Safety Evaluation (Skid Resistance) of Jordan's National Highway Network

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ABSTRACT

Highway safety is a major contributor to highway conditions. Highway agencies continually monitor this feature to ensure that roadway sections are operating at the highest possible level of safety. The principal measure of highway safety is its skid resistance.

In this research, the portable skid resistance tester; British pendulum skid tester was used to perform non-destructive tests (NDTs) to measure the skid resistance of almost all the primary and secondary highways in the Hashemite Kingdom of Jordan. This is the first time that such a study was performed on a national scale for pavement evaluation with an ultimate objective to develop the maintenance management system for roads in Jordan.

The survey included 38 test locations at primary and secondary highways across the Kingdom. The skid resistance measurements were performed on the right slow lane; the truck lane. The obtained skid resistance survey results showed that 66% of the tested roads have skid resistance levels lower than the minimum acceptable levels.

Since only about one third of Jordan's national highway network has acceptable surface skid resistance levels, it is recommended that serious actions and maintenance plans be taken to improve road safety in Jordan.

KEYWORDS: Pavement performance, Pavement maintenance, Road safety, Skid resistance, Portable skid resistance tester, British pendulum skid tester.

INTRODUCTION

Roads that transport people and commodities from one place to another are subjected to heavy loadings and harsh environmental conditions, due to which they deteriorate with time. The rate of deterioration depends on the construction materials used, construction and maintenance history, rate of loading and environmental conditions. Therefore, road performance has to be monitored to evaluate the rate of deterioration, need for maintenance and rehabilitation and proper scheduling of maintenance and rehabilitation activities.

Worldwide, more than one million people are killed yearly due to traffic accidents. Although a high percentage of these accidents is due to drivers' errors, highways have a significant effect on this high percentage of traffic accidents. The most important factor in highways affecting traffic accident rates is the skid resistance (Saplioğlu et al., 2012).

Highway safety, as a general term, is often defined in two ways; the quality or condition of being safe (i.e., freedom from danger, injury or damage) or any of certain devices or actions designed to prevent a crash from happening (Hall et al., 2009).

Safety characteristics of a pavement are another

Received on 3/1/2015.
Accepted for Publication on 8/6/2015.

measure of its condition and highway agencies continually monitor this aspect to ensure that roadway sections are operating at the highest possible level of safety. The principal measure of pavement safety is its skid resistance (Garber and Hoel, 2010; Fwa et al., 2003). Adequate skid resistance, or surface friction, is an important functional characteristic that influences directional control and stopping ability on a wet or dry pavement. Most agencies become aware of surface friction problems during inclement weather (Asi, 2007), when the potential for hydroplaning (in which the vehicle tire has lost contact with the pavement surface and is actually riding on a thin film of water) is high. However, safety can also be compromised on dry pavement surfaces where surface friction is low (Asphalt Institute, 2007).

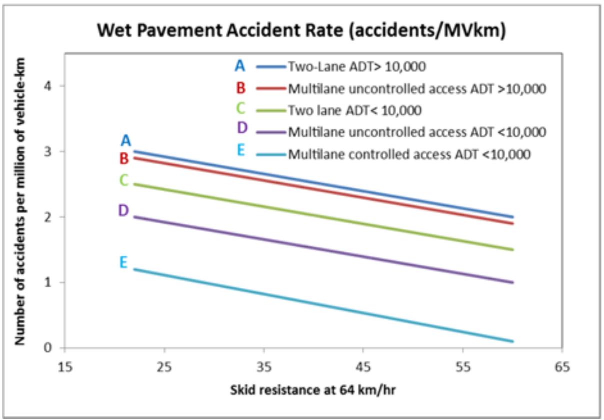

Figure (1): Relation between skid resistance and number of accidents (Belgian Road Research Center, 2009)

Skid resistance is defined as the frictional resistance at the tire-pavement contact interface. Skid resistance plays an important part in the safety of road users; i.e., the higher the skid resistance the lower the number of accidents, as indicated in Figure 1. Accidents have several other causes: human failure, defective vehicle technology, weather conditions, other infrastructure-related causes,… etc. (Belgian Road Research Center, 2009).

