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Effects of Pavement Skid Resistance on Traffic Accidents

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تاثير مقاومة انزلاق الرصف على الحوادث المرورية

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الخلاصة: متقوم وزارة النقل بالمملكة العربية السعودية بعمل قياسات دورية لمقاومة الانزلاق على شبكة الطرق الرئيسية وجمع بيانات الحوادث المرورية. تهدف هذه الرسالة الى الاستفادة من هذه البيانات لبحث تأثير مقاومة الانزلاق على الحوادث المرورية. شملت الدراسة ربط مقاومة الانزلاق بالحوادث المرورية ل ٨٩ موقع لاربعة اصناف من الطرق. شملت الدراسة تطوير علاقات بين مقاومة الانزلاق وكل من عدد وخطورة وكثافة الحوادث. لقد بينت الدراسة ان انخفاض معامل مقاومة الانزلاق يؤدي الى زيادة الحوادث المرورية كما حددت الدراسة قيم حرجة لمقاومة الانزلاق بناء على عدد وخطورة وكثافة الحوادث لكل صنف من الطرق.

المفردات المفتاحية: رصف، مقاومة الانزلاق، حوادث مرورية، كثافة الحوادث، درجة الخطورة، القيم الحرجة.

Abstract: The Ministry of Transport (MOT) in the Kingdom of Saudi Arabia had collected a massive amount of friction measurements using a Mu-meter covering most of the major highway network in the kingdom. Traffic accident data of 89 high accident rate locations from four main different highway classes were extracted from the MOT accident records. Pavement skid resistance for the selected locations was determined from the pavement skid resistance records. The objective of this paper is to utilize these data to investigate the effects of pavement skid resistance on traffic accidents. The analysis included establishing relationships between skid resistance and accident number, accident significance and accident density. It was determined that a decreasing skid resistance leads to an increase in traffic accidents. A critical value of skid resistance was also established based on number, significance and density of accidents.

Keywords: Pavement, Skid resistance, Traffic accidents, Density, Significance degree, Critical value

1. Introduction

The main function of a highway pavement is to transport people and goods in a safe, comfortable, and economic manner. This implies that the pavement structure should provide two basic types of services. First, the pavement should provide a functional service by giving the users a safe and comfortable ride for a specific range of speed. Second, the pavement must provide a structural service by supporting traffic loading and withstanding environmental influences.

One of the important factors that determine a pavement functional service is the level of skid resistance. Safe driving depends on an adequate surface friction for vehicle maneuvering, turning and braking. Surface friction is generally given by the following equation:

$$F = fW \tag{1}$$

where,

F = tractive force (horizontal force applied to the test tire at the tire-pavement contact), (pound-force, lbf);
f = friction factor or friction coefficient; and
W = dynamic vertical load on test wheel (lbf).

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The value of the coefficient f depends upon several factors including tire pressure; tire wear and inflation pressure; vehicle speed; environmental conditions (wet and dry); pavement temperature; aggregate angularity; and asphalt content. The effect of these factors will be discussed later. A standard test procedure would apply the above test under preset values of the above mentioned factors. An example of such standard procedures is that recommended by ASTM E274, from which a Skid Number, SN is calculated as:

$$SN = 100\ f = 100F/W \tag{2}$$

where F is obtained in a precisely defined manner (for example, by sliding a locked standard sized tire from a constant speed, typically 40 mph, along an artificially wetted pavement surface). It is important at this point, and for subsequent discussions, to indicate that the higher is the SN value the more skidding resistant is the pavement surface.

The importance of pavement friction is basically related to driver safety during wet weather. To ensure a safe highway travel in a wet weather, a pavement must have sufficient skid resistance to enable drivers to perform driving tasks without the risk of skidding and loss of vehicle control. Pavement surfaces without sufficient skid resistance would endanger the safety of users in two ways.

First, it increases the stopping distance, which is a direct function of the coefficient of friction, provided by the pavement surface. Secondly, it increases the risk of hydroplaning. When the water film on a pavement is of a certain thickness, vehicles may hydroplane; *i.e*. the tires may be separated from the pavement by the water wedge formed between the tire surface and the pavement surface. Total hydroplaning occurs when fluid pressure forces (generated as a result of change in momentum of the fluid particles) in the water-wedged region exceed the total downward load on the tire (Agrawal *et al*. 1977). The direct consequence of these two events is the high probability of the driver being involved in an accident.

