A Preliminary Evaluation of FC-5 and FC-6 Friction Courses in Florida

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Abstract

Friction courses are employed on state roadways in Florida to maintain stopping friction and improve safety during wet weather conditions. On high-speed, multi-lane facilities, open-graded friction courses (FC-5) are specified to provide an open texture to allow water to be transmitted away from tire contact surfaces. These surfaces help reduce hydroplaning as well as the amount of spray experienced by the traveling public, thus enhancing safety. Dense-graded friction courses (FC-6) are placed on all other state-owned facilities.

Historically, the mean Friction Numbers (FN_{40R}) for surface courses in Florida have been satisfactory. However, on occasion, these mixes have exhibited unacceptably variable frictional properties, necessitating remedial measures on new pavement surfaces in some cases. Although the affected pavement surfaces were generally found to have been designed and constructed in accordance with prescriptive methods, the desired frictional properties were not always obtained.

It has been shown that the performance of friction courses in relation to wet weather crash rates is a function of material properties, vehicle speed, tire conditions, pavement geometry, traffic volumes, mix design, environmental conditions, and other project specific considerations. Each of these factors is currently being scrutinized in Florida in an attempt to evaluate the variability of FN_{40R} values for FC-5 and FC-6 friction courses.

The preliminary results of this investigation are presented herein. This paper provides evidence that remedial measures taken to date to improve the durability of friction courses have not increased the variability in FN_{40R} values on Florida roadways.
Key words: Friction course, skid test, durability, safety, wet-weather accidents, hydroplaning.

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Introduction

In a complete sense, a "good" pavement provides satisfactory riding comfort to its users, does not require extensive maintenance for the repair of distress, is structurally adequate for the traffic loads, and provides sufficient friction to avoid skidding accidents (1). This paper documents the measures taken in recent years to ensure the friction courses placed on state roadways in Florida meet or exceed these expectations. More specifically, this paper addresses the perceived variability in Friction Numbers (FN_{40R}) of the surface courses used by the Florida Department of Transportation (FDOT).

Many of the native limestone aggregates found throughout Florida are prone to polishing under traffic. Consequently, friction courses are employed on the majority of state roadways to maintain stopping friction and improve safety during wet weather conditions. Historically, aggregates that have been used in friction courses in Florida include oolitic limestone, granite, siliceous river gravel, slag and washed concrete sands. On high-speed, multi-lane facilities, open-graded friction courses provide an open texture to allow water to be transmitted away from tire contact surfaces. This mechanism helps reduce the potential for hydroplaning and also reduces the amount of spray experienced by the traveling public, thus enhancing safety. Dense-graded friction courses are used on all other state-owned facilities.

In general, the FN_{40R} for surface courses in Florida have historically been satisfactory. However, on occasion, these mixes have exhibited variable frictional properties, sometimes necessitating remedial measures on new pavements. This variability in frictional properties is found most often with native limestone materials.

It has been documented by others that the performance of friction courses in relation to wet-weather crash rates is a function of material properties, vehicle speed, tire condition, pavement geometry, traffic volumes, mix design, environmental conditions, and other project specific considerations. Each of these factors is currently being evaluated in Florida in an attempt to identify the essential factors contributing to variable FN_{40R} values.

Pavement Friction

Friction Measurement in Florida

The FDOT has conducted skid tests on state roadways since 1958. The first skid trailer, meeting the requirements of ASTM Committee E-17 on Vehicle-Pavement Systems was fabricated for the Department in 1966. All friction testing currently conducted by FDOT is performed in accordance with the provisions outlined in ASTM E 274, "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (2)." Testing is typically performed at the specified speed of 40 mph (65 km/h), using the standard "Ribbed Tire" as specified by ASTM E 501, "Specification for Standard Rib Tire for Pavement Skid-Resistance Tests (3)."

Friction testing is conducted by FDOT on all newly constructed pavement surfaces; all overlays; spot hazard locations identified as having an unusual number of wet weather accidents; re-test locations where the initial FN_{40R} was found to be less than 34; and special requests, including research test sections, milled surfaces, or bridge decks. Testing is performed in the center of the left wheel path of the traffic lane, in both directions for four-lane and multi-lane roadways. For two-lane roadways, only one lane is tested, unless otherwise requested (4).

