The INDOT Friction Testing Program: Calibration, Testing, Data Management, and Application

Shuo Li, Ph.D., P.E.
Transportation Research Engineer
Phone: 765.463.1521
Email: sli@indot.in.gov

Office of Research and Development
Indiana Department of Transportation
West Lafayette, IN 47906

1. Purposes of Pavement Friction Testing Program

- To identify possible slick pavements and monitor network pavement friction conditions
- To provide pavement surface condition data for planning pavement resurfacing projects
- To provide performance evaluation for pavement preservation projects
- To measure the friction performance of pavement warranty projects
- To investigate the skid resistance of new pavements and materials
- To provide evidences for INDOT's legal defenses

2. Friction Testing Resources

- The team

  - Main persons

    1 pavement friction engineer

    1 system analyst

    1 testing coordinator

    1 testing technician

  - Supporting persons

    Electrical technician

    Mechanical technician

- The testing system

  2 ASTM E-274 locked wheel testers

Fig. 1 ASTM E-274 Locked-Wheel Tester

- The system calibration facilities

Fig. 2(a) In-House Transducer Calibration Platform

Fig. 2(b) Friction test Track: Testing System Calibration

3. Testing System Calibration

3.1 Types of Calibration

- **Monthly calibration and checking**

  Force transducer calibration

  Water flow, brake, speed, mileage …

  Verification testing on the friction test track

- **Weekly verification and checking**

  Temperature sensor, wiring, plumbing, nozzle …

  Verification testing on the friction test track

- **Others**

  Annual calibration (force plate …)

  Daily checking (tire …)

3.2 Surface Characteristics of the Friction Test Track

- **Slick concrete pavement**
  Normal cement concrete mix
  Surface finishing: steel floating
- **HMA pavement**
  9.5 mm hot mix asphalt (asphalt binder PG 76-22)
  Coarse aggregates: 27% slag/dolomite
- **Transversely tined concrete pavement**
  Normal cement concrete mix
  Surface texturing (transverse tining):
  3-mm wide, 3-mm deep, 18~20-mm spacing
- **Advantages**
  Safety, accuracy, and convenience

TABLE 1 Friction test track surface characteristics

Section	MPD (mm)	DFT20	F60	FN40 (Smooth tire)
Slick Concrete	0.04	0.58	0.08	< 10.0
Asphalt	0.45	0.75	0.33	35.0 ~ 50.0
Tined Concrete	1.35	0.86	0.56	>60.0

MPD = surface texture depth (circular texture meter)
DFT20 = friction value (dynamic friction tester at 20 km/h)
F60 = friction value at 60 km/h computed from MPD and DFT20
FN40 = friction number at 40 mph measured (ASTM E 274)

3.3 System Calibration Testing

- **Minimum Sample Size Requirements**

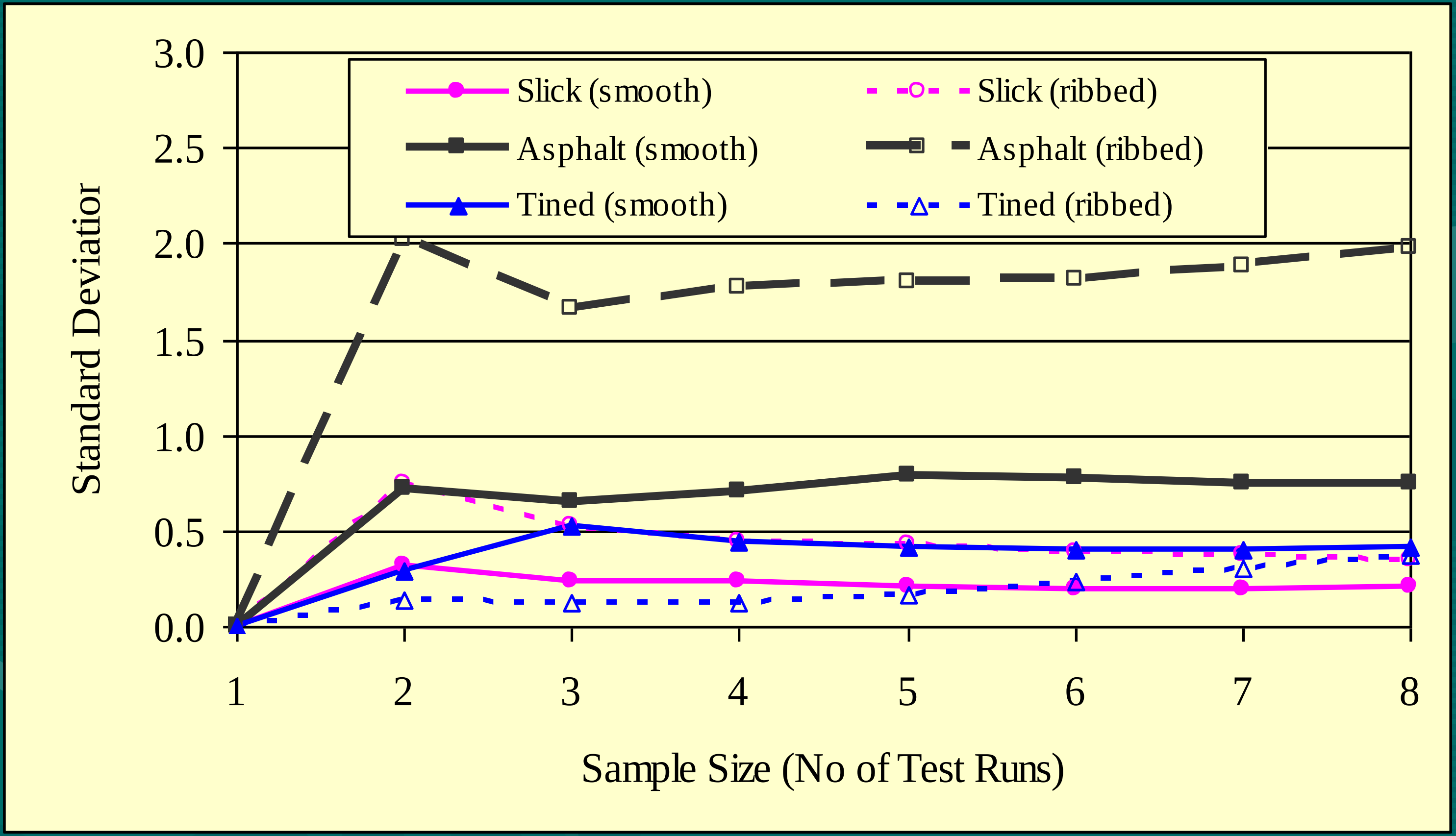

Fig. 3 Standard deviations versus sample size

- Significant errors arising when sample size <3
- Standard deviations utilized to measure the potential errors

$$N = \left(\frac{1.96\sigma}{\varepsilon}\right)^2 + 3$$

in which,

N = minimum sample size

σ = population standard deviation of the friction test results

ε = allowable error for verification testing

TABLE 2 Friction Test Results and 95% Confidence Intervals

Tester	Test Section	Smooth Tire		Ribbed Tire	
		Mean	Interval	Mean	Interval
300-4	Slick	8.3	(7.8, 8.8)	33.3	(32.4, 34.2)
	Asphalt	51.8	(49.8, 53.8)	60.2	(59.0, 61.4)
	Tined	71.6	(70.5, 72.7)	73.4	(72.5, 74.3)
379-6	Slick	8.3	(7.9, 8.7)	31.6	(31.0, 32.2)
	Asphalt	54.2	(52.1, 56.3)	66.8	(65.4, 68.2)
	Tined	71.3	(70.6, 72.0)	73.1	(72.3, 73.9)

