VTRC

Virginia Transportation
Research Council

A partnership of the **Virginia Department of Transportation**
and the **University of Virginia** since 1948.

USE Deflection Measurements in Virginia's PMS

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Introduction

- Approximately 25,000 lane-miles managed by VDOT (~2500)
- Pavement management system
- Skid numbers / IRI
- Safety and ride quality estimated
- **No evaluation of structural capacity**
  - Need of structural classification for our pavements similar to roughness (IRI) or pavement condition ratings.

Current tools

- Destructive
  - Cores and boring operations
  - Laboratory testing and characterizations
- Non Destructive
  - FWD testing
  - RWD testing
  - GPR testing
    - Combination of all of the above

FWD Testing and Analysis

- The most powerful and comprehensive available tool to structurally classify our existing pavement structure
- Representation of the existing pavement conditions
  - AASHTO Evaluation
    - Asphalt (MR & SN) + area
    - Concrete (k and EPCC) + area
    - Composite (MR, k, EPCC) + area
  - Backcalculation
    - ME analysis

Destructive Evaluation

Destructive Pavement Evaluation

Traffic Control?

Destructive

Current Goal Using Deflection & Deflection Analysis in PMS

- Network level FWD data collection for the asset management division of VDOT
- Database of FWD deflection and subsequent structural analysis (MR, SN)
- Characterization of current in-situ pavement condition (Structural Index)
- Proper use of pavement rehabilitation fund
- Future implementation in MEPDG

Current VDOT specifications for FWD data collection

- Project level
  - 25, 50 or 75 feet interval
  - 4 load levels (6,000, 9,000, 12,000 & 16,000 lbf)
  - Three deflection basins at each load level
- Network level
  - 0.1 mile interval to match PMS data

Objective

- Minimum testing frequency for FWD deflection testing on the network level
- Minimum number of load levels used in FWD deflection testing on the network level
- Accuracy of at least a 95% confidence level

[Minimum number of load levels used in FWD deflection testing for stress sensitivity analysis of subgrade]

Literature review

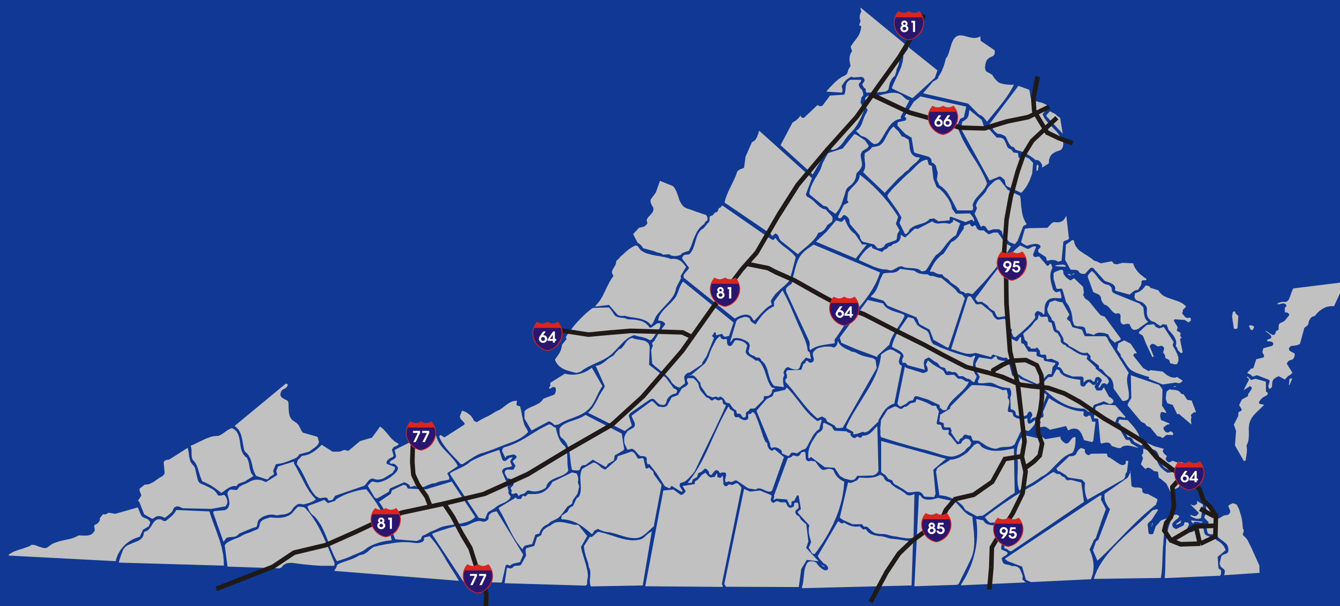
- Noureldin et al.
  - 5 points per mile, single load level, one deflection basin
- Damnajanovic and Zhang
  - 4 points per mile
- Hossain et al.
  - 3 points per mile

Response parameters

- **AASHTO 1993**
  - Resilient modulus *(Mr)*
  - Effective structural number *(SNEff)*
  - Variability analysis

- **ELMOD 5.0**
  - Moduli of the surface layer (*E1*)
  - Moduli of the base layer (E2)
  - Moduli of the subgrade (*E3*)
  - Variability Analysis