In 1984, FDOT began collecting "Smooth-Tread" skid data at wet-weather accident sites in accordance with ASTM E 524, "Specification for Standard Smooth Tire for Pavement Skid Resistance Tests," in addition to ribbed tire data (5). It has been documented by others that the ribbed tire test is predominantly influenced by micro-texture, whereas the smooth tire test is influenced to a greater extent by macro-texture (6). Analysis of the smooth-tire data collected by FDOT at wet-weather accident sites is summarized in Figure 1 (7). As presented by the horizontal line corresponding to a mean, smooth-tire Friction Number (FN_{40S}) of 25, the smooth tire data appears to correlate well with wet-weather accidents. Smooth-tire friction testing has not been adopted as the standard method of testing in Florida. One reason for this is the lack of historical data relative to the ribbed tire test. Ultimately, it is noted that because many other factors contribute to accidents, one should not expect to be able to predict accident frequency from skid resistance data alone (7). The smooth tire test continues to be used by FDOT as a tool in the investigation of specific surfaces exhibiting significant wet-weather accident rates.

Equipment and Calibration

FDOT currently maintains four skid trailers meeting ASTM specifications, as previously described. A photograph of a typical unit is presented in Figure 2. These units are equipped with Mobile Data Recorders (MDR 4040) for automated data acquisition purposes. The units are calibrated biennially at the Central/Western Field Test and Evaluation Center, Texas Transportation Institute, Texas A&M University System, College Station, Texas. FDOT personnel check the calibration of these units using a force plate every thirty to forty-five days. Water flow checks are also performed every six months to ensure proper water flow and distribution. The units are also checked for repeatability on four test sections located in the vicinity of the State Materials Office after each calibration check (4).

FDOT Friction Surfaces

FDOT makes use of two (2) classifications of friction courses. These include open-graded (FC-5) and dense-graded (FC-6) mixtures. The application criteria for friction courses are provided in the FDOT "Flexible Pavement Design Manual for New Construction and Pavement Rehabilitation (8)." In general, FC-5 mixtures are specified for multi-lane and high-speed facilities. FC-6 mixtures are specified where an open-graded texture is not required.

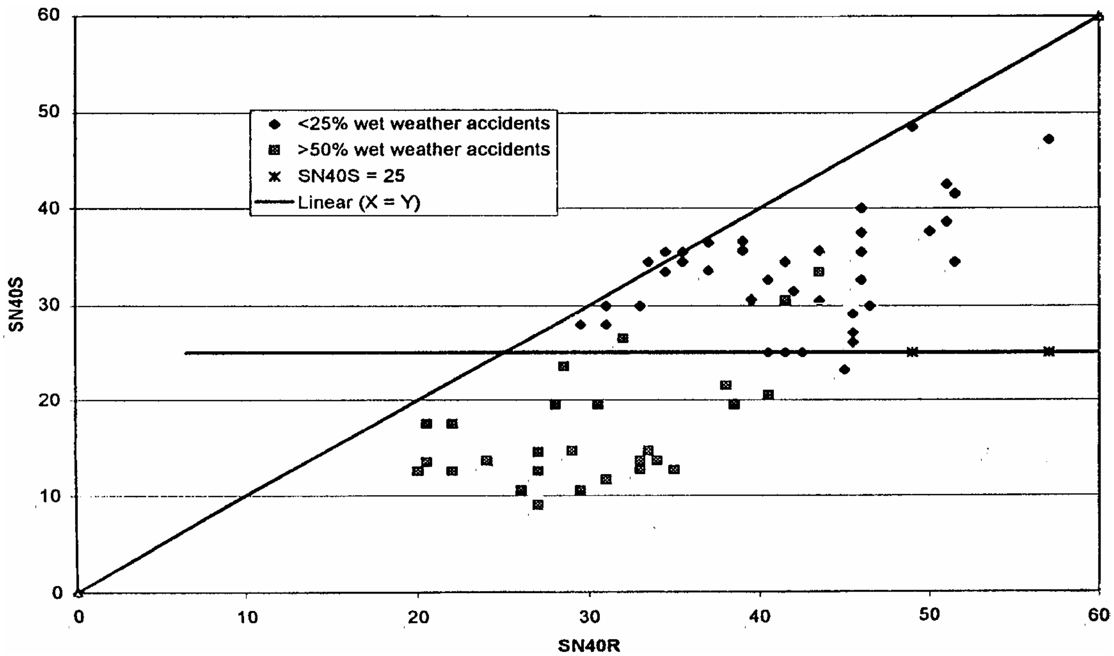

Figure 1. Ribbed-Tire versus Smooth-Tire Friction Numbers for Florida Pavements (7).