3.4 Friction Variations due to System Anomalies

- Standard Deviations

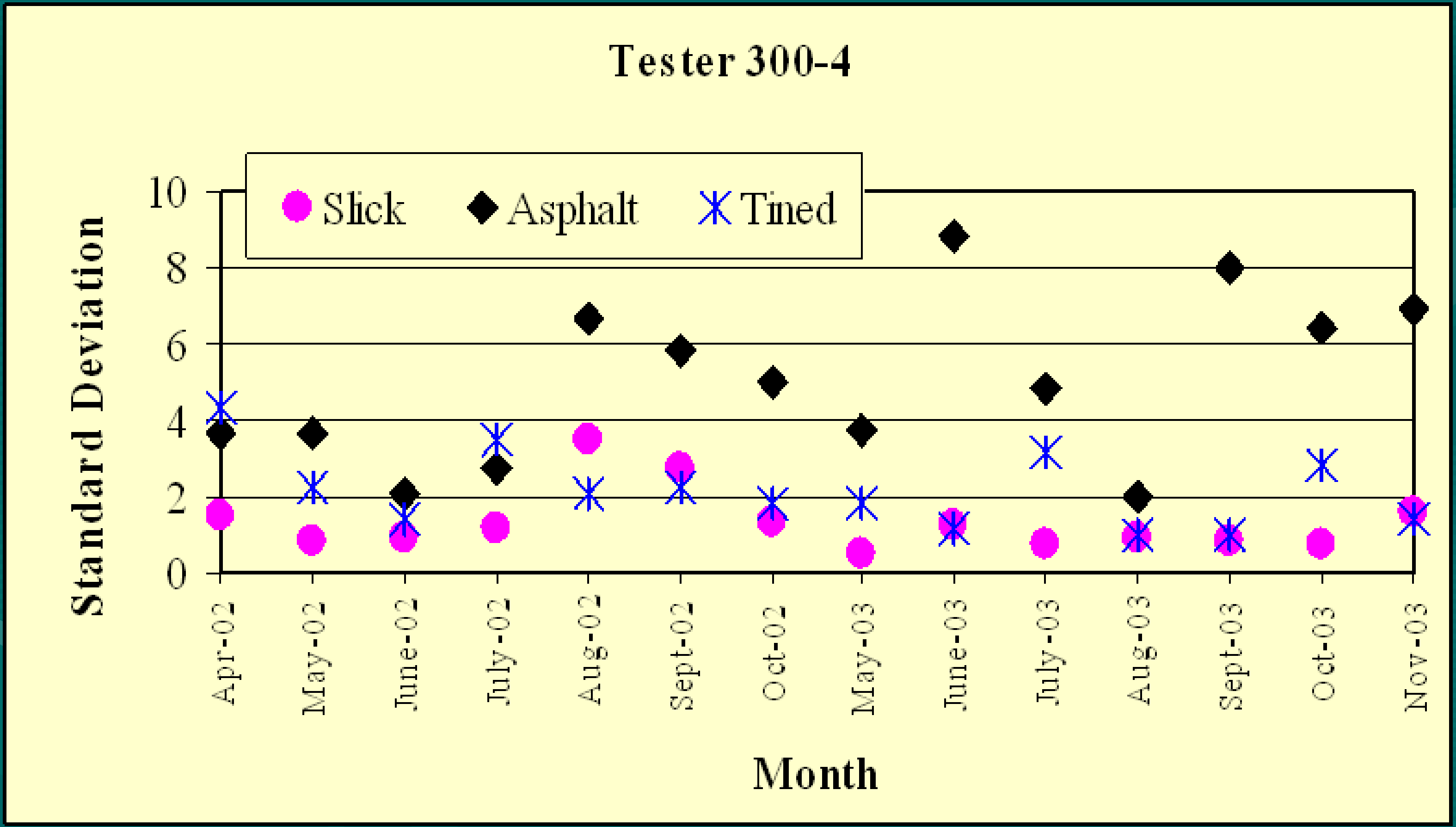

Fig. 4(a) Standard deviations with smooth tire

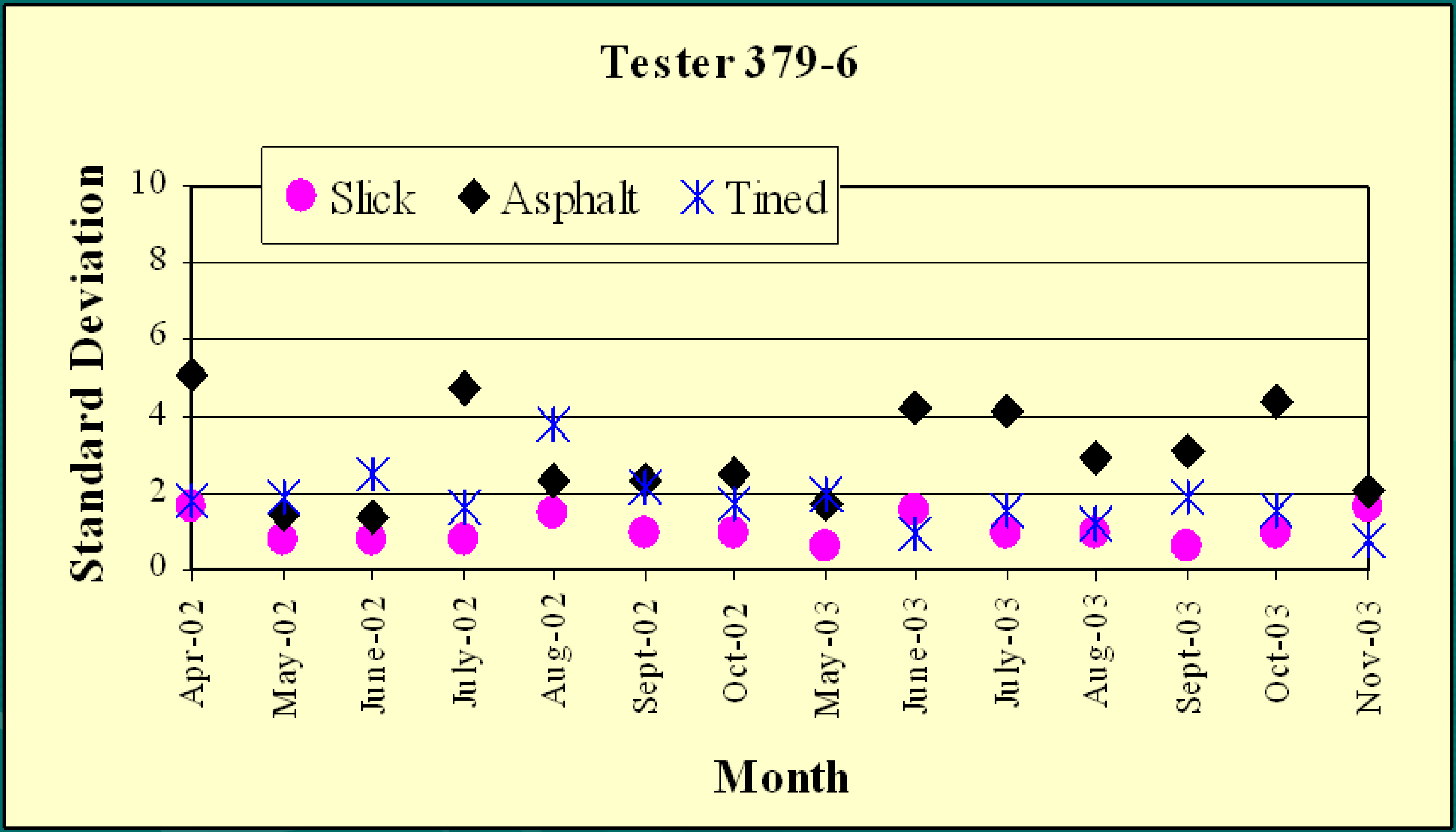

Fig. 4(b) Standard deviations with smooth tire

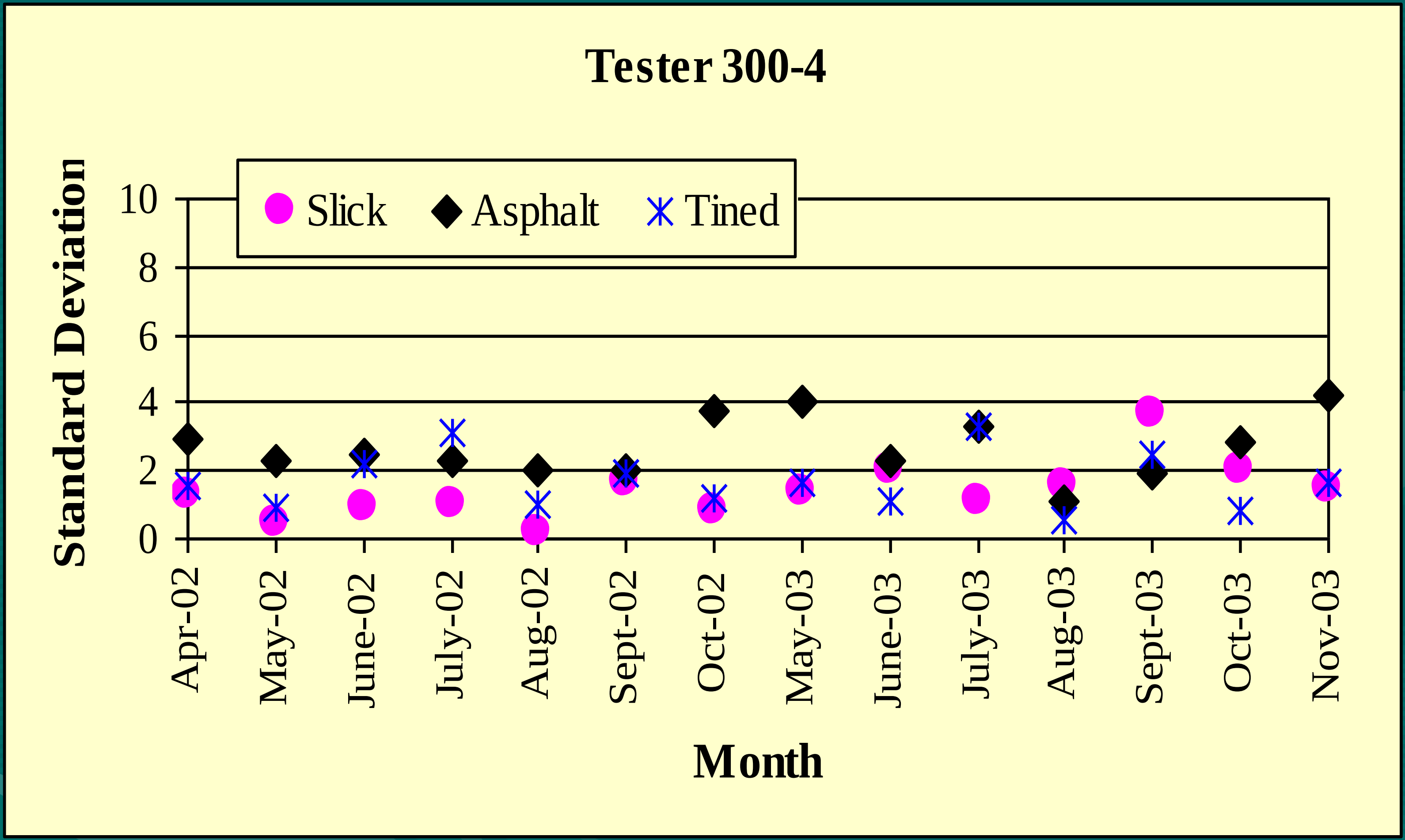

Fig. 4(c) Standard deviations with ribbed tire

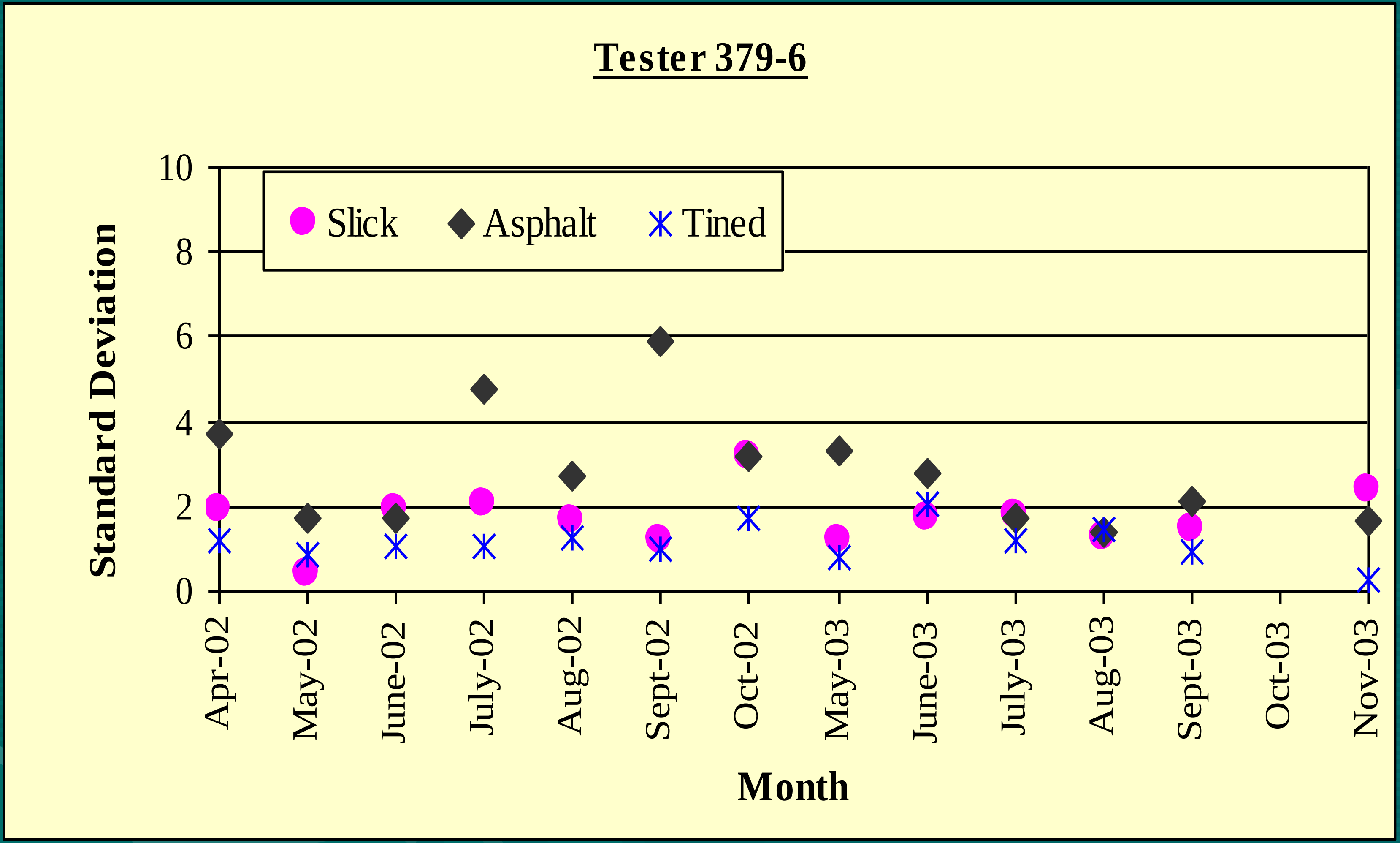

Fig. 4(d) Standard deviations with ribbed tire

- Coefficients of Variations

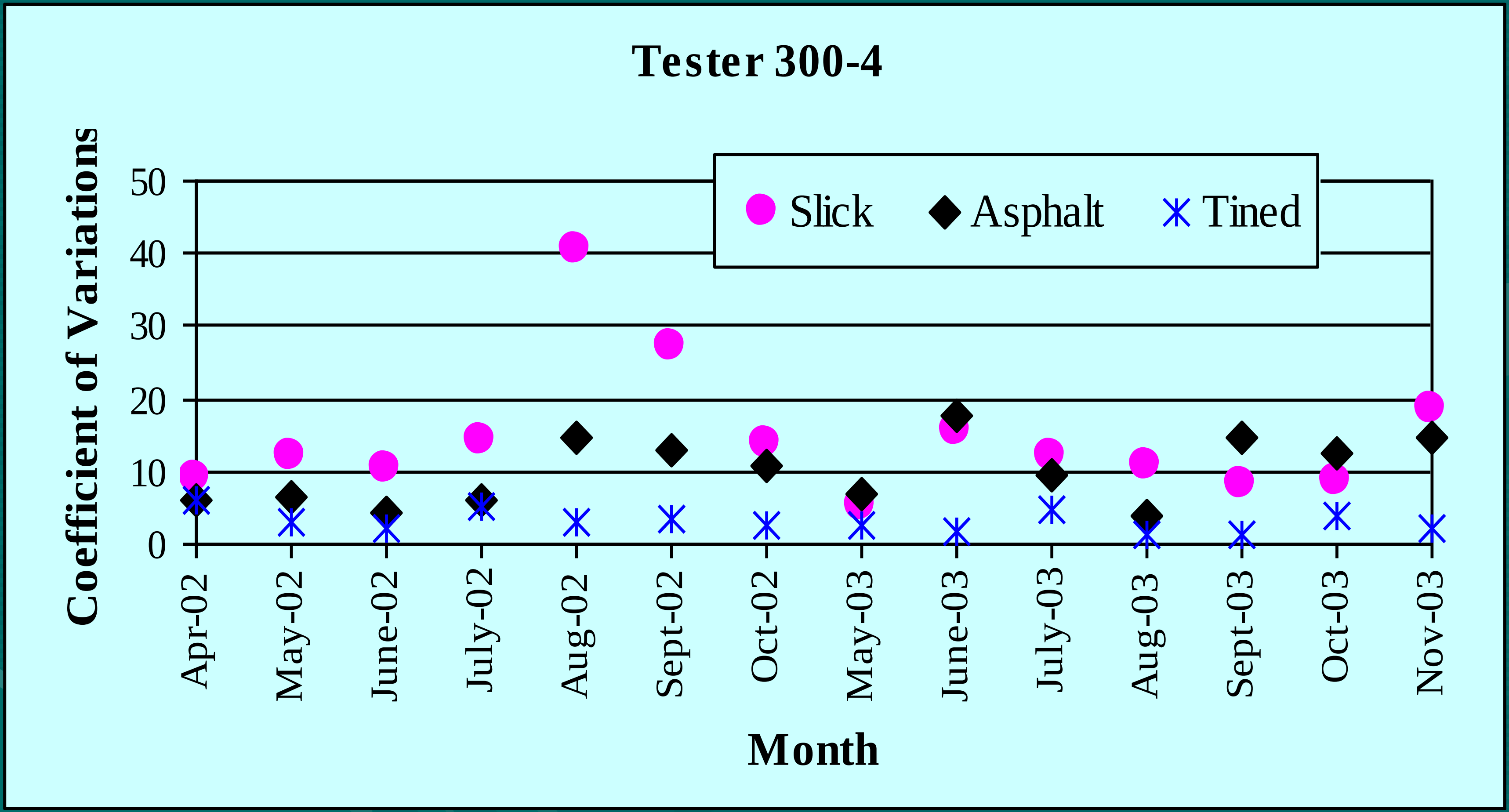

Fig. 5(a) Coefficients of variations with smooth tire

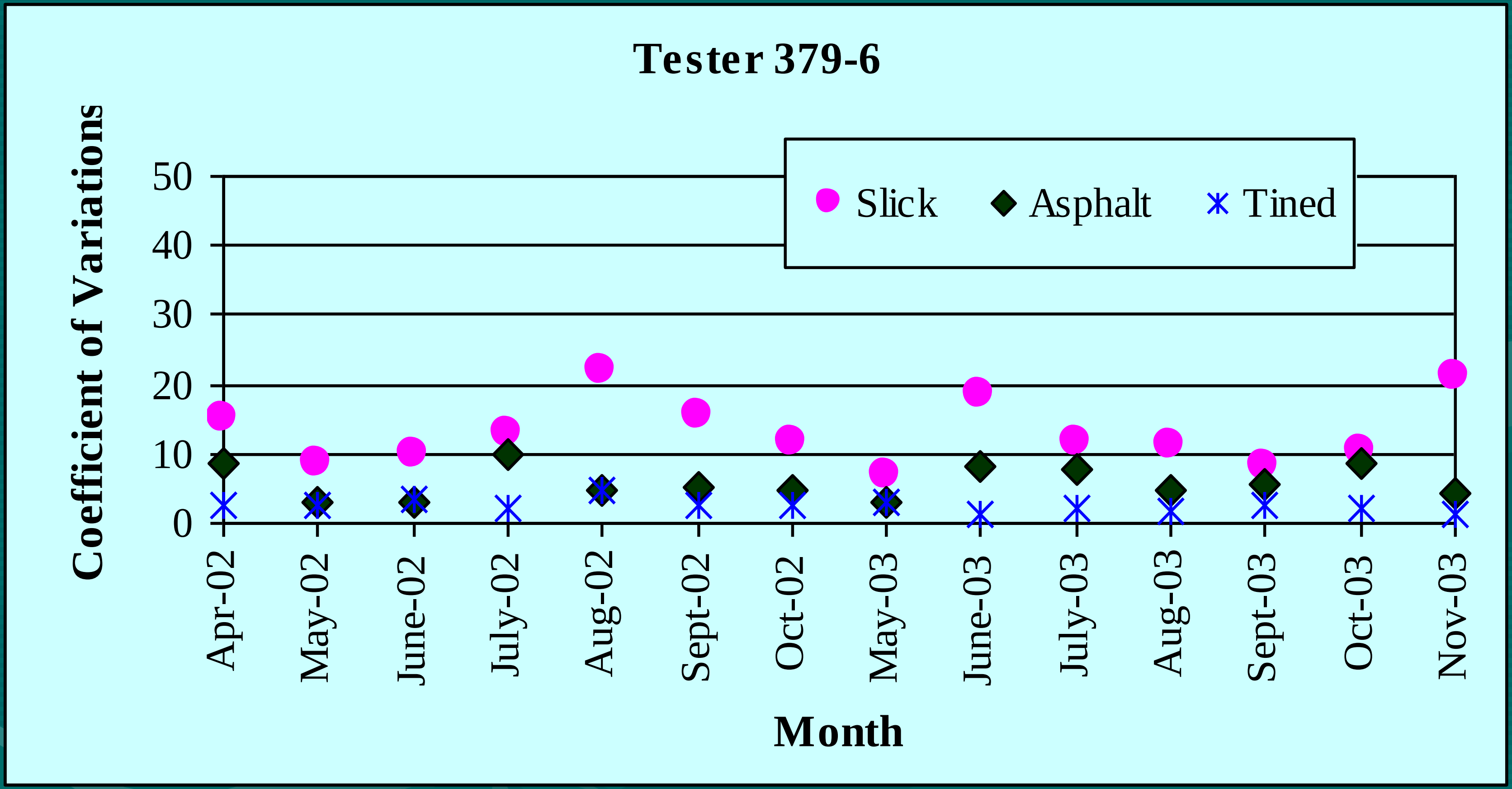

Fig. 5(b) Coefficients of variations with smooth tire

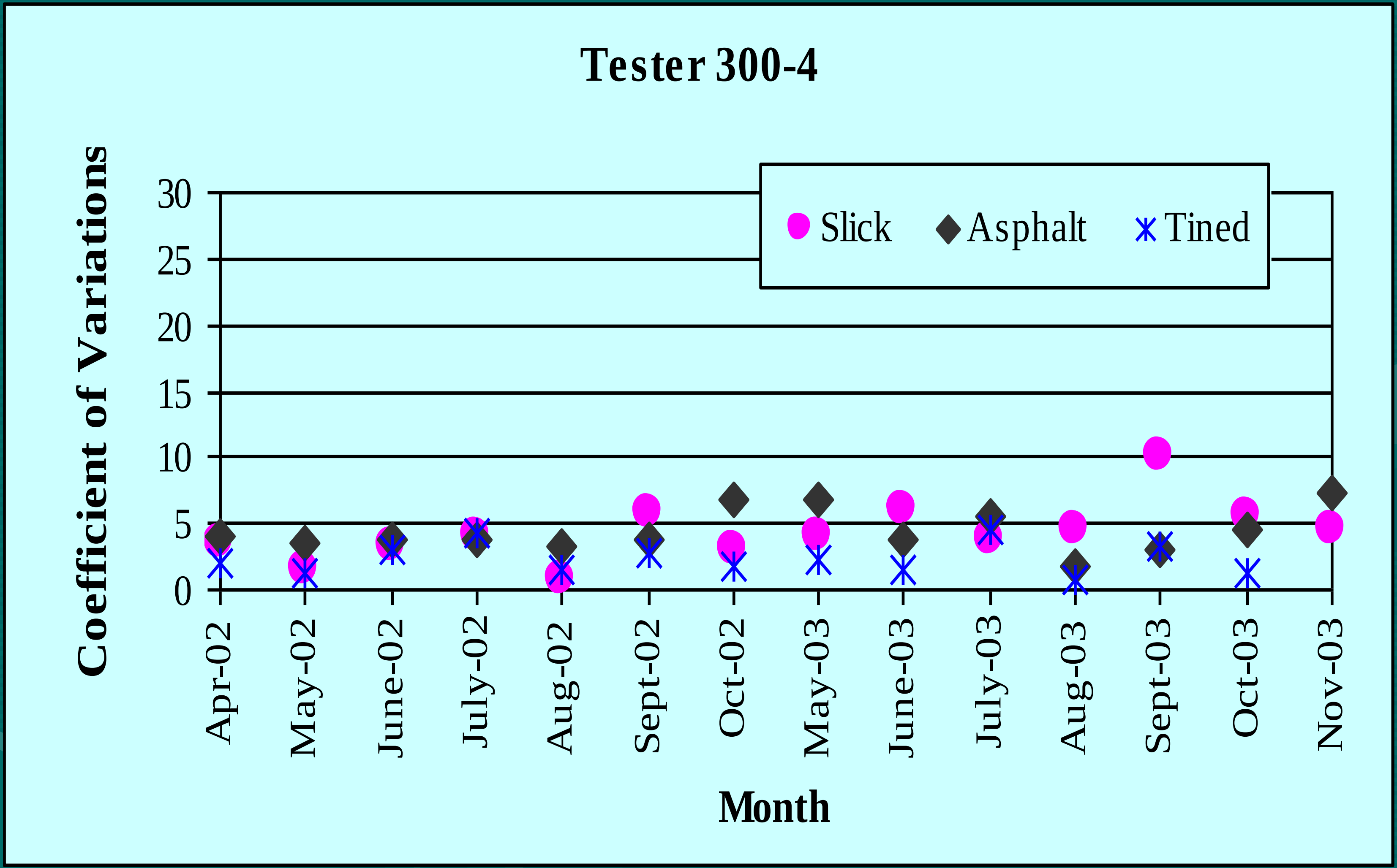

Fig. 5(c) Coefficients of variations with ribbed tire

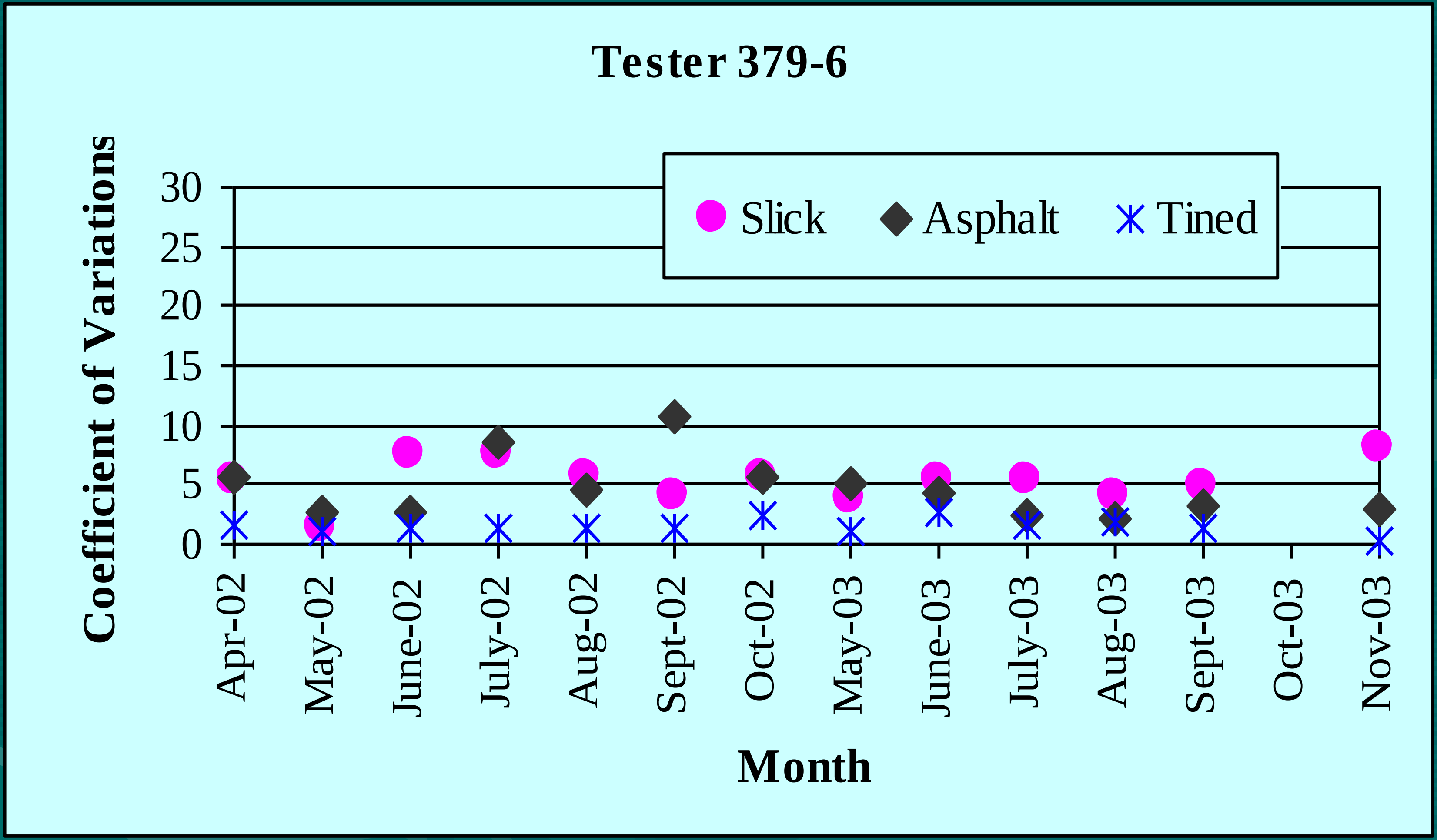

Fig. 5(d) Coefficients of variations with ribbed tire

TABLE 3 Average Friction Numbers, Standard Deviations, and Coefficients of Variation

Trailer	Statistics	Slick Concrete	Asphalt	Tined Concrete
300-4	Average	8.3	50.2	70.5
	STDEV	1.2	3.8	1.6
	COV	14.7	7.3	2.2
379-6	Average	8.2	53.3	72.4
	STDEV	1.3	3.3	1.7
	COV	15.6	6.1	2.4

- **Observations**

  - Standard deviations:

    Smooth tire: Largest in the asphalt section
    Lowest in the slick concrete section

    Ribbed tire: Largest in the asphalt section