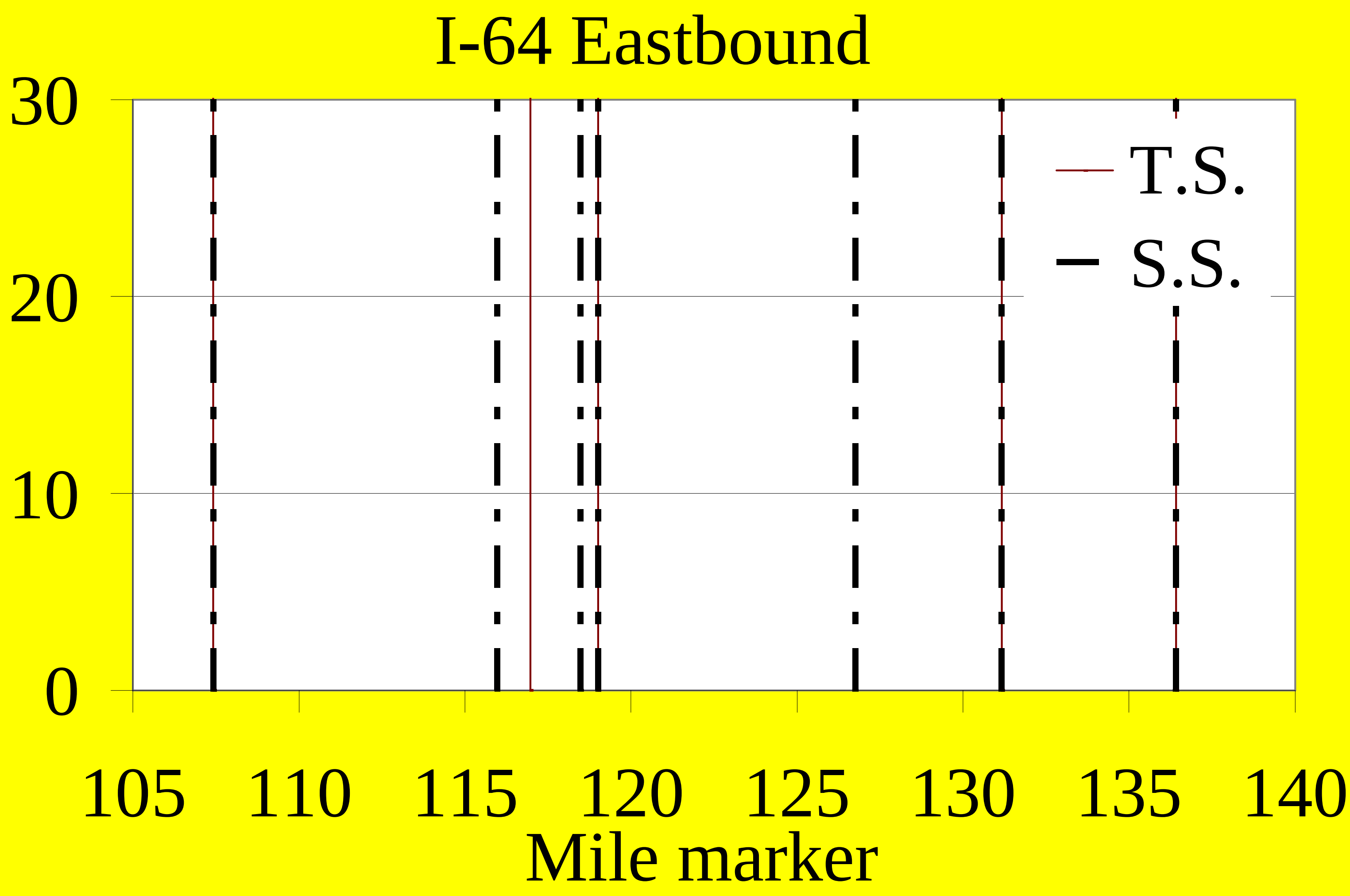
Test sites

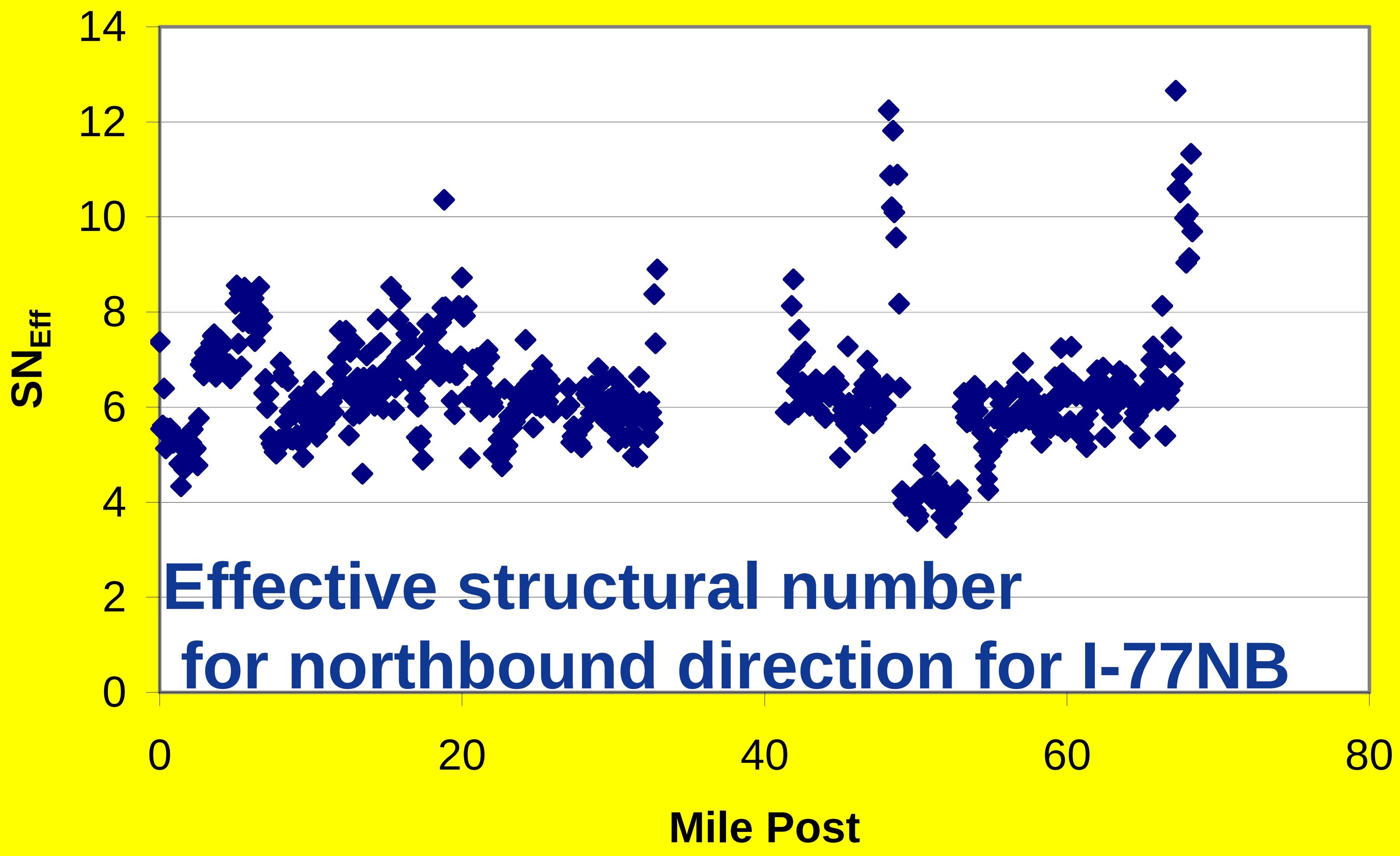


Data collection

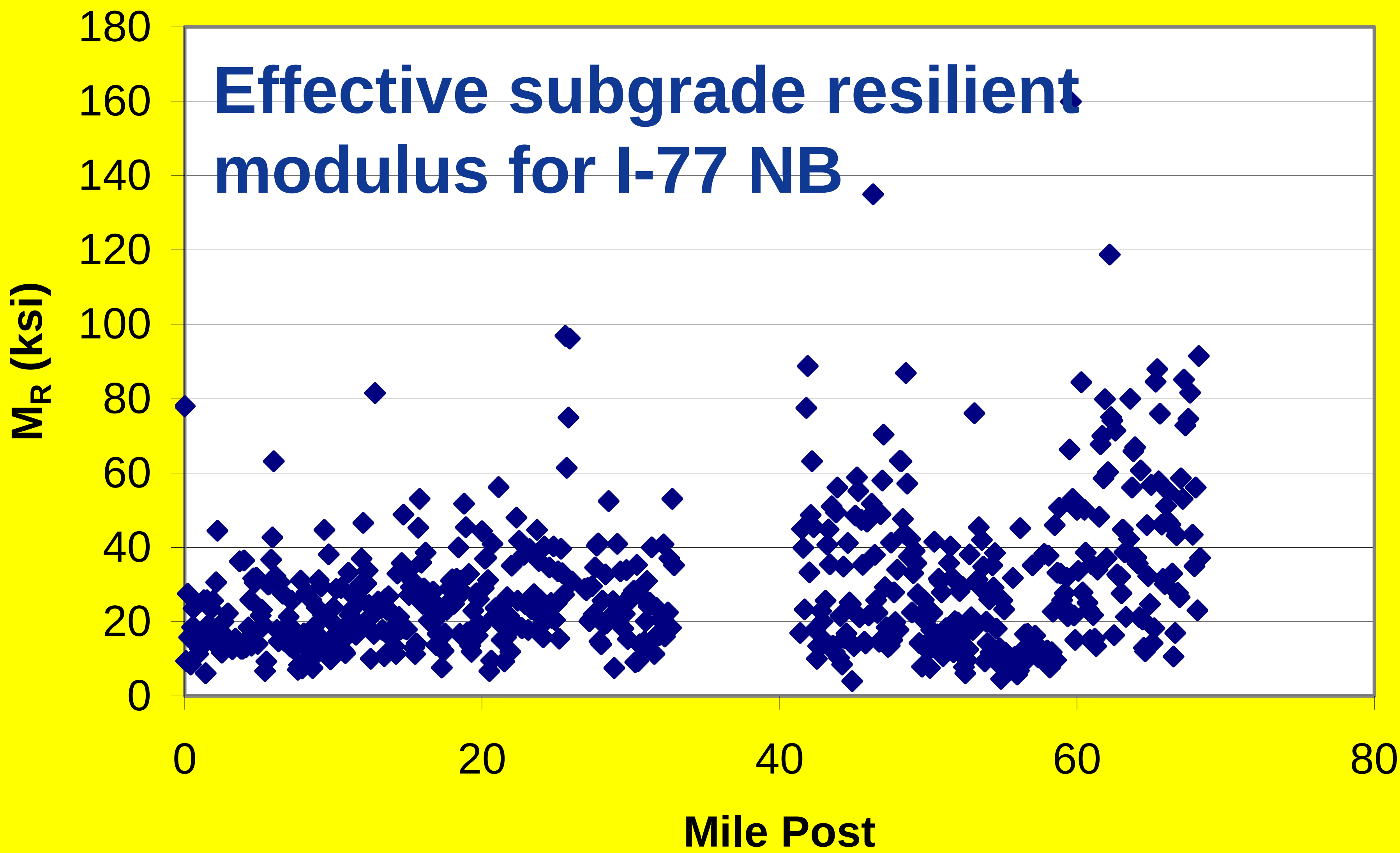
- Both directions
- Driving lane
- Right wheel path, 2-3 feet from the edge
- Two drops per load level
- Homogeneous sections for analysis according to the uniformity of the layer thicknesses

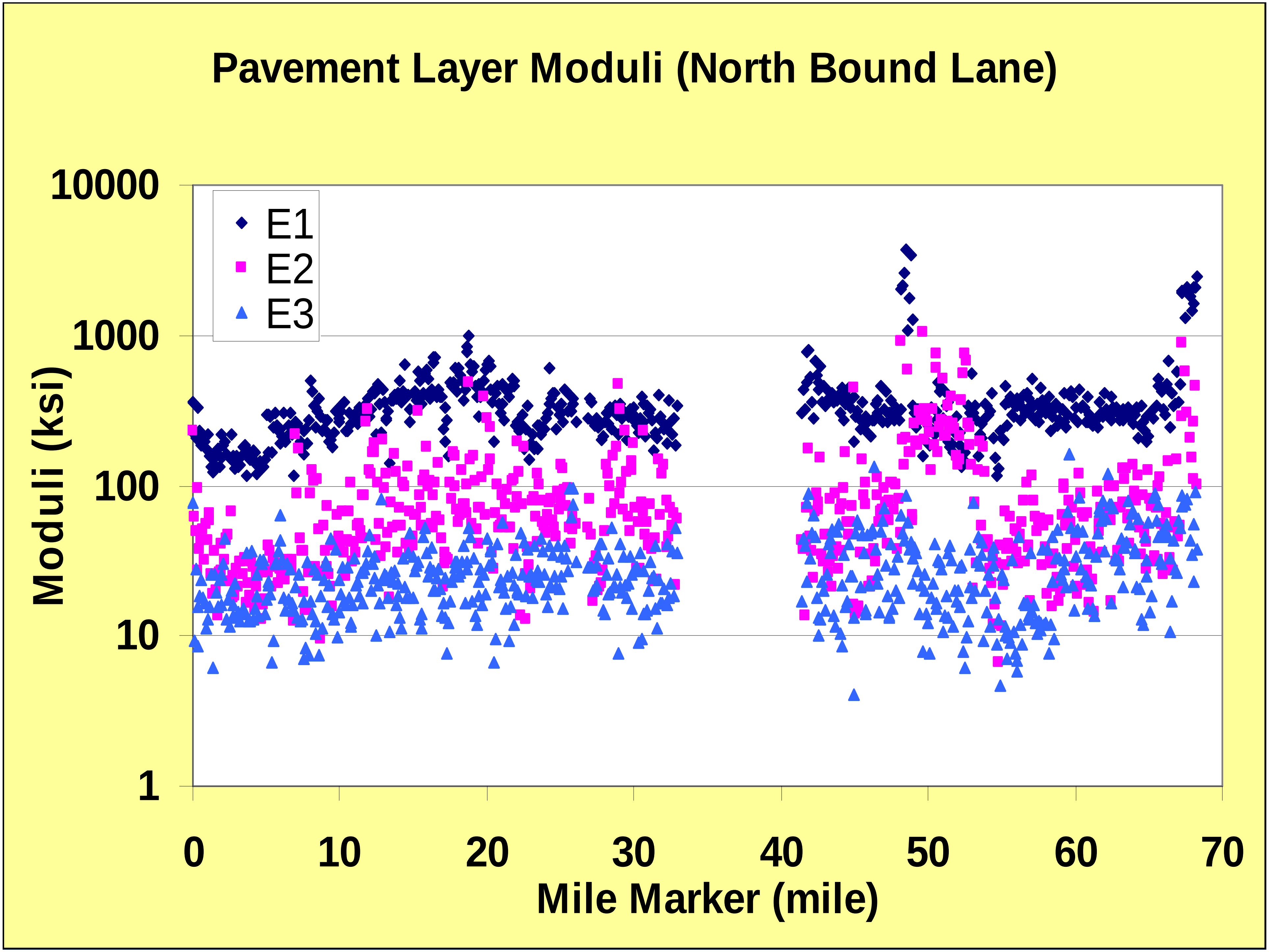
Homogeneous Pavement Sections





14
12
10
8
6
4
2
0
0
20
40
60
80
SN_{Eff}
Mile Post
Effective structural number for northbound direction for I-77NB


Effective subgrade resilient modulus for I-77 NB
M_R (ksi)
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
Mile Post