Figure 2. Typical FDOT Skid Trailer Unit.

Open-Graded (FC-5) Friction Courses

The specific requirements for materials and design of friction courses are described in Section 337 of the FDOT "Standard Specifications for Road and Bridge Construction (9)." The open-graded FC-5 mixtures are specified to contain 100% polish resistant coarse aggregate, consisting of crushed granite or crushed limestone from the oolitic formation (limestone containing a minimum of 12% non-carbonate material, as determined by the FDOT acid insoluble test, FM 5-510). The nominal maximum aggregate size for the coarse aggregate is ½ inch (12.5 mm). Crushed granite or crushed oolitic limestone screenings are also specified for the fine aggregate fraction. Mineral fibers at a dosage rate of 0.4% by total weight of mix or cellulose fibers at a dosage rate of 0.3% by total weight are also specified. An ARB-12, asphalt rubber binder containing 12% ground tire rubber is also specified. Granite mixes are also required to contain 1.0% hydrated lime (by weight of total dry aggregate). FC-5 is typically placed on the roadway at a specified spread rate of 70-80 lb/yd^2 (38-44 kg/m^2), which correlates to an in-place thickness of approximately ¾ inch (20.0 mm).

Dense-Graded (FC-6) Friction Courses

The FDOT dense-graded FC-6 mixtures are also specified to contain polish resistant coarse aggregate, consisting of crushed granite or crushed limestone from the oolitic formation, but may contain up to 40% other materials if they contain a minimum of 60% crushed granite. These mixtures do not contain fibers and specify an ARB-5 asphalt rubber binder containing 5% ground tire rubber. FC-6 is placed on the roadway at a specified spread rate of 150-160 lb/yd^2 (80-88 kg/m^2). This typically correlates to an in-place thickness of approximately 1-½ inches (38.0 mm). The FC-6 is a 12.5 mm Superpave mixture.

Key Specification Revisions

Although Florida has had good success with reducing the hydroplaning potential of its high-speed facilities by using open-graded friction courses, the durability of these mixes have been a concern since their introduction (10). The new FC-5 and FC-6 friction course mixes were developed in a continued effort to improve the durability of pavements in Florida. FC-5 was developed to replace the FC-2 mixes used on high speed, high traffic volume facilities throughout the state. The functional life of the FC-2 surfaces was observed to be about 7 to 8 years. The first FC-5 test section was constructed on I-10 in Suwannee County in late 1996/early 1997. The new FC-5 surfaces are expected to last longer and provide greater drainage characteristics than the FC-2 mixes. The FC-5 mixes are thicker than the earlier FC-2 mixes and are designed for improved durability via the use of fibers and modified binder (asphalt rubber binder, ARB). The new design is very similar to the Georgia D-modified open graded friction course, which has proven to be a very durable mix. FC-6 was designed to replace the dense-graded FC-3 mix used on lower volume facilities throughout the state. The FC-6 mix makes use of Superpave aggregate requirements, larger aggregate size, and also contains asphalt rubber binder. This mix is also expected to provide an extended functional life to the pavement surface.

FDOT Friction Requirements

The FDOT Safety Improvement Program Manual calls for desirable FN_{40R} values of 35 and greater for facilities with posted speed limits greater than 45 mph. FC-5 mixes are typically specified for these facilities. On roadways with a posted speed limit less than or equal to 45 mph, the desirable FN_{40R} value is 30 or greater. FC-6 mixes are typically specified for these facilities. In addition, The FDOT Friction Testing and Action Program calls for FN_{40R} values of 35 and above, and pavements having FN_{40R} values below 34 must be re-tested in one year. These friction requirements are generally consistent with other state transportation departments (6).

