CASE STUDY: RAN OFF ROAD CRASH VARIATION WITH PAVEMENT FRICTION

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ABSTRACT

The goal of this study is to quantify the effects of friction numbers, measured with a locked wheel skid trailer, on Ran-Off-Road (ROR) crashes. In this case study, the crash histories on an Interstate Highway project are compared before and after an overlay. The pavement was originally constructed in 1972 with an open graded friction course. In June of 1995, the project was overlaid with dense-graded asphalt concrete. For the six years prior to the overlay, the friction number averaged 66. For the first three years after the overlay the friction number averaged 41. These numbers were obtained from the FHWA's Long-Term Pavement Performance database. Records of crash data with all corresponding variables including pavement surface conditions, weather conditions, vehicle files, driver and occupant files, and road geometric files were obtained from FHWA's Highway Safety Information System (HSIS.) Analysis of the crash data indicates that in the before period, on the open graded friction course, if we assume the pavement surface is dry 88.9% of the time, there was no increased chance of running off the road when the surface became wet. However, for the after period, on the dense-graded overlay, the W/D ratio was significantly increased by a factor of 7.4 for ROR crashes.

This study found that the W/D ratio of ROR crashes on dense-graded with average friction of 41 were significantly increased compared to the W/D ratio of ROR crashes on open-graded friction course with average friction of 66. Factors for future research include vehicle type, road geometric design, and speed.

INTRODUCTION

In the United States 38 of the 50 State Highway Departments monitor the coefficient of friction, or skid number. 37 of these 38 States use a locked wheel skid trailer for this task. In 2008 the American Association of State Highway and Transportation Officials published the "Guide for Pavement Friction."(1) This Guide presents several methods to set pavement friction thresholds. The most common procedure is to plot the crash rate versus friction number, for each type of; pavement, and class of highways with similar levels of average annual daily traffic (AADT.)

RESOURCES

LONG-TERM PAVEMENT PERFORMANCE DATABASE

The Long-Term Pavement Performance (LTPP) database was conceived as part of the Strategic Highway Research Program, under the National Academy of Science, in 1985. It has been under development by the FHWA since 1991. It includes several thousand pavement sections, from about 900 sites, across the US and Canada. In addition to the primary data set, major modules in the database include traffic, road profile data, and falling weight deflection (FWD) measurements. The primary data set includes files on pavement inventory, maintenance and rehabilitation, material tests and pavement performance monitoring. Another useful file is the seasonal monitoring program that can be used to estimate the percent time the road surface is wet and dry, but it only includes a limited number of pavements. The general database also has a climatic module, with information on an hourly basis, except for precipitation that is reported on a daily basis. The raw data files available from the LTPP contain the hourly precipitation. Alternatively these files can be retrieved at the web site for National Climatic Data Centre that is part of the National Oceanographic and Atmospheric Administration.

HIGHWAY SAFETY INFORMATION SYSTEM

To assist in the study of Highway safety and provide input to program policy decisions, the Federal Highway Administration (FHWA) has developed and maintained the Highway Safety Information System (HSIS) since 1987. The HSIS is a roadway based system, with data files for; crashes, vehicles, drivers, and road geometric designs. Safety information is acquired every year, from selected states, based on the quality and quantity of their crash data.

Crash information on personal injuries includes the number of fatalities, incapacitating injuries, serious injuries, minor injuries, and the number of passengers without injury, for each crash. The type of crash is also specified, as well as the number and types of vehicles. The date, time of day, climatic conditions, and road surface conditions (wet, dry, and snow or ice) are also reported. All crashes back to January 1, 1985 are reported in the HSIS, if they involved a personal injury; or at least $500 dollars in property damage. The dollar amount increased to $1000 on September 18, 1999. In this study, crashes occurring between January 1, 1985 and November 1, 2004, the date of a second overlay, were analysed.