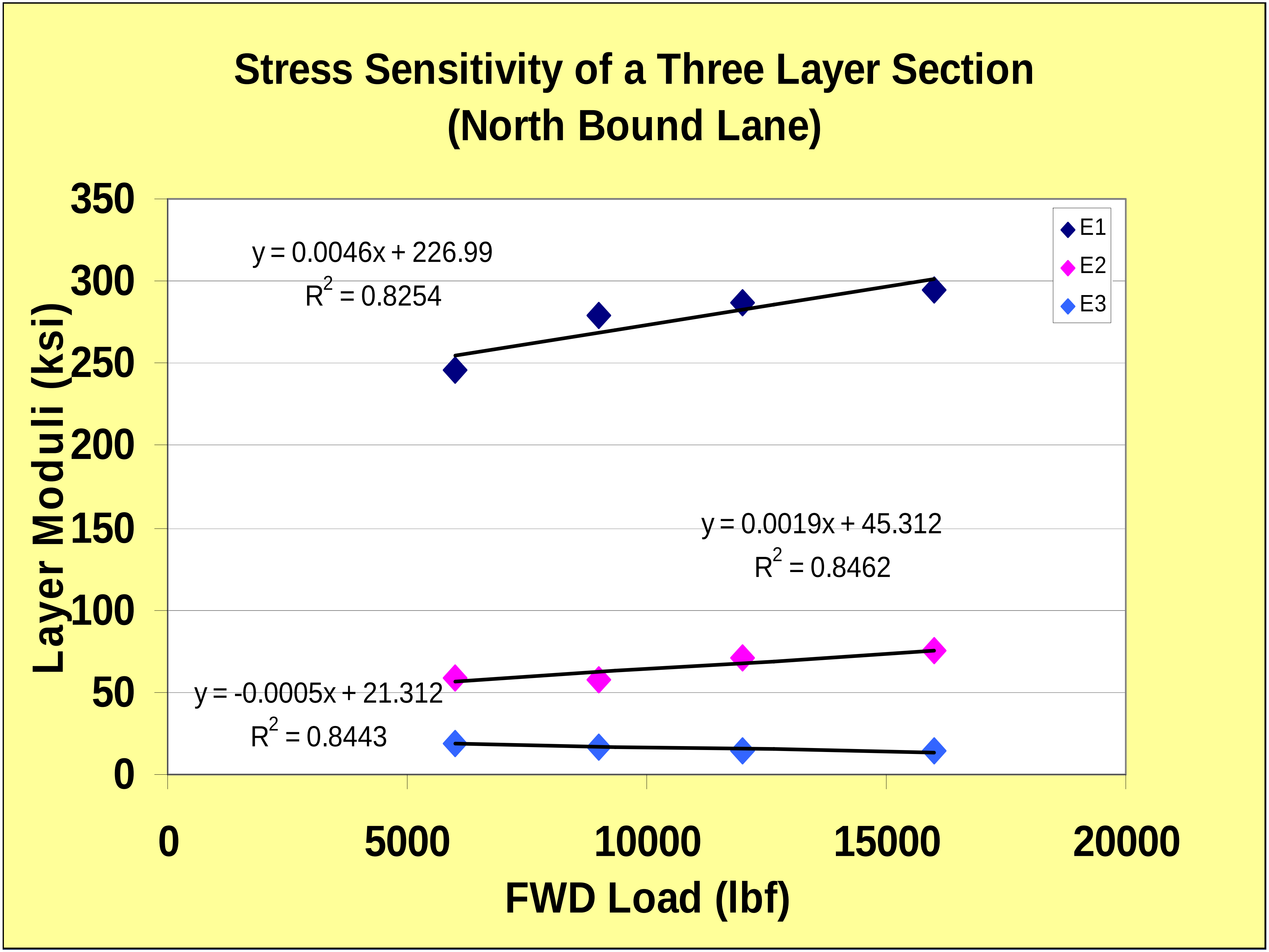
Pavement Layer Moduli (North Bound Lane)
E1
E2
E3
10000
1000
100
10
1
Moduli (ksi)
0
10
20
30
40
50
60
70
Mile Marker (mile)

Statistical Analysis

- Comparison of means
  - Test of hypothesis
  - Two-tailed Welch’s approximate t-test
  - Modified degree of freedom
  - Confidence level of 95%

Stress sensitivity

- Slope of the trend line of the subgrade moduli indicates stress hardening or stress softening
- Comparison of the trend line for 4 load levels and 2 load levels
- 3.7% error (3 out of 81) in predicting stress sensitivity for 2 load levels



Stress Sensitivity of a Three Layer Section
(North Bound Lane)
Layer Moduli (ksi)
350
300
250
200
150
100
50
0
0
5000
10000
15000
20000
FWD Load (lbf)
E1
E2
E3
y = 0.0046x + 226.99
R2 = 0.8254
y = 0.0019x + 45.312
R2 = 0.8462
y = -0.0005x + 21.312
R2 = 0.8443

Conclusion

- Network level FWD deflection testing can be conducted with only 3 points per mile
- Virginia's four-load level (6,000, 9,000, 12,000, and 16,000 lbf) test protocol can be changed to a one-load level protocol
- Stress-sensitivity calculations can be performed with only two load levels

Recommendations

- 5 points per mile
- 3 drop levels (min 2 drop levels)
- 2 deflection basins at each point
  - This recommendation will allow FWD data to be collected at a rate of about 37 to 40 miles per day
- Stress-sensitivity analysis is recommended to be performed with three load levels

Development of FWD Deflection and Structural Criteria

Both numerical and graphical representation of pavement structural quality

FWD & RWD Deflections (D0 in mils)

		<=	6	Very Good	5
>	6	to <=	8	Good	4
>	8	to <=	10	Average	3
>	10	to <=	12	Poor	2
>	12			Very poor	1

RWD Classification (D0) in mils)

		<=	8	Low	1
>	8	to <=	12	Moderate	2
>	12			High	3

VMS- Interstate Structural Number (corrected)

			<=	3.5	Very poor	1
>	3.5	to	<=	4.5	Poor	2
>	4.5	to	<=	5.5	Average	3
>	5.5	to	<=	6.0	Good	4
>	6.0				Very Good-Excellent	5

Subgrade CBR%

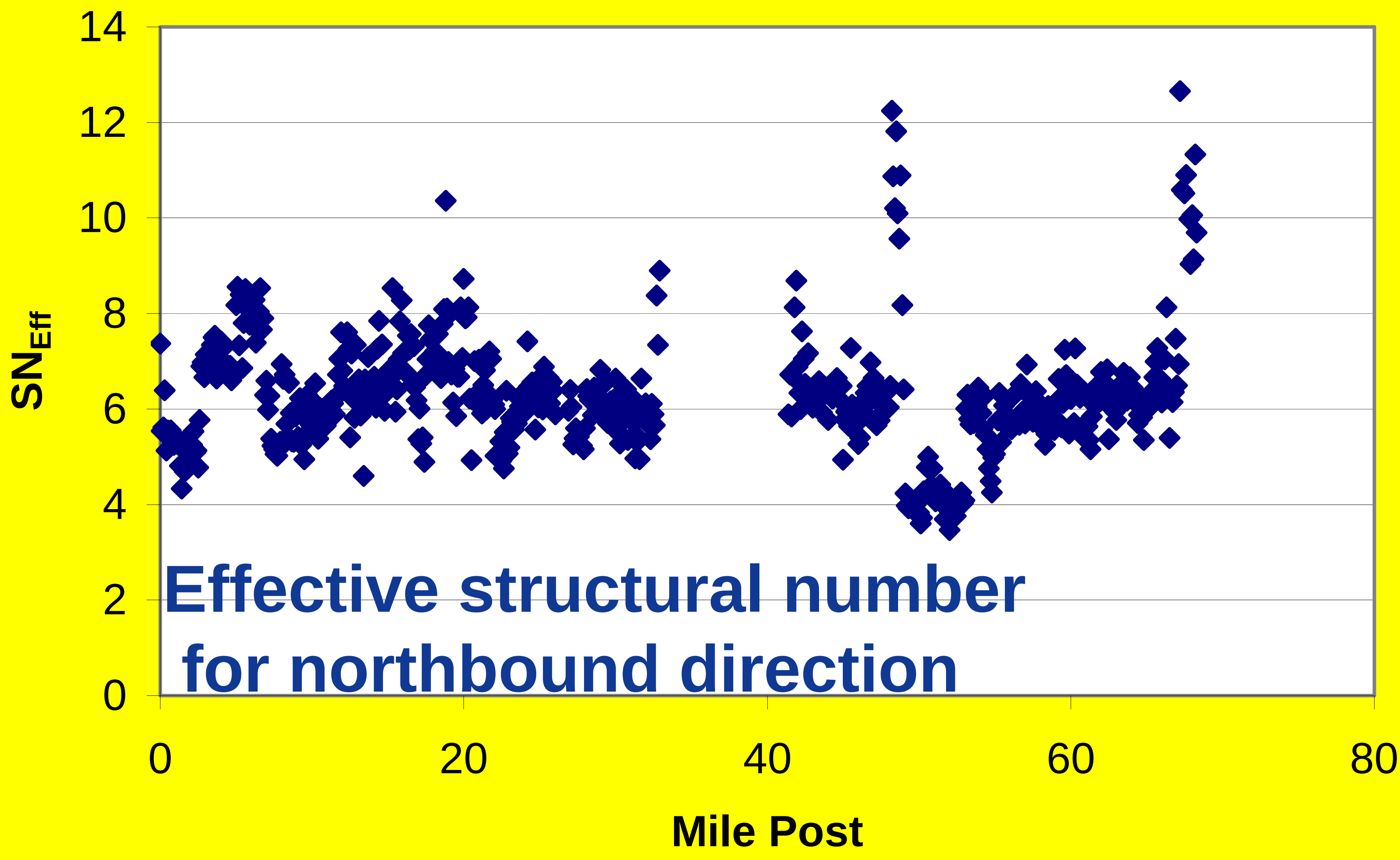
			<=	3	Very poor	1
>	3	to	<=	5	Poor	2
>	5	to	<=	7	Average	3
>	7	to	<=	9	Good	4
>	9				Very Good - Excellent	5

Subgrade MR (PSI)