The ultimate goal of skid resistance measurements is to identify the level of friction provided by the pavement surface in the field. This is typically done either directly by measuring the skid level of the pavement surface, or indirectly by measuring the surface texture. Furthermore, to assess the required skid resistance levels, laboratory tests should be performed to measure texture and relate those measurements to observed levels of skid-resistance on the road.

There are many factors that affect pavement surface friction. The study by Al-Mansour *et al*. (2002) indicated that traffic level, highway class, pavement age and percent of air voids in the asphalt mix have significant effects on pavement friction. Percent of asphalt content in the mix has a marginal effect. Pavement skid resistance is reduced as a pavement gets older. Skid number increases as the percent of air voids in the mix increases and decreases by increasing asphalt content.

Several studies have been conducted over the last three decades with solid conclusions indicating that the rate of accident occurrence during a wet weather is much higher than that during a dry weather. The study by Ryell *et al*. (1979) reported that the rate of wet accidents (number of wet-weather accidents per 100 Million vehicle-miles) increased from about 27 at an average skid number of about 55, to about 75 at an average skid number of about 25. The results of another study (Zipkes, 1976) reported the significant reduction in the percent of wet-pavement accidents from 78% to 30% due to increasing the pavement coefficient of friction from 0.20 to 0.45 by applying surface grooving. On the other hand, other studies analyzed specific sites during wet and dry weather periods and concluded that the risk of being involved in an accident during wet periods is significantly higher than that during dry periods. Salt (1976) concluded that whilst a surface with a friction coefficient of 0.60 and above may by chance be a scene of an accident in which a vehicle skids in wet weather, the risk that it will be the scene of repeated skidding accidents is extremely small. This risk first becomes measurable with a coefficient of 0.55 to 0.60 and increases sharply by more than 20 times as the coefficient falls to values of 0.40 to 0.45 and by about 300 times when the coefficient is 0.30 to 0.35.

There are no standards agreed upon which define minimum acceptable skid resistance levels. Several studies have been conducted to develop criteria for critical skid resistance levels. In general such studies were either based on skid resistance and traffic accident analysis or based on calculating the required stopping sight distance. A study conducted on the streets of Muscat indicated minimum skid number of 0.45 on normal sites (Ali *et al*. 1999). Another study (Rizenbergs *et al*. 1977) concluded that pavement with skid number below 26 are very slippery and must be corrected.

2. Objectives

The Ministry of Transport (MOT) had collected a massive amount of friction measurements using a Mu-meter covering most of the major highway network in the Kingdom of Saudi Arabia. The main objective of this study is to utilize this data to investigate the effect of skid resistance level on traffic accidents.

3. Data Collection

In order to achieve the objective, wet pavement skid resistance data and traffic accidents data for ten main highways with different classes and traffic levels were extracted from the MOT skid resistance and traffic accidents files (Al-Tamime, 2002). Four roadway classes were included: dual roads (A) roads that have double lanes in one-way direction; expressway (B) roads that have three lanes or more in one-way direction; expressway with frontage roads (C); and undivided roads (D). The exact locations of the traffic accidents were matched with pavement skid resistance measurements. This process resulted in determining the skid number of the pavement for accident location. The traffic accident report does not specify clearly the cause of accident. Therefore, all accidents reported in the year 1999 for the selected locations were incorporated in the analysis, including accidents in both wet and dry weather conditions.

In addition to the number of accidents, other data such as types of accidents (death, injury and damage), degree of accident significance, and density of accident were also recorded. Types of accident included accident that resulted in death, injury or damage. An accident degree of significance is defined as a recurring accident site factor. Density of accidents is the number of traffic accidents annually per kilometer of road.

4. Analysis and Results

4.1 Basic Statistics

A total of ten highways with 340 accidents occurred at 89 locations were used in the analysis. The number of accidents and accident locations for each road are shown in Fig. 1. Road Number 15, in the South Western Region of the Kingdom of Saudi Arabia, had 145 accidents which was the highest number of accidents of the roads included in the analysis. Roads Number 500 and 517 had the lowest number of accidents. Similarly, Road Number 15 has the highest number of accident locations and Roads Numbers 500 and 517 had the lowest number of accident location.