SAFETY ANALYSIS

One file under the LTPP monitoring module, of principal use for this study is the optional set of state supplied pavement friction measurements on the test sections. The other principal data of interest is adopted from the inventory files, for the pavement designs and types of surface materials. Figure 1 is a plot of the aggregate gradations, from LTPP, for the open graded friction course and the dense graded overlay. The friction course had a relatively high 6.2 % asphalt cement content, 10 to 11 % air voids, and 23 to 24 % voids in the mineral aggregate. The asphalt concrete for the dense graded overlay wearing surface had targets of 6 % asphalt cement, 15.5 % voids in the mineral aggregate that were 92 % filled, resulting in a very low level of 1.2 % air voids. This low level of air voids can explain why the rut depths of the overlay, after only five to nine years, are similar to the rut depths in the original pavement after 20 to 24 years, i.e. 0.3 to 0.5 in (7.6 to 12.7 mm.).

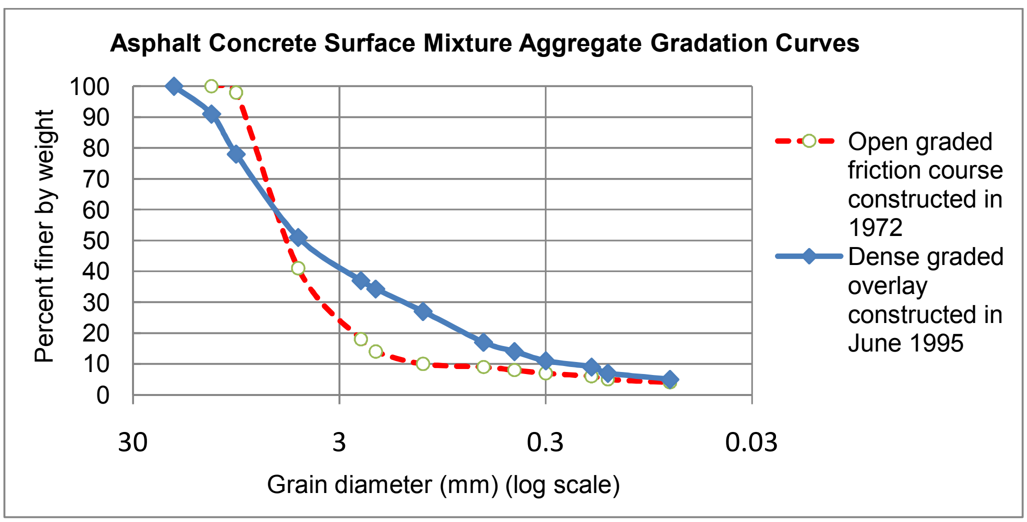

Figure 1: Asphalt concrete surface mixture gradations from LTPP data.

Locked wheel skid numbers, on the open graded friction course and the dense graded overlay, stored in the LTPP database were plotted for both periods of this study, in Figure 2. The average skid number for the six years before the overlay was 66. The average skid number for the first three years on the dense graded overlay was 41. The average skid number for the six years before the overlay was 66. The average skid number for the first three years on the dense graded overlay was 41.

