

Final Report

Evaluation of Variable Friction Properties of FDOT Friction Courses: Phase I

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| 16. Abstract <p>This report provides evidence that recent specification changes made to improve the performance of FDOT friction courses have not significantly increased the variability of FN_{40R} values on Florida roadways. Based on preliminary data, it is anticipated that the new FC-5 and FC-6 mixes will exhibit improved durability without compromising historical frictional performance.</p> <p>It is further pointed out that recent technological advances in mobile testing equipment, specifically lasers, now make it possible to measure pavement texture in conjunction with friction characteristics. This advanced technology could enhance the safety and productivity of the FDOT skid-testing program.</p> <p>There is also great potential for implementation of supplemental laboratory testing to further characterize the polish/friction potential of aggregate sources throughout Florida. Recommended laboratory test methods to be considered include the Accelerated Polishing Wheel, the British Pendulum Tester, and petrography, among others. Such testing could soon become exceedingly valuable as FDOT attempts to implement warranty specifications and seeks to better define performance in terms that can be readily quantified.</p> <p>Finally, it is recommended that a comprehensive monitoring program be initiated to track the durability and performance of both FC-5 and FC-6 surfaces, as these mixes are increasingly placed throughout the state. FDOT State Materials Office personnel have boldly initiated such an effort already, but the amount of data to be collected will quickly become too cumbersome to manipulate in local spreadsheet applications. A more sophisticated database management system is needed.</p> | | | | | |
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Evaluation of Variable Friction Properties of FDOT Friction Courses: Phase I

1.0 Introduction

Friction courses are placed on state roadways in Florida to provide frictional characteristics of the pavement such that loss of control does not occur under normally expected 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 typically 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 less than desirable frictional properties, prompting remedial measures on pavement surfaces in some cases. Although the affected pavement surfaces are typically designed and constructed in accordance with prescriptive methods, the desired frictional properties are not always obtained.

By definition, 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 has appropriate friction characteristics under normally expected conditions (1). This report 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 report documents the results of an investigation of perceived variability in Friction Numbers (FN_{40R}) for the surface courses currently used by the Florida Department of Transportation (FDOT).

2.0 Background

Many of the native limestone aggregates found throughout Florida are known to be prone to polishing under traffic. Consequently, specially designed friction courses are placed 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 water spray experienced by the traveling public, thus enhancing safety during wet weather driving. Dense-graded friction courses are typically 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 less than desirable frictional properties, sometimes necessitating remedial measures. These less than desirable frictional properties have been found most often with native Florida limestone aggregates.

It has been documented by others that the performance of friction courses in relation

to wet-weather crash rates is ultimately a function of vehicle speed, tire condition, pavement geometry, traffic volumes, environmental conditions, and other project specific considerations, in addition to mix design and material properties. Each of these factors is currently being evaluated within FDOT in an attempt to identify the essential factors contributing to safety hazards in Florida. This Phase I study is focused primarily on test methods, materials and mix design issues as they relate to pavement friction, FN_{40R} .

3.0 Pavement Friction

3.1 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 by 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 35; and special request projects, including research test sections, milled surfaces, or bridge decks.

Testing is performed in the center of the left wheel path of the travel lane. Testing is performed in all lanes for new construction and overlay projects. Inventory testing is performed in both directions for four-lane and multi-lane roadways. For two-lane roadways, only one direction 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 a standard method of testing in Florida. One reason for this is the abundance of historical data relative to the ribbed tire test. Another reason is that friction testing is both time consuming and can pose a safety risk to the traveling public. Adding smooth-tire testing to the existing testing protocol is not practical with existing resources. Further, it is noted that because many other factors contribute to accidents, one should not expect to be able to predict accident frequency from friction test 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.

3.2 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 also calibrate these units using a static force plate every thirty to forty-five days. Water flow calibrations are also performed every six months to ensure proper water flow and distribution. The units are also checked for repeatability on five test sections, representing both open and dense-graded friction courses, located in the vicinity of the State Materials Office after each calibration check (4).

3.3 Friction Testing at Elevated Speeds

Due to safety concerns associated with friction testing on high-speed facilities, testing at elevated speeds has been proposed by some FDOT personnel, as well as others in the industry. As previously noted, the ASTM and FDOT standard test speed is 40 mph (65 km/h). It is envisioned that appropriate correlations may be developed for test data obtained at 40 mph (65 km/h) and additional data obtained at elevated speeds. Specific issues still to be addressed however include the impact of testing speed on the repeatability of the data collected, wear and tear on the skid trailer and other equipment, and the personal safety of the FDOT operators and the motoring public.

