	%/84	5/14	%/36	9/17	%/53	22/27	%/81	13/22	%/59	18/22	%/82	33/38	%/87



It has to be considered, that due to differences in the measuring device, the test-tire and water-film thickness certain variations have to be allowed when direct comparison of the values is discussed. Even when the two average values are evaluated under these conditions it can be seen, that the percentage of accidents on wet surface for the ungrooved sections, with about 45%, could be taken as "normal", whereas the percentage of the very dangerous sections (now grooved) is considerably higher and lies at 84% (Figure 8).

Figure 8: Relationship between friction coefficient μ and percentage of accidents on wet surface (6).



Economical Aspects

Each surface problem needing a special treatment to improve traffic safety is connected with an economical question. It is never possible to tell exactly whether additional costs are higher or lower than the amount of avoided accidents, whether an expensive solution is worth the expenses. This study tries to analyse a possible solution from an economical point of view without tragical human problems involved with every accident.

The economical aspect is interesting for the owner, in this case a public road administration, who must provide the expenses for maintenance and repair after the completion of the work and expiration of the guarantee period.

A comparison of the course of the number of accidents on the grooved sections with the course of yearly traffic frequencies shows that the relative number of accidents increased with increasing traffic. In 1973 it reached the same relation to traffic frequencies as in the years 1966 and 1967, before cutting the grooves.

An attempt to consider these facts and to determine the number of statistically possible, expectable but not happened accidents and to capitalize this number with an average sum for each accident leads to the following results.

On the basis of the assumptions which have been made, it is possible to calculate the number of accidents which "did not occurr" as a consequence of grooving from 1968 to 1972.

YEAR	1968	1969	1970	1971	1972	Total
Difference of accident rate	4,56	3,62	1,95	3,20	2,15	
Number of accidents	19,4	12,2	8,75	10,08	7,54	57,97

With the general assumption of 50'000 Swiss Francs for one accident, we would arrive at a sum of about 3 million Francs in 5 years for 58 accidents.

The costs for a very expensive but locally limited measure to increase traffic savety are very low compared to the calculated sum.

Question of Responsibility

The question of responsibility arises at the moment an accident occurs and the following recourses, when a road surface does not fulfill the requirements any more. There are no problems if the accident occurs during the guarentee time of the surface course. In this case it is the contractor who has to come up for the consequences if he cannot prove that he had to fulfill certain specifications which turned out to be unsuitable.

The owner is responsible if the accident occurs after expiration of the guarantee time and is not caused by a concealed defect, construction or other error. It is therefore advantageous to be informed about actual quality and safety conditions and not to be surprised by an accident. A good register must be kept about the condition and the quality of road surfaces in order to be able to establish in time a maintenance and repair program with suitable priorities.

Jurisprudence knows many cases - the first 1932 in Berlin (1) and many other since - in which a road administration was held responsible for damages caused by unsafe qualities of smooth road surface. However, this happened only when it was proved that the accident occurred in spite of a correct behaviour of all persons involved.

A very recent statement about the question of responsibility of a public road administration in relation to such accidents is the one by R. F. Carlson of California's Departement of Transportation (7): "One of the greatest problems facing highway departements is slippery pavements in non-freezing, wet weather, Because of increased legal duties imposed on public entities, highway departments find themselves exposed to liability for accidents that result from what used to be considered purely weatherrelated causes. Immunities are being weakened, engineering decisions are subject to review, and personal responsibilities are being imposed. A program of skid testing is imperative for early detection of low skid resistance areas. The use of mandatory minimum skid numbers is warned against because of possible adverse legal implications. Grooving, as well as other methods (indicated by the author, (8)), has proven to be a solution to problems of low skid resistance. Generally, a public entity is not liable for a highway made slippery by rain alone; however, public entities may be held liable for hazardous low skid resistance conditions that result from their own actions or inactions (worn pavements; defectively designed, slippery PCC pavements; unplanted eroding cut-slopes; improperly applied seal coats; and clogged drains and drainage ditches that cause ponding). They also may be found liable when conditions are purely weather created and the hazard is such that public entity has a duty to remove it entirely or ameliorate it by the use of warning signs. The reasonableness of the public entity's actions generally will be the deciding factor on whether liability will ensue. Justice - so Mr. Carlson closed his words - has put the responsability before the doors of the engineers. It is now in their hands to reach for the correct reaction".

Conclusions

Grooving of polished road surfaces reduces the hazard of accidents when drainage conditions are unfavourable.

The advantage of grooving is the reduction of water-film thickness, which leads to a better contact between tire and road surface for the transmission of forces, although roughness is influenced by very narrow groove distances only. Grooves have a favourable influence on surface drainage if they are cut at such an angle to the line of maximum slope, that water reaches the next grooves after a very short drainage distance. Any further improoved adhesion will however only be reached when grooves at a very narrow distance create an additional keeing action.

The effect of a reduction of accidents by a decrease of waterfilm thickness caused by grooving, as it has been proved in this study, cannot be expected with the same success in all cases. It must be considered that grooving is always just one of the factors, sometimes the most important one, which can influence positively the rate of accidents on wet surfaces. Grooving will always be effective when great water quantities cannot be eliminated rapidely enough from smooth surfaces with insufficient macrotexture.

Grooving has reached the purpose of a reduction of the number of accidents on the observed road. Suitable measures for better skidding conditions on the total length of 44 km would be an additional advantage.

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