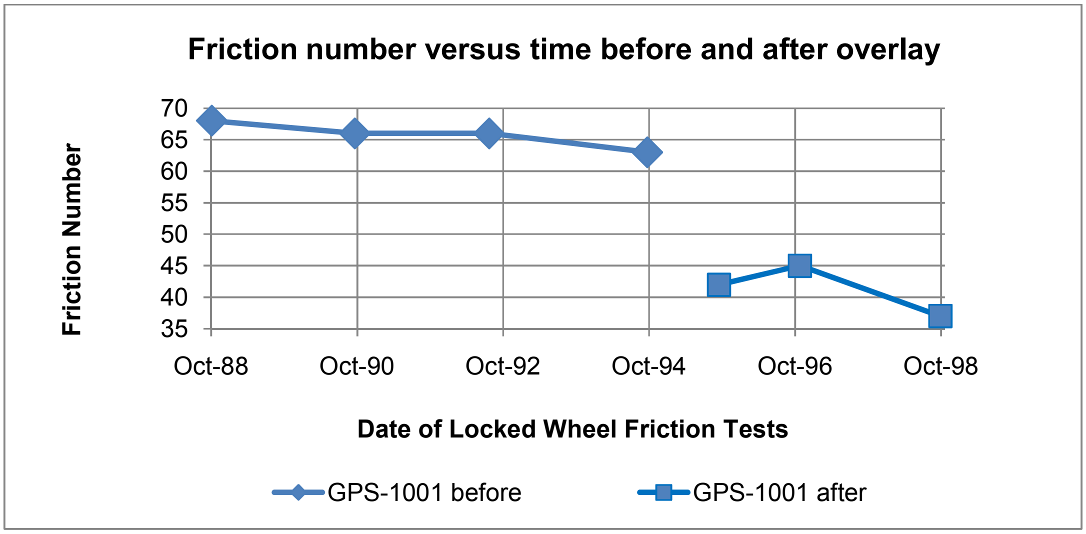

Figure 2: Locked wheel friction numbers on friction course and dense graded overlay.

This 17.12 mile (27.54 km) project has 16.33 miles (26.28 km) between two exits that were selected for analysis, so as to keep the average annual daily traffic (AADT) constant when the HSIS crash data was analysed. For this State, crashes are located to the nearest tenth of a mile, with the Geographic Information System's (GIS) mileposts. The analysis period was divided into two parts, before and after the first overlay, i.e. July 1, 1995. There were a total of 325 crashes, 142 before and 183 after the overlay. Table 1 groups the crashes by type, and road surface conditions, for the two time periods.

On the friction course, (51%) of the crashes occurred on snow and/or ice. On the open graded overlay, (36%) of the crashes occurred on snow and/or ice. A smaller percentage of crashes occurred on wet and dry pavements before 1995 (49% versus 64%) presumably due to higher friction numbers.

Before period descriptive analysis - From January 1, 1985 to June 30, 1995 on the 13 to 23-year-old open graded asphalt concrete friction course, the 142 crashes involved 166 vehicles. There were zero fatalities, 12 incapacitating injuries, 61 serious injuries, 30 minor injuries, and 183 persons without injury.

After period descriptive analysis - From July 1, 1995, to November 1, 2004, on the dense graded asphalt concrete overlay, there were 183 crashes that involved 202 vehicles. There were two fatalities, nine incapacitating injuries, 42 serious injuries, 33 minor injuries, and 239 persons without injury.

To prepare an unbiased sample, the crashes related to snow and/or ice pavement condition were deleted from both before and after period data, because in snow and ice related crashes a slippery solid (zero to a very low friction) exists between the pavement and tire. Another modification to the revised data in Table 2 is to group crashes involving objects in the road, including animals and pedestrians, into one type.

After removing snow/ice related crashes, and other irrelevant crash cases from the sample for the 126 months before period, we have 68 vehicles in 64 crashes. There were zero fatalities, 6 incapacitating injuries, 28 serious injuries, 16 minor injuries, and 77 persons without injury.

After we performed the same modifications to the sample data crash for the 112 months after period, we have 123 vehicles in 111 crashes. There were two fatalities, eight incapacitating injuries, 26 serious injuries, 19 minor injuries, and 154 persons without injury. The two fatalities were both in ROR crashes, one on wet and one on a dry pavement surface, after the overlay.