4.2 Effects of Skid Resistance on Number of

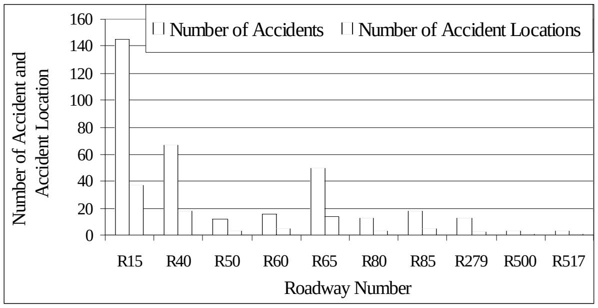

Figure 1. Number of accidents and accident locations

Accidents

Although accident reports did not specify the main cause of accidents, an attempt was made to relate skid resistance measurements to the total number of accidents for the analysis period. The analysis indicated that the number of accidents increased as skid resistance decreased. A low level of skid resistance resulted in an increase in stopping distance and a loss of vehicle control at a high speed. The relationship between number of accidents and pavement friction measured as a skid number is shown in Fig. 2. This data were best fitted in the following form:

$$NA = a\ SN^b \tag{3}$$

where;

NA = number of accidents;
SN = skid number; and
a, b = regression parameters

The values of a and b were estimated to be 2.799 and 0.408, respectively. The coefficient of correlation (R^2) of

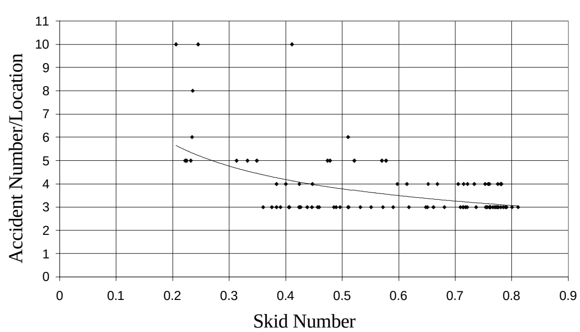

Figure 2. Relationship between skid number and traffic accidents

the regression equation was 0.425.

This relationship indicated that the number of accidents approach almost a constant number at a skid number greater than 0.45. To further investigate this observation, the number of accidents were plotted as a bar chart against the ranges of skid resistance. The plot is presented in Fig. 3. Pavement with skid resistance less than 0.35 have the highest number of accidents. The data also indicate the same observations, that the number of traffic accidents are almost the same for skid number greater than 0.45. These results lead to the conclusion that the critical skid number required at high speed roads is 0.45.

A similar analysis to the one just presented was conducted for each highway class. As indicated earlier four classes of highway are included. These classes are A, B, C, and D. This analysis was conducted on highway class

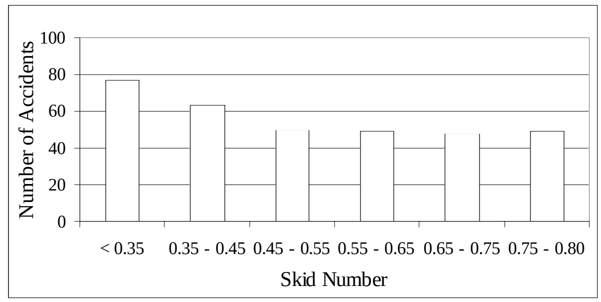

Figure 3. Effect of skid number of traffic accidents

A, B and D. Highway class C was excluded because of the lack accident data. A summary of the results is presented in Table 1. It is clear that as the highway class gets higher the critical skid number value increases. These results were expected since the operating speed on a higher highway class is more than that of a less class highway.

4.3 Effect of Skid Resistance on Accident Density

The density of accidents is defined as the number of traffic accidents made annually for each road kilometer.