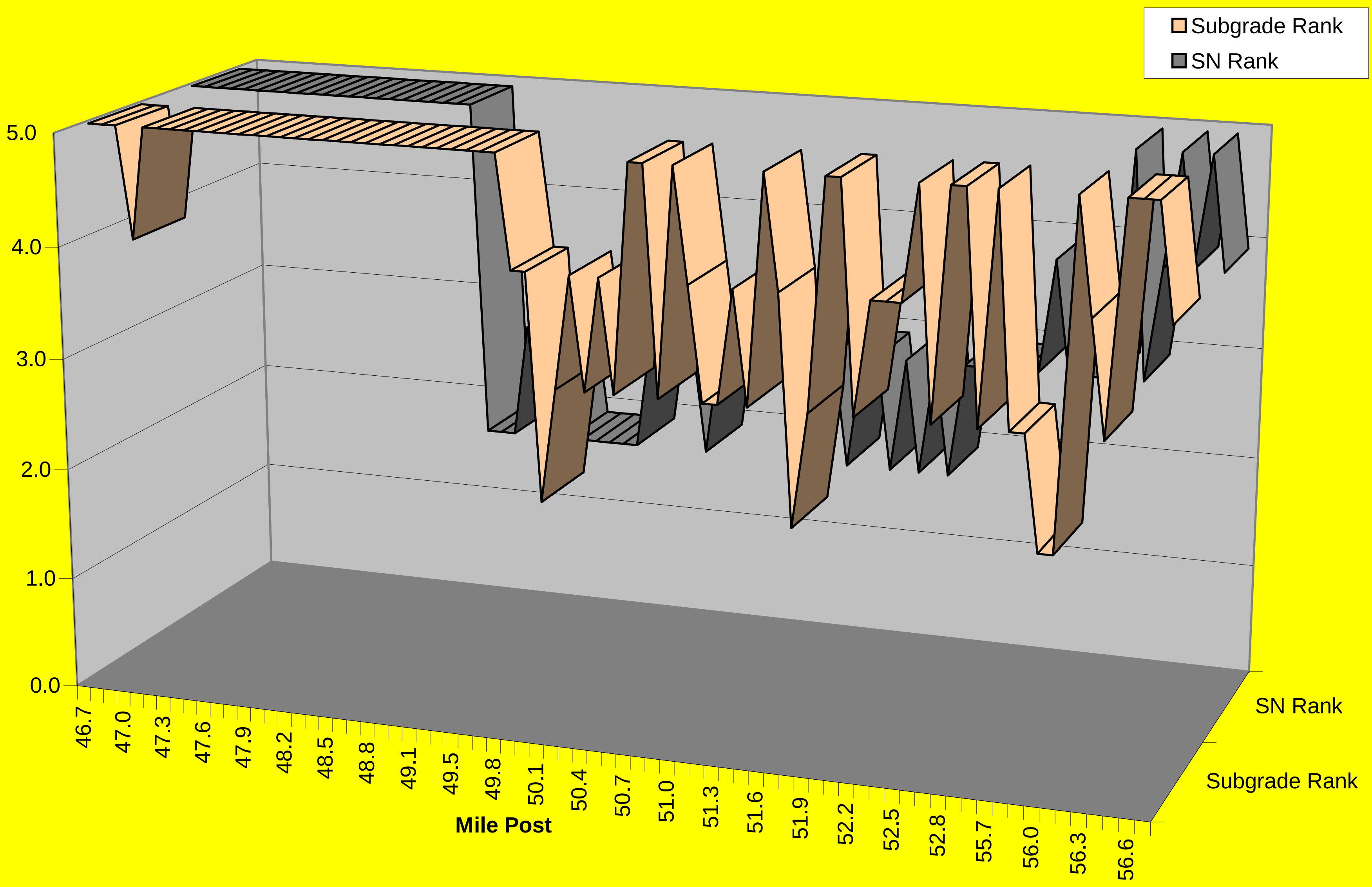
			<=	3000	Very poor	1
>	3000	to	<=	7500	Poor	2
>	7500	to	<=	10500	Average	3
>	10500	to	<=	13500	Good	4
>	13500				Very Good-Excellent	5

Application of structural criteria by:

- Road ID
- County ID
- County Mile Marker
- Road Mile Marker

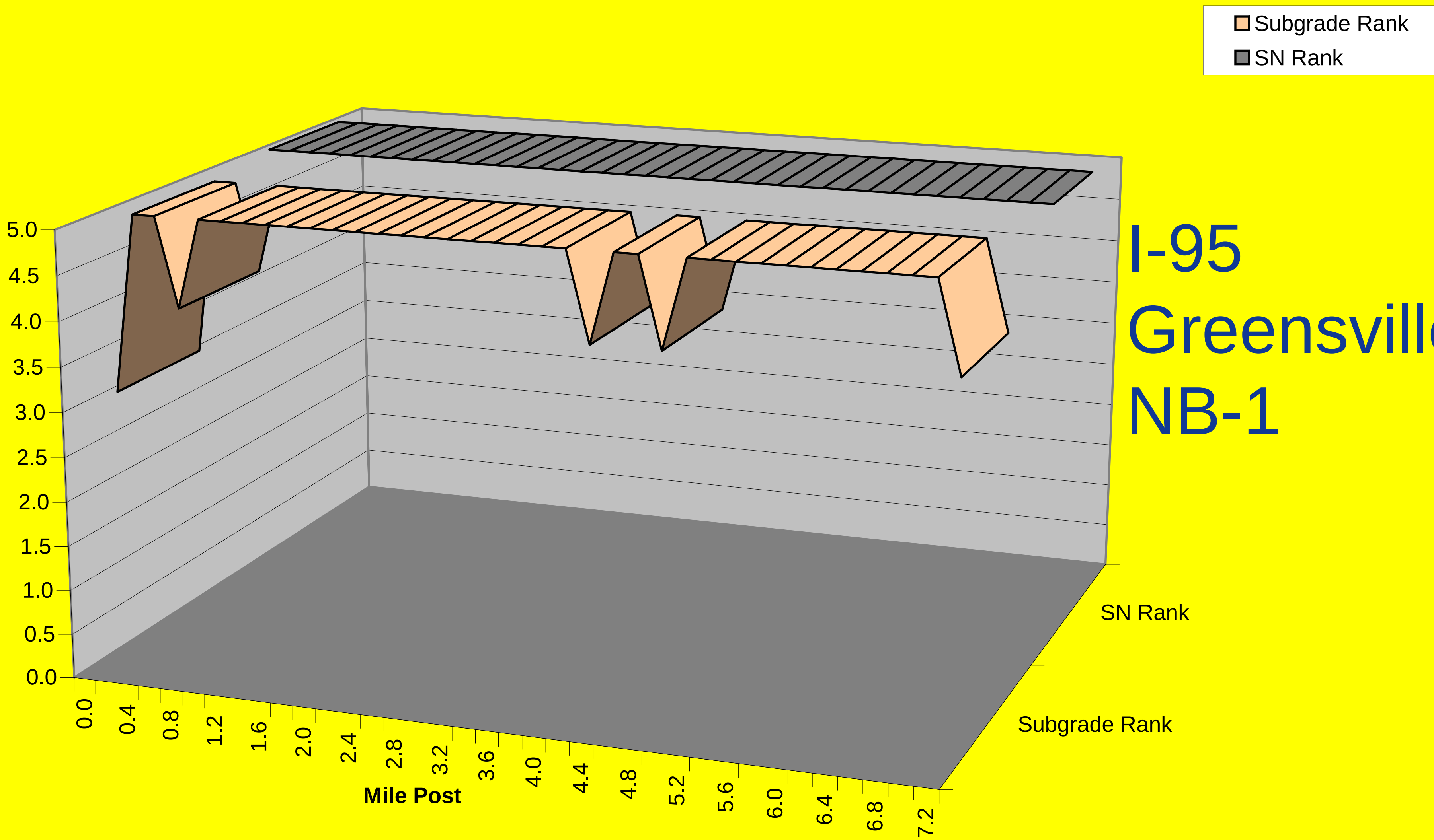


14
12
10
8
6
4
2
0
SN_{Eff}
0
20
40
60
80
Mile Post
Effective structural number
for northbound direction

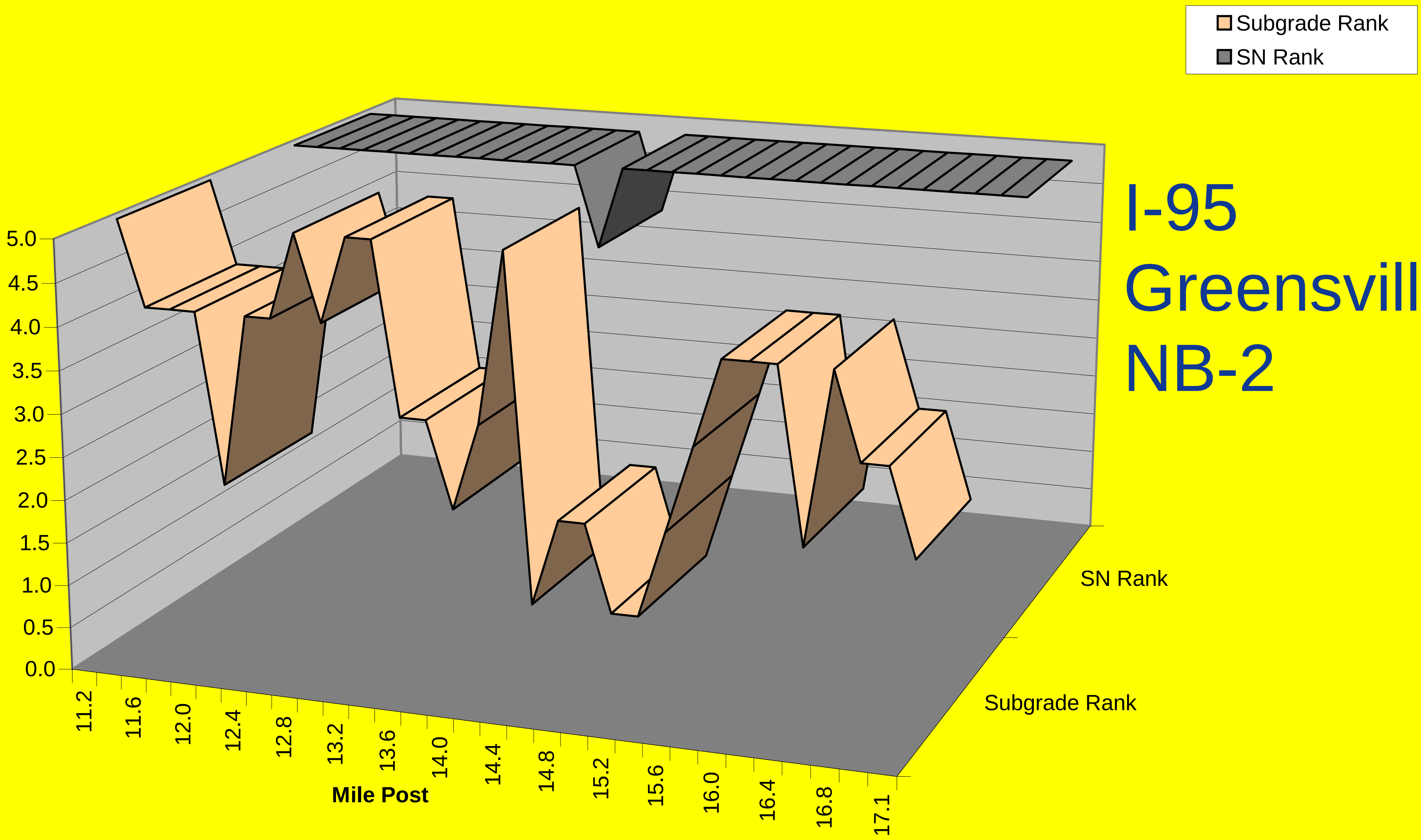


Subgrade Rank
SN Rank
5.0
4.0
3.0
2.0
1.0
0.0
46.7
47.0
47.3
47.6
47.9
48.2
48.5
48.8
49.1
49.5
49.8
50.1
50.4
50.7
51.0
51.3
51.6
51.9
52.2
52.5
52.8
55.7
56.0
56.3
56.6
Mile Post
SN Rank
Subgrade Rank