Table 1: Number of crashes for before and after periods by; type and surface condition

Crash type	Before Overlay (1/1/85 to 6/30/95)			After Overlay (7/1/95 to 11/1/04)		
	Dry	Wet	Snow/ice	Dry	Wet	Snow/ice
Ran off the road	32	4	49	26	24	53
Rear end/sideswipe	4	0	17	6	2	8
Rollover	5	0	4	1	1	1
Jackknife	1	0	0	1	0	2
Object in road	6	1	1	3	0	1
Moose	0	0	0	26	2	0
Deer	0	0	0	14	0	0
Bears	1	0	0	2	0	0
All other animals	8	1	0	1	0	0
Pedestrian	0	0	0	1	0	0
Fixed object	1	0	1	1	0	0
Fire	4	2	0	7	0	0
Total	62	8	72 (51%)	89	29	65 (36%)

Table 2: Before and after overlay crashes by type, on wet and dry surfaces,

Crash type	Open graded friction course (1/1/85 to 6/30/95)			Dense graded overlay (7/1/95 to 11/1/04)		
	Dry	Wet	Total	Dry	Wet	Total
Ran-off –road (ROR)	32	4	36	26	24	50
Rear-end/ sideswipe	4	0	4	6	2	8
Rollover	5	0	5	1	1	2
Jackknife	1	0	1	1	0	1
Object in road	15	2	17	47	2	49
Fixed object	1	0	1	1	0	1
Total	58	6	64	82	29	111

Conventional analysis methods

Figure 3 plots the Average Annual Daily Traffic (AADT,) and the Average Annual Daily Truck Traffic (AADTT), from 1972 to 2004. Since the HSIS and Long-Term Pavement Performance (LTPP) information system have traffic volumes, the AADT can be used to compute crash rates, i.e. per vehicle mile travelled (VMT.) The LTPP traffic table “Historic Estimate Equivalent Single Axle Loads (ESAL)” lists the AADT for the first 17 years the project was in service, 1972 through 1989. It also lists the Average Annual Daily Truck Traffic (AADTT) for the same years. The percent trucks ranges from 15.2 to 15.6%, with an average of 15.38%. For the years 1972 and 1982, they factored a single count taken at the site, to get the AADT. For the other years, they used an estimated growth factor. The LTPP traffic monitoring table "Estimated ESALs" gives the average daily total and truck volumes, for the years 1990 to 1999 and 2004. A straight-line connects the 1999 to 2004 LTPP values for AADT. The LTPP traffic monitoring table LTPP Lane gives the volumes, by vehicle class 4 to 10 (heavy trucks) for the years 2001 to 2004. A straight-line was also used to plot the value for the average annual daily truck traffic for the year 2000. If we assume a linear growth of 3.1 per set, from the initial value of 2930 in 1985, we get the dotted line and the value of 4660 vehicles per day in 2004.

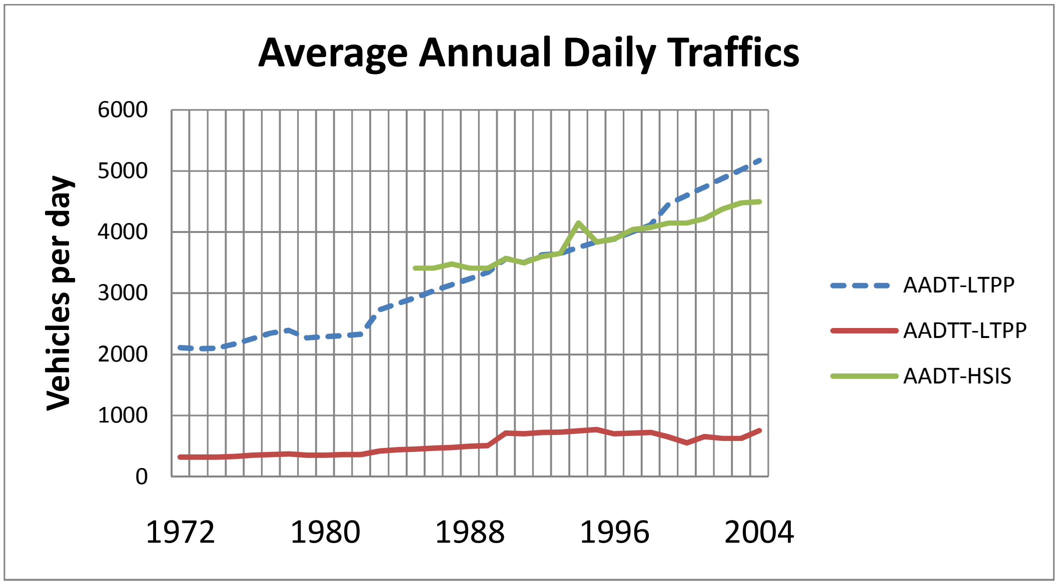

Figure 3: Average Annual Daily Traffic from 1972 to 2004.

