INFLUENCE OF PAVEMENT CONDITION, SURFACE DRAINAGE, TIRE TREAD AND VEHICLE SPEED ON THE HYDROPLANING PHENOMENON

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ABSTRACT

In a forensic analysis, the establishment of hydroplaning as the cause of a traffic accident is not an easy task, as it might seem at a first moment. The simple presence of water on the asphalt pavement surface, at the moment of the accident, is not a guarantee that hydroplaning has occurred. The investigation must collect information from both the vehicle and the road, aiming at a more adequate analysis of the real cause of an accident. The micro and macro texture characteristics of the pavement, as well as the condition of the tires, are decisive factors for the occurrence of hydroplaning. Thus, responsibility for an accident can be not only attributed to the driver, but also to the roadway agency responsible for the maintenance of the highway conditions above the recommended safety limits. This paper presents a discussion of the main factors and also a case study of a forensic hydroplaning analysis.

Keywords: highway safety, forensic analysis, hydroplaning, pavement condition, vehicle speed

INTRODUCTION

Annually, as a result of traffic accidents in the whole world, more than a million people die, and approximately 40 million people get injured (Sany and Navin, 2004). It is estimated that pavement condition is responsible for approximately 30% of the accidents. Studies developed in the U.S. indicate that 14% of all accidents with fatal victims occur on wet tracks (Pottinger and Yager, 1986), a number four times superior to the number of accidents that occur on dry tracks (Wambold et al., 1986).

In many accidents that occur on wet track, comments emerge saying that conditions of the track have decisively contributed for the occurrence of “aquaplaning. Such statements, frequently made by lawyers, are exclusively based on the fact that the track was wet and the conductor lost the directional control of the vehicle. However, accidents due to the phenomenon of hydroplaning generally happen in particular situations, with the combination of some factors, such as vehicle speed, thickness of water film, hydrodynamic pressure, pavement texture, and tire tread condition. Therefore, a deeper study must be performed before the establishment of the cause of a traffic accident.

Studies reported by Wambold et al. (1986), from the analysis of 500 accidents, all in wet tracks, have indicated four situations that were repeated in the majority of the cases:

- The pavements presented small macro-texture (closed macro-texture);
- The depths of the tire ridges were small;
- The values of the friction coefficients were low;
- The speed of the vehicles immediately before the accident was high.

Thus, the analysis of an accident on wet track requires, before claiming the occurrence of hydroplaning, studies both on the vehicle and, mainly, on the track, in order to verify if the existing conditions were propitious to the occurrence of the hydroplaning phenomenon.

INTERVENING FACTORS ON HYDROPLANING PHENOMENON

A water film on the track creates hydrodynamic pressures in the tire-pavement contact area, which increase with the speed developed by the vehicle. Depending on the pavement surface texture, the hydrodynamic pressures may be of such a magnitude that will tend to raise the tires on the top of a wave that is formed ahead of them. Thus, the hydroplaning phenomenon of hydroplaning occurs when the resultant of hydrodynamic pressures is superior to the load applied to the tires by the weight of the vehicle. In these conditions, the friction is reduced to values that are insufficient to keep the drivability of the vehicle and the tires slide without keeping direct contact with the pavement, loosing the directional control and the capacity of braking. To regain the directional control of the vehicle the driver must significantly reduce the speed (Aps, 2006).

According to Negrini Neto (2009), the phenomenon of hydroplaning may happen in three forms:

- Dynamic Hydroplaning: it occurs when the water film on the track presents a height superior to 0.25 cm, which is associated to high intensity precipitations;
- Viscous Hydroplaning: it occurs when the water film has thickness of hundredths of millimeter, condition where the viscous properties of the water make it act as a lubricant, generating enough hydrostatic pressures to raise the tires;
- Reverted Rubber Hydroplaning: it is a rare phenomenon in road traffic accidents, but not uncommon in aircraft accidents. It occurs when, as a result of a long sideslip of a tire, there is the generation of high temperatures. The rubber of the tires, under the effect of the heat, reverts to its pre-vulcanized state, forming a black deposit in the track and making the surface of the tire sticky.

Research performed by the National Aeronautics and Space Administration (NASA) demonstrates that there are three distinct zones of tire-wet pavement contact, where the percentage of occurrence of hydroplaning in these areas depends on the vehicle speed, pavement texture, and tire inflation pressure, as presented in Table 1 (Silva and Rodrigues Filho, 1981):

- Zone 1 (Z1): it is the region of contact area covered by a thick water film, subjects to the dynamic hydroplaning, called "wet zone", where the tire in movement pushes the water ahead, forming a wave;
- Zone 2 (Z2): it is the region of contact area covered by a thin water film, prone to viscous hydroplaning, called "zone of transition or intermediate", where the tire starts to have partial contact with the pavement due to the small thickness of the water film;
- Zone 3 (Z3): it is the region of the contact area theoretically without water, known as "dry zone", where the direct contact between the tire and the pavement occurs, contributing for the deceleration and the control of the vehicle.