3.4 Recent Technological Advances

In recent years, technological advances in microprocessors and personal computers have made it possible to consider the use of high-speed lasers in the evaluation of pavement surface characteristics, such as profile, distress, and even texture. It is conceivable that this technology has progressed to the point where it is possible to collect both surface texture measurements and friction data (FN_{40R} and FN_{40S}), simultaneously. With both texture and friction data, it may be possible to develop a correlation between FN_{40R} and International Friction Index (IFI) in accordance with ASTM E 1960, "Standard Practice for Calculating International Friction Index of a Pavement Surface (8)." The IFI was developed as a common reference scale for quantifying the pavement surface frictional properties (9). The IFI uses measurements of skid resistance and texture to evaluate the pavement surface characteristics and is currently being adopted worldwide for skid resistance comparison. To calculate the IFI it is necessary to have at least one friction measurement and one texture measurement. In order to accomplish this for the FDOT, it will be necessary to install a high-speed laser on the FDOT skid trailers to obtain an appropriate measure of texture during friction testing. The use of high-speed lasers to measure texture and the use of the ribbed-tire skid test to measure pavement friction at variable speeds could be the ultimate solution to safety concerns associated with friction test data collection in Florida.

4.0 FDOT Friction Surfaces

FDOT currently 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 (10).” In general, FC-5 mixtures are specified for multi-lane and high-speed facilities. FC-6 mixtures are specified on reduced speed facilities with curb and gutter, where an open-graded texture is not warranted.

4.1 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 (11).” 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). 100% 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/yd² (38-44 kg/m²), which correlates to an in-place thickness of

approximately $\frac{3}{4}$ inch (20.0 mm).

4.2 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 105-110 lb/yd² (54-60 kg/m²) for a maximum aggregate size of $\frac{3}{8}$ inches (9.5 mm), and 150-160 lb/yd² (80-88 kg/m²) for mixtures designed with a maximum aggregate size of $\frac{1}{2}$ inches (12.5 mm). This typically correlates to an in-place thickness of 1-inch (25.0 mm) to 1- $\frac{1}{2}$ inches (38.0 mm), respectively. The new FC-6 mixes are also described as FC 9.5 mm or FC 12.5 mm SuperpaveTM mixtures, depending on maximum aggregate size.

4.3 Key Specification Revisions

Although Florida has had great success with reducing the hydroplaning potential of its high-speed facilities by using open-graded friction courses, the durability of these mixes has been a concern since their introduction (12). 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 previously used on high speed, high traffic volume facilities throughout the state. The functional life of the FC-2 surfaces was observed to be as short as 7 to 8 years. The first FC-5 test section was constructed on

I-10 in Suwannee County in late 1996/early 1997. Based on preliminary observations, the new FC-5 surfaces are expected to last longer and provide greater drainage characteristics than the earlier 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 Department of Transportation, 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, previously 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, while incorporating Superpave™ aggregate gradation specifications.

5.0 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 mean FN_{40R} values below 35 must be re-tested in one year. These friction requirements are generally consistent with other state transportation departments (6).

6.0 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 for FC-5 and FC-6 surfaces. Figures 3 and 4 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 ± 1.96 standard deviations of the mean). Figures 5 and 6 present the mean FN_{40R} values for the FC-5 and FC-6 surfaces bounded by 1.96 standard deviations.

6.1 Confidence in the Mean

As can be derived from the data presented in Tables 1 and 2, the confidence in the mean progressively improved for the FC-5 and FC-6 surfaces from 1998 to 2001. For example, as presented in Table 2, the mean FN_{40R} value for FC-6 in 1998 was 41.2, with a standard deviation of 4.9. The corresponding 95% confidence interval for the mean, based on these data, can be calculated to range from about 38 to 44, a range of almost 6 FN_{40R} points. By 2001, the confidence interval for the mean for the FC-6 mixes was reduced to a range of about 1- $\frac{1}{2}$ FN_{40R} points, a 4- $\frac{1}{2}$ point reduction. It should be noted, however, that this apparent 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. With increasing data, it is expected that one would observe increased confidence in the mean.