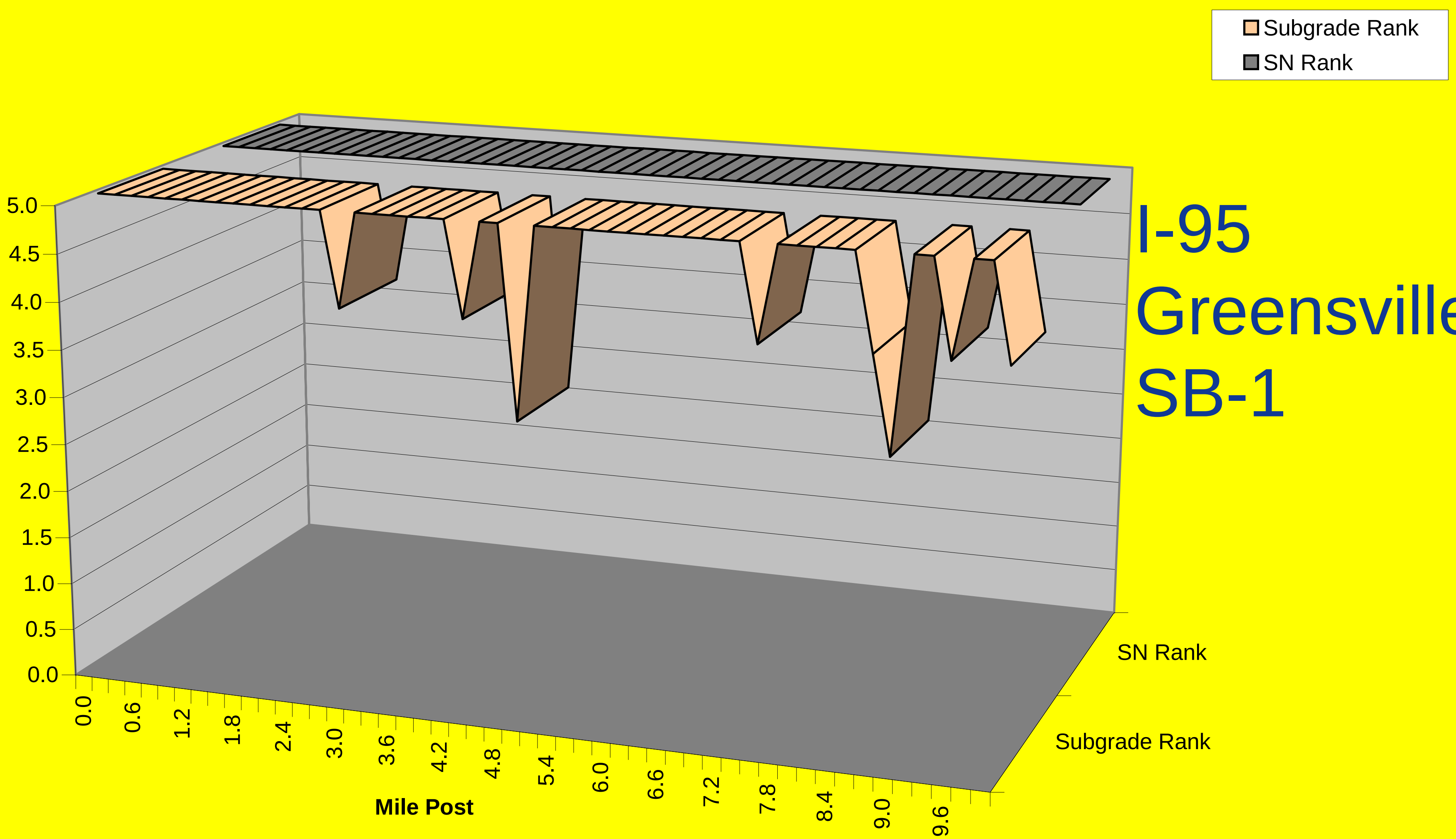
I-95 Greensville NB-1



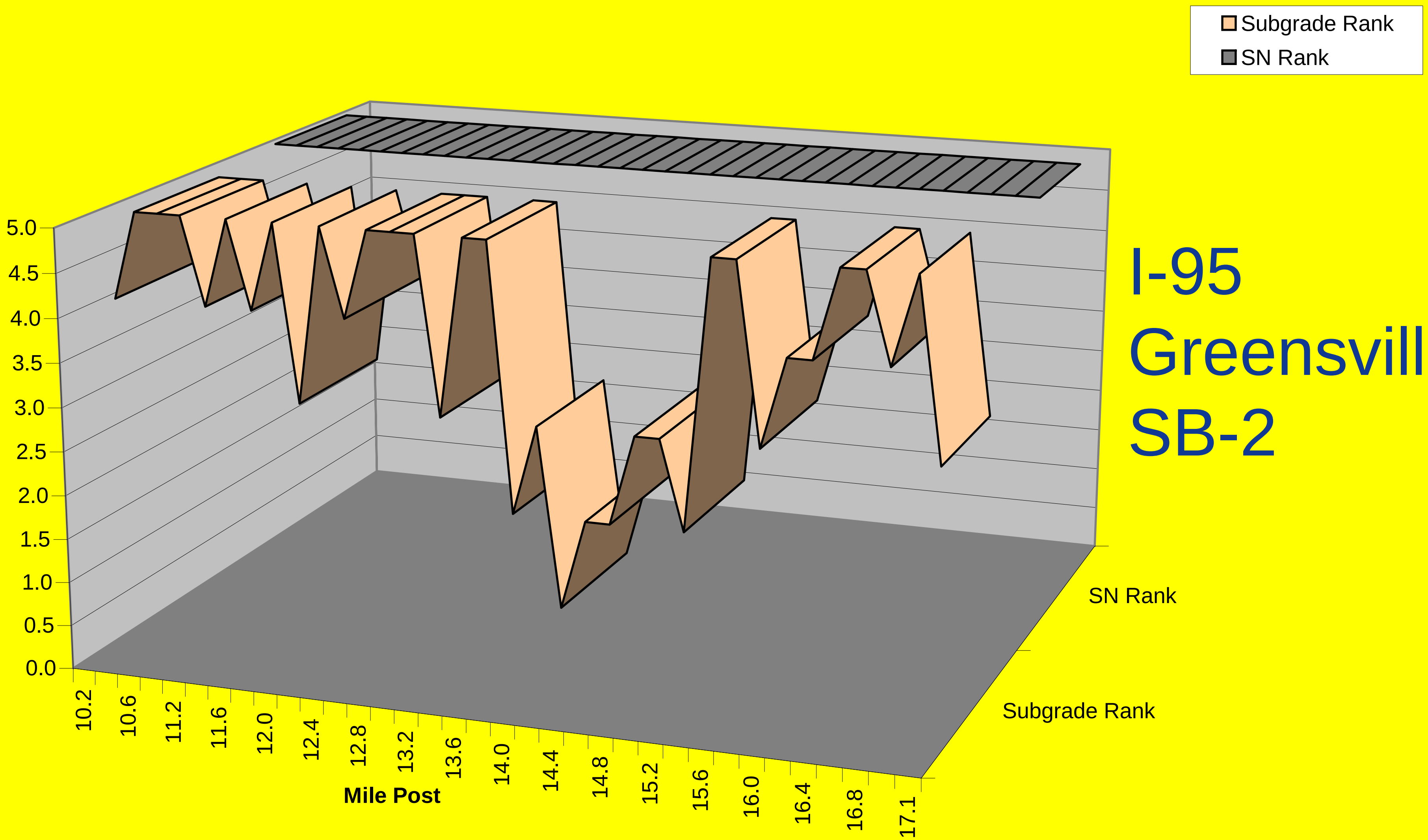
I-95 Greensville NB-2



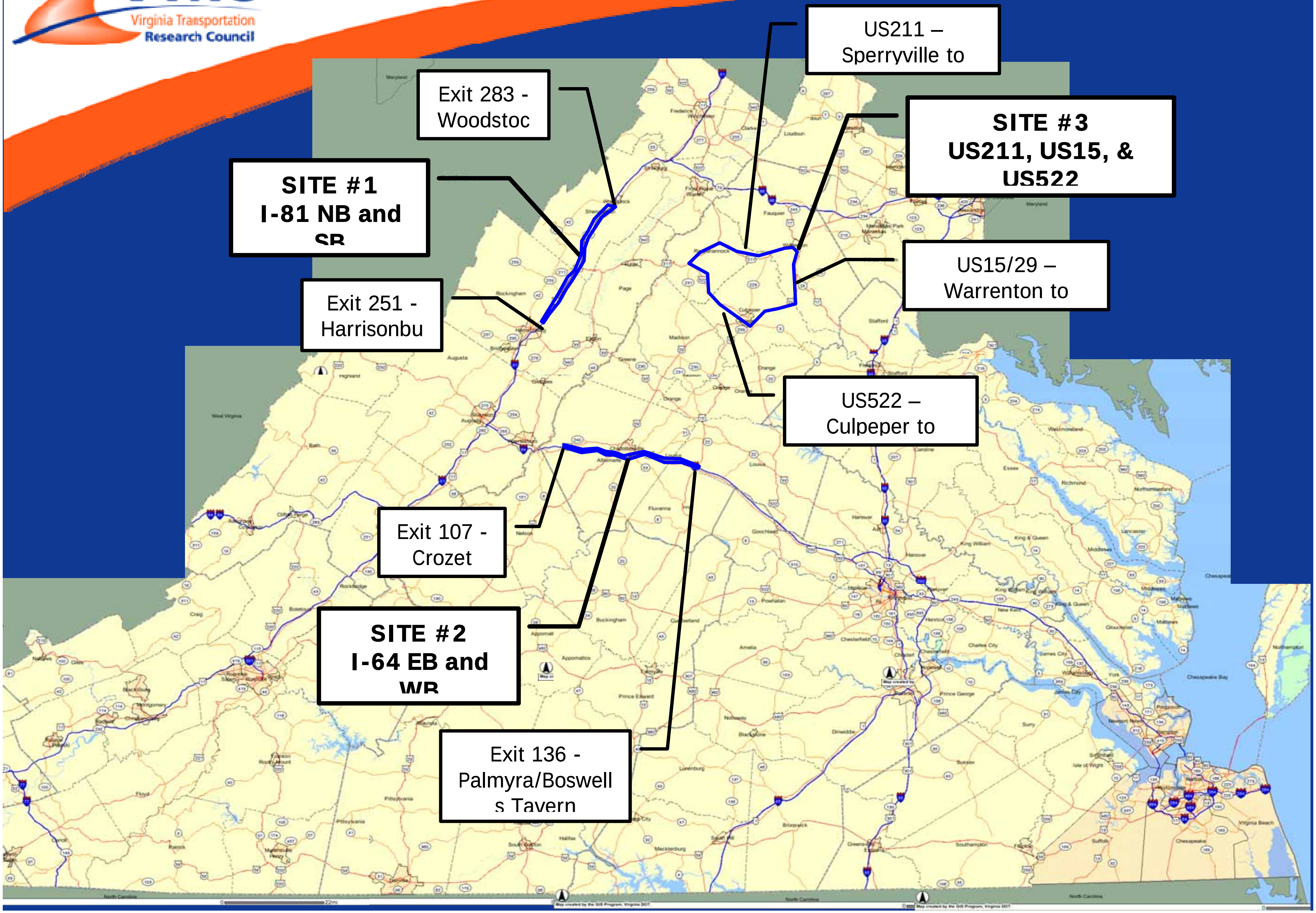
I-95 Greensville SB-1



I-95 Greensville SB-2



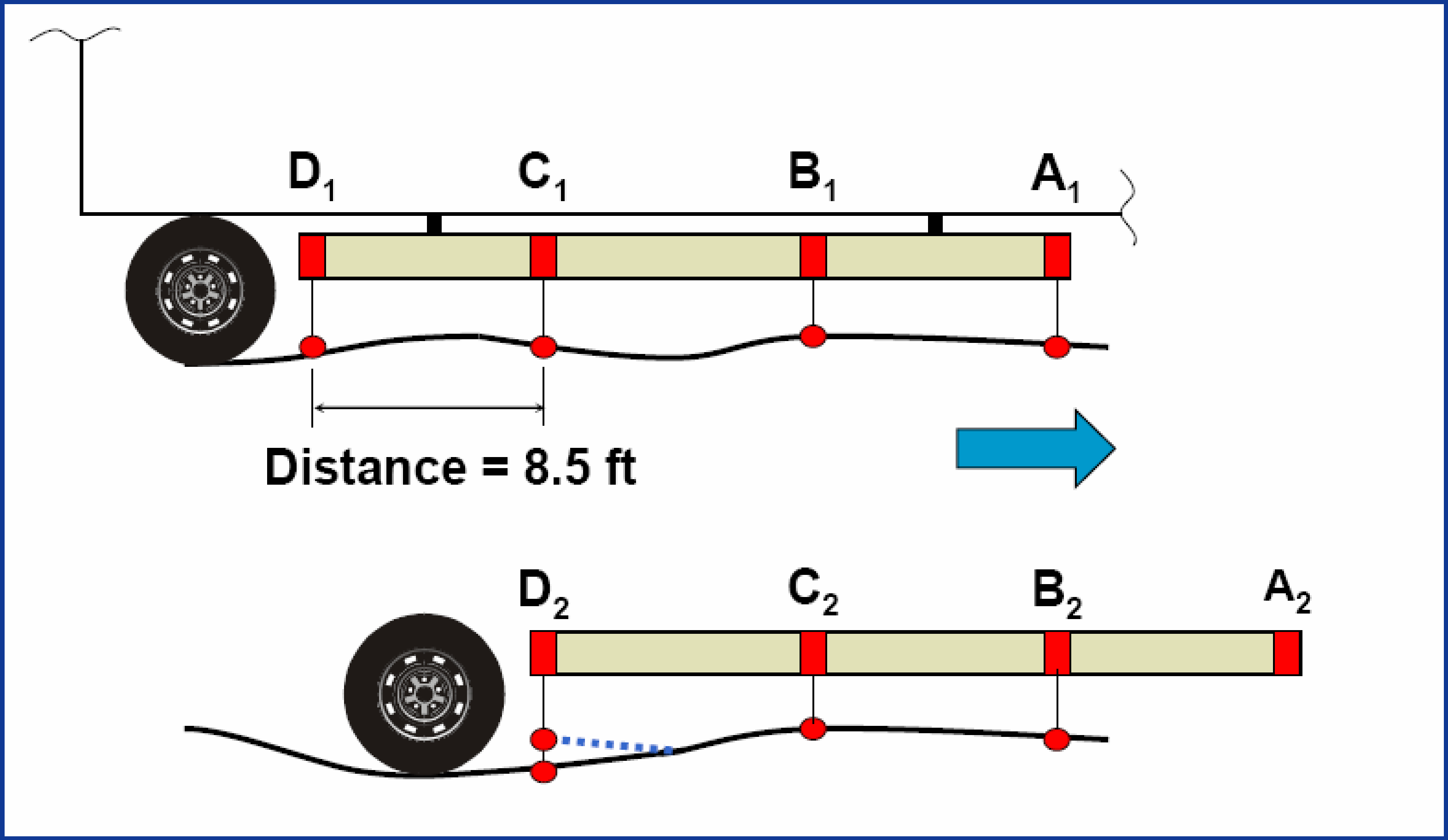
RWD Testing