Friction Test Data

The results of friction testing of FC-2 and FC-3 surfaces paved throughout the state of Florida, from 1998 through 2001 are summarized in Table 1. Table 1 provides a listing of the mean FN_{40R} value, the standard deviation, and the number of tests performed for the FC-2 and FC-3 mixes tested during this 4-year period. Similar results are summarized in Table 2 and Figures 3 and 4 for FC-5 and FC-6 surfaces. Figures 3 and 4 present the mean FN_{40R} values for the FC-5 and FC-6 surfaces bounded by 95% confidence intervals. These figures illustrate the relative variability associated with the mean values for the respective years. Figures 5 and 6 present the mean FN_{40R} values for the FC-2 and FC-3 surfaces bounded by 1.96 standard deviations (95% of data falls within $\pm$1.96 standard deviations of the mean). Figures 7 and 8 present the mean FN_{40R} values for the FC-5 and FC-6 surfaces bounded by 1.96 standard deviations.

Table1. Statistical Data for FC-2 and FC-3 Mixes Placed During 1998-2001.

Property	1998		1999		2000		2001	
	FC-2	FC-3	FC-2	FC-3	FC-2	FC-3	FC-2	FC-3
Mean FN_{40R}	39.9	43.9	38.3	43.7	39.2	41.8	41.9	42.6
Std. Dev.	4.1	6.3	4.5	6.8	4.7	7.1	4.4	6.8
Sample Size	269	469	251	483	190	471	169	305

Table2. Statistical Data for FC-5 and FC-6 Mixes Placed During 1998-2001.

Property	1998		1999		2000		2001	
	FC-5	FC-6	FC-5	FC-6	FC-5	FC-6	FC-5	FC-6
Mean FN_{40R}	43.4	41.2	41.3	39.8	37.3	41.1	40.6	43.5
Std. Dev.	4.1	4.9	5.1	5.5	4.1	6.5	4.9	7.6
Sample Size	60	12	82	54	203	303	313	515

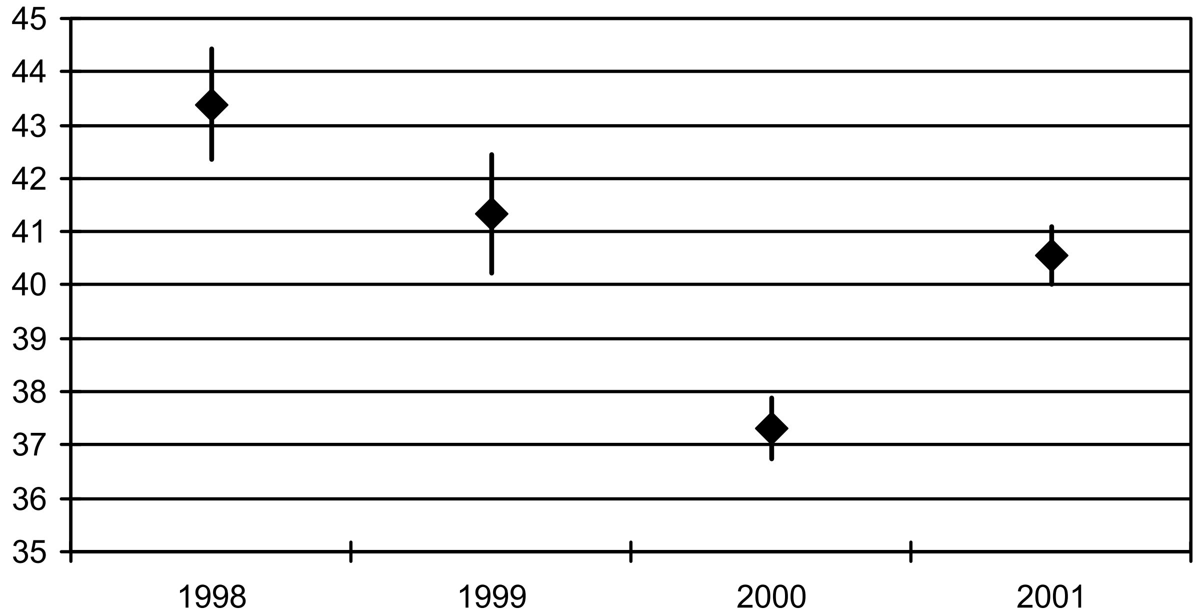

Figure 3. **Mean FN_{40R} Data for FC-5 Mixes, Bounded by the 95% Confidence Interval for the Mean.**