6.2 Standard Deviation

The standard deviation provides a better indicator of variability in test data. 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 (13). With this in mind, the data presented in Tables 1 and 2, and Figures 3 through 6 show that the variability in FN_{40R} has not changed significantly due to switching from FC-2 and FC-3 designs to the newer FC-5 and FC-6 designs. **There is no statistical evidence of increased variability in FN_{40R} as a result of switching from FC-2 and FC-3 designs to the new FC-5 and FC-6 designs.**

As previously noted, Figures 3 through 6 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 almost all cases. In fact, it can be shown that about 10% of the data collected since 1998 fall below a FN_{40R} value of 35. 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 will 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).

7.0 Aggregate Testing

The current FDOT specifications address frictional properties of aggregate by requiring the use of 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 objective of this specification is to ensure that any limestone to be used in friction courses in Florida is of oolitic origin and will perform satisfactorily in service.

The acid insoluble test, FM 5-510 is only an indirect measure of the polish/friction performance characteristics of the aggregate, at best. A 12% non-carbonate limestone will not necessarily provide adequate frictional characteristics. It is believed that more reliable laboratory test methods are available.

A widely accepted method of measuring the relative friction properties of aggregates in the laboratory is the British Pendulum Tester (14) in conjunction with the Accelerated Polishing Wheel (15). Since concern regarding the use of native Florida limestone aggregates in FDOT friction courses appears to exist, it would be beneficial to develop a comprehensive database containing the polish/friction characteristics of all aggregates proposed for use in friction courses throughout Florida. Such a comprehensive database could ultimately enable FDOT engineers and paving contractors to better quantify the performance of new and existing sources relative to well-defined standards of performance. A limited study of aggregate performance relative to results from the Accelerated Polishing Wheel, the British Pendulum Tester, petrography, and other

promising laboratory test methods could certainly provide much-needed data to support the development and implementation of contractor warranty and performance specifications. If such specifications are to include friction courses, well-defined performance measures, including aggregate polishing characteristics, must be identified and accepted by both FDOT and contractors.

8.0 Phase I Conclusions

The results of a Phase I evaluation of the properties of FDOT friction courses are presented herein. This report documents that remedial measures taken to date to improve the durability of FDOT friction courses have not significantly increased the variability of FN_{40R} values on Florida roadways. In fact, based on preliminary data, it is anticipated that the new FC-5 and FC-6 mixes will exhibit improved durability without sacrificing frictional performance.

It is further pointed out that recent technological advances in equipment, specifically lasers, have now made it possible to measure pavement texture in conjunction with friction data. This advanced technology will ultimately enhance the safety and productivity of the existing FDOT skid-testing program.

There is also great potential for implementation of supplemental laboratory testing to further characterize the polish/friction potential of aggregate sources throughout Florida. It is envisioned that such testing could provide both FDOT and contractors with added confidence in material selection when designing friction courses. This added confidence

could facilitate the implementation of contractor warranty and performance specifications.

Potential test methods to be considered include the Accelerated Polishing Wheel, the British Pendulum Tester, and petrography, among others.

9.0 Phase I Recommendations

Based on the results of this Phase I evaluation, it is recommended that a comprehensive monitoring program be initiated to track the durability and performance of both FC-5 and FC-6 surfaces, as these mixes are increasingly placed throughout the state. State Materials Office personnel have boldly initiated such an effort already, but the amount of data to be collected will quickly become too cumbersome to manipulate in local spreadsheet applications. It is proposed that an interactive database be developed to readily provide authorized users access to project, mix design, aggregate mine source, and materials test data from a single location. It was discovered in the course of this research that the absence of such comprehensive data was of significant impedance to this study.

It is recommended that research into the measurement of pavement texture through instrumentation of a skid-test vehicle with state-of-the-art laser technology be pursued as soon as possible. This recommended research has potential for improved safety as well as enhanced data collection.

It is also recommended that research into the collection of aggregate polish/friction properties in the laboratory using the British Pendulum Tester in conjunction with the Accelerated Polishing Wheel be initiated as soon as possible. This testing is currently

being performed extensively in other limestone states (Texas, Alabama, among others) and has exhibited great promise in differentiating frictional performance of aggregates at the source. Such data will soon become exceedingly valuable as FDOT attempts to implement warranty specifications and seeks to define performance in terms that can be readily quantified.