    Lowest in the tined concrete section

  - Coefficients of variations:

    Both tires: Largest in the slick concrete section
    Lowest in the tined concrete section

  - Coefficients of variations more consistent than standard deviations

  - Variations by the smooth tire greater than the ribbed tire

3.5 Multi-Parameter Assessment of System Performance

- Step 1: Examine mean values

(Current mean – Reference mean) ≤ Allowable error

- Step 2: Examine standard deviations or coefficients of variations

Current standard deviation ≤ Allowable value

or

Current coefficient of variations ≤ Allowable value

TABLE 4 Requirements for system verification testing

Test Section	Min. No. of Tests	Test Speed	Allowable Errors for Friction Values		
			Mean	S.D.	COV
Slick Concrete	4	±1 mph	±3	2	20%
Asphalt	4	±1 mph	±5	4	12%
Tined Concrete	4	±1 mph	±4	3	5%

S.D. = standard deviation
COV = coefficient of variations

4. Test Tires and Speeds

4.1 Test Tires

- ASTM E-274 standard tires

  Rib tire (ASTM E-501)

  Smooth tire (ASTM E-524)
- INDOT

  Before 1997: rib tire

  Since 1997: smooth tire
- Friction measurement

Fig. 6 Test tires

$$\mu = \frac{F}{N} \times 100$$

where μ = friction number;
F = tractive force or friction force; and
N = normal force on the test wheel.