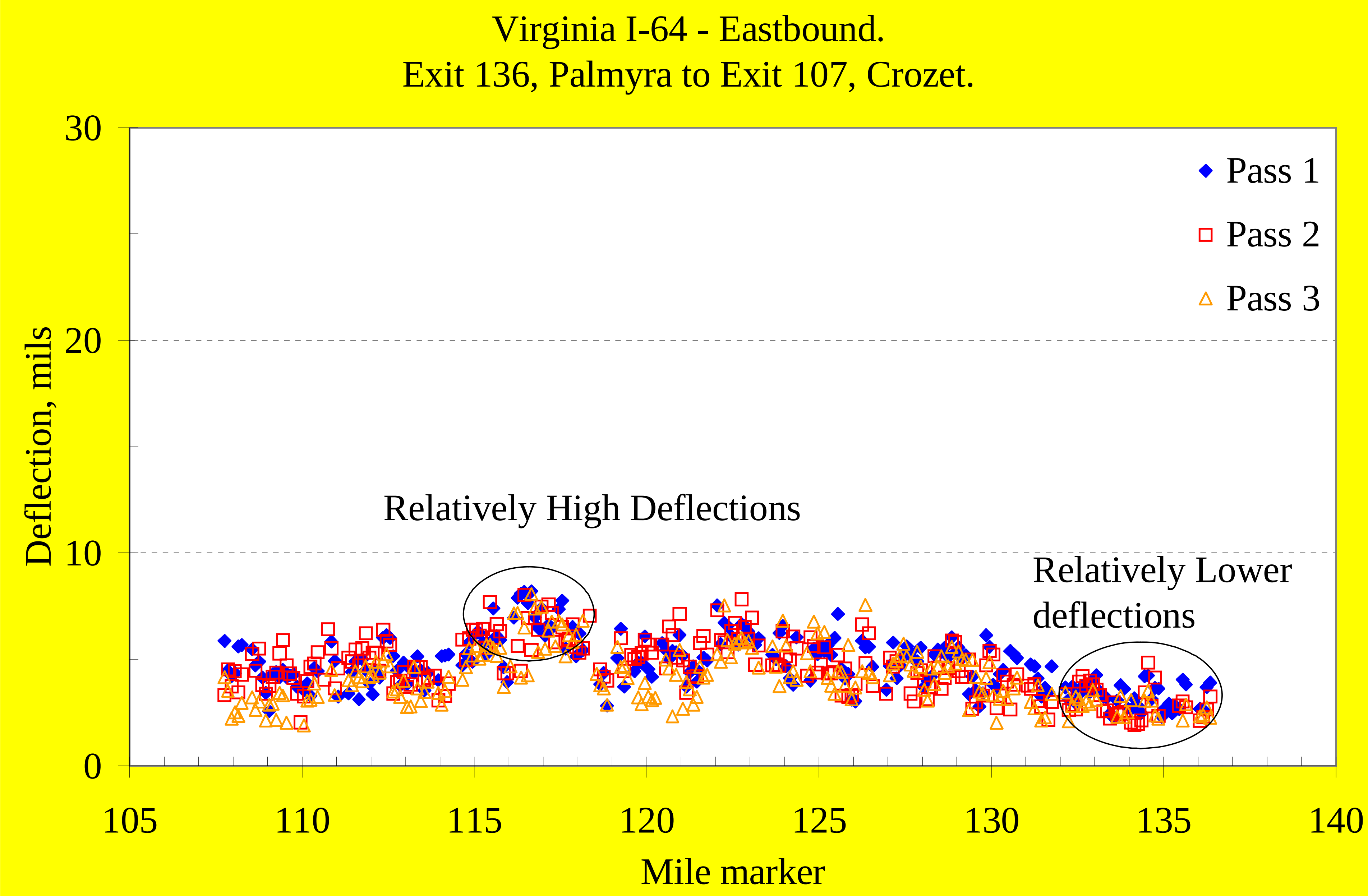


Exit 283 -
Woodstoc
SITE #1
I-81 NB and
Exit 251 -
Harrisonbu
US211 –
Sperryville to
SITE #3
US211, US15, &
US522
US15/29 –
Warrenton to
US522 –
Culpeper to
Exit 107 -
Crozet
SITE #2
I-64 EB and
Exit 136 -
Palmyra/Boswell
s Tavern