Accident rates increase in the rainy season, especially after the initial rain showers (Jung et al., 2010). One of the main reasons for this increase is attributed to low skid resistance of highway surfaces. In addition, a number of drivers do not give much attention to the depth of the grooves in their tire treads and their driving habits do not change much during the rain period.

In general, the highway surface should have some sort of roughness to facilitate friction between the car wheels and pavement surface. Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface (Pavement Management Committee, 2011). Skid resistance is a measure of the resistance of the pavement surface to sliding or skidding of the vehicle. It is a relationship between the vertical force and the horizontal force developed as a tire slides along the pavement surface (Asi, 2007). Therefore, the texture of the pavement surface and its ability to resist the polishing effect of traffic are of prime importance in providing skidding resistance.

Skid resistance is an important pavement evaluation parameter, because:

- Inadequate skid resistance leads to higher incidences of skid-related accidents.
- Most agencies have an obligation to provide users with a roadway that is ''reasonably'' safe.
- Skid resistance measurements can be used to evaluate various types of materials and construction practices.

Highway crashes are complex events that are the result of one or more contributing factors. Such factors fall under three main categories; driver-related, vehicle-related and highway condition-related (Noyce et al., 2005). Of these three categories, highway agencies can control only highway conditions. This can be done by developing and administering effective design, construction, maintenance and management practices and policies. Figures 2 and 3 present summaries of total crashes and resulting fatalities in the USA between 1990 and 2003. According to the National Transportation Safety Board (NTSB) and the FHWA, approximately

13.5% of fatal crashes and 25% of all crashes occur when pavements are wet (Kuemmel et al., 2000).

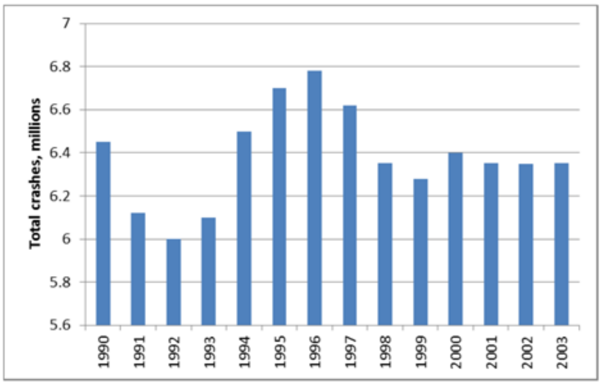

Figure (2): Total crashes (from all vehicle types) on U.S. highways from 1990 to 2003 (NHTSA, 2004)

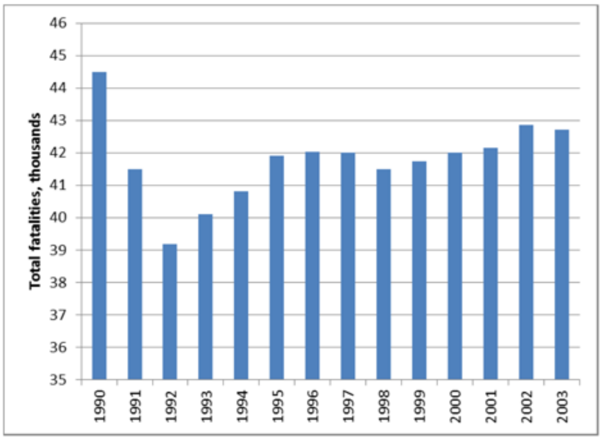

Figure (3): Total fatalities (from all vehicle types) on U.S. highways from 1990 to 2003 (NHTSA, 2004)

The exact nature of the relationship between pavement friction and wet crashes is site-specific, as it is defined not only by pavement friction, but also by many others factors. Thus, pavement friction and wet crashes' relationship must be developed for the sites that are typically present in a given pavement network. An example of such a relationship developed for single carriageways in the U.K. shows that crash risks approximately halves as pavement friction doubles over normal ranges, as shown in Figure 4 (Viner et al., 2004).