• Smooth Tire versus Rib Tire

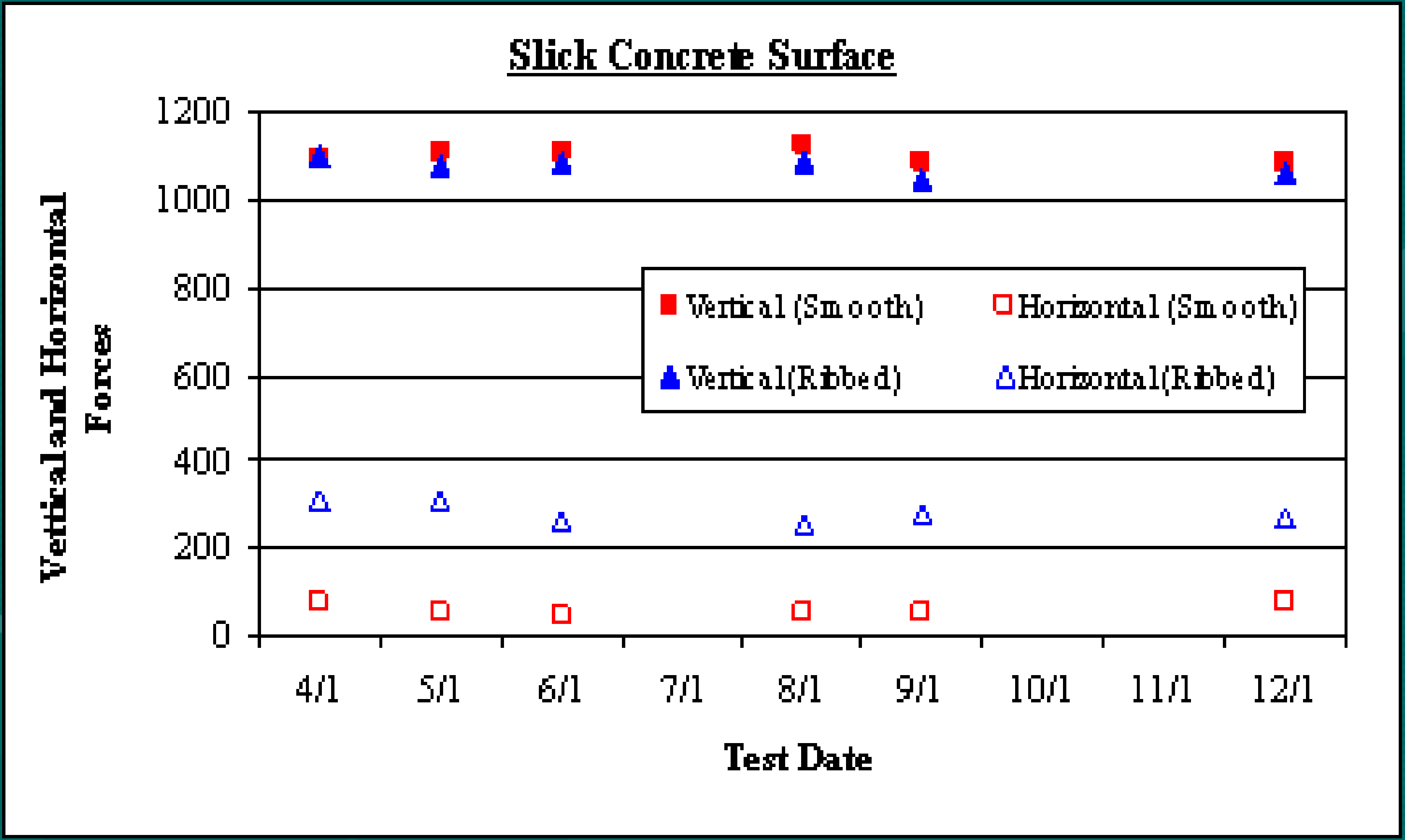

Fig. 7(a) Friction measurements on slick concrete surface

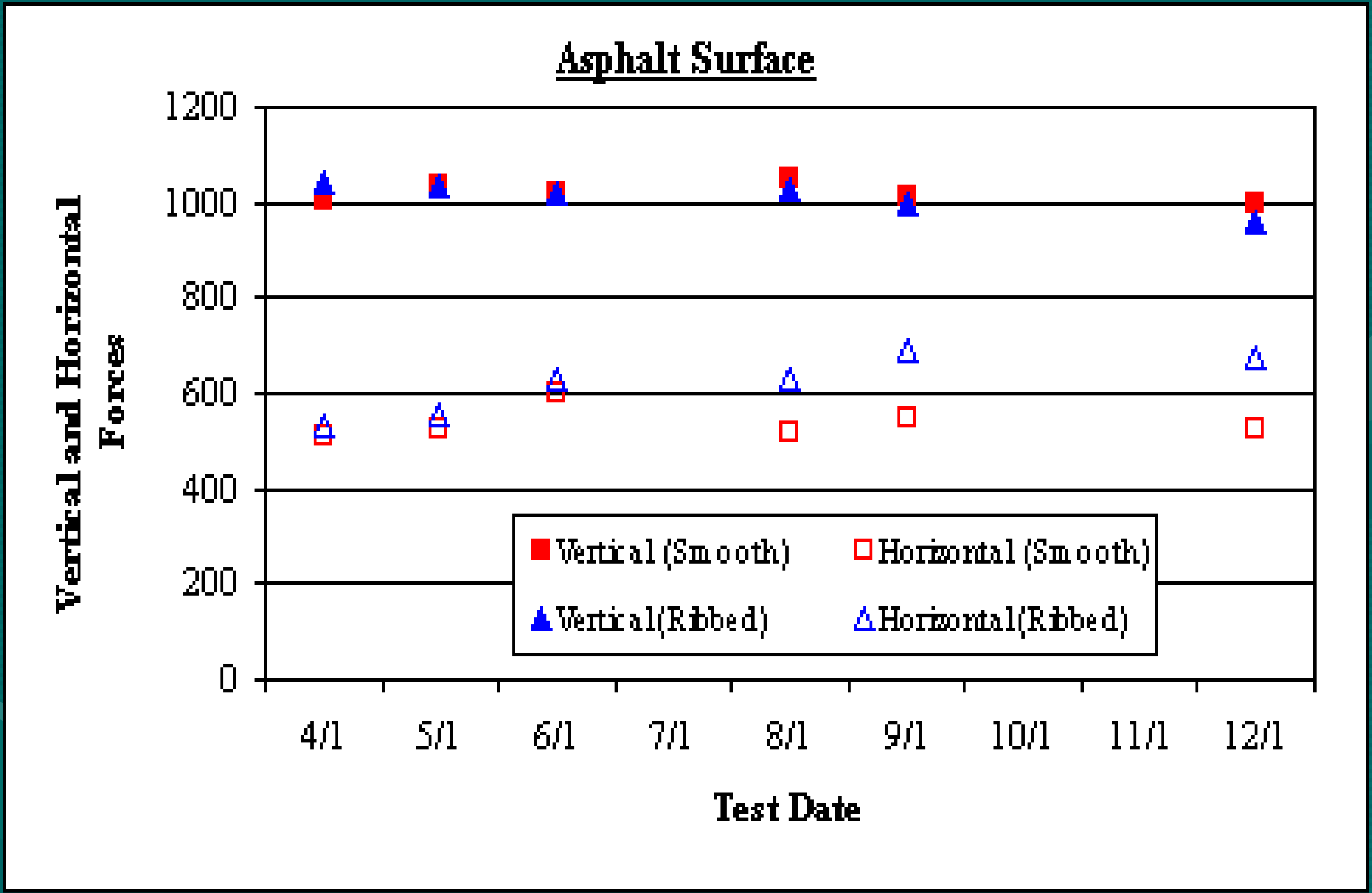

Fig. 7(b) Friction measurements on asphalt surface

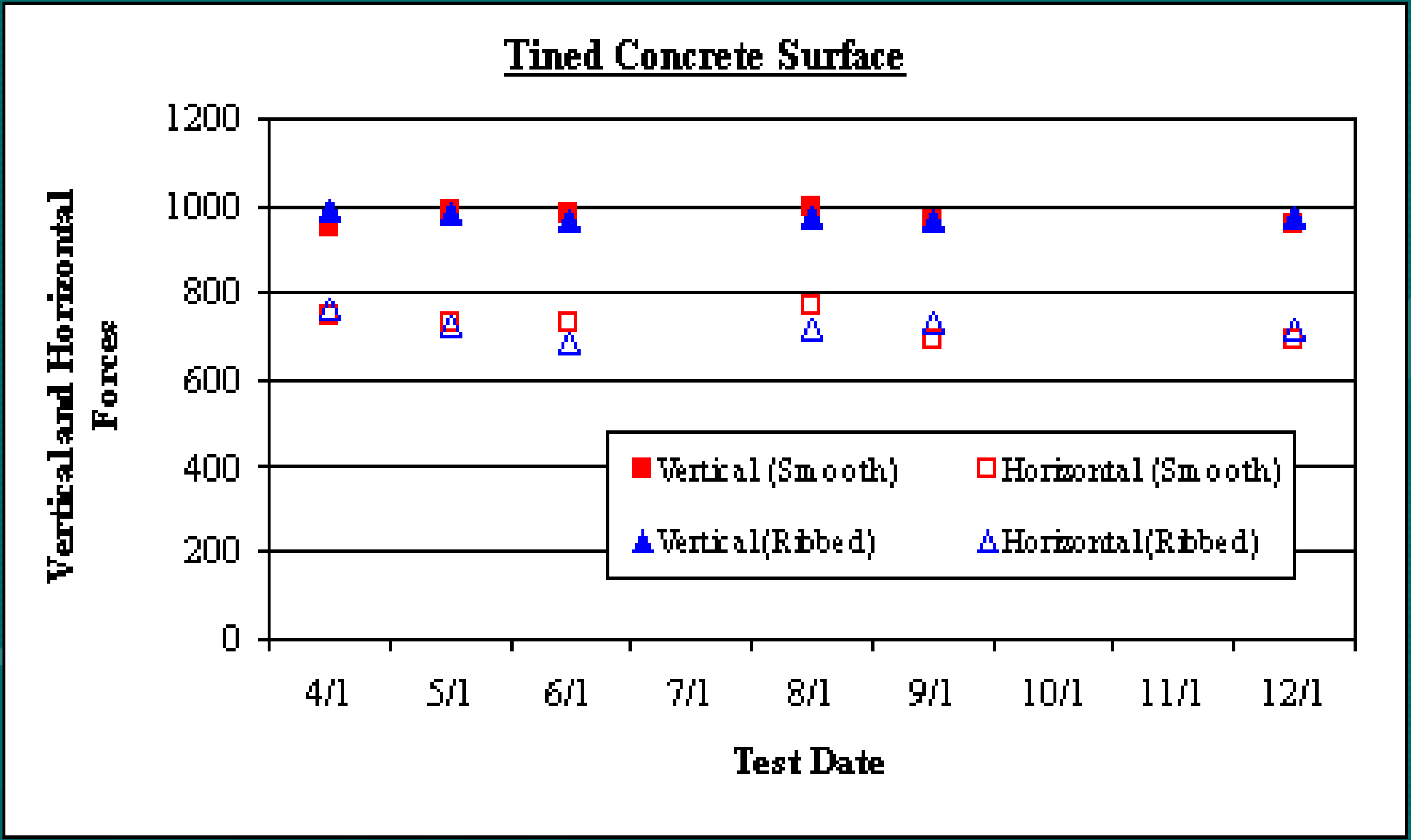

Fig. 7(c) Friction measurements on tined concrete surface

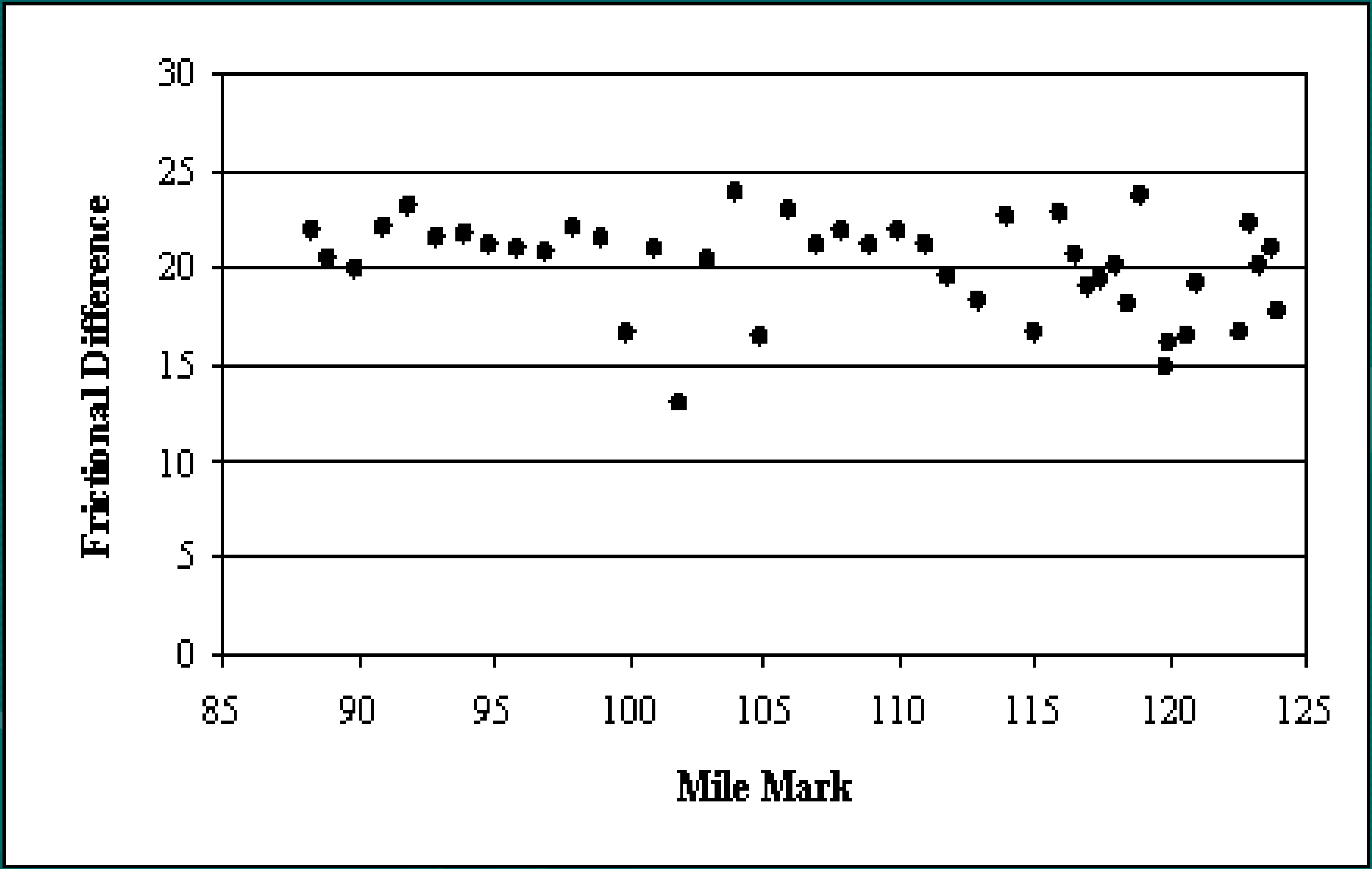

Fig. 7(d) Friction differences on SR-37

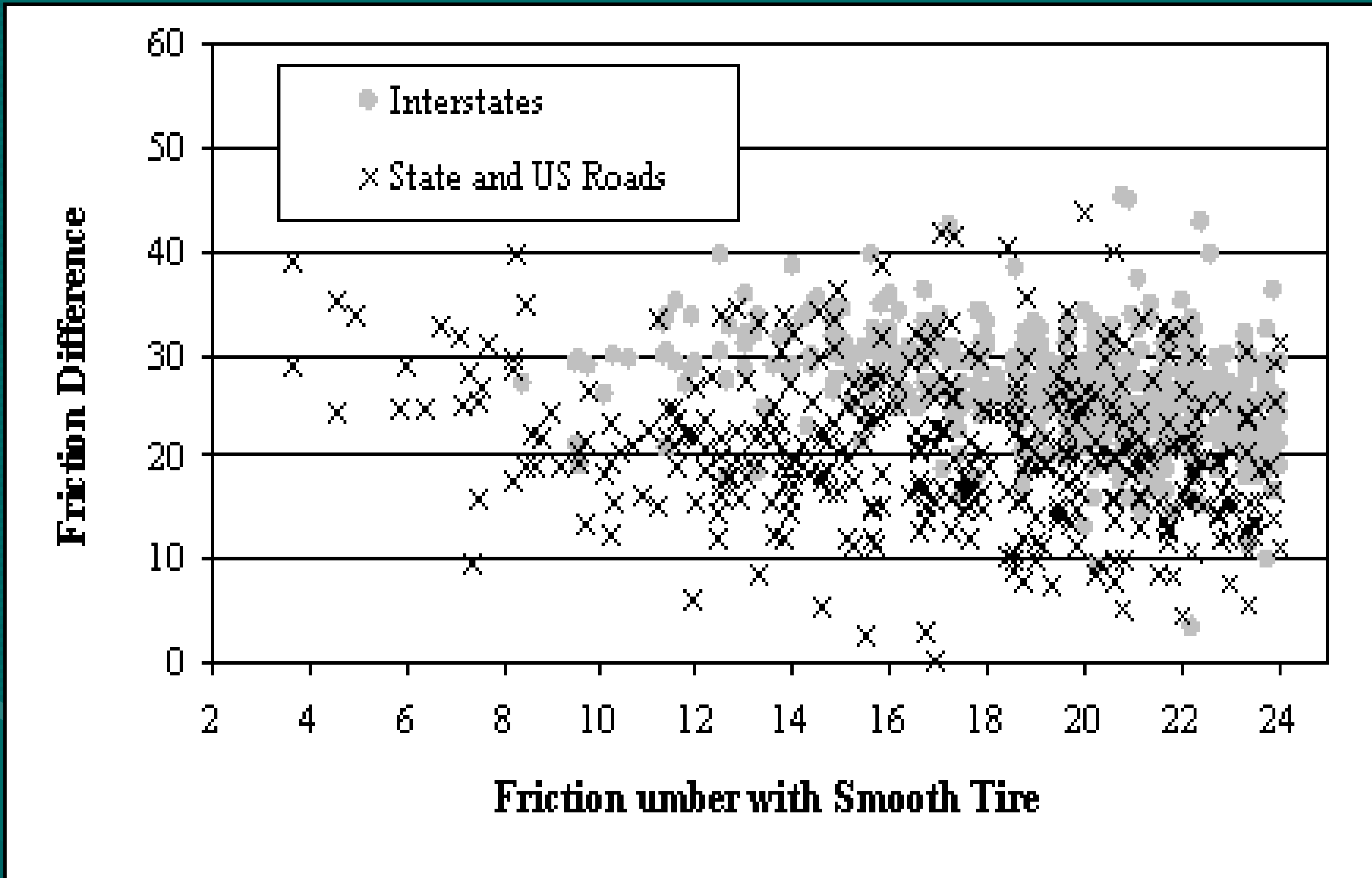

Fig. 7(e) Friction differences in the network

- Summary of Friction Differences between the 2 Tires

  - On INDOT friction test track

    Slick concrete surface: 17

    Asphalt surface: 12

    Transversely tined concrete surface: 0

  - On real-life pavements

    Interstates: 23

    US and State roads: 20

4.2 Test Speeds

- ASTM E-274 standard test speed

  40 miles per hour

- INDOT friction test speed

  - Warranty pavement friction test

  - Special friction test

  - Network inventory friction test

    Interstates: 50 mph

    US and State roads: 50 mph (30 or 40 mph)

- Speed gradients

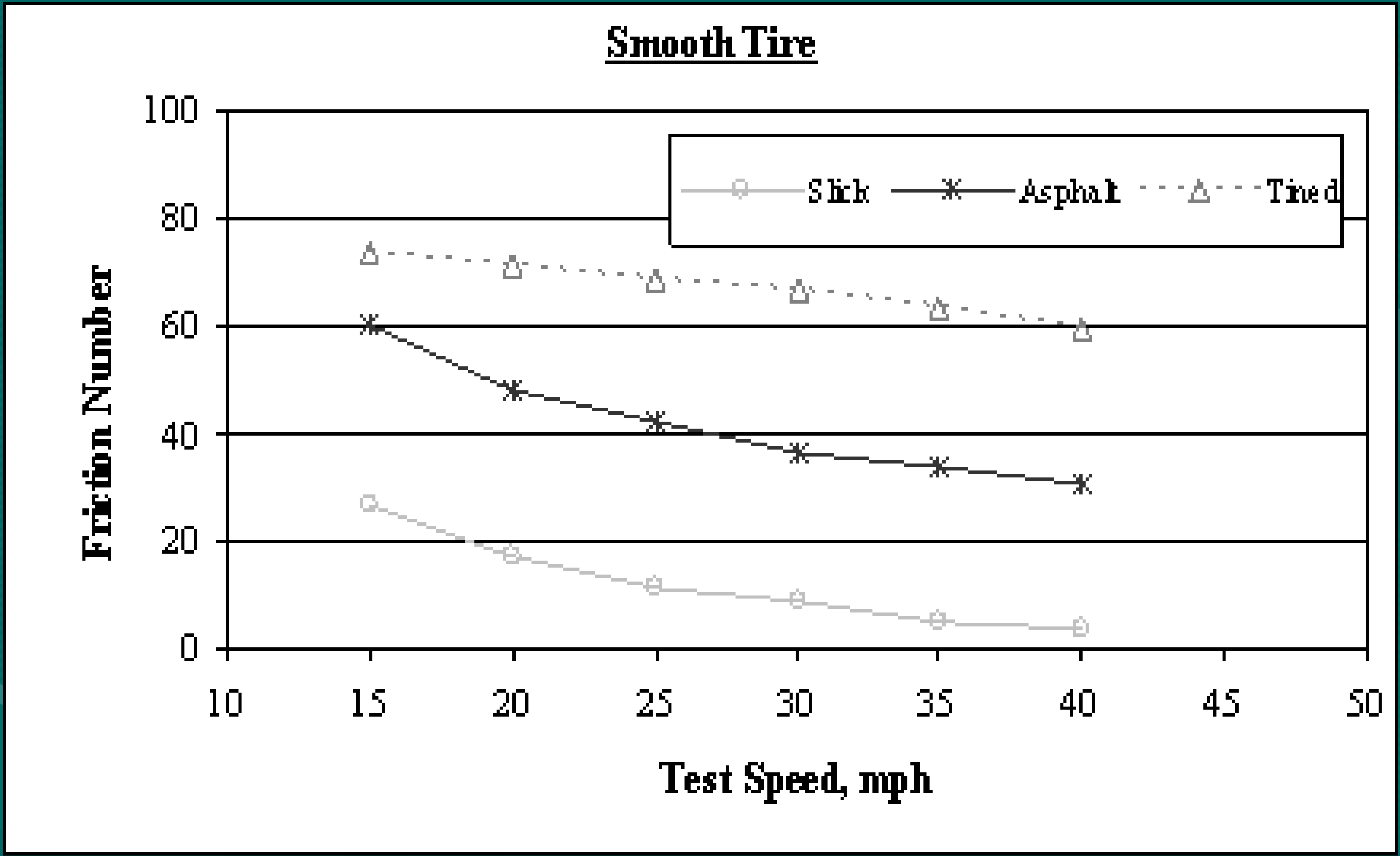

Fig. 8(a) Speed gradients by smooth tire

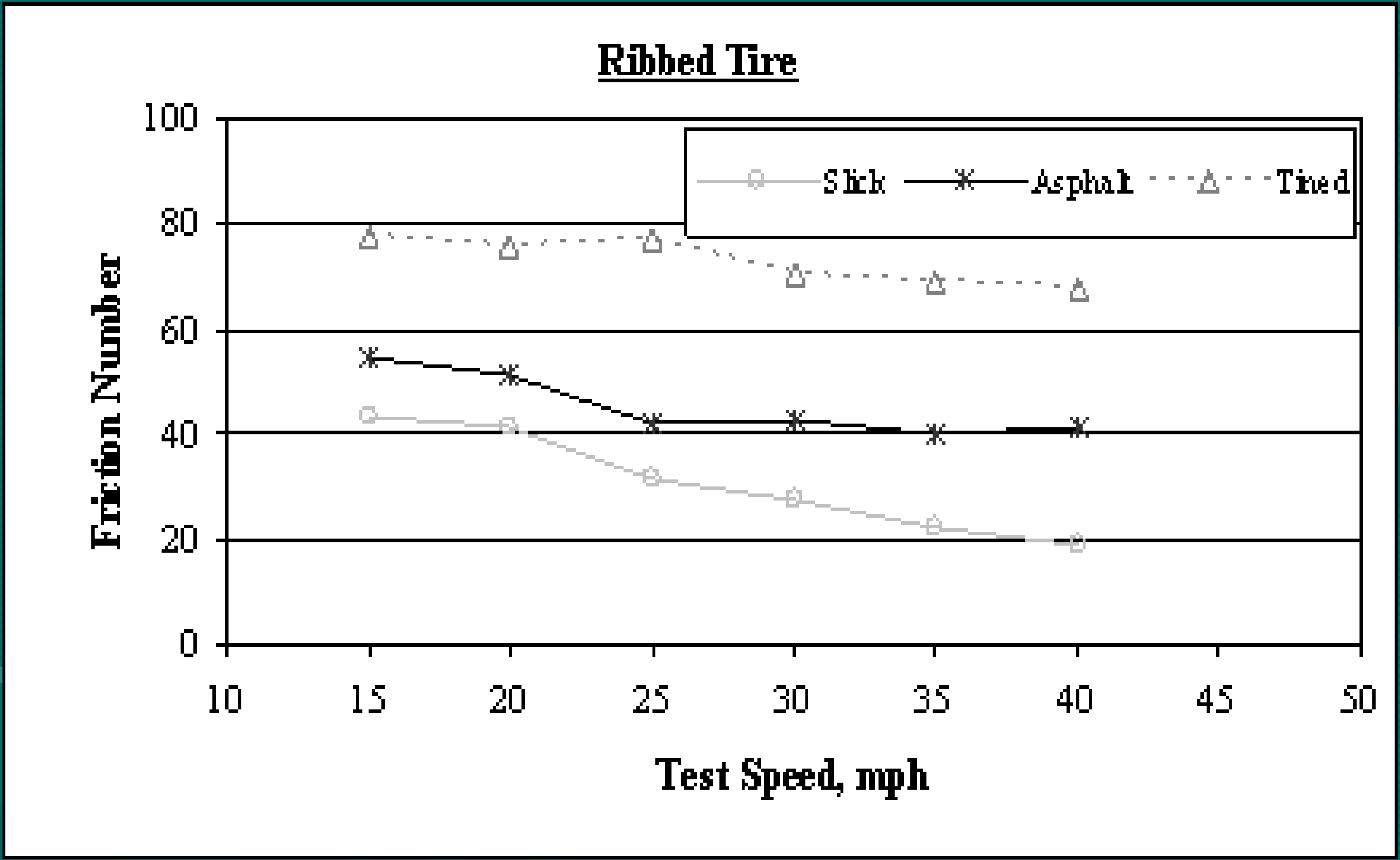

Fig. 8(b) Speed gradients by rib tire

- Conversion constants

- System 300-4

Smooth tire:

$FN40=0.898418\times FN30$

$FN40=1.168647\times FN50$

Rib tire:

$FN40=0.951607\times FN30$

$FN40=1.045475\times FN50$

5. Variations of Pavement Friction

5.1 Effects of Air and Pavement Temperatures

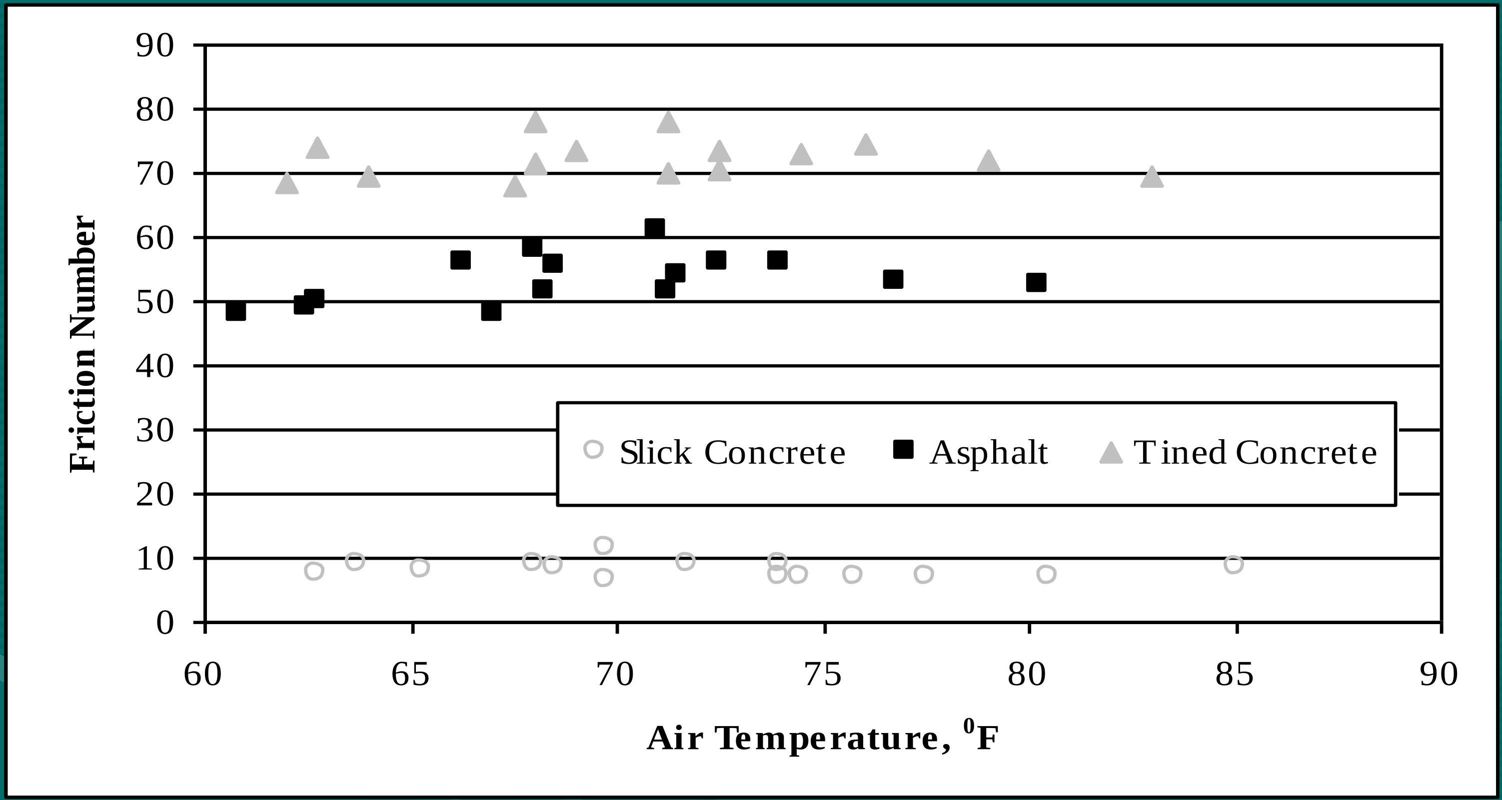

Fig. 9(a) Friction number vs. air temperature

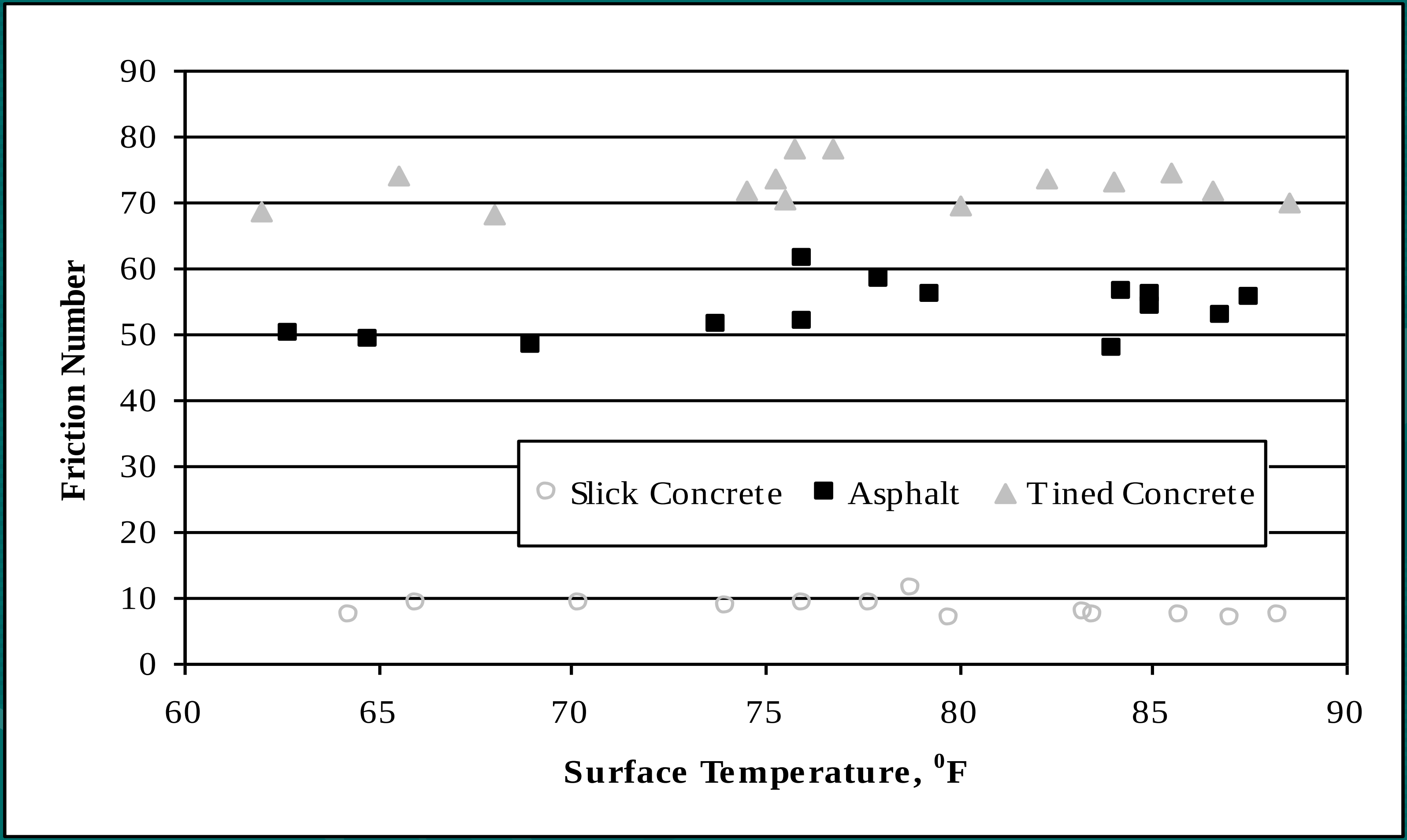

Fig. 9(b) Friction number vs. pavement surface temperature

- Variations due to seasonal effects equivalent to those due to system errors
- Effects of air and pavement surface temperatures not significant
- No seasonal or temperature corrections for INDOT network pavement inventory friction testing

5.2 Spatial Variations of Pavement Friction

- Lateral friction variations

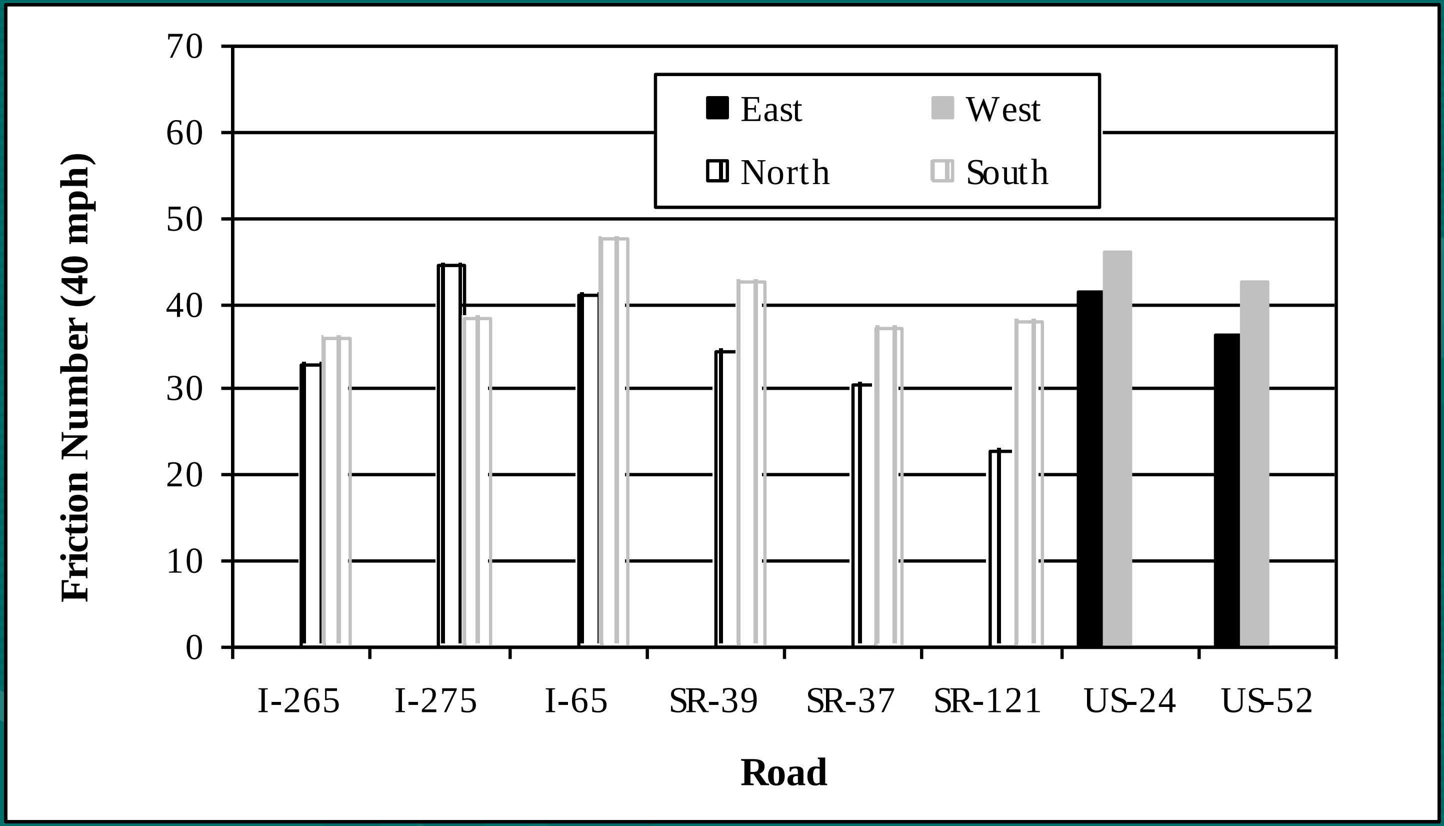

Fig. 10(a) Directional friction variations

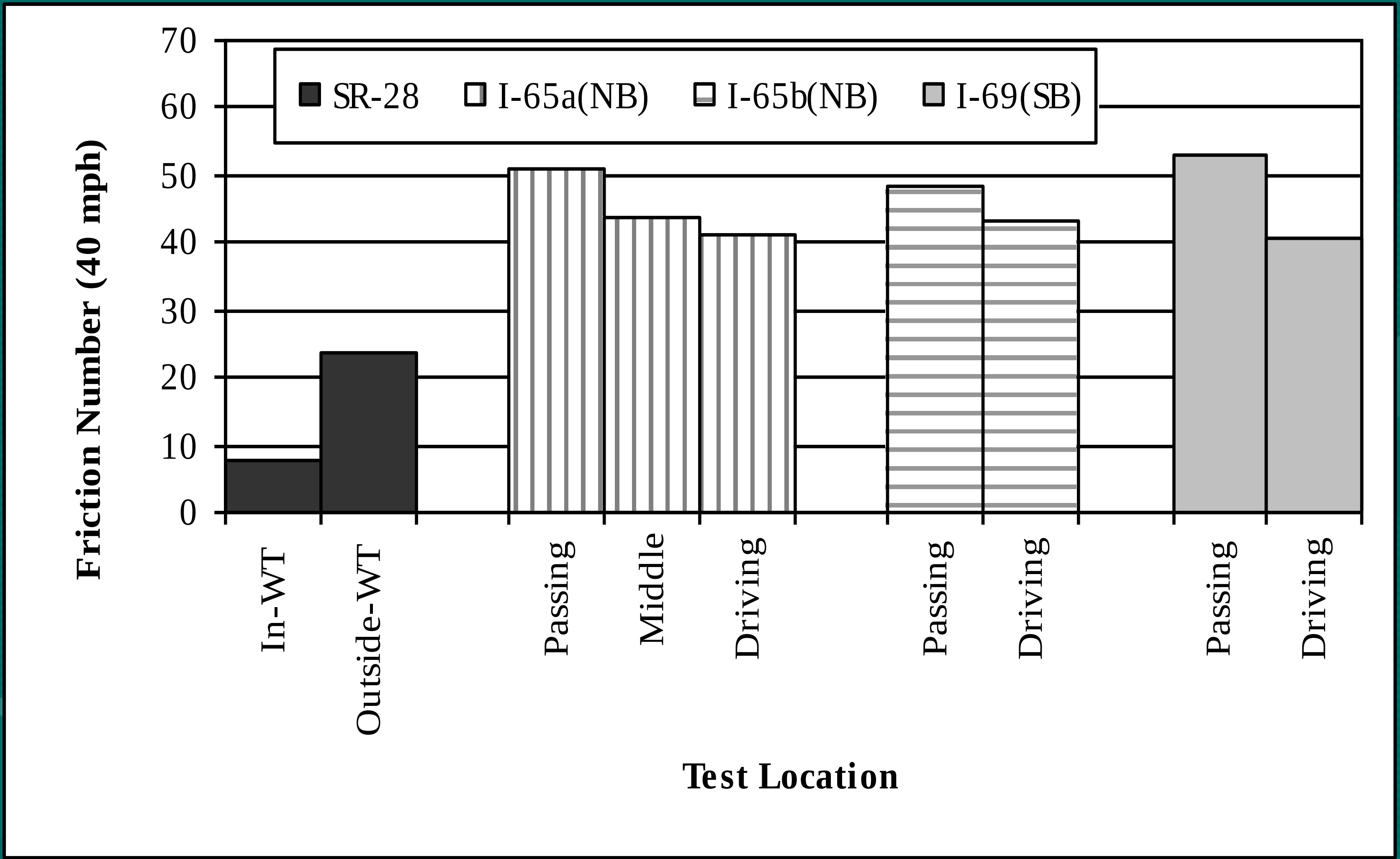

Fig. 10(b) Lane friction variations

- Directional friction variation up to 16
- Friction variation up to 13 between passing and driving lanes
- Friction variation up to 16 in the wheel track and outside the wheel track
- INDOT network pavement inventory friction testing conducted