Tble 1. Critical skid number values

Highway Class	Critical SN	Model	Adj R^2
A	0.48	$NA = 2.79\ SN^{-0.41}$	0.425
B	0.42	$NA = 2.76\ SN^{-0.38}$	0.265
D	0.38	$NA = 2.73\ SN^{-0.36}$	0.588

Accident density is calculated as number of accidents divided by the analysis period and multiplied by section length. The relationship between skid number and accident density is presented in Fig. 4. It was found that as skid number decreases, accident density increased. The maximum accident density of 2.66 occurs at a skid number less than 0.35. At a range of 0.75 - 0.80, accident density was found to be 1.76. Accident density seems to be constant at about 1.85 for a skid number greater than 0.45 (critical value).

The statistical regression procedure (Neter *et al*. 1985) was used to model the accident density based on skid resistance number. The best model was found to be in the following form:

$$AD = a\ SN^b \tag{4}$$

The values of the parameters a and b were estimated to be 1.59 and 0.278, respectively. The p-value for the model is 0.0023 and the adjusted coefficient of determination (R^2) is 0.36.

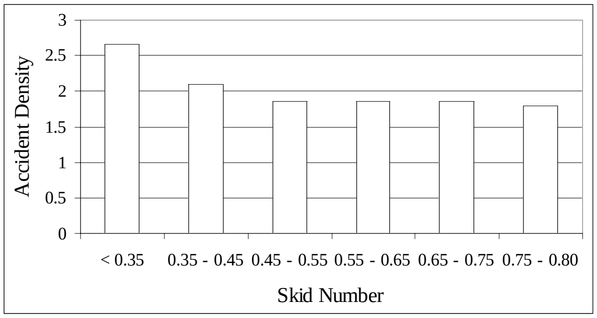

Figure 4. Effect of skid number level on accident density

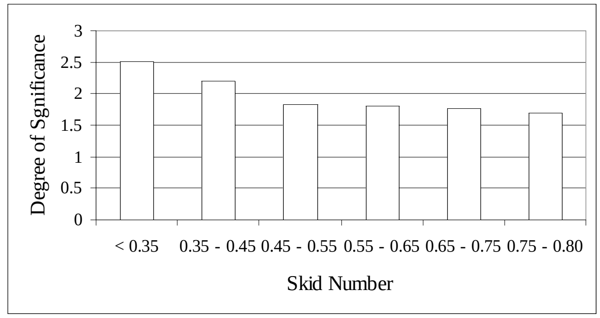

Figure 5. Effect of skid nuber level on accident degree of significance

4.4 Effect of Skid Resistance on Accident Degree of Significance

The accident degree of significance is defined as recurring accident site factor. This factor was determined by multiplying number of accidents by accident seriousness divided by analysis period multiplied by average annual traffic and section length. The seriousness of accident is calculated as:

[1 + (number of death accident + number of injury accidents + number of damage accident)/ total number of accidents].

The accident degree of significance is strongly bounded with the number of accidents. Whenever skid resistance level is low, accident degree of significance increases. The effect of skid resistance on accident degree of significance is shown in Fig. 5. Pavement sections with skid number less than 0.35 has an accident degree of significance of 2.51.

The results also indicated that the accident degree of significance is almost the same for all sections with skid resistance number greater than 0.45. This is another indication that the critical skid resistance number on high speed road can be considered as 0.45. At this critical skid resistance level, the degree of accident significance for all highway classes is 1.7; highway class "A" is 1.7; highway class "B" is 2.1; and for highway class "D" is 2.2.

5. Conclusions

Within the scope of this investigation and based on the results obtained, the following may be concluded:

1. The most common method of evaluating pavement skid resistance was the locked-wheel skid test using ASTM E274 test method.
2. There are no standards defined for minimum acceptable skid resistance levels.
3. Road Number 15, in the southwestern region of the Kingdom has the highest number of accidents and accident locations of all the roads included in the analysis.
4. Pavements with a skid resistance number less than 0.35 have the highest number of traffic accidents. The number of traffic accidents seems to be constant for all sections with a skid resistance number equal to or greater than 0.45.
5. The maximum accident density of 2.66 occurred at pavement sections with a skid resistance less than 0.35. Accident density remained constant on all sections with a skid resistance number equal to or greater than 0.45.
6. Whenever skid resistance number is low, accident degree of significance increases. Pavement sections with skid resistance number less than 0.35 have 2.51 accident degree of significance. Accident degree of significance remains constant for all sections with skid resistance number equal to or greater than 0.45.

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