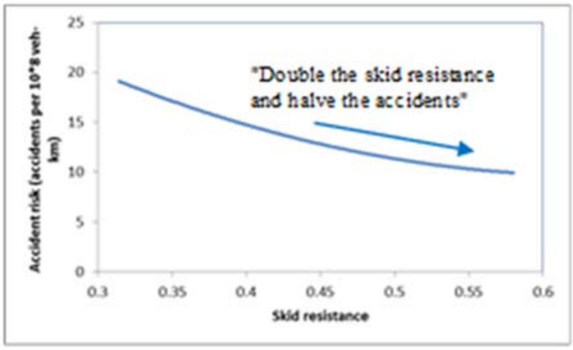

Figure (4): Relationship between pavement friction and crash risk (Viner et al., 2004)

The Kingdom of Jordan has a highway road network of about 7,909 km of asphalted roads mostly built within the past four to five decades. To ensure that the highway network of the Kingdom continues to serve the traffic safely, economically and comfortably, a comprehensive pavement maintenance management system must be developed. This requires periodic monitoring of pavement network using noon-destructive testing (NDT). NDT is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage to it (Soutsos and Bungey, 2010). Pavement management system is used to evaluate important pavement properties, such as deflection, roughness, skid resistance and pavement condition in terms of distress manifestations that are known to influence the pavement performance without damaging it (Garber and Hoel, 2010). In the Kingdom of Jordan, there is no systematic and routine measuring pavement evaluation program to the relevant pavement properties for the entire highway network.

In this study, skid resistance evaluation was performed on almost all primary and secondary highways across the Kingdom.

The Mechanics of Skidding

The mechanics of skidding are related to energy losses. If one considers a car skidding on a wet road surface, due to its weight and speed it will possess a considerable amount of momentum and will only stop once that energy is dissipated; i.e., the car's momentum energy must be transferred to the road surface through the interaction of tire and surface. The surface water that is present acts as a lubricant. So, in terms of energy losses, there are two main components: (a) a friction component between the tire and the road surface, causing energy to be dissipated as heat and (b) a hysteresis component that relates to a tire's ability to deform its shape around the aggregate particles in the road surface and so cause loss of energy (O'Flaherty, 2002).

Factors Affecting Skid Accidents

Friction demands on a pavement vary greatly, depending on the speed of a vehicle, its design and the design and condition of its braking system. The skill of the operator also affects the potential for loss of control or skidding. Weather, especially in terms of wet pavements and the thickness of water film on the pavement, also affects the available friction. If the water layer on the pavement is very thick and the tire moves at a high speed, hydroplaning occurs. This phenomenon is analogous to water skiing and makes the vehicle uncontrollable (Huang, 2004). The following are some of the surface conditions that are indicative of potential safety hazards:

1. Bleeding of asphalt, which covers the aggregate and obscures the effectiveness of skid resistant qualities.
2. Polished aggregate with smooth microtexture, which reduces friction between the aggregate and the tire.
3. Smooth macro-texture, which lacks suitable channels to facilitate drainage.
4. Rutting, which holds water in the wheel paths after rain and causes hydroplaning.
5. Inadequate cross slope, which retains water on the pavement for a longer time, reduces friction and increases the thickness of the water layer and the potential for hydroplaning.

OBJECTIVES

The main objective of this study is to find the British Pendulum Number (BPN) of both primary and secondary highways across the Hashemite Kingdom of Jordan. This study was performed on a national scale for pavement evaluation with an ultimate objective to develop a maintenance management system for the primary and secondary highways in Jordan.

The survey included 38 test locations at primary and secondary highways across the entire Kingdom. Selected locations are considered representative of Jordan’s national roadway network, since they are distributed over the entire network. The skid resistance measurements were taken on the exterior right lane; the truck lane.