  - In both directions

  - In driving lane

  - Inside the wheel track

- **Longitudinal friction variations**

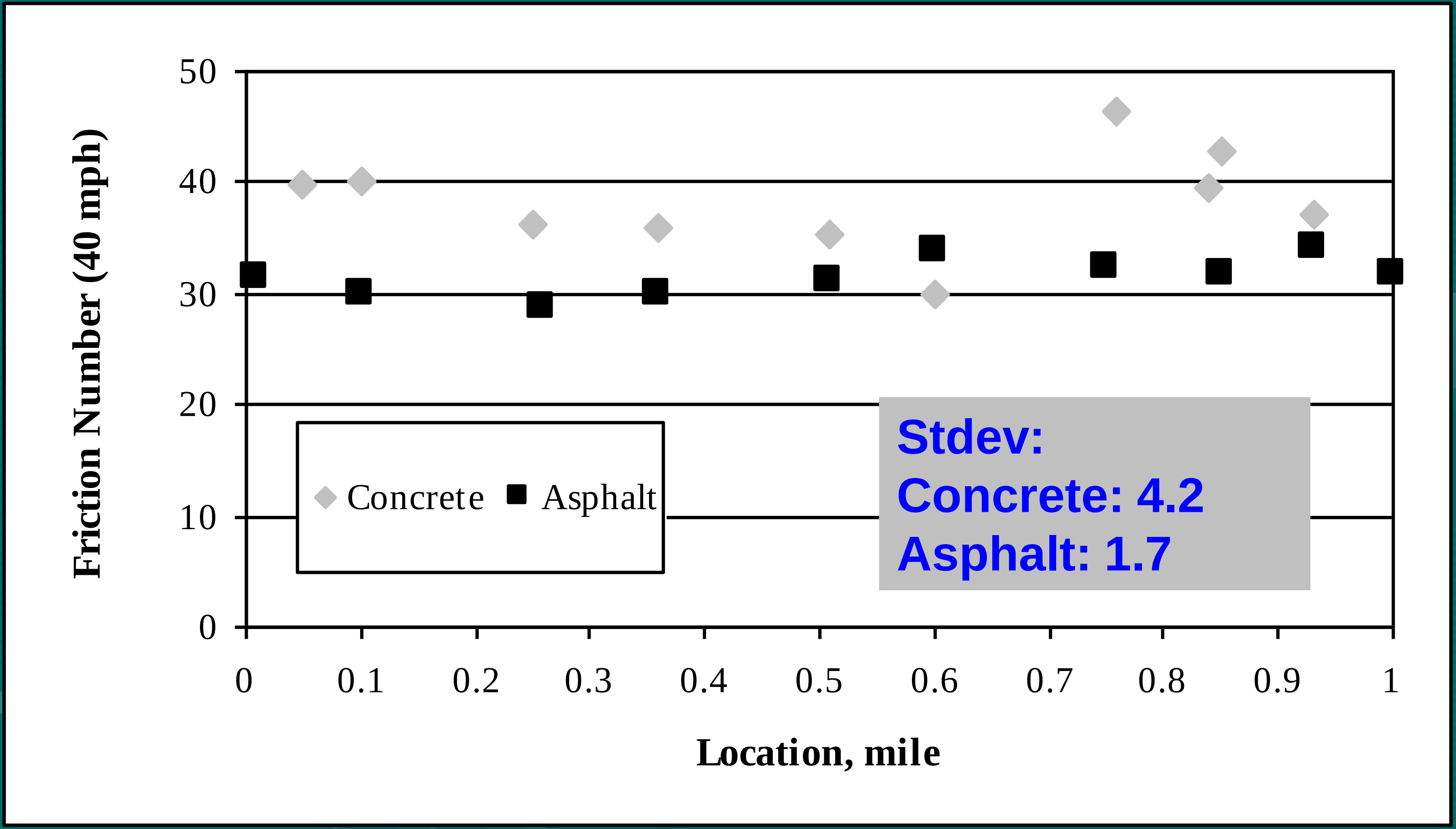

Fig. 11(a) Friction variations on asphalt and concrete pavements

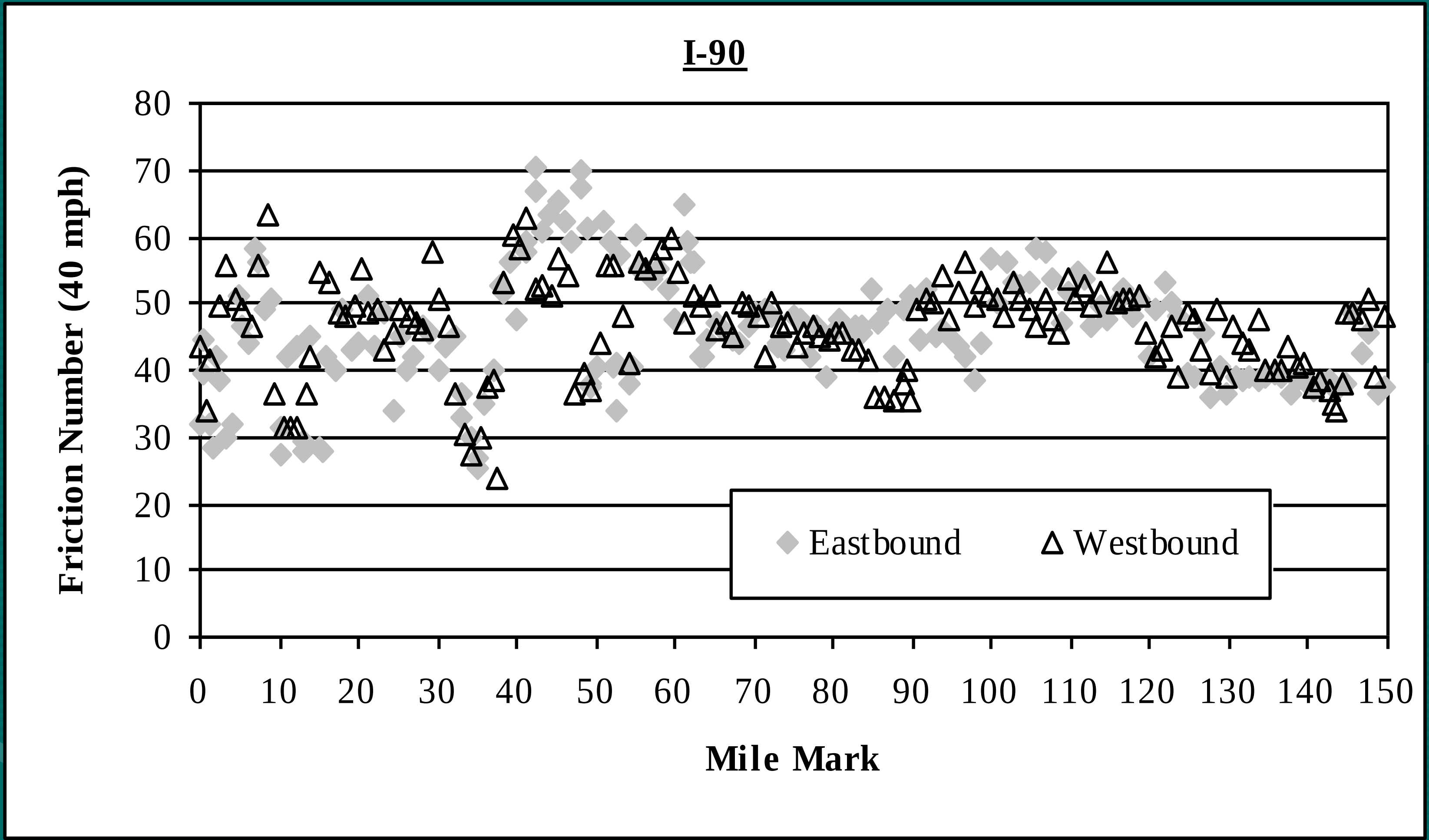

Fig. 11(b) Longitudinal friction variations on interstate highway

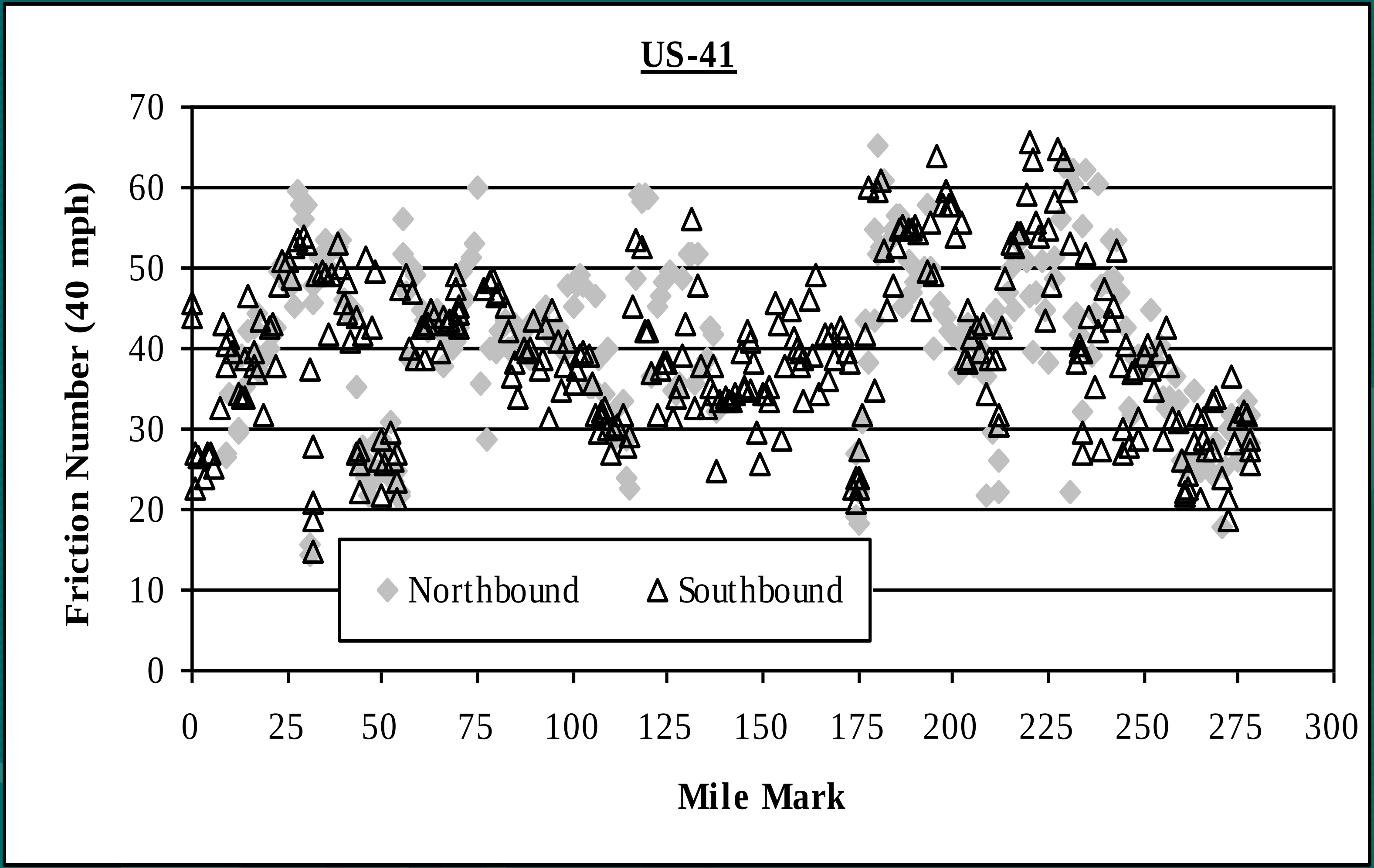

FIG. 11(C) Longitudinal friction variations on US highway

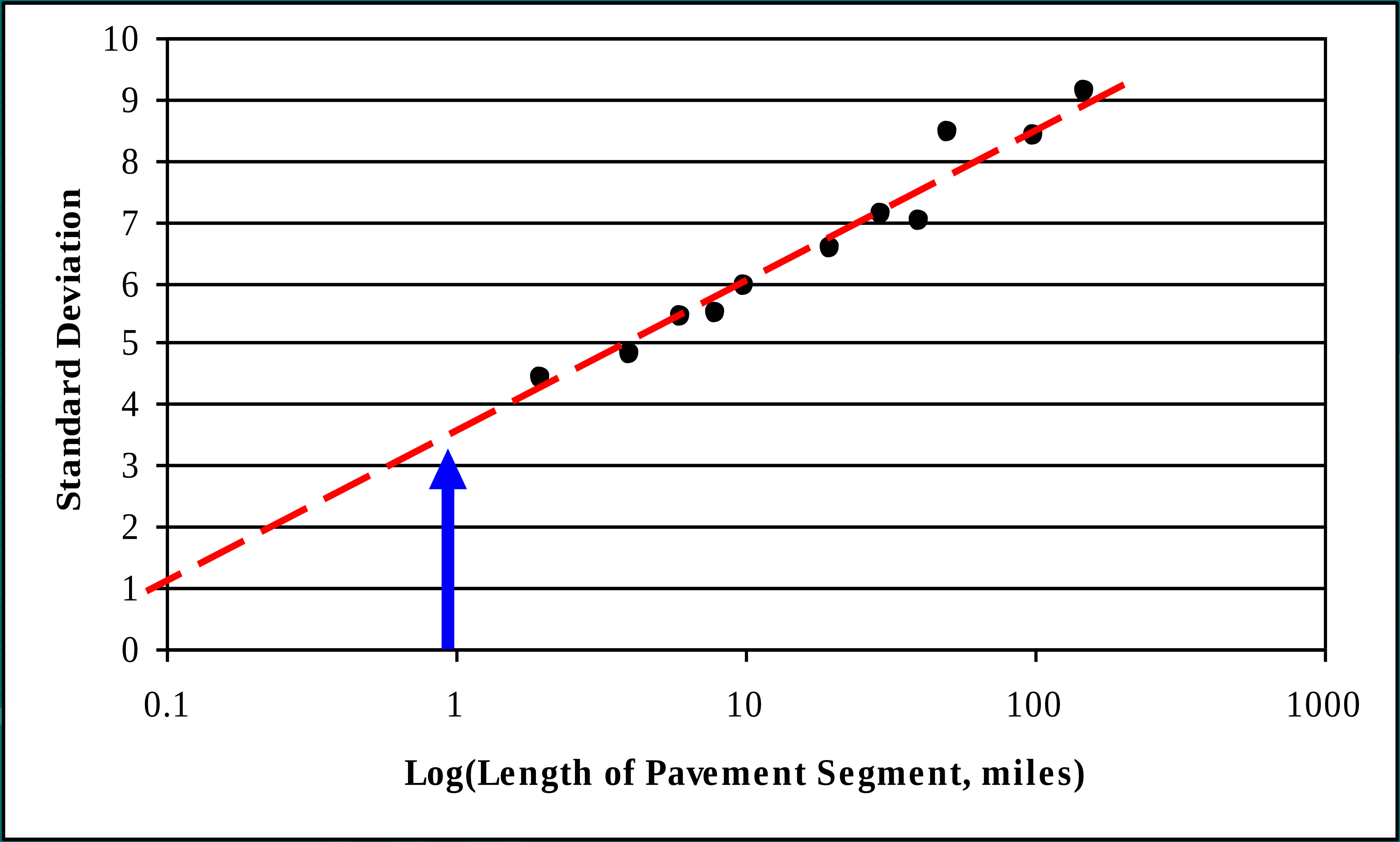

Fig. 11(d) Standard deviations vs. pavement segment length

- A linear relationship between the standard deviation and log of pavement section length
- The standard deviation

  - Stdev = 3.4 when section length = 1 mile

    Close to the stdev at 0.1 mile spacing in Fig. 9(a)

  - Stdev = 1.3 when section length very small

    Close to those due to system errors in Table 3
- INDOT network pavement inventory friction testing conducted at 1-mile spacing

