TRAFFIC ACCIDENTS AND ROAD SURFACE SKIDDING RESISTANCE

An investigation into the statistical relationship between the skidding resistance of the road surface and relative road risk.

Summary of the research report of Sub-committee V of the Working Group on Tyres, Road Surfaces and Skidding Accidents of the Institute for Road Safety Research, SWOV

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PREFACE

In 1966 the Ministry of Traffic and Transportation in office at that time requested the Institute for Road Safety Research, SWOV, to carry out an investigation into the extent of the phenomenon of "skidding" and the effect of various factors which contribute to skidding.

The Minister authorised this investigation for the following reasons:- Although the phenomenon of skidding is generally accepted as a factor which contributes greatly to causing accidents, it is difficult to establish the extent of this effect. This is because skidding is not a clearly defined term in the registration of accidents; it is not specifically investigated in each accident, whether or not, skidding played a part.

As a result of the instructions given by the Minister, the Board of SWOV set up a Working Group on Tyres, Road-Surfaces and Skidding Accidents. The Working Group had the following terms of reference:

1) Investigation of the technical factors (car, road) which may affect the skidding accidents.

2) Investigation into the extent to which such technical factors actually affect the occurrence of skidding accidents, in other words, a classification of first and second order factors.

3) Investigation into the possibilities of improving such technical factors, which would have a favourable effect on the prevention of skidding accidents.

4) Construction and calibration of measuring instruments, with which the road surface characteristics, (which may cause skidding accidents), can be determined quantitatively.

The first interim report of the Working Group (SWOV publication, 1970-4) was submitted in 1969. This report contained a survey of the entire investigation programme in addition to a survey of the state of affairs (at that time) and a provisional recommendation relating to road-surface skidding resistance. A part of this programme consists of an investigation into the relationship between the skidding resistance of the road-surface and relative road risks. Such relative road risk can be defined as the total number of accidents per million vehicle kilometers.

In this part of the investigation influencing factors other than

the road-surface skidding resistance were taken as constant as far as possible. It has been realised that it would be difficult to find a sufficient number of road sectors of corresponding geometrical parameters and traffic flows. When the influence of bends, intersections, on and off ramps, had to be considered, the difficulties seemed to be so considerable, that the Working Group came to the conclusion, even in the preparatory stage, that the investigation could not be carried out strictly according to the original plan. However, a comparative study seemed possible, if the limited nature of a single-factor investigation was partly modified.
Based on the results of a preliminary investigation, carried out according to a modified scheme, the decision was taken to carry on with the studies on a more extended scale. This extended study, described in the present report, has been carried out by Sub-committee V of the above-mentioned Working Group on Tyres, Road-surfaces and Skidding Accidents. The Sub-committee was made up of representatives of the following bodies:-

- Dutch State Road Laboratory: Messrs. J.C. de Bree en P.M.W. Elsenaar
- Traffic and Transportation Engineering Division Rijkswaterstaat: Messrs. E.W. Hennevanger (successor to Mr. S. Cohen Rodrigues) and Mr. G.J.V. Hotze (successor to Mr. J.H. Jenezon).
- Institute for Road Safety Research, SWOV: Messrs. J.M.J. Bos, J.C.A. Carlquist and H.G. Paar (earlier also Mr. M. Slop).

This summary is adapted from the original subcommittee report by Mr. L.H.M. Schlösser, Institute for Road Safety Research, SWOV.

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Director Institute for Road Safety Research, SWOV.

SUMMARY

The investigation

This study forms part of an extended research programme of the Working Group on Tyres, Road-surfaces and Skidding accidents. According to the terms of reference a statistical relationship had to be established between the skidding resistance of a road-surface and the number of accidents per million vehicle kilometers, based on available data.
The research procedure for studying skidding resistance had to be developed taking into consideration its possible use in future by the authorities in establishing a traffic safety programme. Wherever possible, the research results should be directly applicable for establishing the necessary counter measures.
The research has been carried out on the basic data referring to the years 1965 and 1966. It covers nearly all important road sectors of the Dutch motorway system in which two road types have been distinguished. Road type I, comprises mainly roads with (separate) dual carriageways, while Road type II comprise all other types of roads, such as dual carriageways, and single lane roads.
The data on road-surface skidding resistance, used in this study, refer to wet road-surfaces. The high degree of skidding resistance of dry road-surfaces cannot normally be matched by any kind of wet road-surface. Thus also the available volume data had to be related to wet road-surfaces, and this was only possible by analysing material collected during times of precipitation. The manner in which road-surfaces dry up is not yet sufficiently understood.
The accident data contain a direct indication of the weather conditions. Thus, the terms of reference also included, and mainly concentrated on, the atmospheric conditions of rain. Accidents on road-surfaces made extremely slippery by snow, sleet, frost, were excluded from the investigation.
The relative road risk referred to in the terms of reference, is expressed in the study in two ways. The term "accident quotient" indicates the relationship between the number of accidents, occurring on a given road-sector in a given period of time, and the

total number of vehicle kilometers for the same road-sector and the same period of time. When the number of cars of a given category, involved in accidents, is compared with the total number of vehicle kilometers covered by the given category, the quotient of involvement is established.
The quotient of involvement in the present study is not only established for the total of all cars per road type, but also separately for passenger cars and goods vehicles. The above-mentioned quotients have been calculated for all classes of road-surface skidding resistance from fairly well detailed basic material. In addition, further classifications have been made within each skidding resistance class, for all occurring classes of the total hourly-volume of traffic.

Results and recommendations

Within the framework of the terms of reference the study succeeded in establishing an acceptable object of the investigations; in collecting the necessary data; in correlating such data by indication of a certain sector of a road-surface, the data then having been processed by a computer, according to the objects of the investigation into realistic results.
However, due to the statistical, non-experimental nature of the investigation, the procedure followed in the investigation can only be used as an instrument for traffic safety to a limited extent.
Nevertheless, it seems probable that the relationship established by the investigation, that a lower degree of road surface skidding resistance is related to a higher degree of relative road risk, has a factual basis.
It will therefore be recommended, that as a general measure for traffic safety a minimum skidding resistance has to be established for wet road surfaces. However, care must be taken that the investigation results obtained should not be applied without a thorough analysis of local road and traffic circumstances, within the framework of a very local traffic safety policy.

1. INTRODUCTION

"Skidding" has been defined in the publication dated 1970-4, by the Institute for Road Safety Research (SWOV), referred to in the preface, as "a car movement involving the sliding of one or more wheels". It is evident, that such a phenomenon cannot always be clearly reconstructed after a traffic accident has taken place. In addition, there is no category for "skidding accidents" in the Dutch accident registration system, although under the heading "short description of the accident" in the Central Bureau of Statistics' questionnaire it is quite often indicated whether the accident was strongly influenced by "skidding". Therefore, the extent of the phenomenon "skidding" and consequently, the importance of road-surface skidding resistance for traffic safety, have been almost completely hidden.
However, some earlier investigations have already indicated that road-surface skidding resistance may have an important part in the occurence of accidents. Due to these observations, the controlling authority of national motorways was able to establish a "guide value" for the minimum skidding resistance of a (wet) road-surface. The desired level of this guide value, however, was not defined distinctly. These circumstances lead to an extended investigation, covering not only the skidding resistance of the road-surface, but also the characteristics of tyres and the type of tread pattern, with all their mutual implications.
The present study forms part V of this investigation. Its object is to develope a procedure to find a statistical relationship between road-surface skidding resistance and road risk per million vehicle kilometers, using actual data. The investigation had to confirm such relationship, on the basis of such data.
In order to define relative road risk, both data concerning accidents and those referring to exhibits (in this case: volume and road length therefore vehicle kilometers) are necessary. Other factors, such as vehicle type and other road characteristics, will be dealt with in the next chapter.
The accident data have been derived from the statistical questionnaires, issued by the Central Bureau of Statistics, filled in by the police.

Since 1967, in this questionnaire no data are included concerning minor material damage (it is not yet known how this new procedure will affect the quality of the accident statistics). The present investigation, therefore, needed to use the data of the more complete accident statistics as they were before the above-mentioned modification, which are available, relating to motorways, at Rijkswaterstaat.
The available volume data were obtained from the general five-yearly traffic census by Rijkswaterstaat, taken in 1965 and 1970. On a more limited scale counts are made regularly and also intermittently on the most important motorways.
The data of skidding resistance used in this study were obtained from the Dutch State Road Laboratory, which carried out systematic annual measurements on the motorways and the most important roads of the provincial and municipal road systems; these measurements covered, among other things, the skidding resistance of wet road surfaces.
Finally, the precipitation data - which play an important part in determining the periods in which road-surfaces were wet - are permanently recorded by the Royal Netherlands Meteorological Institute.
On the basis of the available data, the investigation area was limited to the most important Dutch motorways over the years 1965 and 1966.
In this connection it must be pointed out that this choice is not absolutely essential either to the form of the relation to which the investigation was directed, or to the relative importance of the studied factors of influence.