Portable Skid Resistance Tester Used

Portable Skid Resistance Tester or British Portable Skid Tester shown in Figure 5 was developed in the 1950s and widely used to assess the slipperiness of road surfaces. This is often referred to as the Pendulum Tester. A pad of tire-tread rubber mounted at the end of the pendulum arm slides over the road surface on which the machine is placed. The stand is adjusted and leveled, so that as the pendulum swings the rubber slider makes contact with the surface for a distance of 125 mm (O'Flaherty, 2002). The difference in height of the center of gravity of the slider head between the horizontal release position and the highest point of the swing after the slider has passed over the road is used to calculate the loss of energy arising from friction. The test conditions, which must be closely observed and controlled, have been chosen so that the values read off the calibrated scale of the instrument correspond to the Skid Resistance Value (SRV) of a patterned tire skidding at 30 mi/h (48 km/h). The test is carried out with the pavement surface wetted in a standard manner and a number of tests spaced at 5 to 10 m intervals are required to give an average value (Corney and Corney, 1998).

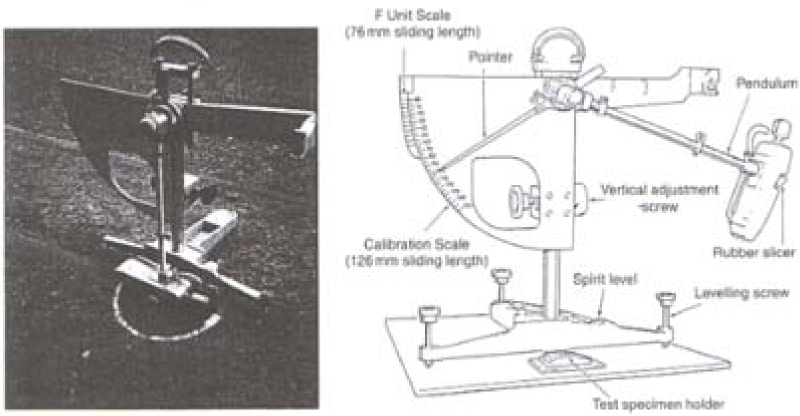

Figure (5): Portable skid resistance tester

The British Portable Skid Tester is very useful in that it is portable, easily operated and may be used both to measure *in situ* road surfaces and for the laboratory determination of the Polished Stone Value (PSV). The equipment can be used to determine wet skid resistance up to equivalent vehicle speeds of about 50 km/h. The relevance of the results may be questioned at speeds in excess of this, due to the effect of texture depth on the retardation of vehicle (O'Flaherty, 2002; ASTM E303, 2013).

Skid Resistance Measurements

The British Pendulum Tester was used in this evaluation study to measure skid resistance at the selected test locations across Jordan’s road network. Table 1 shows the selected 38 test locations and Figure 6 shows these locations on Jordan’s map.

Table 1. Skid resistance test locations

No.	Location	Road	Intersection Roads		Test No.
1	Maan-Aqaba	35	812	814	35-12d
2		35	823	826	35-13d
3		817	35	826	817-1d
4		5	834	Mudawar	5-5d
5		5	810	68	5-3d
6		90	65	90	90-1d
7		65	70	15	65-10d
8		15	35	844	15-14d
9	Karak-Tafileh	35	556	624	35-8d
10		35	50	641	35-9d
11		65	65W	50	65-6d
12		50	35	15	50-1d
13		15	634	60	15-11d
14		60	15	35	60-1d
15	Salt	65	30W	437	65-4d
16		30	431	423	30-4d

17	Zarka-Jarash-Ajloun	30	40	313	30-2d
18		20	234	25	20-1d
19		37	35	166	37-1d
20		236	25	35	236-1d
21		65	171	176	65-2d
22		20	182	55	20-5d
23		55	172	146	55-2d
24		25	144	35	25-2d
25	Mafraq	10	211	5	10-2d
26		10	217	221	10-4d
27		15	Syrian border	232	5-1d
28		15	274	314	15-3d
29		212	212	223	212-2d
30		5	10	30	15-1d
31	Irbid	10	234	25	10-8d
32		10	154	65	10-10d
33		35	10	142	35-2d
34		232	15	25	232-1d
35	Amman-Madaba	40	534	15	40-4d
36		40	436	541	40-5d
37		35	542	522	35-6d
38		556	15	557	556-1d