Figure 4 plots the crashes per year normalized per 100 million vehicle miles travelled. In summary the crash rates are quite variable. The mean crash rate on the open graded friction course is 28.24 crashes per hundred million vehicle miles travelled, with a coefficient of variation of 50%. The mean crash rate on the dense graded overlay is 73 percent higher, at an annual average rate of 48 crashes per hundred million vehicle miles travelled, with a coefficient of variation of 23%.%.

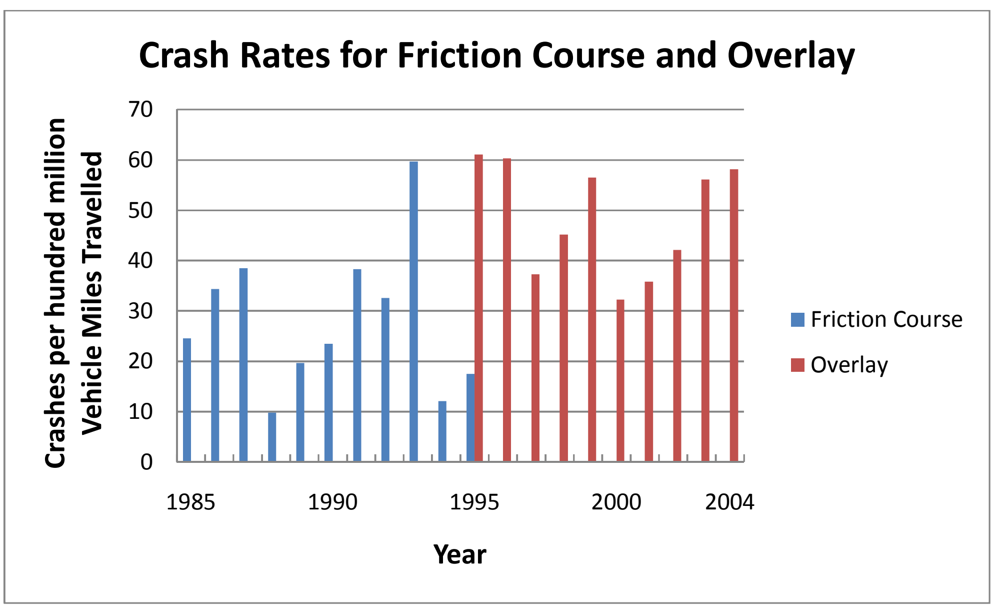

Figure 4: Crash rates before (on friction course) and after (on a dense graded overlay.)

We can also derive several ratios from this data to show the effects of open graded friction courses, with high friction numbers, on crash rates. One involves the percentage of ROR crashes on wet pavements. Before the overlay, four out of 36 ROR crashes (11 %) were on wet pavements. The ratio of wet to dry crashes is (4/32) = 12.5%. After the overlay, 24 out of 50 ROR crashes (48%) were on wet pavements. The ratio of wet to dry ROR crashes is (24/26) = 92%.

Proposed Wet/Dry Ratio analysis procedure

A procedure to compute the extent of ROR crash increases, on wet pavements, is to factor these wet to dry crash ratios, by the ratio of time the pavement surface is dry to the time it is wet.