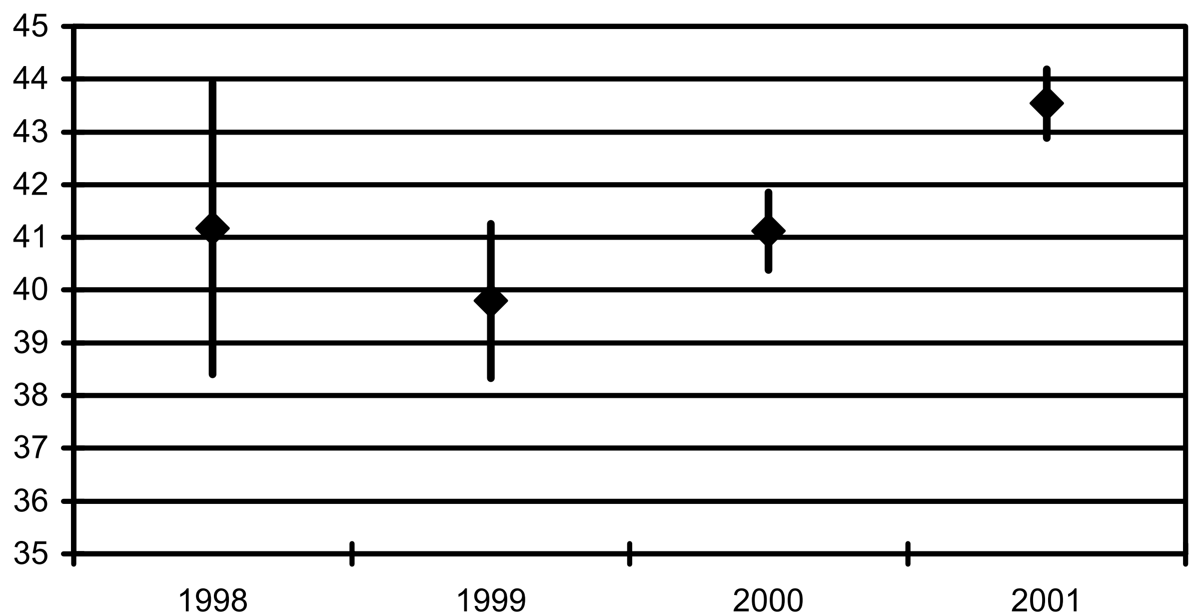

Figure 4. **Mean FN_{40R} Data for FC-6 Mixes, Bounded by the 95% Confidence Interval for the Mean.**