5.3 Temporal Variations of Pavement Friction

- Asphalt Pavements

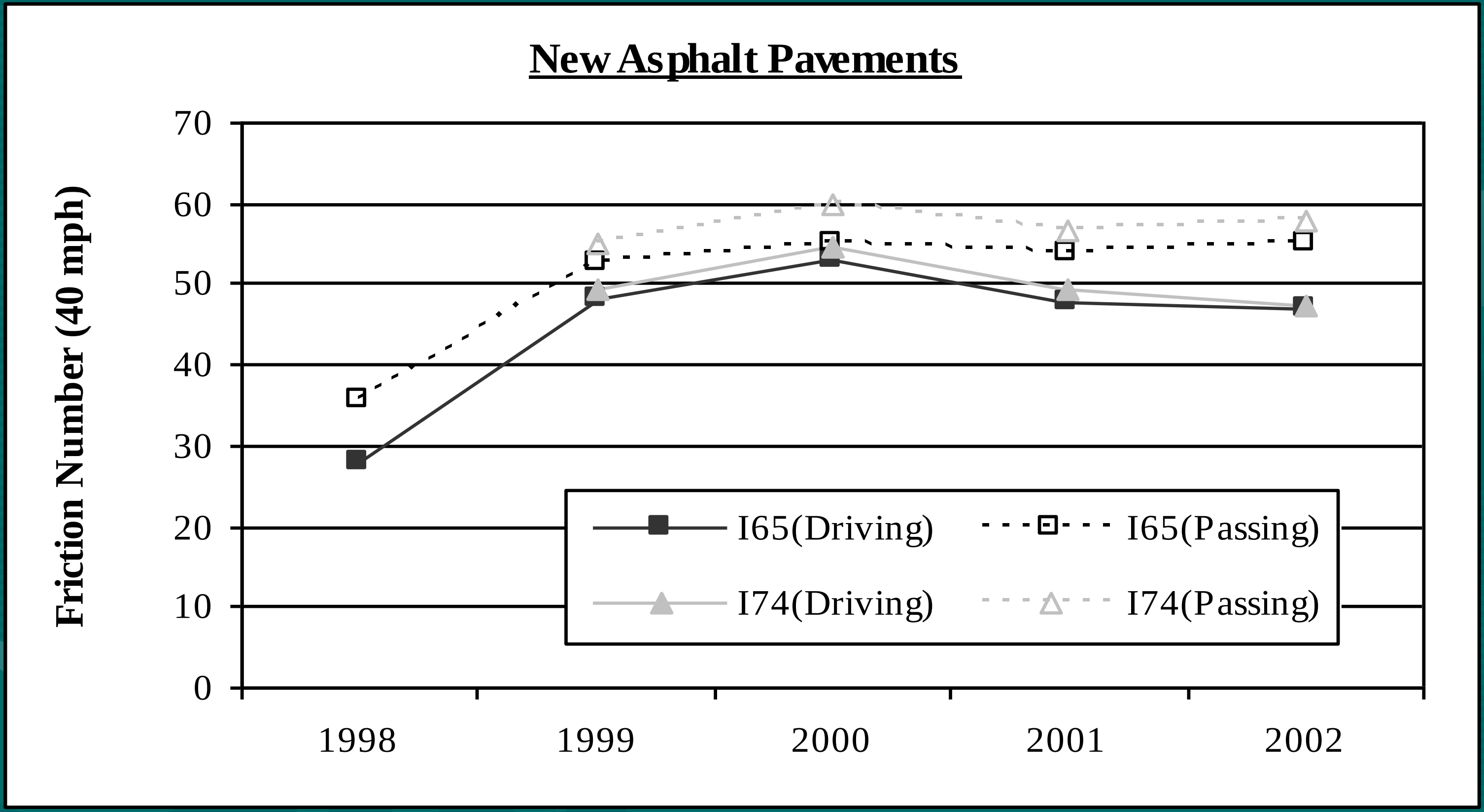

Fig. 12(a) Friction variations with time in new HMA pavements

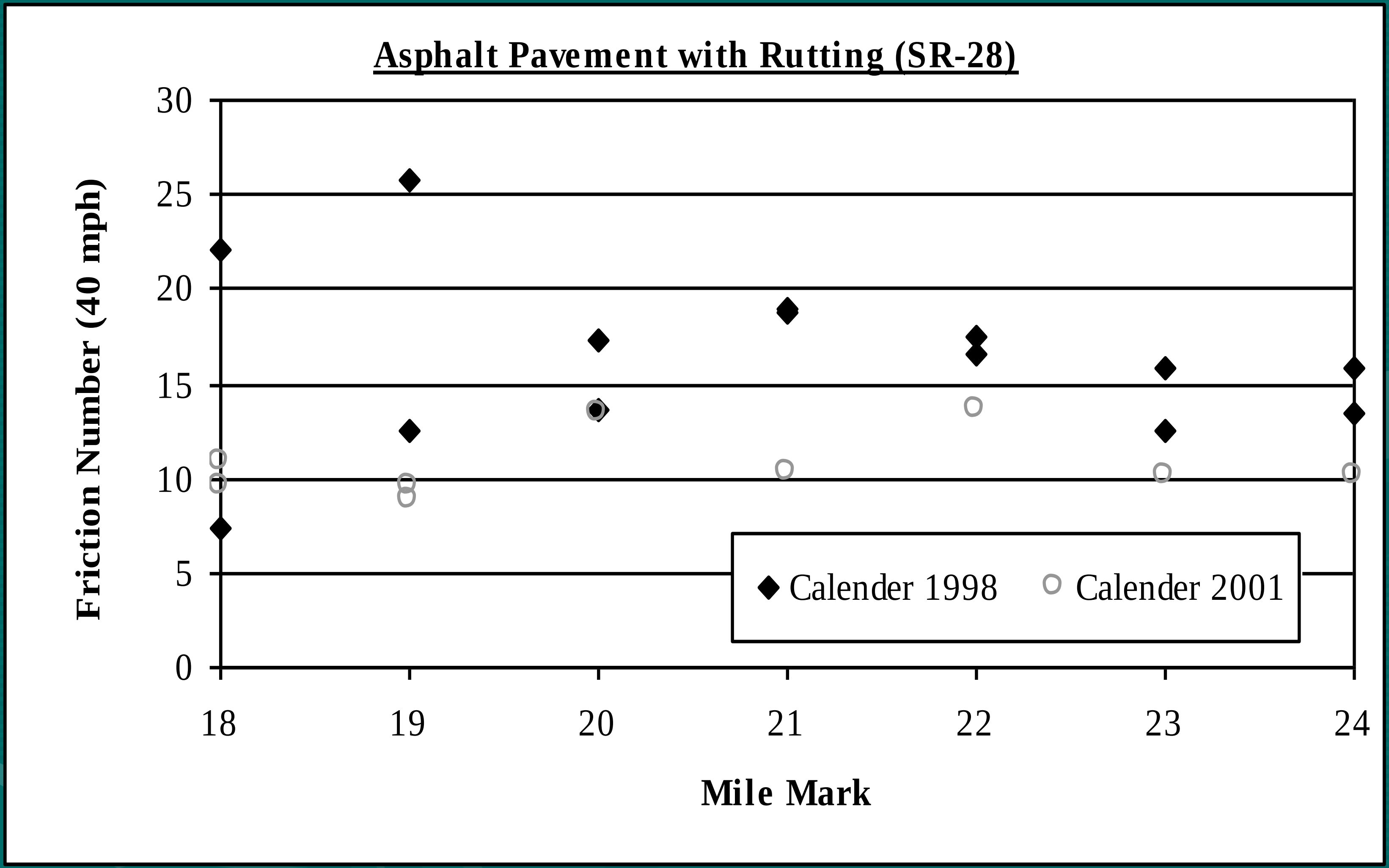

Fig. 12(b) Friction variations with time in rutted HMA pavements

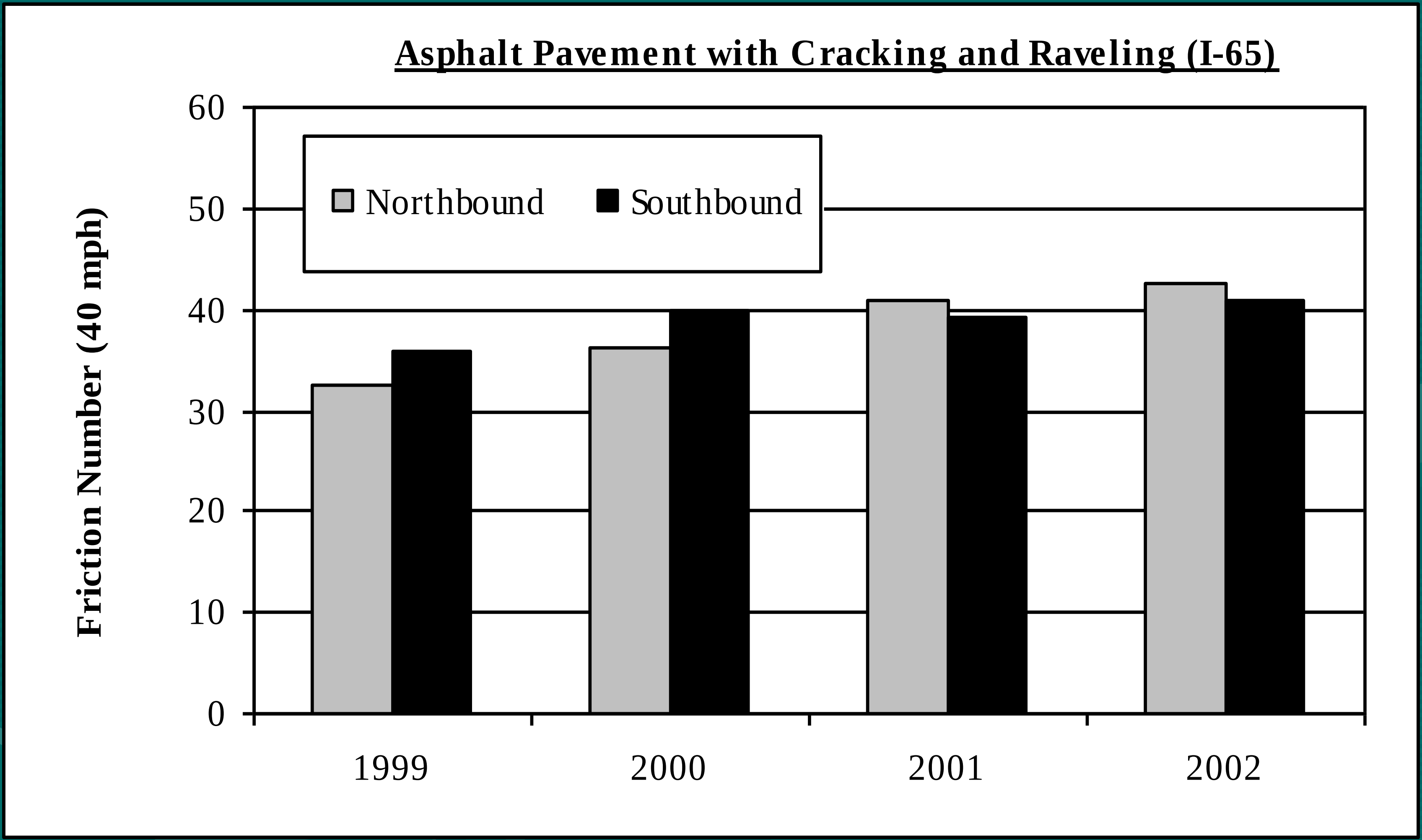

Fig. 12(c) Friction variations with time in cracked HMA pavements

- Concrete Pavements

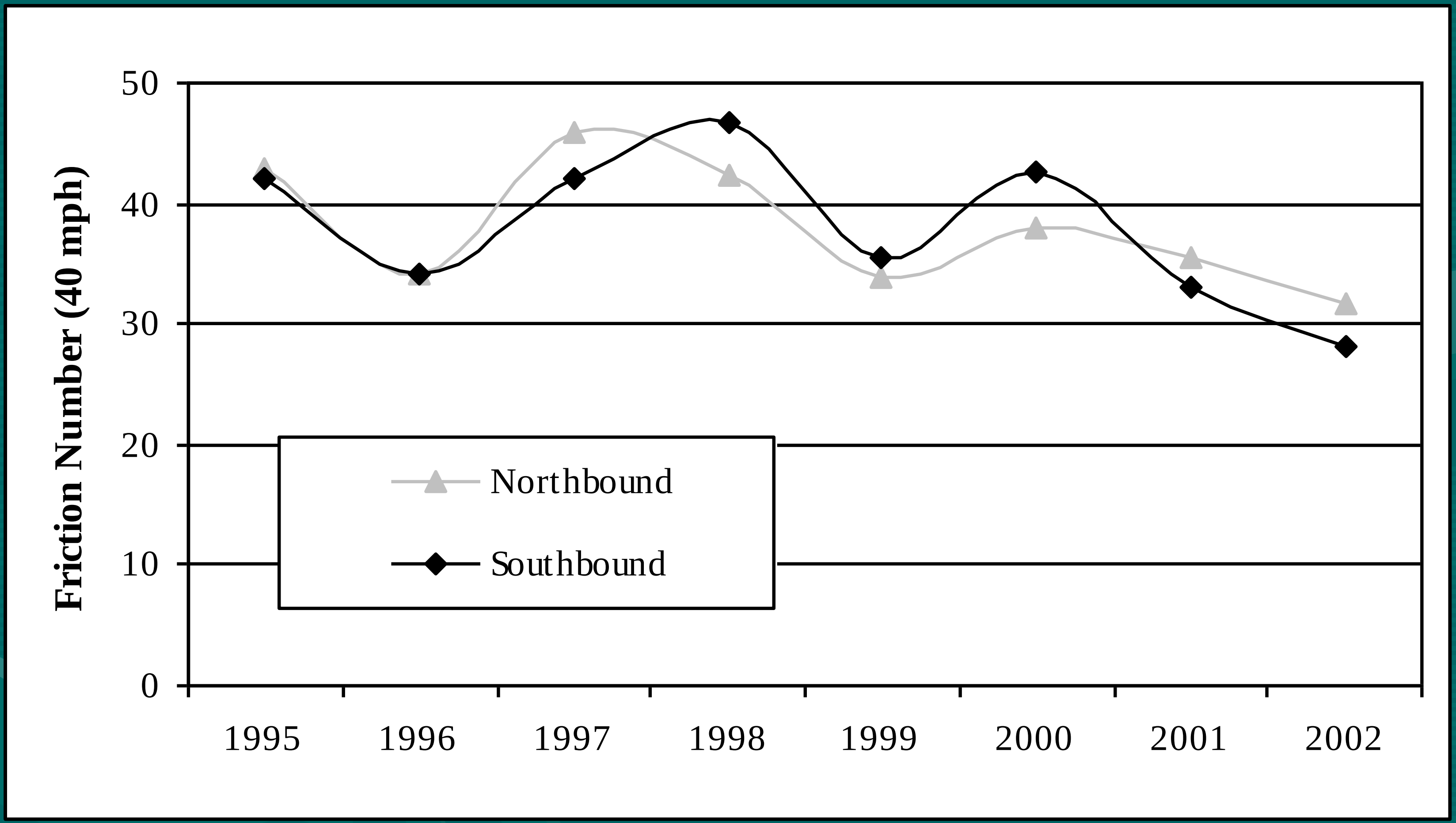

Fig. 13 Friction variations with time in concrete pavements

- **Pavement Network**

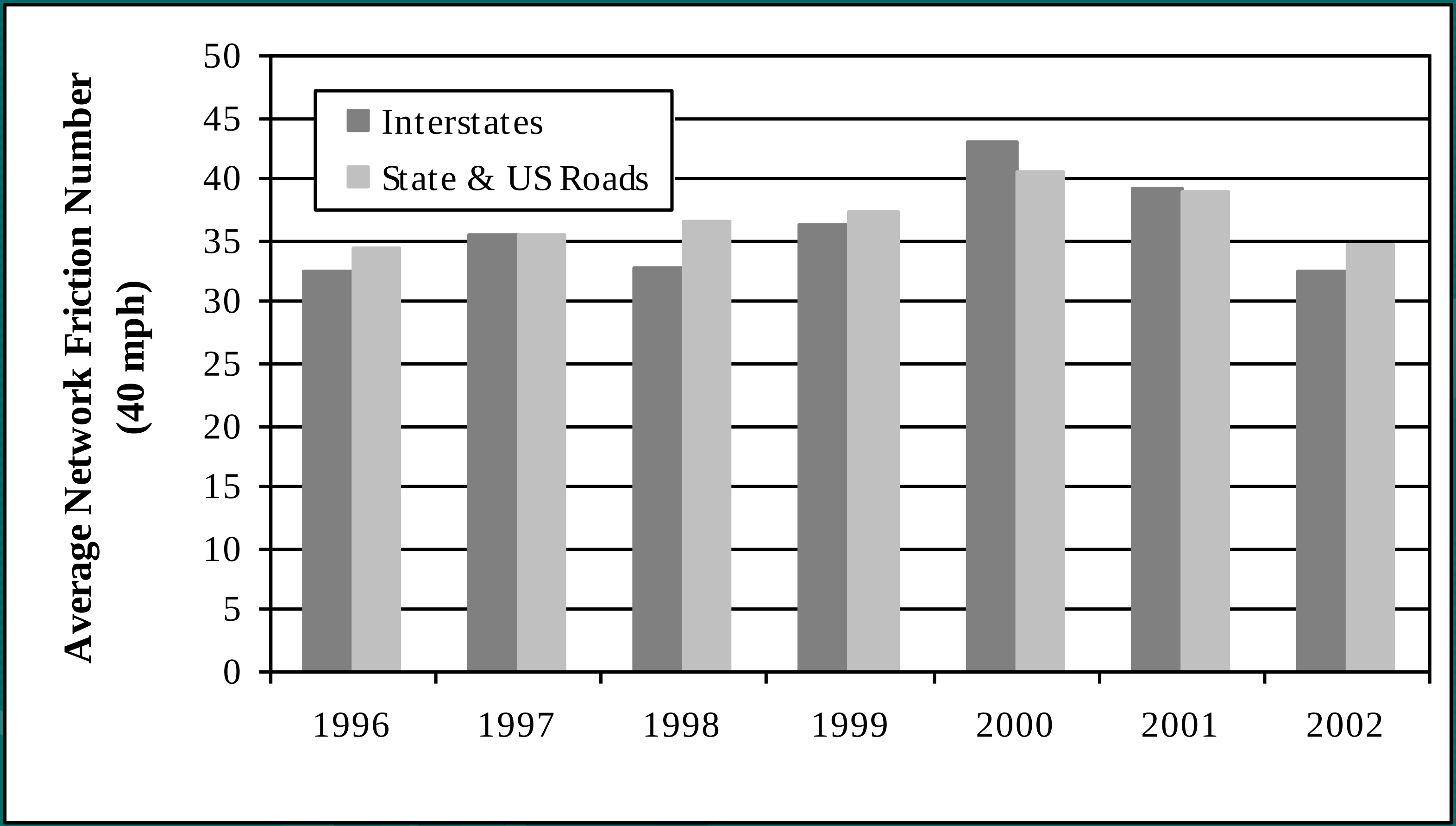

Fig. 14 Friction variations with time in pavement network

- Friction fluctuated over time depending on surface conditions; but decreasing overall
- Largest average annual friction decrease of up to 7 observed on interstates
- Largest average annual friction decrease of 4 observed on US and State highways
- INDOT network pavement friction testing conducted on all interstates every year and on US and State highways every three years