Table I – Hydroplaning: total and partial, according to the three zones model (Aps, 2006)

Parameter	**Total Hydroplaning**	**Partial Hydroplaning**	**Contact**
Zone	Z1	Z2	Z3
Condition of the pavement	Wet	Humid	Dry
Type of Interaction	Skid	Partial Contac	Rolling
Relevant property	Macrotexture	Microtexture	Macro e Micro
Occuring Phenomenon	Dynamic hydroplaning	Viscous Hydroplaning	Friction

For the analysis of a traffic accident in a wet track situation, aiming at verifying if pavement and vehicle technical conditions from the made possible the occurrence of hydroplaning, six characteristics of the event must be verified.

Friction in the Tire-Pavement Interface

The mobility and the drivability of a motor vehicle are directly conditioned by the adherence of tire treads to the road surface. The coefficient of friction in the tire-pavement interface is composed by two parcels:

- Friction by adhesion, resulting from the molecular attraction of the contact surfaces (van der Waals forces);
- Friction due to hysteresis loss, resulting from the cyclical deformation of the surface of the tires, due to the harshness of the pavement.

Two situations may occur when there is friction between tire and the pavement surface layer: rolling or skidding. And there are two types of friction coefficients: longitudinal and transversal.

The Longitudinal Friction Coefficient (LFC) refers to the force developed in the tire-pavement contact area when a stopped wheel is dragged. The determination of the LFC simulates the skid resistance during emergency braking or when a vehicle is braked, sped up or decelerated in the longitudinal direction. The Transversal Friction Coefficient (TFC) refers to the force developed in the tire-pavement contact area of perpendicular to the plan of rotation of the wheel, forming an angle in relation to its direction of rotation. The determination of the TFC simulates the resistance to the transversal skid necessary to maintain the vehicle in curves or sideslips.

Pavement Surface Texture

There are three classes of pavement texture: micro-texture, macro-texture and mega-texture (Wambold et al., 1995). The limits between the domains have been established considering wave length (horizontal) and amplitude (vertical), as seen in Table 2.

Table II – Classification of Pavement Texture (ASTM E-867, 1997)

Domain	Interval of Dimensions	
	Horizontal	Vertical
Micro-texture	0 – 0,5 mm	0 – 0,2 mm
Macro-texture	0,5 mm – 50 mm	0,2 mm – 10 mm
Mega-texture	50 mm – 500 mm	1 mm – 50 mm
Irregularity	0,5 m – 50 m	1 mm – 20 cm

The combinations between micro and macro-texture result in four distinct types of textures: rough and opened; rough and closed; polished and opened; polished and closed. It is observed, thus, that the rolling surface depends on the joint characteristics of the macro and micro-texture, which can lead to a safe traffic or to accidents due to skid in situations of braking or in emergency maneuvers, especially on wet pavements.

Pavement Macro-Texture

A pavement must present an adequate potential for surface draining, conducting the water through its micro-channels. The evaluation of pavement macro-texture can be performed by several methods, and the most used, but the most used in Brazil is the “Sand Spot” (ASTM E 965-96). The values recommended by the Brazilian Department of Transportation Infrastructure (DNIT) are in the interval between 0.60 and 1.20 mm (DNER, 2000).

Pavement Micro-Texture

The pavement surface layer must present aggregates with roughness enough to breach the water film. There are several tests to evaluate the micro-texture, but the most used, in Brazil, is the “British Pendulum” - ASTM E303-93 (ASTM, 1998). Besides the evaluation of micro-texture, it allows the evaluation of pavement surface friction, related to the loss of kinetic energy due to the friction of a rubber with the wet surface of pavement. The values recommended by the Brazilian Department of Transportation Infrastructure (DNIT) are in the interval between 47 and 75 (DNER, 2000).

Pavement Surface Drainage

The surface drainage of a pavement intends to quickly remove the pluvial water, in order to protect the integrity of the pavement structure and to warrant a safe drive, since the accumulation of water on the pavement surface can decisively contribute to the occurrence of hydroplaning.

Tire Tread

The tread design, the tire wear and the inflation pressure play important role in the occurrence of hydroplaning. For instance, the Tire Wear Index (TWI) is a parameter that evaluate the tire condition (the ridge depth must be at least 1.6 mm).