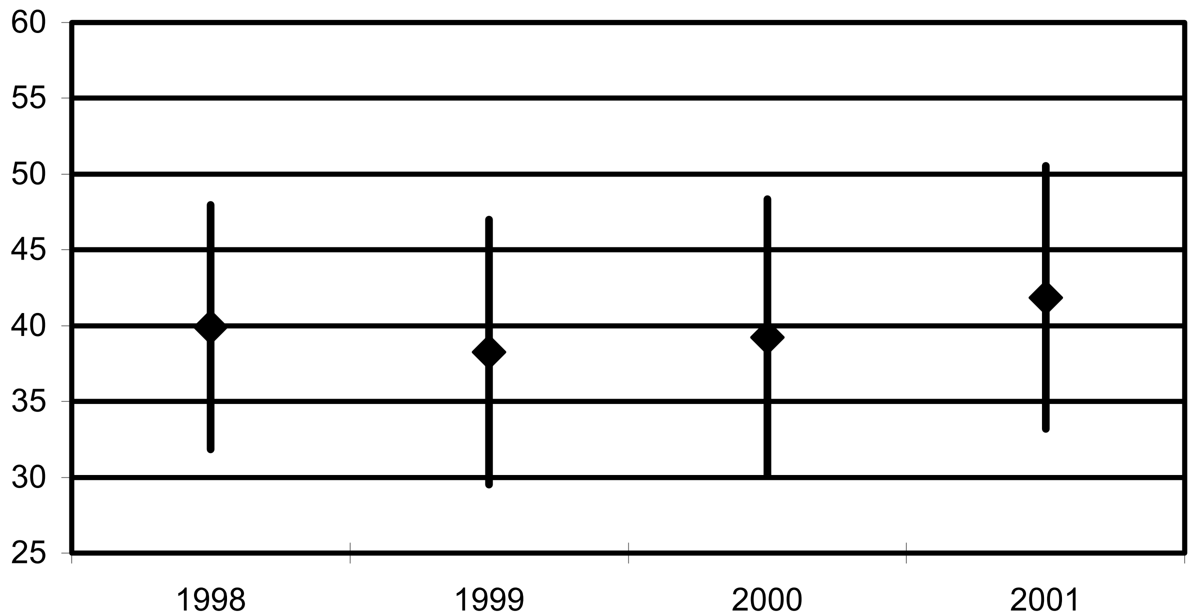

Figure 5. **Mean FN_{40R} Data for FC-2 Mixes, Bounded by $\pm$1.96 Std. Dev. Bands (95% of Data Falls Within Limits).**

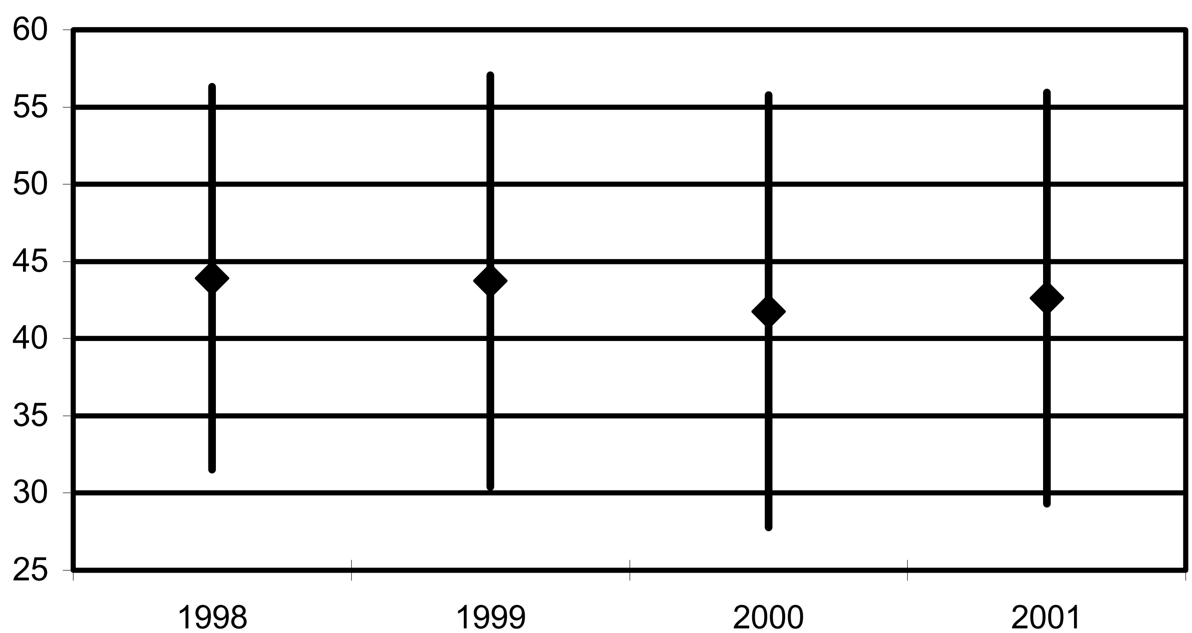

Figure 6. **Mean FN_{40R} Data for FC-3 Mixes, Bounded by $\pm$1.96 Std. Dev. Bands (95% of Data Falls Within Limits).**