2. SCOPE OF THE INVESTIGATION

The investigation aims at drawing conclusions from a number of traffic accidents concerning the actual importance of road-surface skidding resistance related to the traffic.
It can be assumed that an accident will occur more easily at a lower road-surface skidding resistance than at a higher one. However several other factors will also contribute to the cause of an accident, with the result that the effect of road-surface skidding resistance as such may be masked. For this reason it is important to take into

account all the relevant factors. Therefore in addition to road-surface skidding resistance, some additional factors will be studied. For other observed or unobserved factor or imponderable effects, suitable assumptions will be made, sufficient for an approximation.
The number of accidents occurring on a given road sector will increase - under otherwise identical conditions - firstly, with increasing length of the road sector, and secondly, as a function of the number of cars driving over the given sector; thus, finally, depending on the number of vehicle kilometers performed thereon. Therefore, in order to be able to compare road sectors, the relative road risk, and not the number of accidents, is taken into account.
A second factor, which has a great influence on the occurrence of accidents, is the presence of intersections, bends or other discontinuities in the course of the road. Since it is rather difficult to indicate the measure of discontinuities present on a road, the study was limited to making a distinction between more or less discontinuous road types. Road type I comprises roads with two separate dual carriageways, each comprising two or three lanes and grade-separated intersections (motorways). All other test-roads belong to road type II, which comprises all roads with level intersections, and roads with grade-separated intersections, insofar they have only one path (dual carriage ways and single lane roads).
The hourly-volume of traffic is also of such importance related to the occurrence of accidents, that it cannot be neglected. Combined with the road type, it determines to a large extent the traffic flow characteristics, such as average follow-up distances, driving speed and the number of overtaking manoeuvres. The possible interrelation of traffic volume on road-surface skidding resistance is to be taken into consideration. It is understandable that Rijkswaterstaat tends to establish a high level of road-surface skidding resistance on motorways with very heavy traffic. Lower skidding resistances are then found, relatively more frequently, at the lower hourly-volumes of dual carriage ways with less heavy traffic. Conversely it could be that the heavily loaded road-surfaces will often be less rough due to the polishing effect of traffic.

Goods vehicles traffic and passenger car traffic have different requirements relating to road-surface skidding resistance. These vehicle categories differ from one another in respect to tyre characteristics and loads, and the parameters of motion and dimensions. For this reason the study preferred to establish not only the accident quotients, but also the quotient of involvement for each vehicle category. The category of goods vehicles includes all types of lorries from delivery vans, with or without trailer, to trucks, with or without trailers, of any kind and including buses.
Minibuses, combination-cars and passenger cars, all with or without trailer belong to the category of passenger cars. Other types of vehicles (for example motorcycles) have a small share in traffic volume which can easily be neglected.
Sofar general road factors, factors of driving behaviour, and vehicle factors, were given a greater, although somewhat sketchy attention. Now it is important, that these factors provide for more differentiated measures, relating to road-surface skidding resistance.
The occurrence of accidents will also depend on weather conditions. Moreover, a wet road surface will display a considerably lower skidding resistance than a dry road surface.
All that is known about the skidding resistance of dry road-surfaces is that it is in general higher than the highest skidding resistance found on wet road surfaces. Such high degrees of skidding resistance are not of great importance for the purposes of the present study, and for this reason they will only be discussed incidentally. Furthermore, no definite answer can be found to the following questions:- how long it takes for a road-surface of a certain quality to dry under the effect of sun, wind and traffic; when can the road surface be regarded as dry after a heavy shower and before a further rainfall starts.
For this reason vehicle kilometers can only be computed for the periods of rainfall or for the periods of no rainfall. So, for technical reasons too, the study is mainly concerned with weather conditions of rain.
Based on the above-mentioned factors it is possible to classify the general traffic situations, roughly, with regard to the number of accidents caused thereby. Other circumstances of the accident and the

process of the accident itself are not taken into account, even if they can be established and made available for counter-measures. The skidding resistance of the road-surface by itself, within wide limits, and even under exceptional circumstances, must ensure that the car can be steered in a sufficiently safe manner, thereby contributing to the prevention of accidents.

3. DEFINITIONS OF TERMS

3.1. Skidding resistance

The measure of skidding resistance, as used in this study, is defined as the coefficient of longitudinal force (quotient of braking force and vertical wheel load), such as is found on wet road-surfaces according to the standard measuring process "retarded wheel", between a standard measuring wheel and a road surface. The drift angel is 0^o. The measuring wheel is 5.60 x 13" and has a natural rubber running surface with a V83 profile. Under a tyre load of 200 kgf the tyre tension amounts to 2 kgf/cm^2 (the units are those as found in practice). A water film, 0.5 mm thick, is spread over the road-surface to be measured. The measuring wheel is pulled at a constant speed of 50 km/hr over the wet road-surface. By means of gearing it is made to rotate at such an angular speed, that skidding resistance can be measured with a forward slip of 86%.
The Dutch State Road Laboratory posesses a measuring car with these specifications, type SW8 (see appendix) for carrying out its annual systematic skidding resistance investigations. Measurements are normally made in the months of August and September. The skidding resistance of the road-surface generally attains its lowest value at this time of the year. On all roads with three or more lanes the skidding resistance is determined at the right hand wheel track of the traffic. The overtaking lanes, which are not included in the measuring programme, display, as a rule, a skidding resistance higher by one class, but can be indicated by the skidding resistance of the adjoining lanes (see classification in paragraph 4.1. and in appendix 6.2.). On roads with two-way traffic measuring is effected in one driving direction. The result obtained is then applied to

the other lane. This is permissible, in the case of roads having the same sort of pavement which have been exposed over their entire length to the effects of climate, and a comparable traffic flow.
In the systematic measuring investigations the skidding resistance will be measured, depending on the road length, in one or more sectors of 100 m length, chosen at random. During the investigation period The Dutch State Road Laboratory carried out, in this way, skidding resistance measurements on approximately 2000 sectors over a road length of more than 3500 kilometers.
After road reconstruction extra measurements were made on about 2000 sectors. The new skidding resistance value was found to be valid, for the road sector in question, a month after the reconstruction.

3.2. Hourly-volume

The total number of vehicles passing through a given section of the road, in the same direction, during 1 hour, is indicated in the present study as the hourly-volume for that sector, in the driving direction, over a period of one hour.
If each of a number of vehicles drives over a given distance, their total performance, i.e. the given distance multiplied by the number of vehicles in question, is expressed as vehicle kilometers.
During the general traffic census in 1965, Rijkswaterstaat carried out counts on an extended scale, at 38 basic counting points. During the whole year these counting points were provided with pneumatic counting devices, which recorded the number of vehicle axles passing, on mechanical counting instruments. The counts were read daily at a fixed time. In addition, during 40 days of that year, at each basic point the partial volumes of the most important vehicle categories were counted visually.
On the basis of the material collected, which had been extended into 1966 to a limited extent, a number of mechanisms (assumed constant) were formulated, whereby the manner in which the traffic would take place could be forecast, to a certain extent, at the chosen basic counting point. Such mechanisms are:

1. The percentage distribution of the annual average of traffic volume over 24 hours for a working day, a Saturday and a Sunday. These hour-distributions were applied unchanged to both investigation years. For roads with separated lanes, on which a separate pneumatic measuring tube was placed in each lane, the hour-distribution have been established for both driving directions.
2. The relative level of the annual average traffic volumes for a Saturday and a Sunday with regard to the annual average traffic volume on a working day. These two level-factors were applied unchanged for both investigation years.
3. The percentage distribution of the annual average partial volume of goods vehicles over the 24 hours of a working day. The hourly distribution was applied unchanged for both investigation years. The volume of goods vehicle traffic on Saturdays and Sundays could be neglected.
4. The relative levels of average daily volumes in each of the 12 months. These monthly coefficients did not refer separately to goods vehicle traffic, which was found to take place at the same level approximately throughout the year.
5. The relative level of average daily volume in 1966 as compared to that in 1965.

The above-mentioned mechanisms have been established for a road sector studied at an absolute level, from two basic figures:
1. The absolute level of annual average traffic volume on a working day on a given road sector in 1965.
2. The absolute level of the annual average partial volume for goods vehicles on a working day, on the given road sector in 1965, expressed as the average portion of goods vehicles in the total annual average traffic volume on a working day. The basic figures were obtained for the road sectors at the basic counting points from the above-mentioned counts. (Road sector in this connection means a continuous stretch of road, determined as a measuring sector for skidding resistance measurement. It is assumed that this road sector will display the same overall skidding resistance.)

For the other road sectors a supplementary counting system was set up, with about 800 common counting points, during 1965. For this purpose Rijkswaterstaat, established on motorways, at each counting point, mechanical counting systems for two whole weeks. Alternatively for one week or for three whole days, visual counting systems were applied.

3.3. Duration of rainfall

In the study, the Netherlands have been divided into 21 rainfall zones. Within each zone there should be two mechanisms governing the occurrence of rainfall. The assumed constants are:

1. The percentage of the average duration of the daily rainfall over the 24 hours.
2. The period of time for which (calculated in absolute figures) rain must fall (on average) in order to obtain 1 mm of rain.