The following equation can be used to compute the W/D proportion for ROR crashes using the dry/wet time factor: Basically this equation computes the increased likelihood of a crash when the pavement surface becomes wet.

$$ROR\frac{W}{D}Proportion = \frac{number\ of\ wet\ accidents}{number\ of\ dry\ accidents} \times \frac{time\ surface\ is\ dry}{time\ surface\ is\ wet}$$

ROR W/D ratio Calculation

The pavement surface is estimated to be wet 11.1% of the time, and the W/D ratio of vehicles running off the road on the open graded friction course is the same whether the road surface is wet or dry.

$$\frac{4}{32} \times \frac{88.9}{11.1} = 1$$

In this case study if we assume the same percentages of time for wet and dry pavements after the overlay (considering compatible long periods of study for both before and after periods) the W/D ratio of vehicles running off the road is 7.4 times higher, when the pavement surface condition becomes wet.

$$\frac{24}{26} \times \frac{88.9}{11.1} = 7.4$$

Using Table 2, Z-Test was performed for; the before period proportion of ROR wet pavement crashes (p1= 4/36), and the after period ROR proportion of wet pavement crashes (p2= 24/50), and the result indicates that these two ROR, wet pavement crash proportions are significantly (P-value= 0.0001) different.

Road surface conditions

Since information on road surface condition, overall percent time dry and wet, from 1985 to 2004, is currently unavailable for this site, we have to estimate the factor from climatic data. The closest weather station in operation in 1985 was at Orono. However this station recorded precipitation only when the running cumulative total reached one-tenth of an inch. On this basis they recorded rain for 264 hours in 1985, or 3 % of the hours. At another station, in the same zone, Grand Lake Stream, they recorded rain when it reached one hundredth of an inch. On this basis, in 1985 they recorded rain for 631 hours, or 7.2 % of the hours in a year. Unfortunately in 1986 they switched the threshold to one tenth of an inch at the Grand Lake Stream Station. Table 3 shows this information on a monthly basis. Although the annual total measured is nearly the same for the two stations, about 1.1 % difference, the hours with rain are 140 % greater at Grand Lake Stream.

These values for total annual rainfall, for 1985, agree closely with the average value from the Mechanistic Empirical Pavement Design Guide (MEPDG,) based on the weather station at Bangor International Airport, for the seven years 1998 to 2005. The MEPDG has an average total of 34.3 in (871 mm.). The MEPDG reports daily totals to the nearest thousandth of an inch. There is an average 196 days with at least 0.001 in measured rain but less than 0.01 in. There was an average 129 days with at least 0.01 in but less than 0.02 in, which is close to the 112 days at the Grand Lake Stream Station. There was an average of 44 days per year with at least 0.25 in. There was an average of 22 days per year with at least 0.5 in. There was an average of 7 days per year with at least 1 in. The annual average daily maximum is 2.05 in. This poses the question of how much precipitation causes a wet surface and for what percent of the time. This depends on the evaporation rate, which is higher during the summer. Thus during the winter we might expect the surface to remain wet longer. There are no LTPP seasonal monitoring program sites in this interior region of the state. The only LTPP seasonal monitoring site is in the coastal climate region. In 1994 it rained 9.8 % of the hours at this site, and in 1998 it rained 10.2 % of the hours at this site. Thus we use engineering judgement to estimate the surfaces are wet about 11.1 % of the time. Based on friction and drainage tests of an open graded friction course, and medium textured slurry seal at controlled water depths (6) we find the pavement seldom reaches the extreme test conditions.

Table 3 Effect of Reporting Precision on Number of Hours with Rain in 1985

Weather Station	Month	Days with rain	Hours with measured rain	Total rainfall (mm)	Total Yearly Days and Hours with Rain, and Rainfall (mm)
Grand Lake Stream (Reported in hundredths of an inch (0.254 mm))	1	4	25	18	112 days 631 hours (7.2 %) 875 mm (34.4 in)
	2	9	61	66	
	3	8	47	89	
	4	6	38	23	
	5	12	58	96	
	6	12	82	122	
	7	6	13	7	
	8	10	65	117	
	9	8	52	79	
	10	9	31	73	
	11	14	84	114	
	12	13	74	64	
Orono 2 (Reported in tenths of an inch (2.54 mm))	1	4	6	15	**95 days 264 hours (3.0 %) 885 mm (34.8 in)**
	2	9	24	74	
	3	8	20	71	
	4	6	14	36	
	5	12	24	117	
	6	11	36	122	
	7	7	14	41	
	8	10	35	127	
	9	6	23	74	
	10	6	17	69	
	11	8	32	86	
	12	8	19	53	