10.0 Acknowledgements

I would like to thank FDOT and the University of North Florida (UNF) for the opportunity to participate in this Phase I study. Without the generous support of these partners in research and education, this project would not have been possible. I would like to further acknowledge the employees of the State Materials Office, under the direction of Tom Malerk, and the Center for Pavement Excellence, under the direction of Dr. Bouzid Choubane, for their participation and assistance with this effort. Last, but not least, I thank the staff of the Division of Sponsored Research and Training at UNF. I look forward to a long and rewarding partnership with this energetic team of professionals.

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Table 1. 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 |

Table 2. 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 |

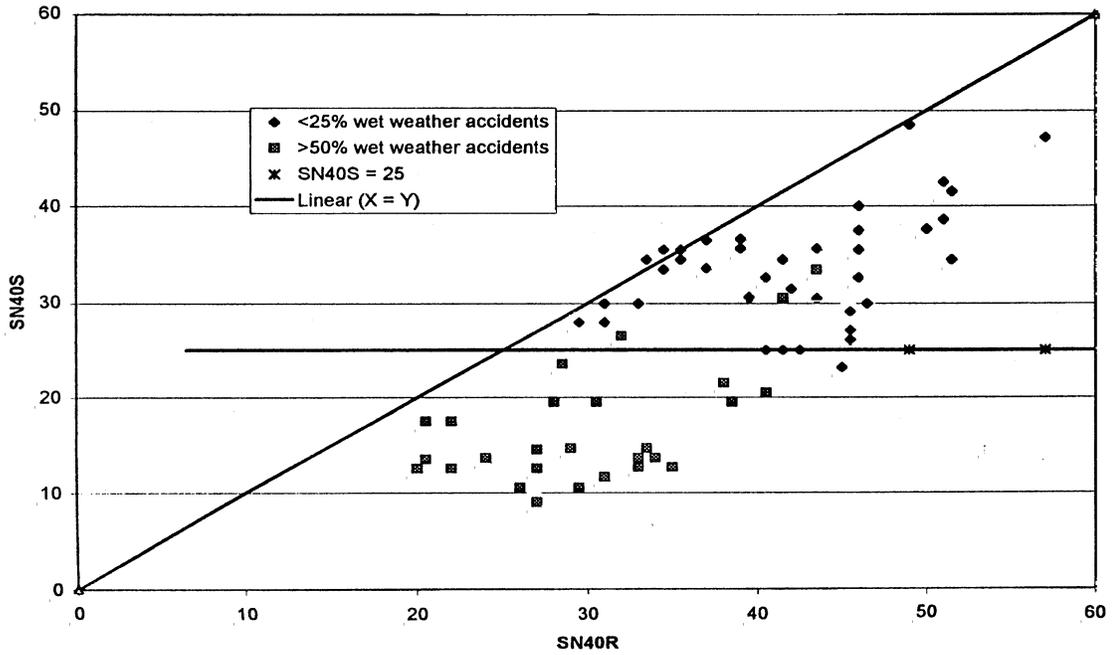


Figure 1. Ribbed-Tire versus Smooth-Tire Friction Numbers for Florida Pavements (7).



Figure 2. Typical FDOT Skid Trailer Unit.