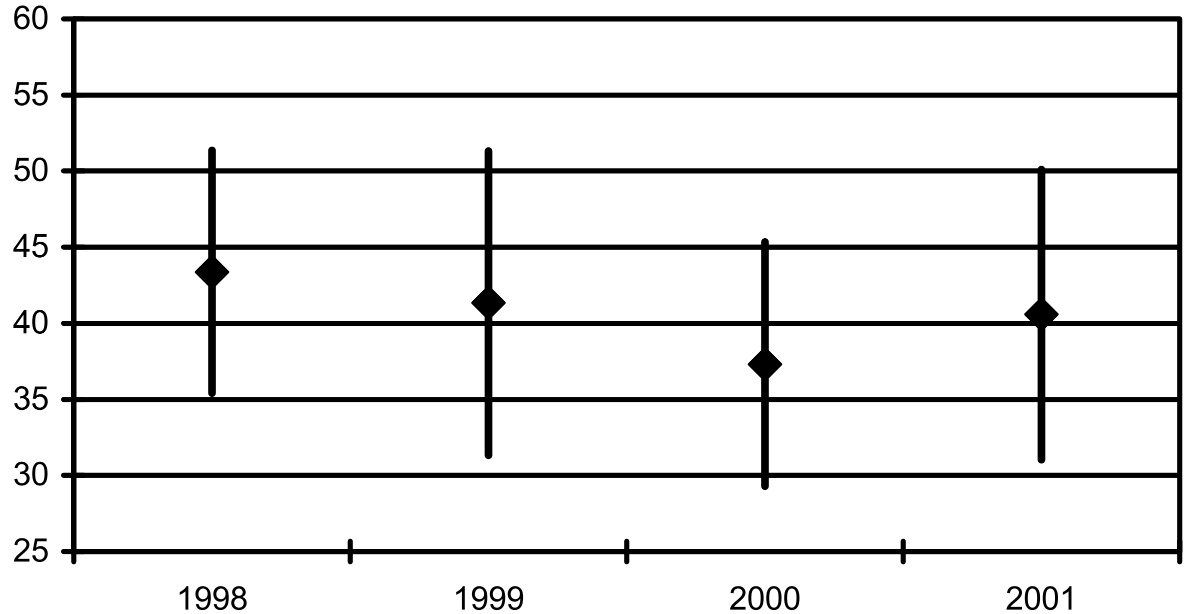

Figure 7. **Mean FN_{40R} Data for FC-5 Mixes, Bounded by ±1.96 Std. Dev. Bands (95% of Data Falls Within Limits).**