Pavement performance before and after overlay

Figure 5 plots the International Roughness Index (IRI) before and after the overlay. The pavement was about two to three times rougher from 1985 to 1995, as from 1995 to 2004. It is possible this roughness caused the speeds to be reduced before the overlay, thus decreasing the number of crashes. Before any conclusions are drawn on this matter we will attempt to get more definitive information from the raw weigh in motion and vehicle classification data for the LTPP.

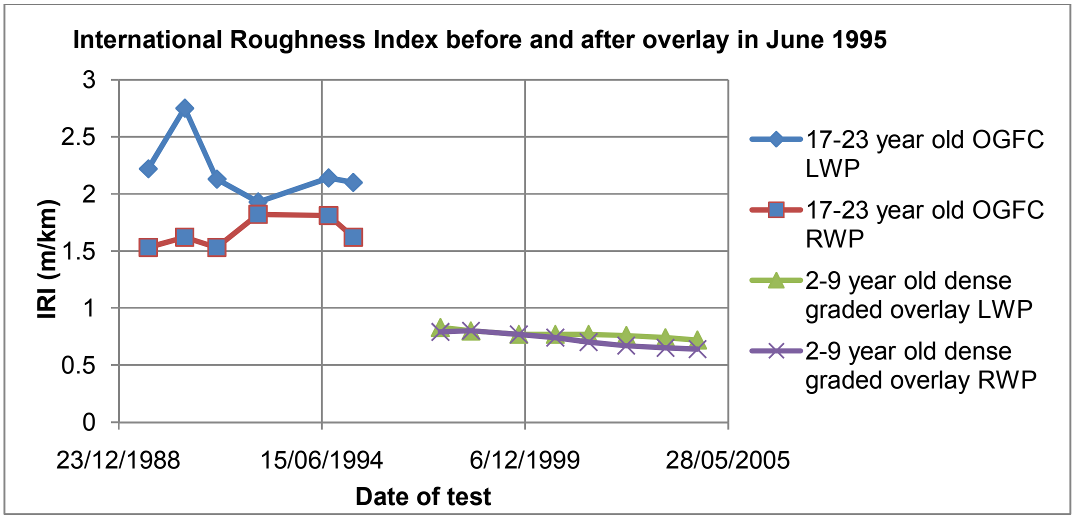

Figure 5: IRI versus time for the open graded friction course and dense graded overlay.

Figure 6 plots the rut depths versus age for the 18 to 22 year old OGFC (1990 to 1994) and the 0 to 8 year old dense graded overlay (1995 to 2003.) In 2004 there were 4 wet ROR crashes, 2003 had 5, 2002 had 4, 2001 had 0, 2000 had 3, 1999 had 4, 1998 had 2, 1997 had 1, 1996 had 1, and the second half of 1995 had 2. After January 1990 there were no wet ROR crashes on the OGFC. Thus it is concluded high rut depths have little effect on the probability of ROR crashes on either the OGFC or the dense graded overlay. However the low level of voids in the dense graded overlay resulted in a more rut prone mixture with high ruts at an early age.