For the central zone and the four corner zones, these quantities could be measured directly for each test month. The main meteorological stations De Bilt (central zone), Den Helder, Vlissingen, Beek (L) and Eelde are in these zones. From these stations (which all have automatic recording precipitation meters) the Royal Netherlands Meteorological Institute collects data, following a continuous and extensive measurement programme, relating to the duration and quantity of the rainfall. All the other meteorological stations only make daily measurements of the quantity of rainfall at fixed intervals. Both mechanisms are quantified for all other rainfall zones, by lineair interpolation, based on the established constants of two or three neighbouring basic zones.
The absolute levels, concerning the hourly-distribution of the duration of rainfall, formed part of a set of measurement results from the basic stations. For each of the 82 meteorological stations, which were selected from the observation stations of the Meteorological Institute for the purposes of the investigation, assessments were made for these levels, based on the quantity of rainfall measured locally. In this case, use was made of the second mechanism, relating to the month in question in the corresponding rainfall zone.

3.4. Accidents

All accidents which occurred on the test sectors of the Dutch national road system during 1965 and 1966, have been processed in the investigation, insofar as they were registered by the police. In

general, the road lane is unknown. From practical considerations there could have been some selection, in the police reports, on the basis of injury, the degree of material damage or legal severity of the offence. In 1967 these aspects resulted in an official limitation of police recording activity in the Netherlands.
In each separate accident several vehicles can be involved; their number is dependant on whether the police regarded their involvement as having the same "cause" with regard to place, time and circumstance. Relative road risk is expressed in various terms in the study. Accident quotient indicates the number of accidents per million vehicle kilometers. The quotient of involvement for a certain vehicle category indicates the number of vehicles of a given category, involved in accidents per million kilometers covered by vehicles of the given category.

4. EXECUTION OF THE INVESTIGATION

4.1. Collection of data

Each test road is divided into sectors. It is assumed that within each sector approximately identical volume and skidding resistance data are obtained. A road sector is accurately defined by its road type, road number, road-sector number and length in hundreds of meters.
The basic material of skidding resistance data comprises the skidding resistance in the case of a wet road-surface, for each road sector. With regard to double lane roads, the sector is divided into two part-sectors of opposed driving direction, each having an individual skidding resistance. The longitudinal force coefficients of wet road-surfaces are divided into nine skidding resistance classes, with a band width of 0.05 except for the lowest and highest class which have no under and upper limit respectively. The lowest skidding resistance class 1 refers to coefficients less than 0.36. Dry road-surfaces are assessed as belonging to class 9, with a longitudinal force coefficient of 0.71 or greater (see appendix 6.2).
The fundamental material of volume data comprises, for each road sector, the two above-mentioned basic figures referring to the level

of volume. In addition each sector is related to a basic counting point, whereby a connection is established between the above described mechanisms relating to the volume. In the case of a double lane road, each of the two-part sectors of opposite driving directions, has its individual portion of the total hourly-volume.

The total hourly-volume, as causal factor in the occurrence of accidents is divided into 20 classes, with a band width of 100 vehicles per hour per driving direction, for the road-type I. For road-type II, 15 classes are provided, with a band width of 200 vehicles per hour, for both driving directions, taken together, in case of single-lane roads; and separately for each driving direction, in the case of double-lane roads. The highest classes have no upper limit (see appendices 7.1. and 7.2. respectively).

Each road sector is related to a weather station, while each weather station, in turn, is related to a given rainfall zone. In this manner the above-mentioned rainfall data were made available for the study.

The accident data used consist of the following:

1. The road sector of the accident.
2. Weather conditions at the location of the accident in terms of rainfall or no-rainfall.
3. The wetness condition of the road-surface at the time and place of the accident in terms of wet or dry.
4. Date and actual time of the accident.
5. The number of passenger cars, lorries and other vehicles involved in the accident.

4.2. Data processing

The investigation data have been processed essentially in three phases:

1a. The accidents are classified according to the skidding-resistance-class of the road sector where they occurred. It was found that the month, sometimes even the year, in which the accident took place, was always important.

Accidents on dry road-surfaces are placed in the highest skidding resistance class 9, whereas accidents occurring during rainfall are assigned to the class wet-road-surface skidding resistance. If there was no rainfall at the time of the accident, and the road-surface, however, was wet, the accident was related to the highest skidding resistance class 9. In addition to this, all accidents occurring on wet road-surfaces, but not during rain, are sub-divided into different classes of wet skidding resistance. In this way it was possible to make a comparison between accidents occurring on a wet road-surface during rainfall and accidents occurring on a wet road-surface, when no rain was falling.

When an accident occurred on a sector of a double-lane road, the driving-direction being unknown, it was assigned on a 50-50% basis, to each of the skidding resistance classes of both part-sectors. The passenger cars, goods vehicles and the total number of vehicles, involved in the accident, were also related individually to the skidding resistance class established.

1b. The accidents were also divided according to the hourly-volume class of the time at which the accident took place. As mentioned earlier, the road sector, the day of the week, the month and year of the accident, are of importance. General holidays were taken as Sundays.

If the accident occurred on a sector of a double-lane road, the direction of driving being unknown, it was again assigned on a 50-50% basis to the hourly-volume classes of both part-sectors. The passenger cars, lorries and total number of vehicles involved in the accident were again related individually to the hourly-volume class established.

2. The total hourly-volume was then calculated for all the road sectors of the investigation, essentially for each hourly-interval of both investigation years. Firstly, this total hourly-volume is related each time to an hourly-volume class; secondly, the total hourly-volume, allows the total number of vehicle kilometers to be determined (by multiplying by the road sector length) for a given road sector, in the hour-interval concerned.

In addition, the partial volume of goods vehicles was established for the road sector and for the time in question. Upon multiplying by the road sector length, the figure obtained indicates the number of goods vehicle kilometers, in a similar way. The difference in vehicle kilometers, then refers only to passenger-car kilometers.

Finally, the three types of kilometers, already associated with an hourly-volume class, were also apportioned according to the skidding resistance class of the road sector. For this purpose the duration of rainfall was calculated for the road sector and the hourly-interval in question. The portion of time, during which there was rain, with consequent wet road-surfaces, must correspond to the portion of mileage which had been covered on wet-road-surfaces. The corresponding number of kilometers were related to the (wet) roughness-class of the road. The remaining mileage is indicated by the skidding resistance class 9.

3. From the foregoing, three types of cross-reference tables are obtained. The first type comprises four tables of the number of accidents or the number of vehicles involved in accidents.

The tables of the second type are compiled exclusively on the basis of data about accidents, which occurred on a wet road-surface, but not during rainfall, (insofar as they were classified into the class of actual wet road-surface skidding resistance.)

The third type comprises three tables with the kilometers covered. The horizontal variable in the tables indicates the road-surface skidding resistance class, the vertical variable - the class of hourly-volume.

The fourth type of cross-reference tables which must be established, will have four tables per road-type and quotients for accidents, and can be obtained by comparing the elements of the first type of tables with the corresponding tables of the third type (Appendix 2.).

5. RESULTS

5.1. General considerations

For the 36,364 traffic accidents registered in the chosen two years on the test-road sectors of the Dutch road system, - of which 2,360 occurred on road-type I and 5.243 on road-type II, during rainfall - it was possible to establish the road-surface skidding resistance classes and hourly-volumes (Appendix 3.1.). About 4% of the accidents occurring on road-surfaces which were made extra slippery by snow, sleet or dust, have not been included in the investigation.

Accidents during rainfall form more than 20% of the total number of

accidents (Appendix 3.2.), while only about 8½% of the total vehicle mileage occurred during rainfall. In total, about 35% of all accidents occurred on a wet road-surface.
The accidents relate to a road length of about 1100 km on road-type I and about 2300 km on road-type II (Appendix 4). More than 40% of the totale vehicle mileage was driven over roads of type I, while less than 30% of all accidents occurred on these roads.
The average number of vehicles involved in an accident increased from about 1.5. to about 2.5. with increasing hourly-volume of the traffic. The overall average was nearly 2. In the accidents the proportion of goods vehicles amounted to about 20-23%, except on road-type I, where this proportion was less than 16% under conditions of rain. However, only 15-17% of the mileage covered relates to goods vehicle traffic.
In comparison with accidents during rainfall, accidents on wet road-surfaces (but no during rain), occurred less frequently at higher hourly-volumes, than at lower hourly-volumes (Appendix 5). Where the hourly-volume of traffic is important to the drying process of the wet road-surface after rain, a relatively lower vehicle mileage should result at higher hourly-volumes with no rain on a wet road-surface, than at a lower hourly-volume. However, no data are available in this respect.

5.2. Conclusions from the investigation

A lower skidding resistance results in a higher relative road risk. Thus the relationship between road-surface skidding resistance and relative road risk can be established, from the investigation carried out according to the requirements of the assignment (Appendix 6).
In Chapter 2 it was pointed out that many factors have an influence on this relationship. The investigation mainly dealt with the mechanisms of the probably most important of these factors.
As already indicated in para. 5.1., a greater relative road risk can be observed for more discontinuous types of roads and for vehicles of a heavier category. The relative road risk increases in general with increasing total hourly-volume of traffic, with the exception of the lowest and highest classes (Appendix 7).
The irrationality of some of the results can be ascribed to chance

fluctuations in the quotients of accidents and involvement (Appendix 8). It was found that the relationship between road-surface skidding resistance and relative road risk, which was required to be investigated in the inquiry, always displays, apart from the level, the general pattern as described above.