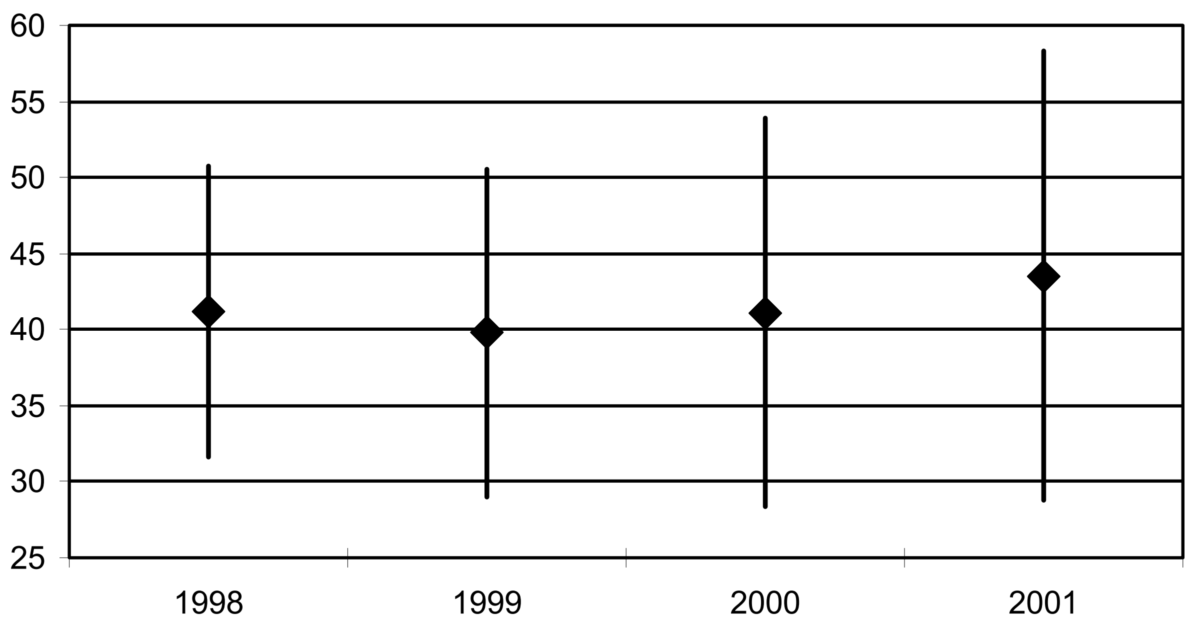

Figure 8. **Mean FN_{40R} Data for FC-6 Mixes, Bounded by ±1.96 Std. Dev. Bands (95% of Data Falls Within Limits).**

Confidence in the Mean

As presented in Figures 3 and 4, the confidence in the mean has progressively improved for the FC-5 and FC-6 surfaces from 1998 to 2001. This is demonstrated by the decreasing size of the 95% confidence interval bands on either side of the mean value. For example, as presented in Figure 4, the mean FN_{40R} value for 1998 was a little over 41 and the 95% confidence interval for the mean ranged from about 38 to 44, a range of almost 6 FN_{40R} points. By 2001, the confidence interval for the mean was reduced to a range of about 1-½ points. It should be noted that this improved confidence in the mean is primarily a function of increasing sample size. As presented in Table 2, the sample size for FC-6 mixes increased from 12 tests in 1998 to 515 tests in 2001.

Standard Deviation

The standard deviation provides a better indicator of variability. If we have a small standard deviation, we can expect most of our data to be grouped around the mean. On the other hand, a large standard deviation indicates a greater variability (11). With this in mind, the data presented in Tables 1 and 2, and Figures 5 through 8 show that the variability in FN_{40R} has not changed significantly in switching from FC-2 and FC-3 designs to the newer FC-5 and FC-6 designs. In fact, it appears that this variability has decreased somewhat for the FC-6 surfaces when compared with the former dense-graded FC-3 surfaces.

As previously noted, Figures 5 through 8 illustrate the bands within which there is a 95% probability of any FN_{40R} value falling. It can be seen that these bands extend below the desired minimum FN_{40R} value of 35 in most cases. In fact, it can be shown that about 10% of the data collected since 1998 fall below a FN_{40R} value of 34. In other words, about 10% of pavement surfaces required re-testing after one year to comply with FDOT Safety Improvement Program Manual requirements. These are the surfaces that should be scrutinized in the future with respect to wet-weather accidents. It also appears from the data presented that there is greater variability in the FN_{40R} values for the dense-graded mixes (both FC-3 and FC-6 mixes) than was found for the open-graded mixes (FC-2 and FC-5 mixes).

Preliminary Recommendations

It appears that the open-graded mixes exhibit less variability in FN_{40R} values than the dense-graded mixes. Based on this observation, it is recommended that FC-5 be considered as an option for use on facilities where the posted speed limit is less than or equal to 45 mph. This will presumably expand the use of the open-graded mixes, thus reducing variability in FN_{40R} values. It should be noted that this recommendation is based on the assumption that the new FC-5 mixes will exhibit improved durability over the former FC-2 mixtures as a result of the documented changes in design and material specifications.

It has been documented by others that the smooth tire test correlates well with wet-weather accident data; see Figure 1 (7). Thus, it is recommended that FDOT incorporate the measurement of macro-texture (smooth tire testing) into their routine pavement friction survey regime. Few states currently measure macro-texture on a routine basis, however outside of the US, macro-texture is routinely measured in many countries (6).

Finally, it is recommended that a comprehensive monitoring program be initiated to evaluate the durability of both FC-5 and FC-6 surfaces as these mixes are increasingly placed throughout the state.

Conclusions

The preliminary results of this investigation are presented herein. This paper provides evidence that remedial measures taken to date to improve the durability of friction courses have not increased the variability in FN_{40R} values on Florida roadways. Further, it appears that the expanded use of the open-graded FC-5 surface may be warranted.

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