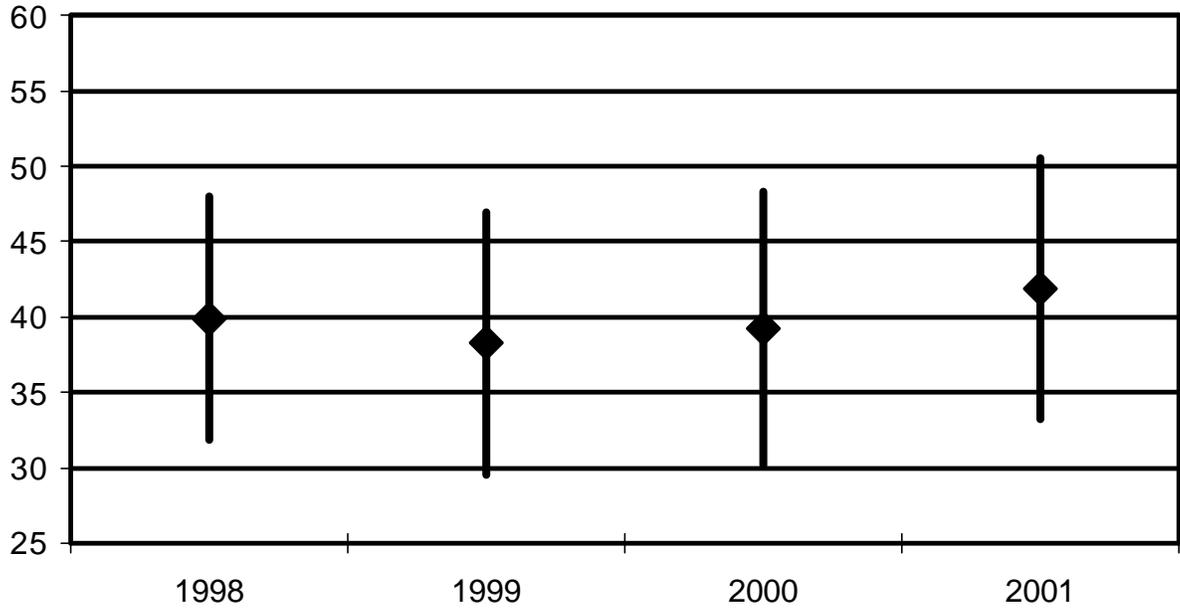


Figure 3. Mean FN_{40R} Data for FC-2 Mixes, Bounded by ± 1.96 Std. Dev. Bands (95% of Data Falls Within Limits).

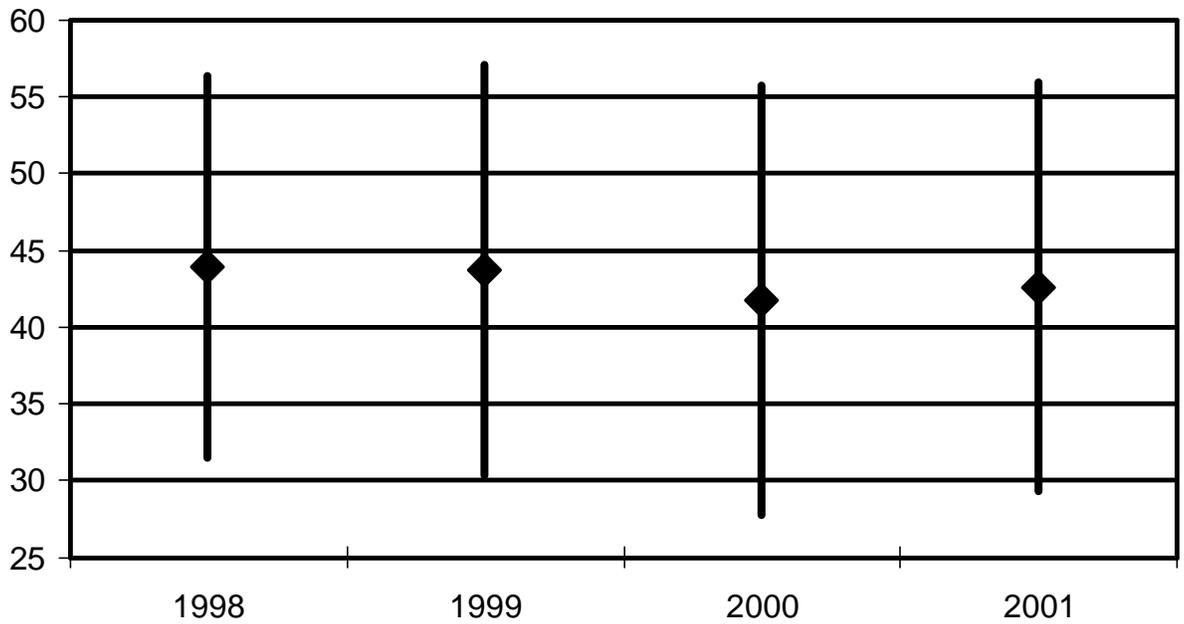


Figure 4. Mean FN_{40R} Data for FC-3 Mixes, Bounded by ± 1.96 Std. Dev. Bands (95% of Data Falls Within Limits).