5.3. Comments

As stated in paragraph 3., road-surface skidding resistances have been measured during the period of the year, when they would display, on average, a relatively low level. This fact will not have a great influence on the form of relationship between the road-surface skidding resistance and relative road risk. However, the skidding resistance class will tend to be shifted towards a lower value.
Overtaking lanes, especially for roads of category I, were given much too low a skidding resistance. Insofar as accidents occurred on these overtaking lanes (with no recording thereof in the accident data), this should result in a more pronounced curve in the relationship to be established.
The result of the skidding resistance class 9 differs from the other results in that rainfall conditions are nearly often absent. Also included in skidding resistance class 9, are those accidents which took place on wet road-surfaces, but not during rainfall. Since the drying process of wet road-surfaces is not sufficiently understood, the same procedure had to be followed with regard to the mileage covered on wet road-surfaces, but not during rainfall. Thus, it might happen that the relative road risk in class 9 is calculated too high.
In the case of non-separated road lanes, the study established average values for the hourly-volume of traffic in both directions. However, it can be imagined that peak traffic in the morning is higher in one direction, while the evening peak is higher in the other direction. The effect of this phenomenon on the results of the investigation for road-type II (where it mainly occurs) is not important. The highest hourly-volumes are determined by the commuting traffic, while the lowest by evening and night traffic. Thus, in addition to the hourly-volume the investigation implicitly established

other factors which affect the accident pattern. It can be imagined, in this connection, that a somewhat higher relative road-risk will be determined for the lowest skidding resistance class, due to the higher relative road-risk in twilight.
It is pointed out that, generally, in the investigation, the hourly-volumes for both road-types I and II were registered in classes having a band width of 100 vehicles per hour for each driving direction. It will be evident that in this way the same class of hourly-volume will indicate quite different traffic circumstances for roads of road-type II (with essentially one lane per driving direction), than for roads of road-type I (with, in general, two lanes per driving direction).
The division into two road types is no more than a means to make the influence of various factors affecting relative road risk, to some extent, evident. The same applies to the distinction between passenger cars and goods vehicles as discussed in Chapter 2.
Finally, it must be pointed out, that accidents on road sectors such as road entrances and exits, would not be included in the investigation. The pattern of accidents established cannot be applied directly to such accidents, which occur relatively infrequently on road of type I. With regard to the difference in road risk between roads of type I and II, it is more important that accidents occurring on intersections have been included in the investigation, simply for the sake of emphasising the greater degree of discontinuity in road-type II.

6. RECOMMENDATIONS

The investigation, yielding the results described above, established a procedure, according to which a relationship can be established between the skidding resistance of the road-surface and the relative road risk, from the available data, provided in routine data collecting programmes. In this way such a procedure can be utilised by the authorities in establishing various traffic safety measures.
However, the procedure can be applied to a limited extent only. Firstly, because changes may occur in the traffic pattern, beyond the range of road-surface skidding resistance, changes which could invalidate comparison and interpretation of the results of the investigation. As an example, the limitation of the police registration activity, relating

to traffic accidents, can be mentioned. Further study has to be done as to whether it is possible to establish improved and more detailed investigation procedures in this respect.

Furthermore, no socio-economic considerations are included in the investigation. In the first place it should be possible to make a more detailed distinction between the accidents and the vehicles involved in the accidents, with regard to the severity of damage. At the same time conclusions should be drawn and investigations made as to how such conclusions could be incorporated into a determinant model.

Finally, the applicability of the procedure is limited by some aspects of methodology. An inherent characteristic of each statistical approximation is the fact that no "causal" relationships can be established. In principle, it is not possible to forecast the effect of a change in road-surface skidding resistance on the number and severity of accidents. Moreover, a change in road-surface skidding resistance can, simultaneously, influence other traffic circumstances, and thereby have an indirect effect on the accident pattern.

However the skidding resistances of road-surfaces, as established by the Dutch State Road Laboratory are statistically indicative of the relative road risk. The results obtained are in accordance with the expectation, that an increase of road-surface skidding resistance, in general, will result in a decrease of the number of accidents. Thus, a general conclusion of the investigation is that any increase in the skidding resistance of wet road-surfaces outside built-up areas, will improve traffic safety.

For practical purposes this conclusion has to be translated into the recommendation that, as a general measure promoting traffic safety, the minimum skidding resistance has to be made as high as possible.

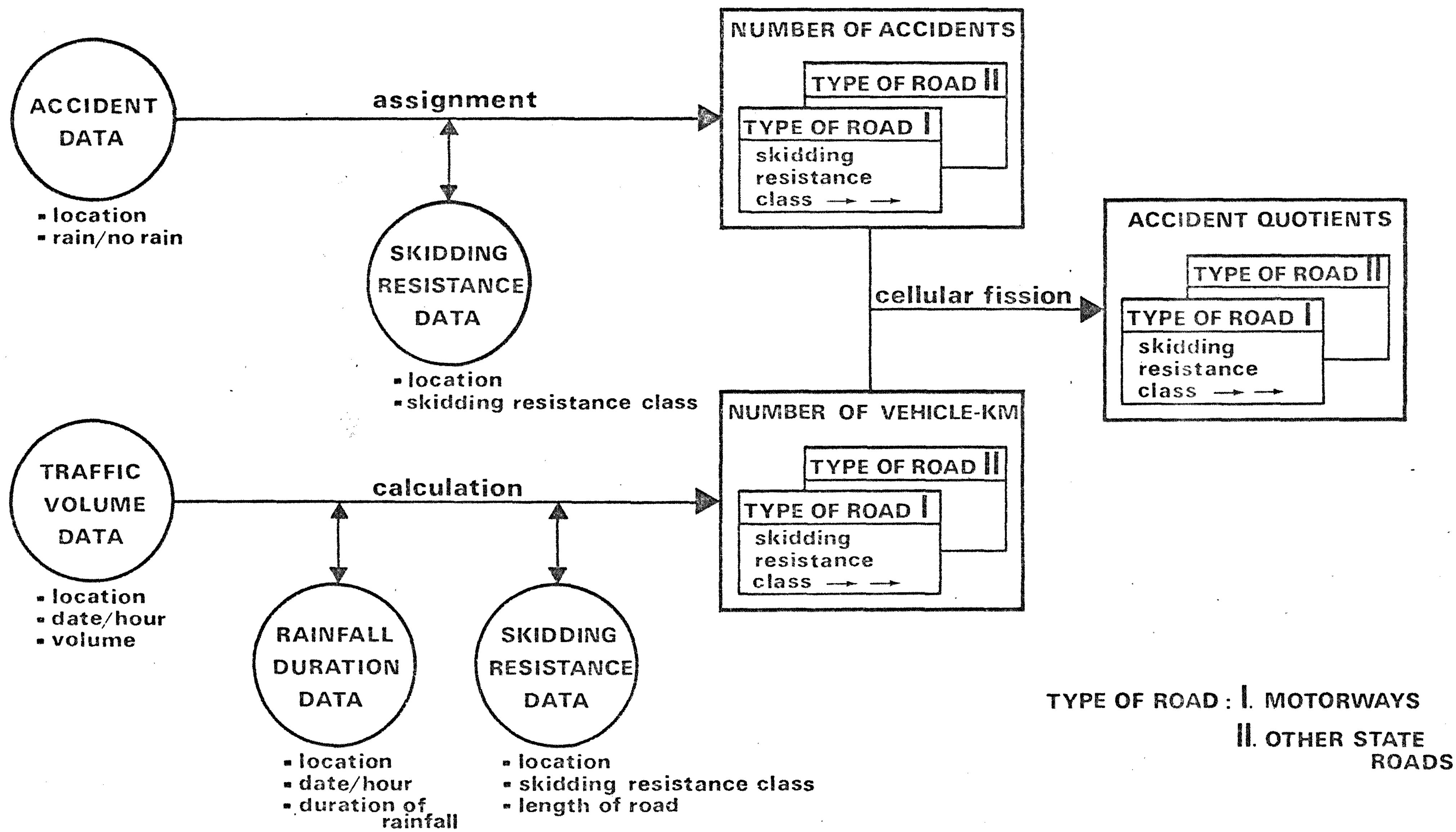
It must be emphasised that the result of the investigation has a global character. It is quite easy to imagine that, at certain places, it is not road-surface skidding resistance, but other factors which have a considerable share in causing accidents, and which could be improved by suitable measures.

The above-mentioned recommendation for a minimum skidding resistance has to be more thoroughly investigated for road-types which have not been included in the investigation. However, on other roads, since no systematic research has been carried out into the skidding resistance of road-surfaces, it is much more difficult to carry out investigations.