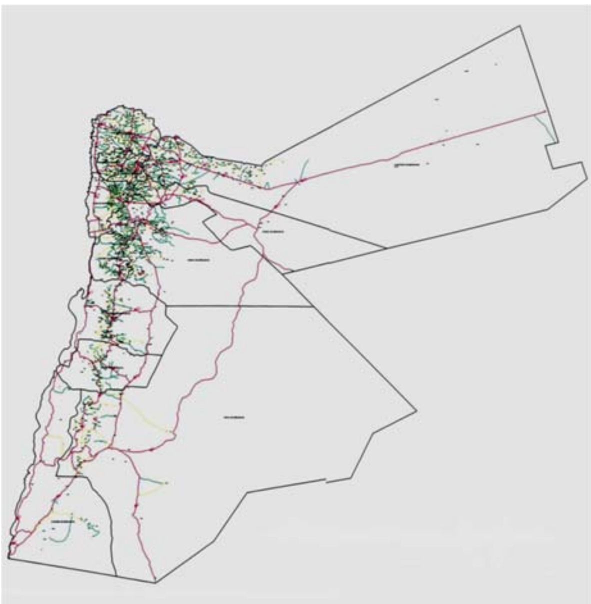

Figure (6): Locations of measured skid resistance across Jordan's road network

Table 2. Field sheet for skid resistance testing

Test Date: 15/6/2010			Test Time: 10:30					
Governorate: Ma`an		Road No.: 817-1			Deflection Test No. : 817-1		Weather:	
Sunny		Pavement Temperature: 32.1 ˚C						
Existing structures within test location Al-Ash`ary Municipality/ Al-Manshyah								
Coordinate N:	**Coordinate E:**	**Surface temperature**	**BPN 1**	**BPN 2**	**BPN 3**	**BPN 4**	**BPN 5**	**Note**
30.40731	35.60396	33.4 ˚C	55	58	57	58	58	

Figure (7): British pendulum skid resistance measurement at test point 817-1

Skid Resistance Measurements Performed

Skid resistance survey included 38 test locations at primary and secondary highways across the entire Jordan's road network. The skid resistance measurements were taken on the exterior right truck lane. At certain locations, the test points had to be moved farther or closer from the adjacent point when they happened to fall on the entrance or exit ramp or on sharp curves that made the locations potentially hazardous.

The starting point on each test location was positioned by the GPS system and the coordinates were input on the test sheet. It is known that the skid resistance number is affected by surface temperature. Therefore, the surface temperature was also measured at each test location as recommended by TRRL (TRRL, 1969). Table 2 shows an example of a filled data sheet and Figure 7 shows a photo during skid resistance testing at one of the test locations.

Skid Resistance Results Obtained

At each of the tested locations, the skid resistance test was repeated five times and the mean value of the recorded five readings was taken as the BPN of the test location (ASTM E303, 2013).

Since the stiffness of the rubber slider varies with temperature, correction of the BPN values obtained was performed to equate the BPN values to 20ºC temperature using TRRL and ARRB correction equation (TRRL, 1969; Oliver, 1980). Table 3 shows the suggested acceptable minimum British Pendulum Number (BPN) limits according to TRRL recommendations for the different road types (TRRL, 1969).

$$\text{BPN } 20 = \frac{\text{BPN at t test temperature}}{1-[0.00525\ (t-20)]} \quad (1)$$

Table 3. Suggested minimum British Pendulum Numbers (BPN) measured with the portable tester according to TRRL recommendations (TRRL, 1969)

Category	Type of site	Minimum skid resistance (surface wet)
A	Difficult sites such as: 1. Roundabouts 2. Bends with radius less than 150 m on unrestricted roads 3. Gradients 1 in 20 or steeper of lengths greater than 100 m 4. Approaches to traffic lights on unrestricted roads	65
B	Motorways, trunk and class 1 roads and heavily trafficked roads in urban areas (carrying more than 2000 vehicles per day)	55
C	All other sites	45

Since all the measured skid resistance locations were selected on heavily trafficked roads, they fall in the B category of the BPN suggested limits shown in Table 3; 55 BPN value. Figure 8 shows the BPN values obtained at the test locations. BPN values obtained were categorized according to the required BPN limit of 55. It can be noticed that whilst 34% of the tested locations are within the acceptable level of surface skid resistance (higher than 55 BPN; TRRL, 1969), 66% of the tested locations fall in the unacceptable range and are considered having dangerous surface skid resistance levels.