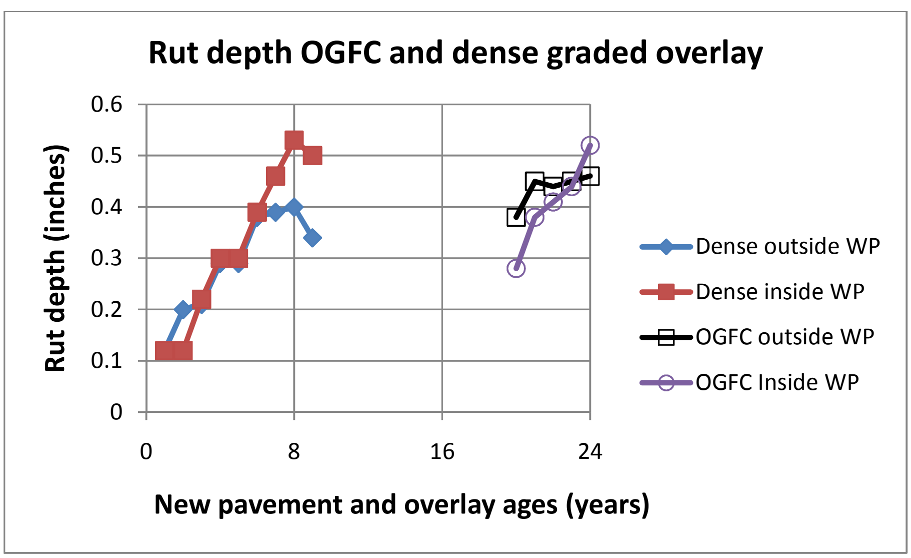

Figure 6: Rut depth versus age for the open graded friction course and dense graded overlay.

CONCLUSIONS

A 20 year case study was conducted, on a 16.33 mile section of interstate highway between two exits. Crashes were related to friction number before and after a dense graded overlay of an open graded friction course (OGFC.) The pavements were a 12.5 to 23 year old OGFC, and a 0 to 9.33 year old dense graded overlay. The total vehicle miles travelled on the overlay were about 6 % higher in the after overly period, but the crash rate on the overlay was about 73 % higher. The wet to dry ratio of ROR crashes was 12.5 % on the OGFC, and 92 % on the dense graded overlay. Also, the study result indicates that ROR, wet pavement crash proportions for before and after periods are significantly (P-value= 0.0001) different.

A procedure has been proposed to compute the increased proportion of Ran-off-Road crashes when the pavement surface becomes wet. Basically it factors the wet to dry crash ratio, by the ratio of the time the surface is dry to the percent time the surface is wet. If we assume the pavement was wet 11.1 % of the time (close to the actual value), there is no increase in the proportion of vehicles running off the friction course if it becomes wet. However, on the dense graded overlay the proportion of vehicles running off the road is 7.4 times greater when the surface becomes wet.

For future research on this 16.33 highway section we need to attempt to get the vehicle speeds for the before and after periods, where roughness was reduced by about 50 %. In other words did vehicles run slower on the rougher road so as to decrease the crash rates?

REFERENCES

1. Guide for Pavement Friction, American Association of State Highway and Transportation Officials, November 2008.
2. Long Term Pavement Performance, Standard Data Release 25.0, January 2011, DVD Version.
3. Highway Safety Information System, www.hsisinfo.org.
4. ASTM E274 – 97 (2006), Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire.
   (AASHTO T 242-96 (2009) Frictional Properties of Paved Surfaces Using a Full-Scale Tire)
5. ASTM E 501, Specification for Rib Tire for Pavement Skid Resistance Tests
   (AASHTO M 261, Standard Tire for Pavement Frictional Property Tests)
6. Report Numbers FHWA-RD-79-30 and 31, *Pavement and Geometric Design Criteria for Minimizing Hydroplaning,* B.M. Galloway, D.L. Ivey, G. Hayes, W.B. Ledbetter, R.M. Olson, D.L. Woods, and R.F. Schiller, Jr., Texas Transportation Institute, December 1979.

AUTHOR BIOGRAPHIES

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Gerardo Flintsch is a Professor at Virginia Polytechnic Institute and State University. He has several FHWA contracts to develop pavement friction and texture measurement equipment. He is also chairman of the Sustainable Pavements Subcommittee, on the Transportation Research Board's Pavement Management Section Executive Board.