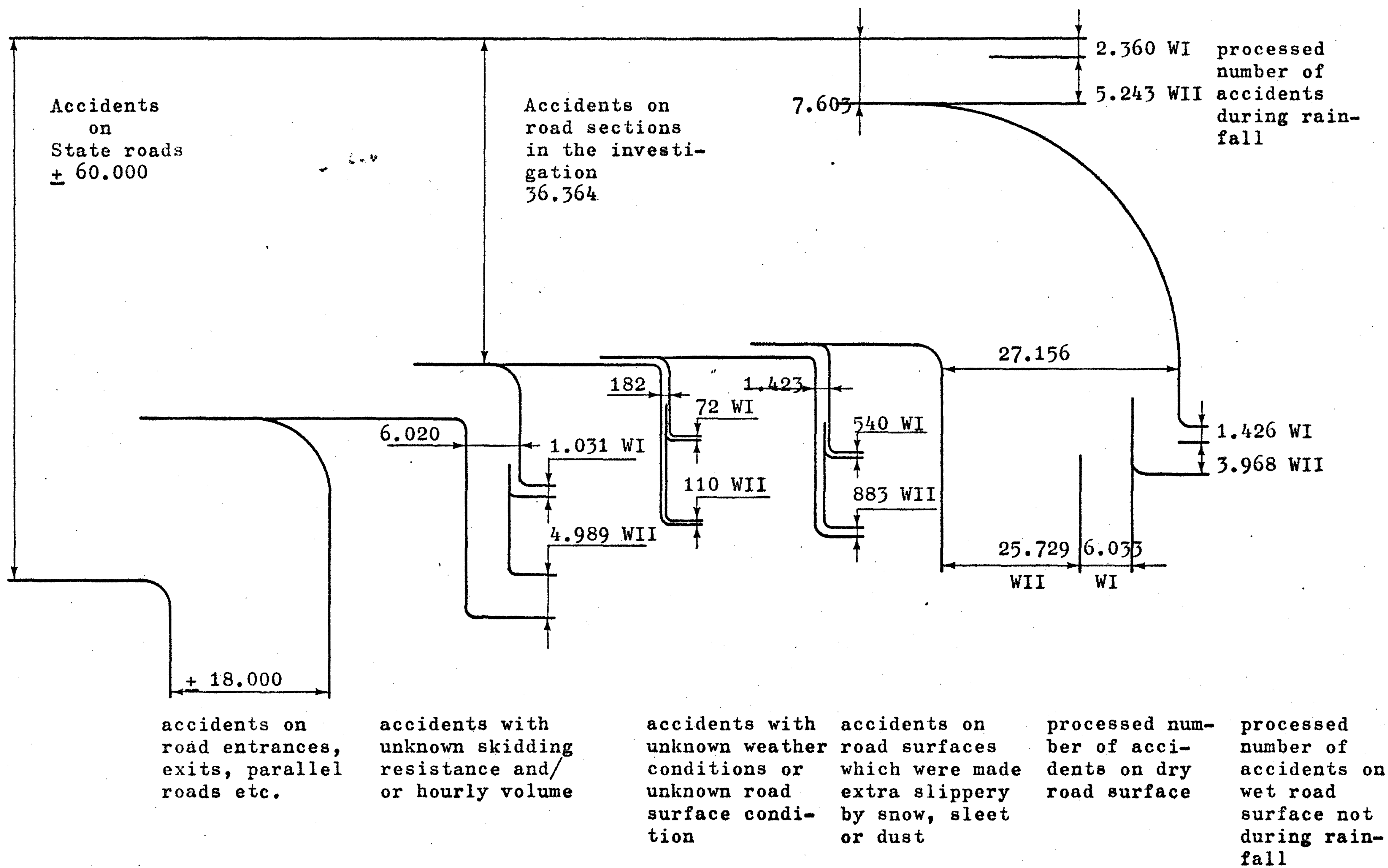
It can be accepted that skidding resistance plays the same part in accidents on roads within built-up areas, as on roads outside of such areas. However, this must be studied more thoroughly.
In order to realise the expected reduction in the number of accidents on the road-types which have been studied, through increasing road-surface skidding resistance, the causal relationship between skidding resistance and accident quotient has to be explained in more detail. On the basis of the established relationship it is possible to calculate the reduction of the number of accidents with increasing skidding resistance at a given road sector. The results of the calculation have to be verified by practical tests.

LIST OF APPENDICES

Appendix 1. Skidding resistance measuring truck of the Dutch State Road Laboratory.



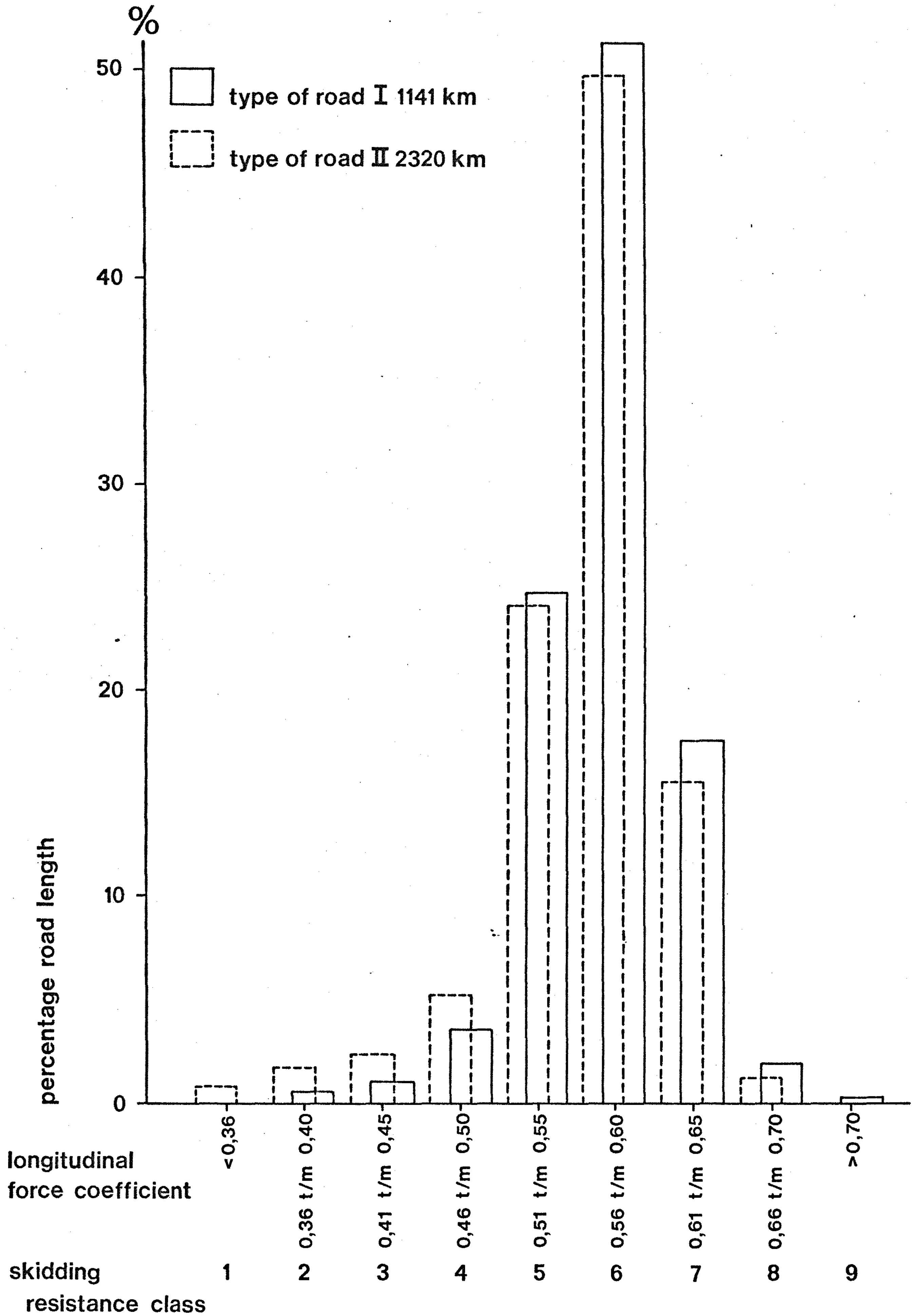
Appendix 2. **Procedure diagram for investigating the relation between the skidding resistance of road surfaces and relative road risks.**



Appendix 3.1. Sankey-diagram of the number of accidents on motorways during the years 1965 and 1966

Degree of wetness of the road surface	Rainfall		No rainfall, wet road surface		Dry roadsurface		Total	
Type of Road	I	II	I	II	I	II	I	II
Accidents	2.360	5.243	1.426	3.968	6.033	15.729	9.819	24.940
% of type of road-total	24,0	21,0	14,5	15,9	61,5	63,1	100,0	100,0
Involved								
passenger cars	3.932	8.207	2.424	5.845	9.402	22.308	15.758	36.360
goods vehicles	729	2.110	626	1.785	2.648	6.790	4.003	10.685
vehicles total	4.661	10.317	3.050	7.630	12.050	29.098	19.761	47.045
Average number of vehicles, involved by accidents	1,98	1,97	2,14	1,92	2,00	1,85	2,01	1,89
% of goods vehicles	15,6	20,5	20,5	23,4	22,0	23,3	20,3	22,7

Appendix. 3.2. Processed number of accidents occurring on the test-road sectors and the number of vehicles involved, related to the degree of wetness of the road surface and according to road-type.