RWD – Deflection measurements laser system

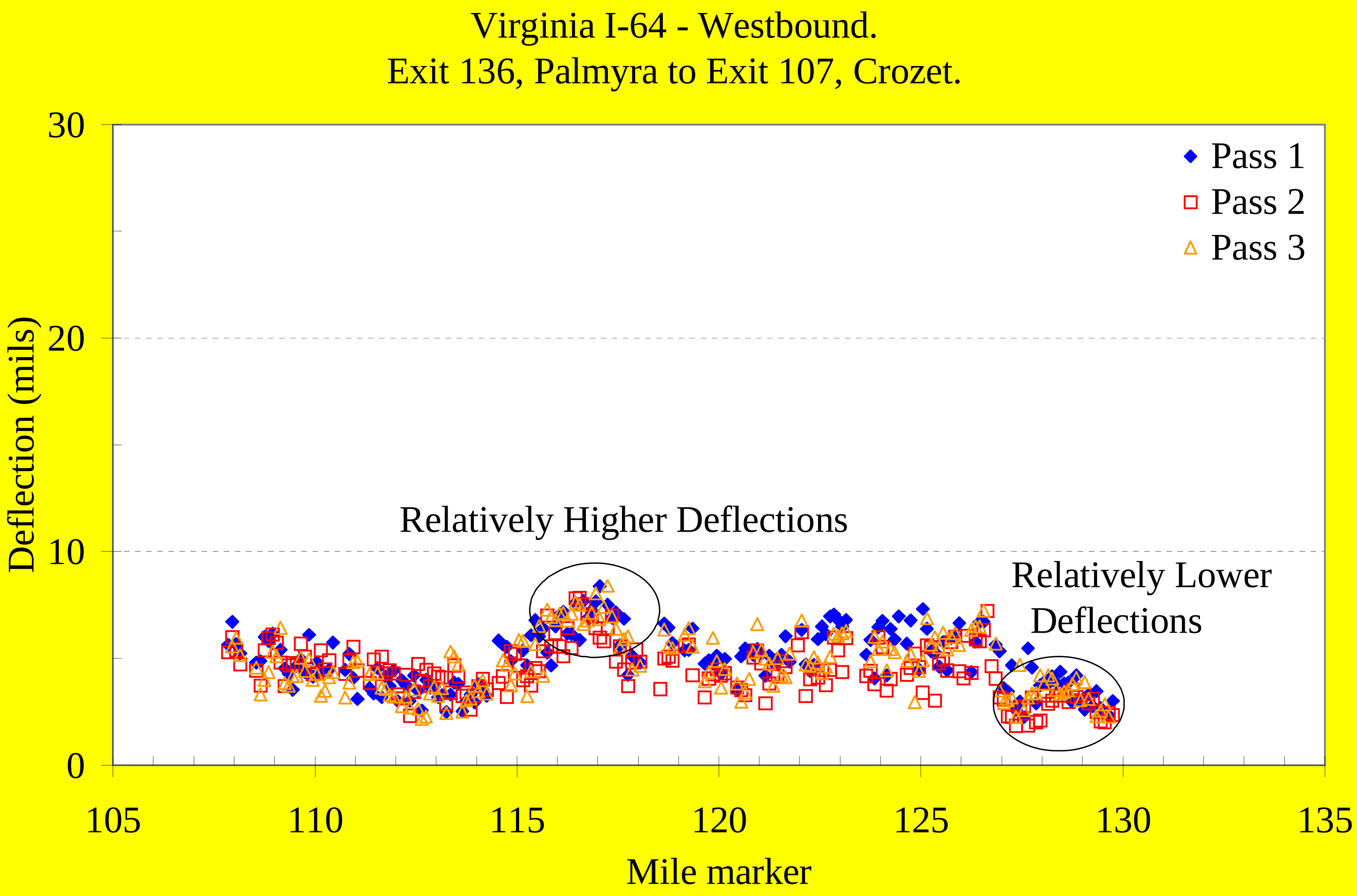
RWD testing



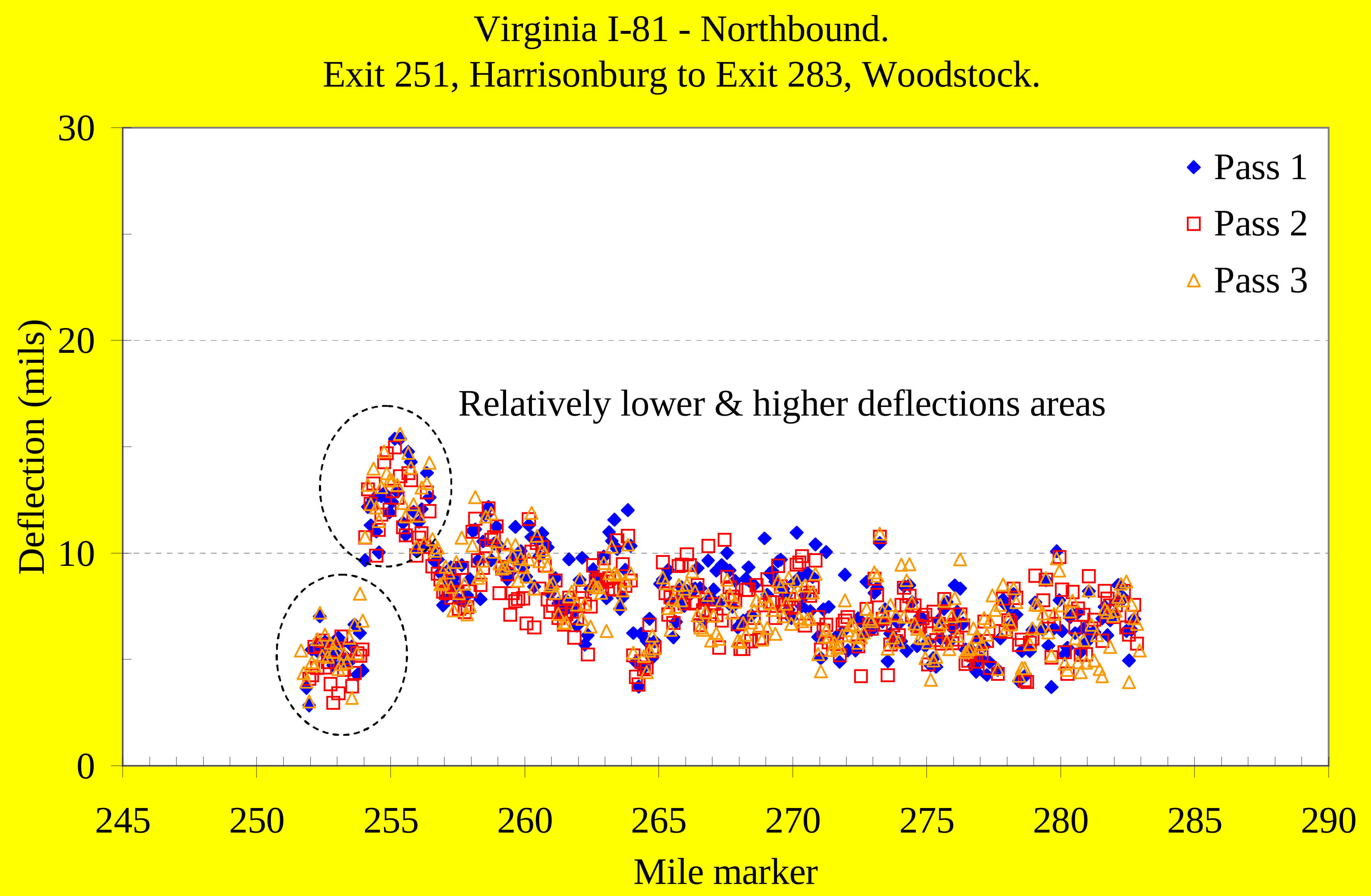


Virginia I-64 - Eastbound.
Exit 136, Palmyra to Exit 107, Crozet.
Deflection, mils
Mile marker
Pass 1
Pass 2
Pass 3
Relatively High Deflections
Relatively Lower deflections
0
10
20
30
105
110
115
120
125
130
135
140

	Total global distance by Milepost	Number of averages	Average deflection mils	Std. Dev. of mils	Average speed mph	Std. Dev. of speed mph	Average temperatur deg F	Std. Dev.of temperatur deg F
Run 1	avg	60797	4.76	44.28	59.17	2.37	78.21	2.58
	std	4884	1.26	13.39	4.19	0.46	5.29	1.17
	cov	8%	26%	30%	7%	19%	7%	45%
	max	84247	8.20	89.11	67.40	3.80	86.50	6.50
	min	53156	2.25	29.10	42.10	1.20	69.40	1.20
Run 2	avg	63540	4.62	45.13	56.54	2.19	86.00	4.19
	std	4898	1.33	13.67	3.77	0.41	7.78	2.10
	cov	8%	29%	30%	7%	19%	9%	50%
	max	88184	8.03	91.68	67.10	3.60	97.70	10.00
	min	53599	1.93	28.81	40.60	1.10	72.20	1.20
Run 3	avg	62863	4.21	45.40	57.27	2.27	92.24	5.38
	std	5482	1.31	13.67	4.20	0.50	8.58	2.41
	cov	9%	31%	30%	7%	22%	9%	45%
	max	86599	8.07	87.23	69.20	4.70	106.60	12.50
	min	52223	1.89	29.33	40.90	1.20	74.90	1.40
Avg	avg	62247	4.50	45.07	57.77	2.28	85.24	4.01
	std	4692	1.18	13.52	3.73	0.34	6.89	1.72
	cov	8%	26%	30%	6%	15%	8%	43%
	max	86343	7.57	91.68	67.90	3.60	101.50	10.90
	min	52993	2.30	29.39	41.20	1.17	71.45	1.47

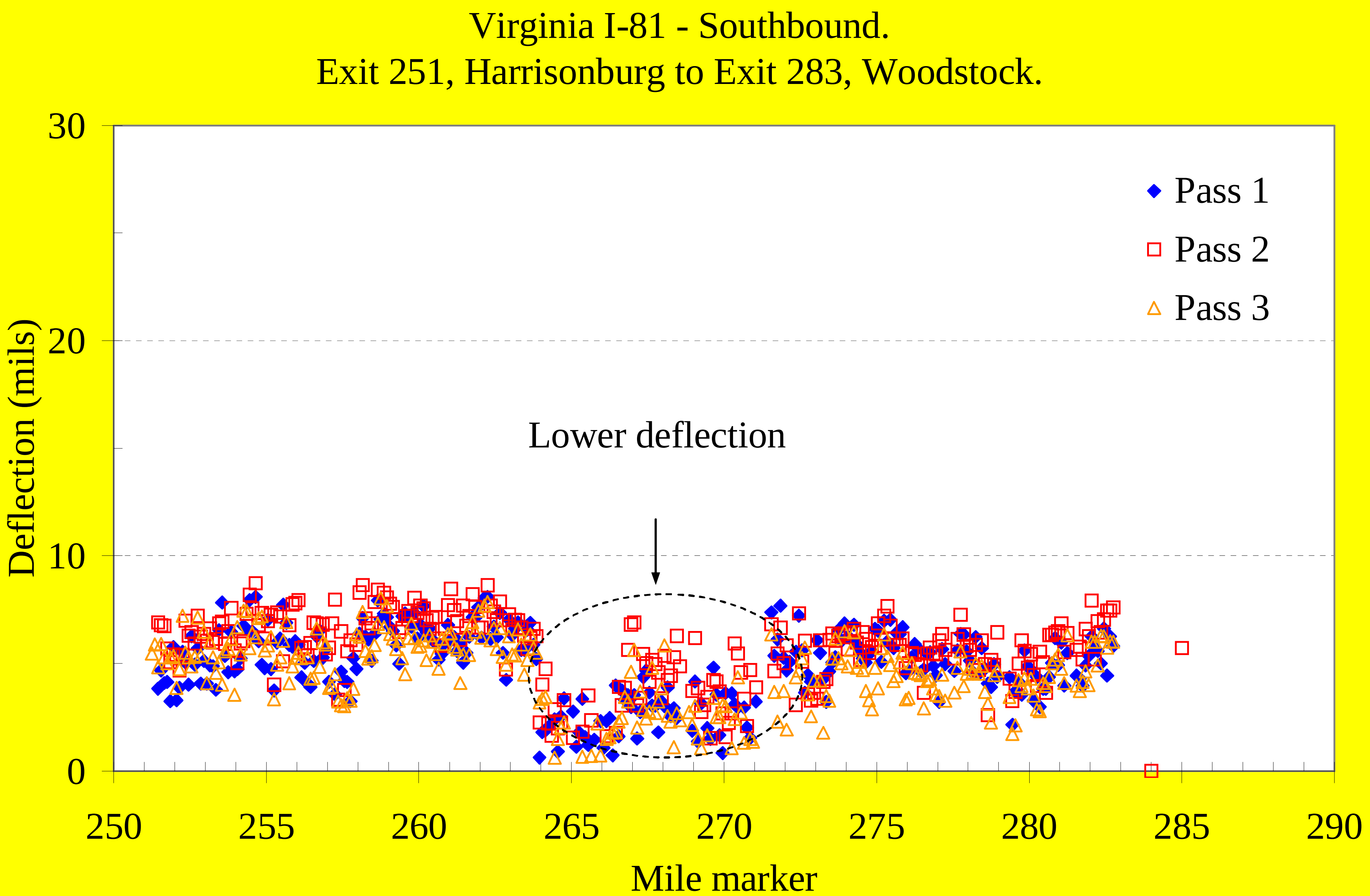


Virginia I-64 - Westbound.
Exit 136, Palmyra to Exit 107, Crozet.
Deflection (mils)
30
20
10
0
105
110
115
120
125
130
135
Mile marker
Pass 1
Pass 2
Pass 3
Relatively Higher Deflections
Relatively Lower Deflections