6. The Friction Flag Value

- Factors

  Safety and cost

- AASHTO Green Book

  Deceleration: 3.4 m/s^2.

  Locked-wheel braking on a poor, wet pavement with worn tires at 40 mph

- Kummer and Meyer (1967)

  37 (standard rib tire)

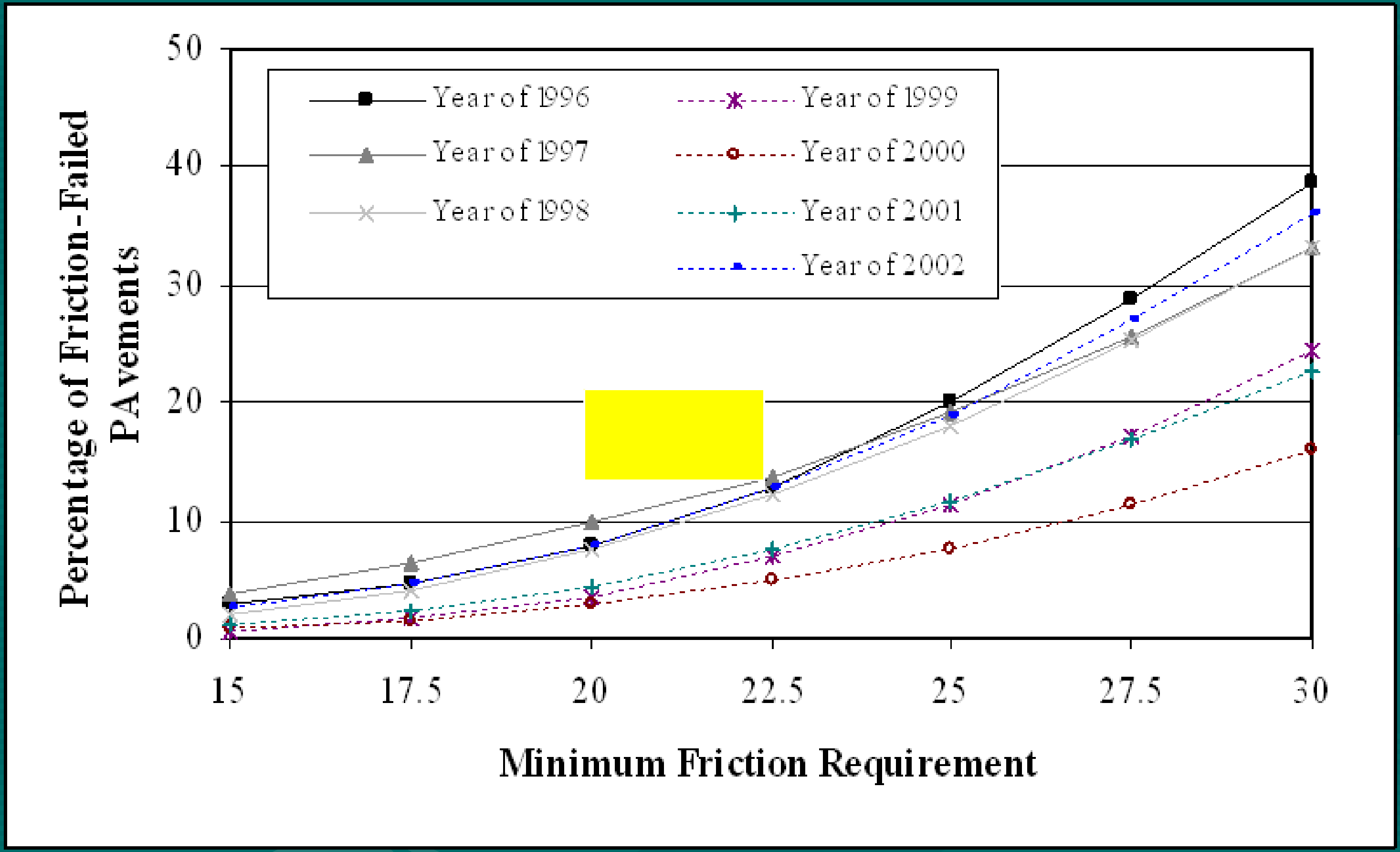

Fig. 15 % of pavements requiring friction treatment

20 smooth tire at 40 mph

7. Friction Data Management

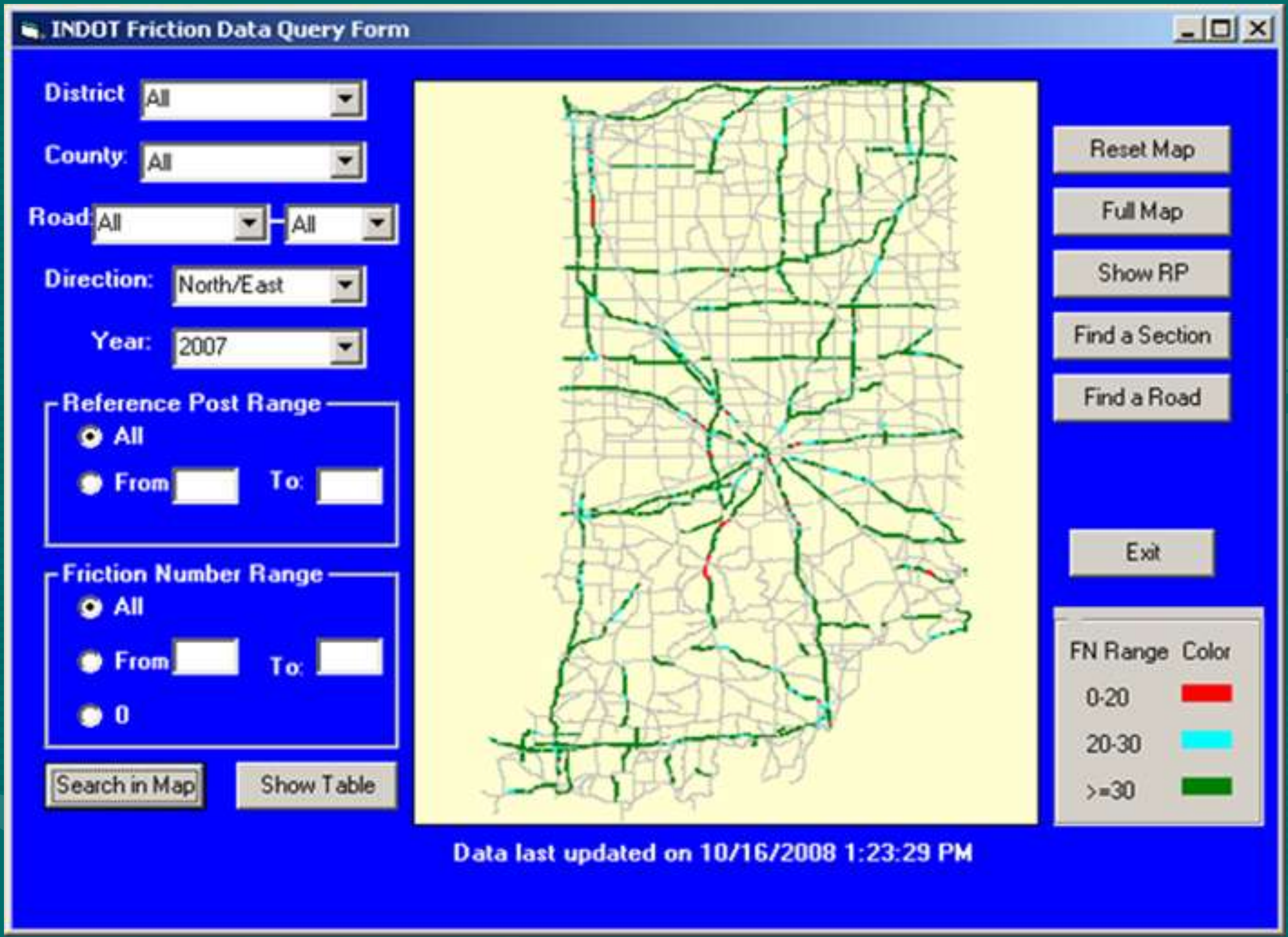

Fig. 16 INDOT pavement friction data management program

8. Facts of INDOT Pavement Frictions

- **Pavement Network Friction Performance**

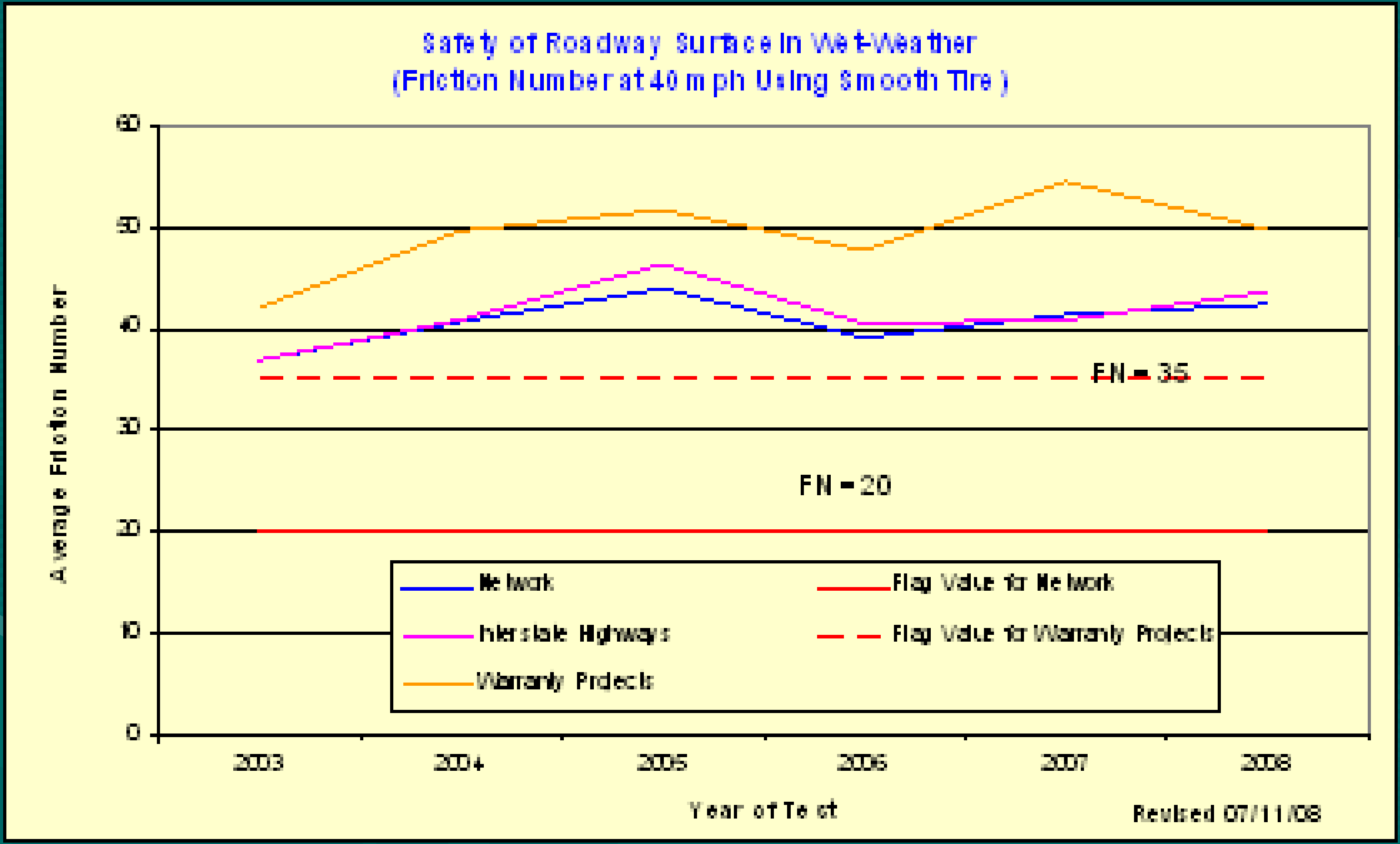

Fig. 17 Mainline pavement friction performance

- Network Ramp Pavement Friction Performance

TABLE 5 Ramp Pavement Friction Performance

Road	Length (miles)	No. of Ramps		Ramp Pavement Friction		
		Observed	Tested	Mean	Min.	Max.
I-164	21	12	2	53.6	47.8	59.4
I-265	7	4	3	42.8	39.8	45.8
I-275	3	1	~	~	~	~
I-465	52	35	12	32.8	31.1	34.5
I-469	31	15	3	59.5	53.1	65.8
I-865	5	1	1	33.6	30.4	36.7
I-64	124	22	3	29.5	22.6	36.4
I-65	261	71	5	42.6	38.5	46.7
I-69	158	43	3	40.7	34.1	47.3
I-70	156	34	4	48.5	44.6	52.4
I-74	171	43	3	37.6	34.5	40.7
I-80/94	62	20	3	37.2	35.6	38.8
I-90	157	17	~	~	~	~

- **Various HMA Mixes**

TABLE 6 Friction Properties for HMA Mixes

Type of Surface Mix	Coarse Aggregate	ESALs (10^6)	Friction Number	
			Year 1	Year 2
OGFC	Steel slag	≥ 30	56.2	
SMA	Crushed gravel	≥ 10	43.7	41.7 - 46.7
	Steel slag		46.8 - 52.9	47.3 - 55.5
SuperPave 9.5 mm Mix	Crushed gravel	3 - 10	34.8 - 41.9	36.7 - 42.8
	Crushed stone		31.1 - 44.6	32.1 - 48.9
	Dolomite		34.5 - 49.6	31.7 - 48.6
	Steel slag		36.7 - 48.2	45.2
Regular	Crushed gravel	3 - 10	47.7	45.1
9.5 mm Mix	Dolomite	3 - 10	44.3	42.6

9. Conclusions

- Monthly and weekly system verifications:

  - Important to maintain consistent system performance, and

  - Enhance testing reliability

- The friction variations due to system errors varying with pavement surface features:

  1.2 (15%) on slick concrete

  3.8 (6.7%) on asphalt

  1.6 (2.3%) on tined concrete

- INDOT network inventory friction testing conducted on interstates every year and other roads every three years from April through November

- INDOT network inventory friction testing conducted using the smooth tire at 30, 40 or 50 mph

- INDOT network inventory friction testing conducted in the driving lanes in both directions

Questions?