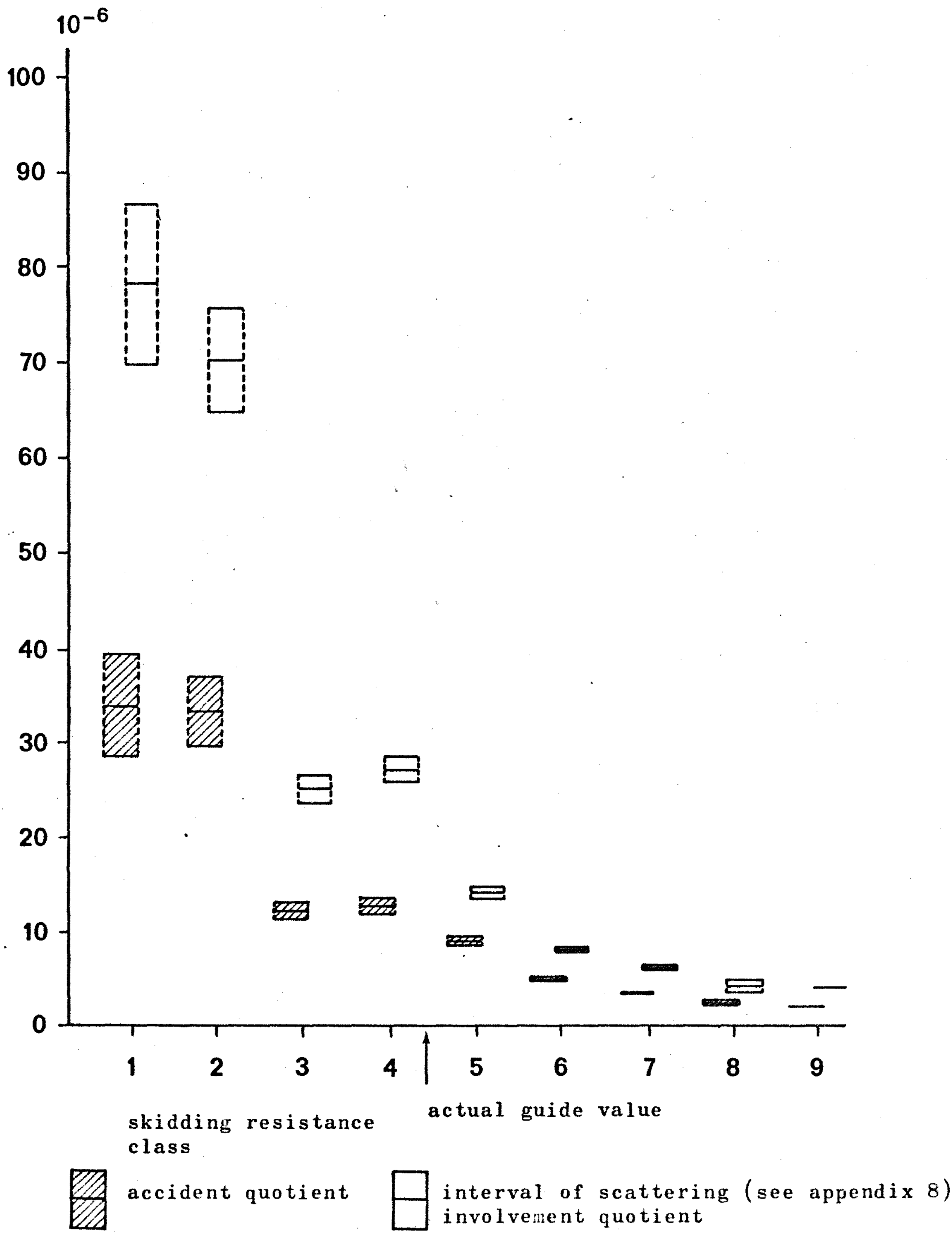
Appendix 4. Total road length of the test road sectors as a percentage of the (average) annual total per road-type.

Skidding resistance class / hourly volume class	2	3	4	5	6	7	8	total
1	-	,24	1,16	1,27	1,53	2,32	-	1,46
2	,55	1,66	1,02	1,27	1,18	1,42	3,31	1,21
3	,83	-	1,13	1,27	1,26	,77	,33	1,18
4	,41	,46	,44	,83	1,20	,85		,92
5	-	,83	,93	,59	1,11	1,69		,91
6	,95	1,38	1,66	1,02	1,25	1,13	-	1,18
7	,99	1,16	2,43	1,11	,97	1,37	-	1,13
8	,92	1,32	,81	1,30	1,12	,63	-	1,11
9	1,03	2,65	,91	,96	,89	1,44		,98
10	,55	1,42	1,33	1,13	1,09	,72		1,10
11	1,66	,99	,92	,91	,81	,47	-	,87
12	,99	1,10	,46	,95	1,04	,91	-	,89
13		16,55	,67	,88	,94	1,61		,94
14	,95	1,10	1,37	,89	,85	,23		,89
15	-	1,10	1,46	,87	,43	-		,82
16		,55	,19	1,01	,45	1,66		,70
17		-	,33	,43	1,29	-		,62
18			,24	,63	,55			,55
19		-	,92	1,42	,89			1,22
20			,85	,52	2,21	-		,82
total	,93	1,21	,90	,95	1,06	1,07	2,36	1,00

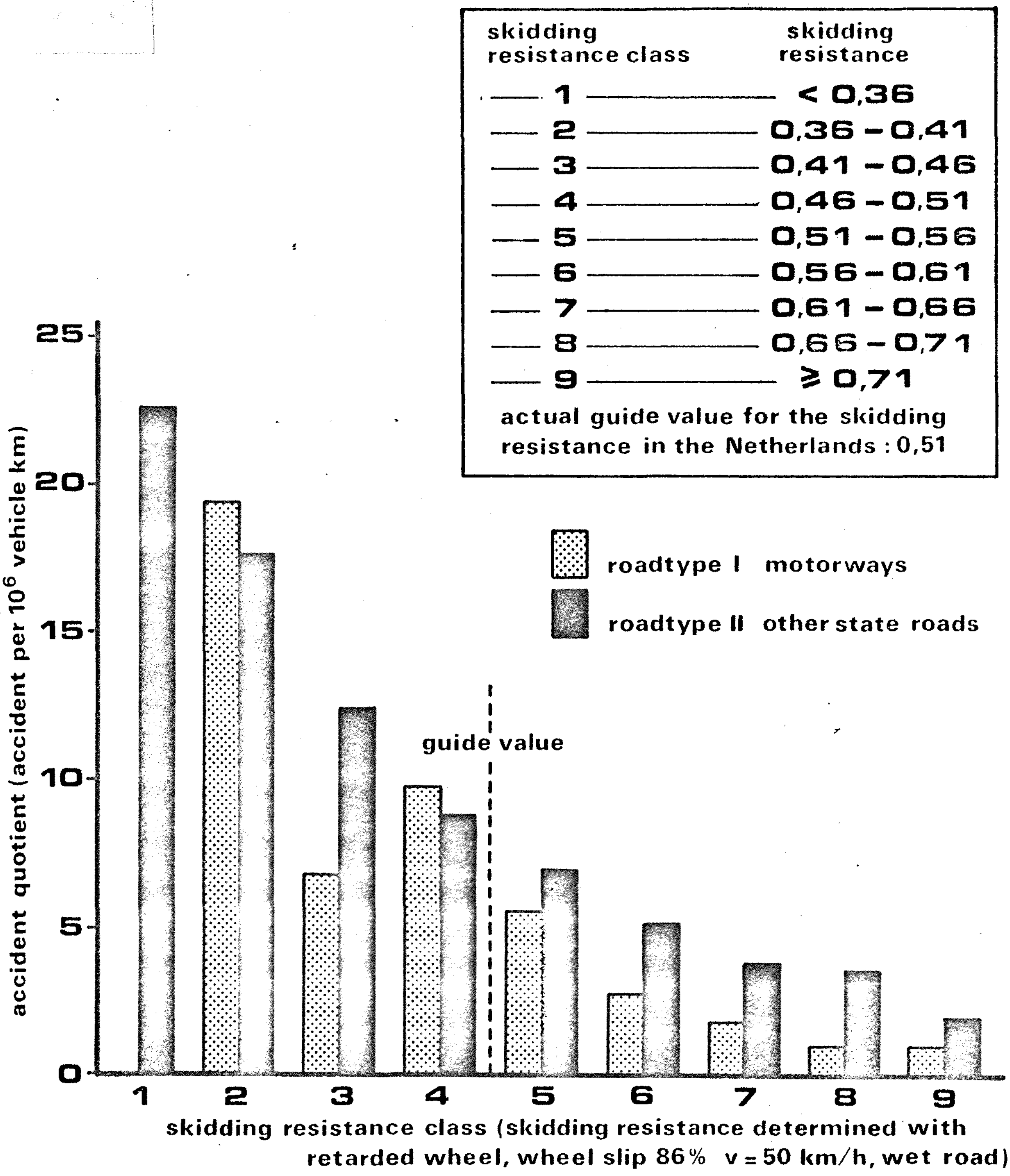
Appendix 5.1. Standardised relationships between number of accidents on wet road surfaces during rainfall no rainfall, according to hourly-volume/skidding resistance class for road type I.