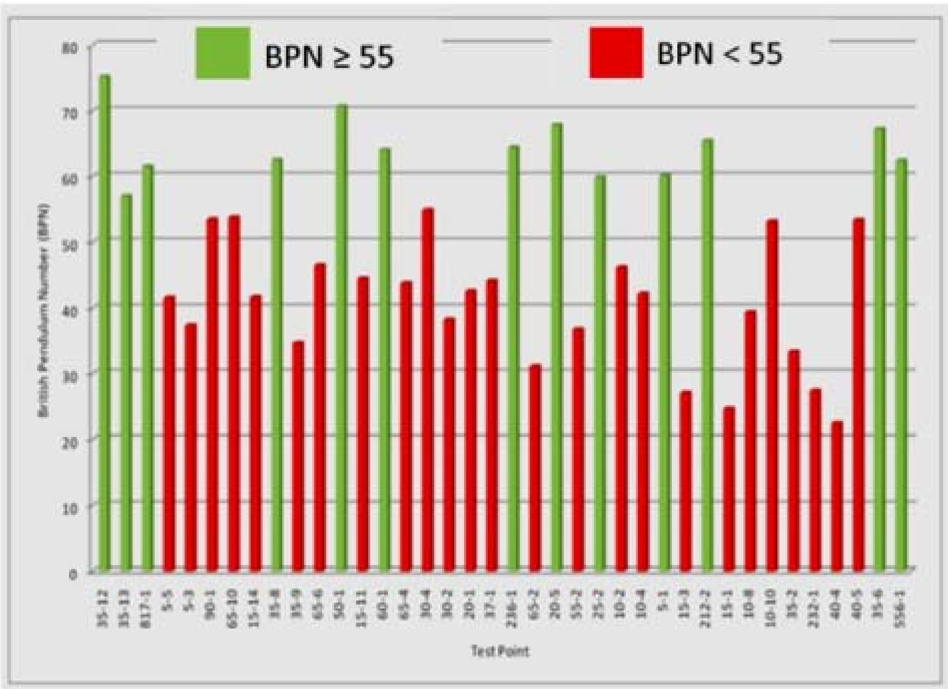

Figure (8): Obtained British pendulum numbers for all test locations

CONCLUSIONS

This investigation was undertaken to find the British Pendulum Number (BPN) of both primary and secondary highways across the Hashemite Kingdom of Jordan. Based on the findings of the skid resistance surveys, the following conclusions can be drawn:

1. 34% of the tested roads on Jordan's road network are within the acceptable levels of surface skid resistance.
2. 66% of the tested roads on Jordan's road network have unacceptable surface skid resistance levels and are considered having dangerous surface skid resistance levels.
3. Approximately two thirds of Jordan's national highway network have unacceptable surface skid resistance levels, which suggests that actions need to be taken to improve road skid resistance levels in Jordan.
4. The current skid resistance levels of Jordan's highway network, if not improved, could have bad impact on Jordan's economy and endanger road safety.
5. It is recommended that more research is needed to evaluate the entire Jordan's national highway network and study the impact of road skid resistance on safety, operating cost and maintenance cost.

RECOMMENDATIONS

This work is considered the first step in generating a database for Jordan's highway road network. This type of work should be repeated annually or at certain selected frequency to update the database and have planned budget scenarios.

Further work has to be conducted to set acceptable limits for British Pendulum Number (BPN) values for Jordan.

Use of more advanced NDT equipment in evaluating highway performance indicators will help in getting better representative values.

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