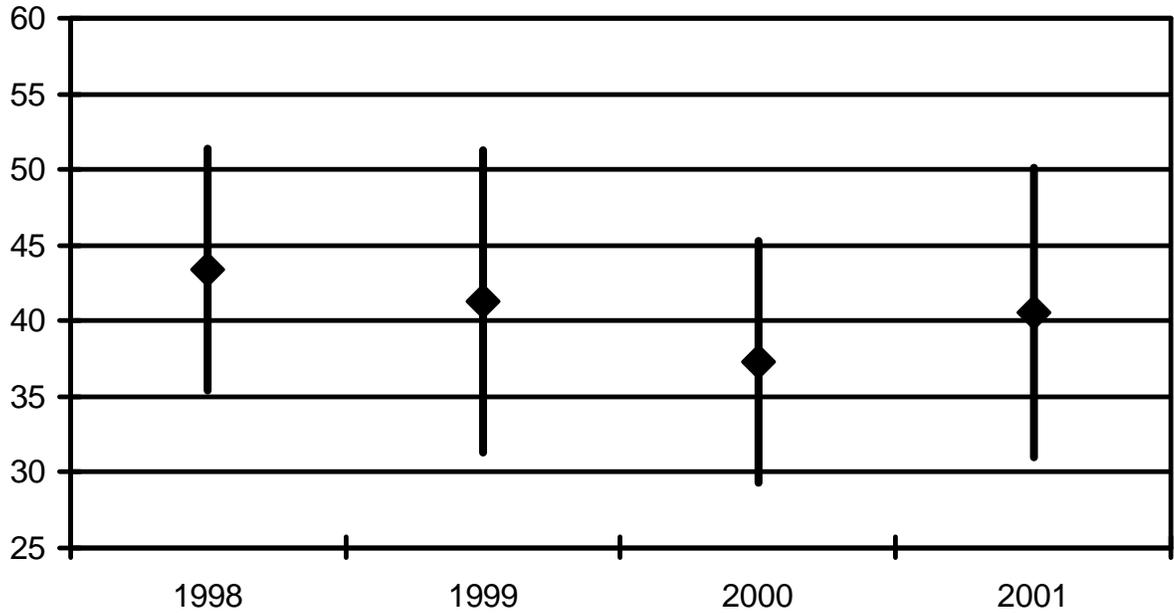


Figure 5. Mean FN_{40R} Data for FC-5 Mixes, Bounded by ±1.96 Std. Dev. Bands (95% of Data Falls Within Limits).

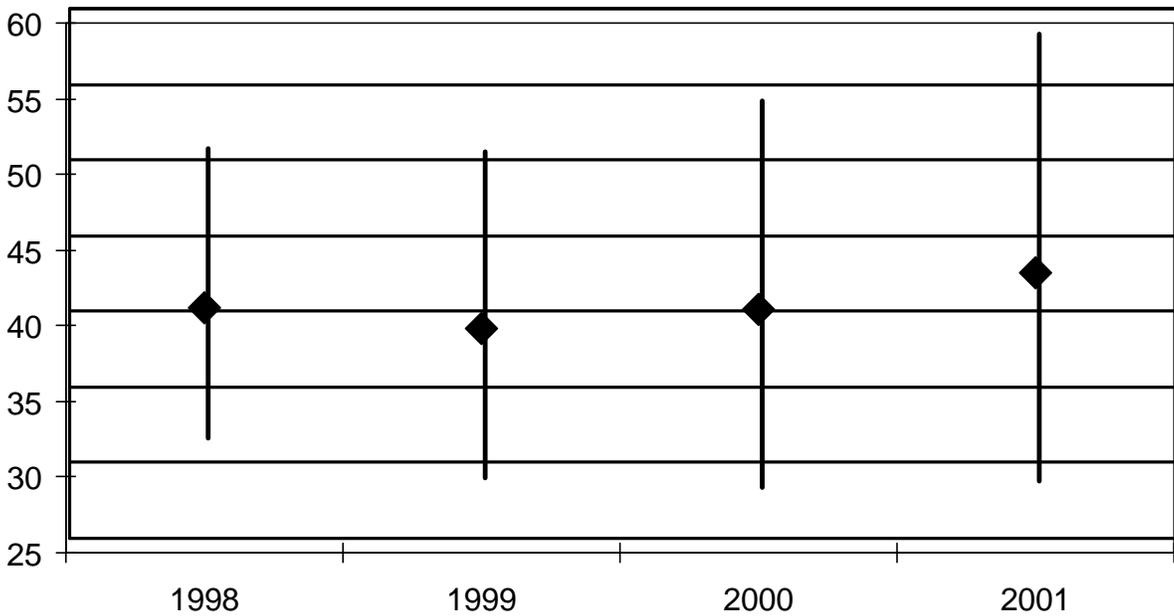


Figure 6. Mean FN_{40R} Data for FC-6 Mixes, Bounded by ±1.96 Std. Dev. Bands (95% of Data Falls Within Limits).