Skidding resistance class / hourly volume class	1	2	3	4	5	6	7	8	total
1	,17	1,21	2,51	1,10	1,18	1,31	1,45	1,98	1,31
2	1,32	1,16	,72	1,22	1,03	1,23	1,34	,59	1,16
3	,74	1,13	1,06	1,11	1,05	1,08	,80	1,32	1,05
4	,84	1,13	,66	,99	,89	,85	1,39	1,32	,90
5	,33	,50	,76	,79	,81	,86	1,25	-	,83
6	-	,22	,64	1,04	,61	,84	,53	-	,71
7	-	,88	,51	,73	,77	,93	1,54		,81
8	-	,38	,66	,71	,74	,61	1,32		,73
9	,44	2,64	,22	,84	,42	,85	5,29		,68
10	,66		1,32	,66	,41	,78	2,64		,61
11	-			,66	,57	,50			,26
12	-	-		,22	,51	,50			,40
13	-	-	-	-	,17	,88			,38
14					-	1,32			,33
15					-	,66			1,65
total	,74	,97	,89	1,00	,90	1,06	1,24	1,11	1,00

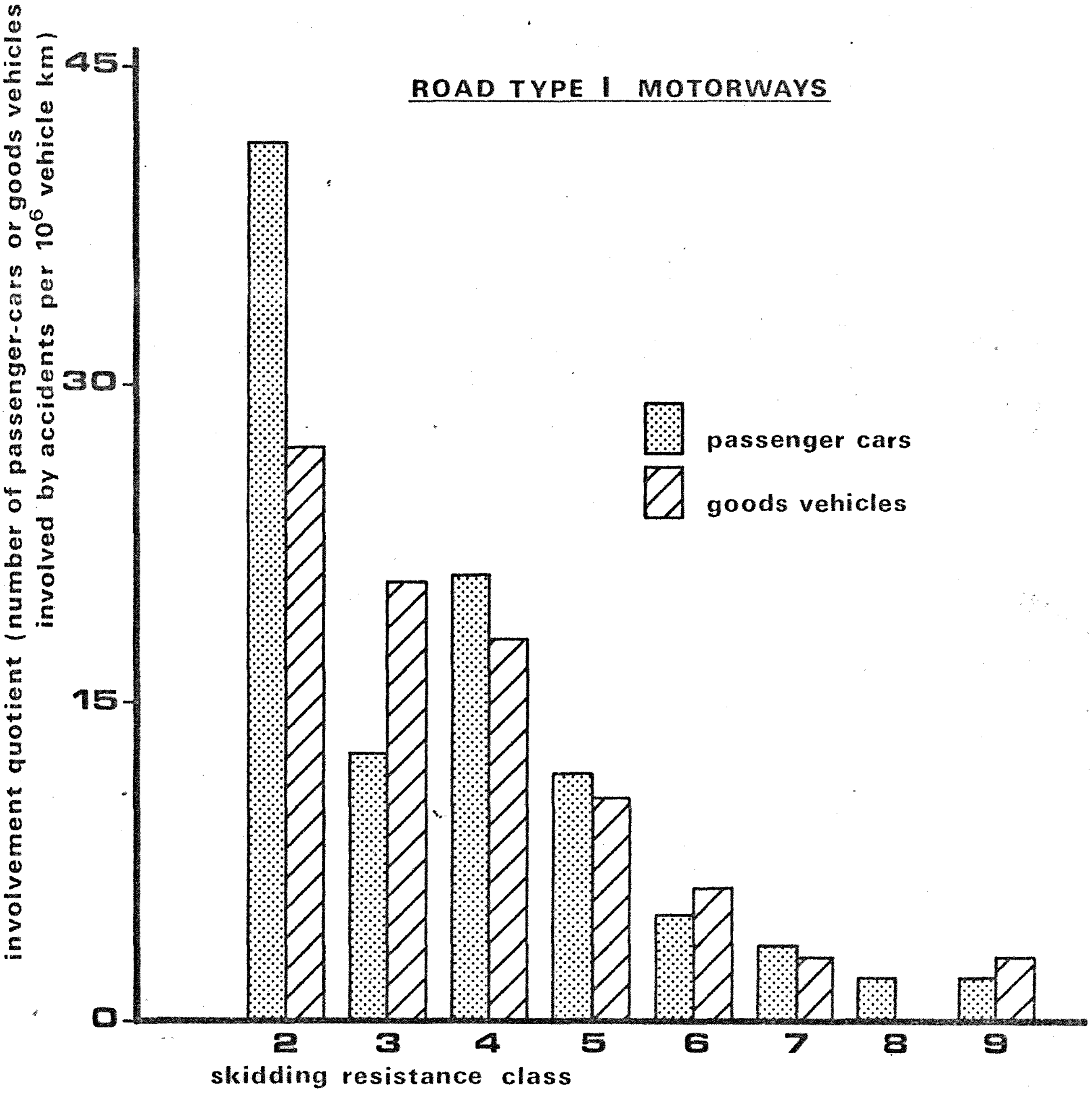
Appendix 5.2. Standardised relationships between number of accidents on wet road-surfaces during rainfall and no rainfall, according to hourly-volume/skidding resistance for road type II.



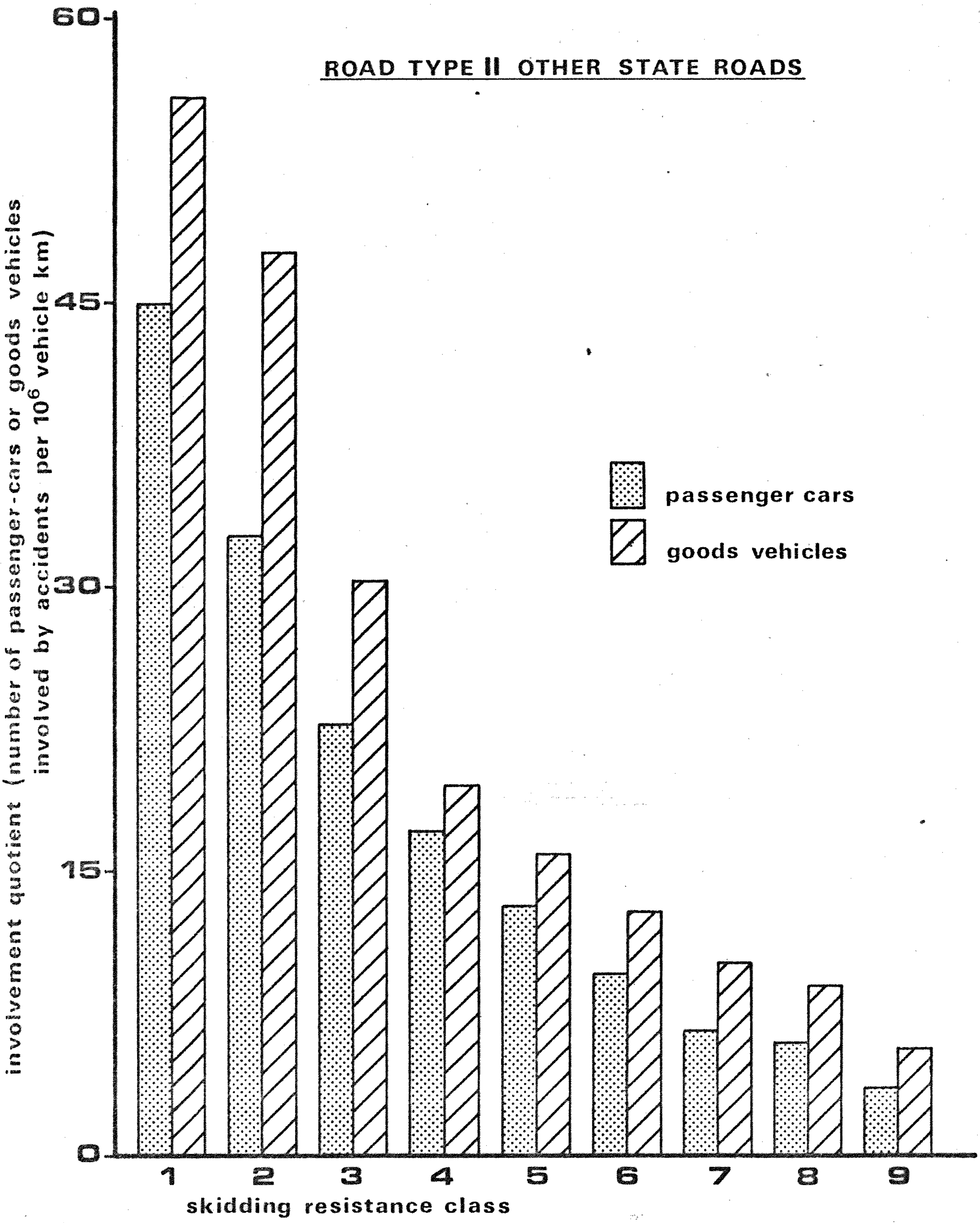
Appendix 6.1. Total quotient of accidents and involvement related to road surface skidding resistance



Appendix 6.2. Accident quotient related to class of road surface skidding resistance.