Intensity of Rain Precipitation

The water film is a function of the intensity of rain precipitated over the track, which is determined from measurements in the nearest meteorological station from the site of the accident.

Vehicle Speed

The vehicle speed is of fundamental importance in forensic analysis of a hydroplaning phenomenon. It is calculated based on the deceleration of the vehicle due to the friction of the tires against the pavement surface, damages in the vehicle, and the final position of the vehicle.

CASE STUDY

It is presented an analysis of a car accident that occurred in a Federal Highway in the State of Parana, Brazil. Initially, the cause was attributed to hydroplaning.

Pavement Type

The pavement surface layer is a Hot-Mix Asphalt (HMA), with an opened and rough texture.

Surface Drainage

The site of the accident is straight and levelled, with a crown cross section (at least 1%). The surface drainage is adequate, with lateral ditches to quickly remove the pluvial water.

Tire Tread

The tires of the vehicle are 175/70, rim size 13. The front tires presented an inflation pressure of 202 kPa (28.7 psi) and the back tires presented an average inflation pressure of 213 kPa (30.2 psi), both according to the values recommended by the tire manufacturer. The depth of the ridges presented the following values: left front tire: 5.9 mm; right front tire: 5.6 mm; left back tire: 5.3 mm; right back tire: 5.5 mm. Thus, the tires can be classified between new and half-life, i.e., they are in adequate conditions for traffic.

Intensity of Rain Precipitation

According to the nearest meteorological station (approximately 7 km far from the accident site), the rain precipitation at the time of the accident was 9 mm/h. Considering the duration of the precipitation (40 minutes) and the pavement surface condition, it is estimated a water film not superior to 1.5 mm.

Vehicle Speed

The speed developed by the vehicle, calculated by classic dynamic equations, was around 90 km/h.

Forensic Final Considerations

Considering that: the macro and micro-texture characteristics of the asphalt layer (opened and rough) facilitate the adherence of the tires, the pavement geometry is adequate for draining the pluvial water, the tire tread ridges present an average value (5.6 mm) much larger than the minimum recommended (1.6 mm), the rain precipitation that occurred at the moment of the accident produced a small water film (maximum of 1.5 mm), and the speed developed by the vehicle (90 km/h) is not excessive compared to the design speed of the highway (110 km/h), it can be concluded that the driver lost the directional control of the vehicle due to ineptitude of conduction. Therefore, technically there is no evidence of hydroplaning phenomenon as the cause of the analyzed accident.

CONCLUSION

The analysis of an automobile accident, in which there is suspicion of hydroplaning as the main cause, must evaluate the following road and vehicle characteristics: pavement macro and micro-texture, pavement surface drainage system, tire tread designs, tire wear (ridge depth), tire inflation pressure, intensity of precipitation at the moment of the accident, and vehicle speed.

REFERENCES

ASTM (1998). American Society for Testing and Materials - E303-93: Standard method for measuring frictional properties using the British pendulum tester. West Conshohocken: ASTM Standards, vol. 04.03, 5p.

ASTM (2001). American Society for Testing and Materials - E965-96: Standard test method for measuring surface macro texture depth using a volumetric technique. West Conshohocken: ASTM Standards, vol. 04.03, 5p.

ASTM (1997). American Society for Testing and Materials - E867-97: Terminology relating to vehicle-pavement systems. West Conshohocken: ASTM Standards, vol. 04.03, 8p.

Aps, M. (2006). Classification of tire-asphalt pavement adherence through IFI – International Friction Index. Ph.D. Dissertation. University of Sao Paulo, Brazil (*in Portuguese*).

Negrini Neto, O. (2009). The hydroplaning problem in traffic accidents. In: http://www.geocities.com/CapeCanaveral/Launchpad/2909/page16.html. Acess in March, 13th 2009 (*In Portuguese*).

Pottingrt, M. G. and Yager, T. J (1986). The tire pavement interface. Baltimore: ASTM Standards. p. 9-15.

Sany, R. Z. and Navin, F. P. D. (2004). Improving traffic safety – a new systems approach. Transportation Research Record 1830, TRB, National Research Council, Washington, D.C., pp. 1-9.

Silva, A. M. and Rodrigues Filho, O. S. (1981). Grooving: theoretical and construction aspects for airport pavements. Sao Paulo, Brazil (*In Portuguese*).

Wambold, J. C., Henry, J. J. and Hegmon, R. R. (1986). Skid resistance of wet-weather accident sites. ASTM Standards, p. 9-15.