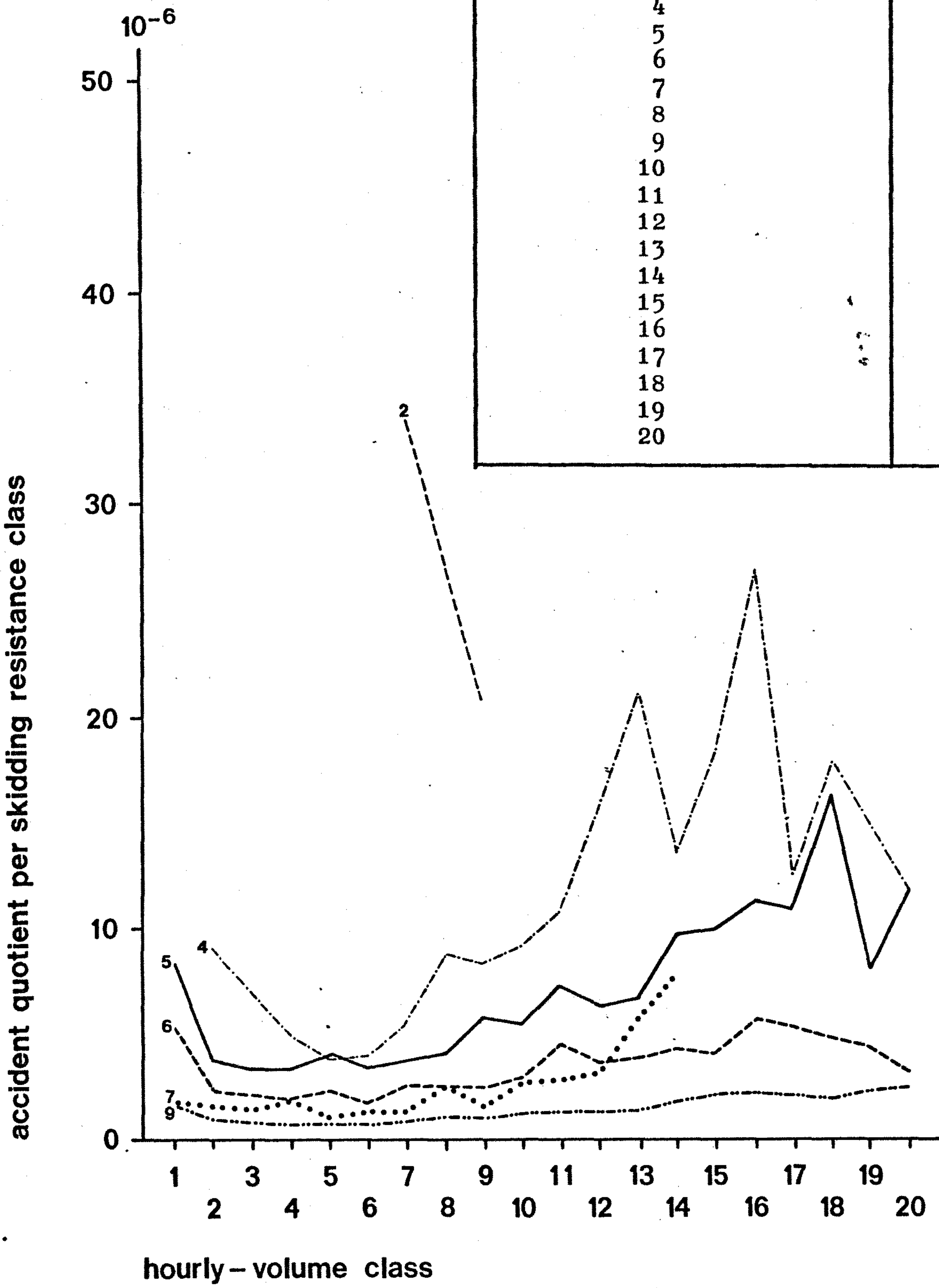


Appendix 6.3. Involvement quotient related to class of road-surface skidding resistance.



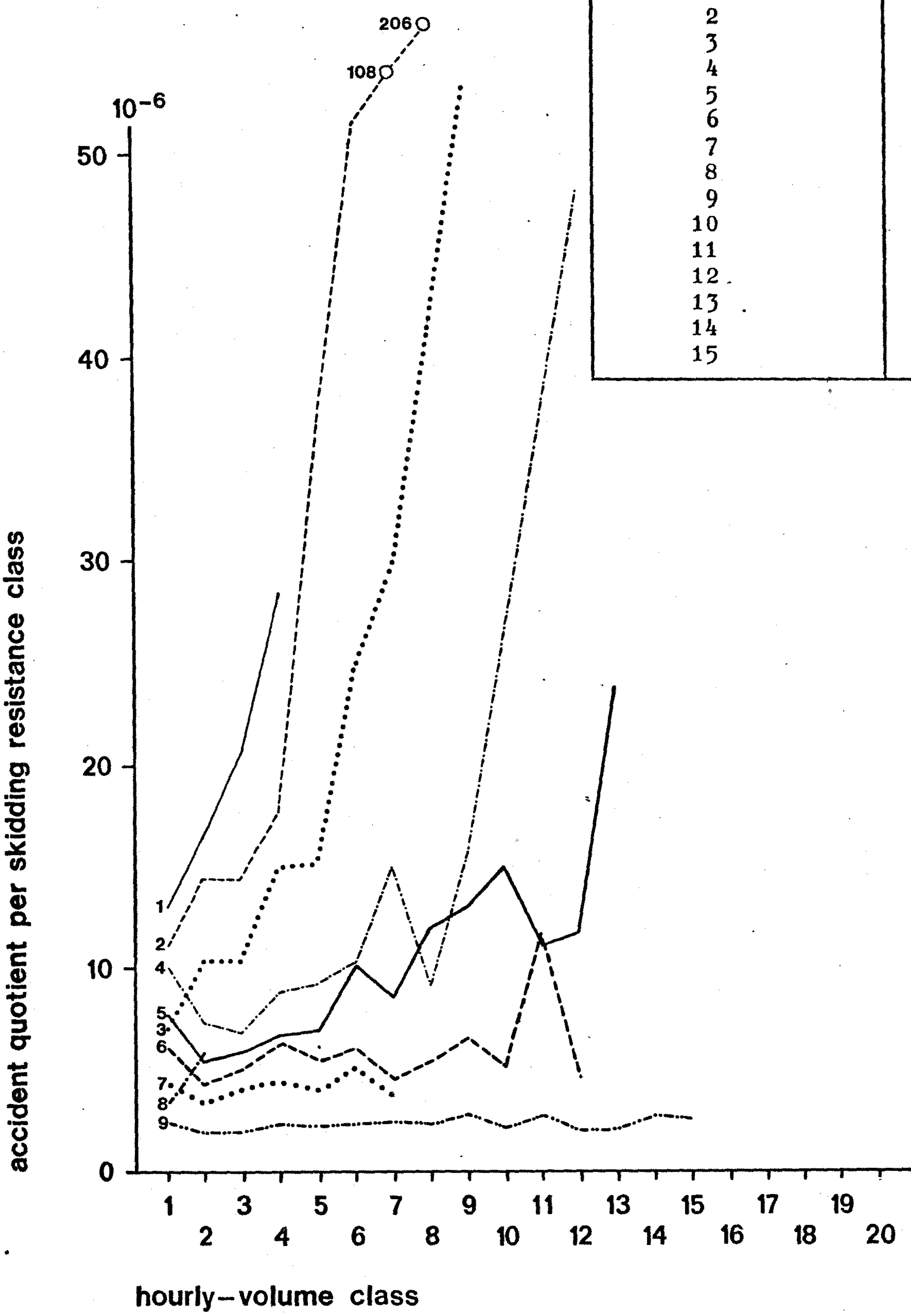
Appendix 6.4. Involvement quotient related to class of road-surface skidding resistance for dual carriageways excluding motorways and single lane roads.

Hourly-volume class Road type I	Number of vehicles per hour
1	0-100
2	101-200
3	201-300
4	301-400
5	401-500
6	501-600
7	601-700
8	701-800
9	801-900
10	901-1000
11	1001-1100
12	1101-1200
13	1201-1300
14	1301-1400
15	1401-1500
16	1501-1600
17	1601-1700
18	1701-1800
19	1801-1900
20	> 1900



Appendix 7.1. Accident quotient per skidding resistance class related to hourly-volume class for road-type I

Hourly-volume class Road-type II	Number of accidents per hour
1	0-200
2	201-400
3	401-600
4	601-800
5	801-1000
6	1001-1200
7	1201-1400
8	1401-1600
9	1601-1800
10	1801-2000
11	2001-2200
12	2201-2400
13	2401-2600
14	2601-2800
15	> 2800



Appendix 7.2. Accident quotient per skidding resistance class according to hourly volume class for road-type II.

APPENDIX 8

Comments on random fluctuations in accident quotients

In view of the reasonable assumption that binomial chance models are applicable to the number of accidents: A_{ij} , and to the number of vehicle kilometers driven: - V_{ij} to a satisfactory degree of approximation; the scattering $S_{(P_{ij})}$, for the investigation results for accident quotients P_{ij} (in the roughness class i and hourly-intensity class j) is: -

$$S_{(P_{ij})} = \sqrt{\frac{P_{ij}}{V_{ij}}}$$

The 80% reliability interval around P_{ij} is bounded by two values: -

$$P_{ij} \left(1 \pm 1.3\, S_{(P_{ij})} / P_{ij}\right) = P_{ij} \left(1 \pm 1.3 / \sqrt{A_{ij}}\right).$$

In the graph, Appendix 7, the measuring points which (based on this consideration) would deviate by more than 50% of the true value, are not plotted. These measuring points relate to less than 6 accidents. The measuring points plotted refer in some cases to accidents, in which only a small number of goods vehicles was involved.
The corresponding involvement quotients will have a greater scatter about the true value.
In Appendix 6, the scattering $S_{(P_{ij})}$ is plotted. The effect of the hourly-volume in this case has not been taken into account.