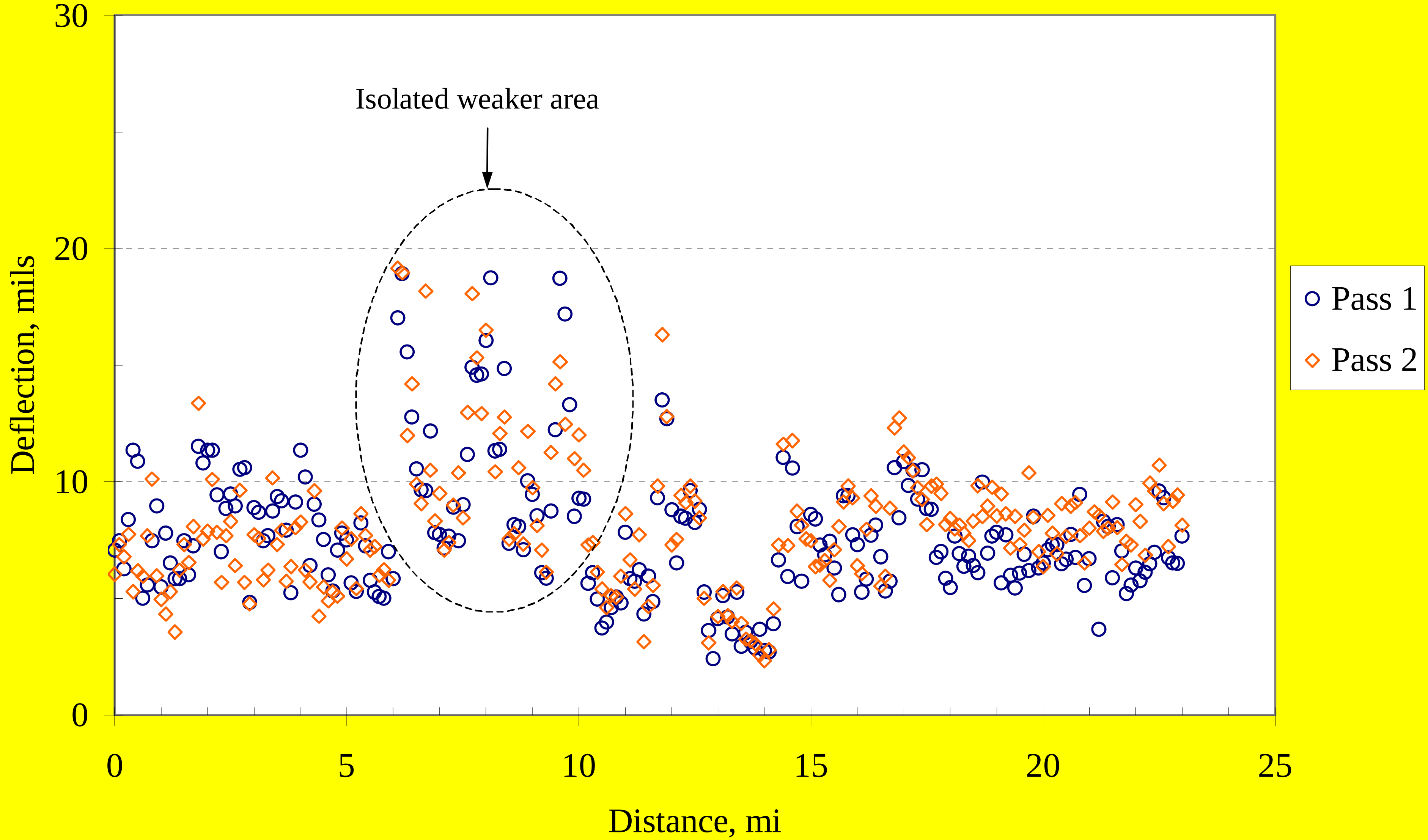
Virginia I-81 - Northbound.
Exit 251, Harrisonburg to Exit 283, Woodstock.
Deflection (mils)
0
10
20
30
Mile marker
245
250
255
260
265
270
275
280
285
290
Pass 1
Pass 2
Pass 3
Relatively lower & higher deflections areas

	Total global distance by Milepost	Number of averages	Average deflection mils	Std. Dev. of deflection mils	Average speed mph	Std. Dev. of speed mph	Average temperature deg F	Std. Dev.of temperature deg F
Run 1	avg	60699	7.93	51.03	58.98	2.26	75.01	1.54
	stdev	1721	2.27	14.51	1.65	0.39	1.15	0.12
	cov	3%	29%	28%	3%	17%	2%	8%
	max	67189	15.38	89.77	64.80	4.30	78.40	1.90
	min	53296	2.83	29.61	53.20	1.80	71.90	1.30
Run 2	avg	59067	7.68	51.51	60.58	2.41	87.76	1.73
	stdev	2217	2.20	14.74	2.13	0.41	3.12	0.68
	cov	4%	29%	29%	4%	17%	4%	39%
	max	65771	14.98	88.36	65.40	3.80	93.80	4.40
	min	47193	2.97	29.57	54.70	1.90	78.20	1.10
Run 3	avg	58398	7.71	50.75	61.21	2.49	97.95	1.73
	stdev	2685	2.29	13.52	2.68	0.41	2.84	0.83
	cov	5%	30%	27%	4%	16%	3%	48%
	max	68265	15.61	89.19	66.80	4.40	103.20	7.00
	min	50800	3.02	29.14	52.60	1.80	87.00	1.10
Avg	avg	59402	7.71	51.13	60.20	2.38	87.20	1.70
	stdev	1810	2.17	13.93	1.80	0.25	3.29	0.54
	cov	3%	28%	27%	3%	11%	4%	32%
	max	66511	15.17	85.19	64.70	3.27	101.10	4.40
	min	50245	3.31	30.08	54.10	1.85	75.30	1.25

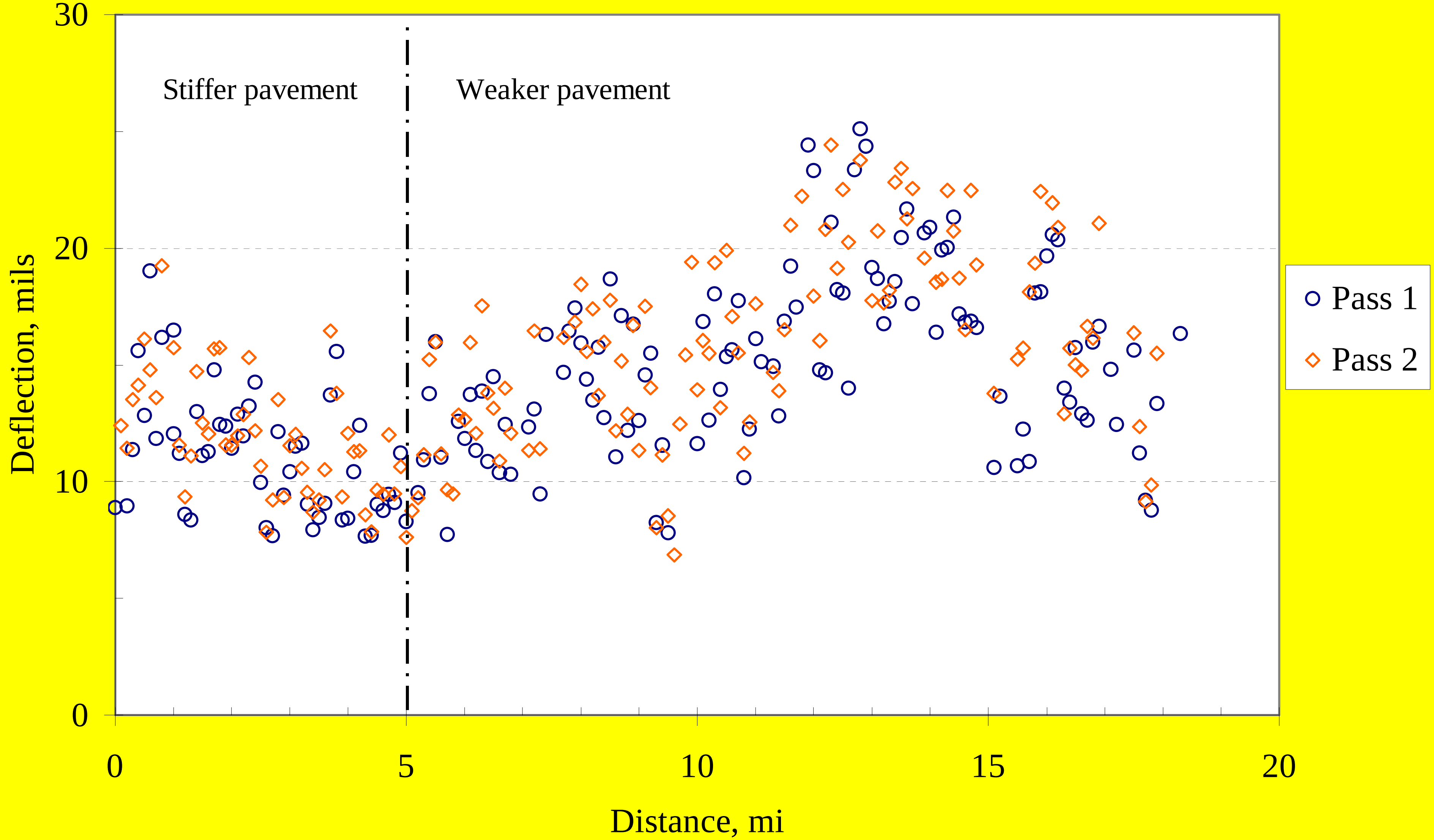


Virginia I-81 - Southbound.
Exit 251, Harrisonburg to Exit 283, Woodstock.
Deflection (mils)
30
20
10
0
250
255
260
265
270
275
280
285
290
Mile marker
Pass 1
Pass 2
Pass 3
Lower deflection

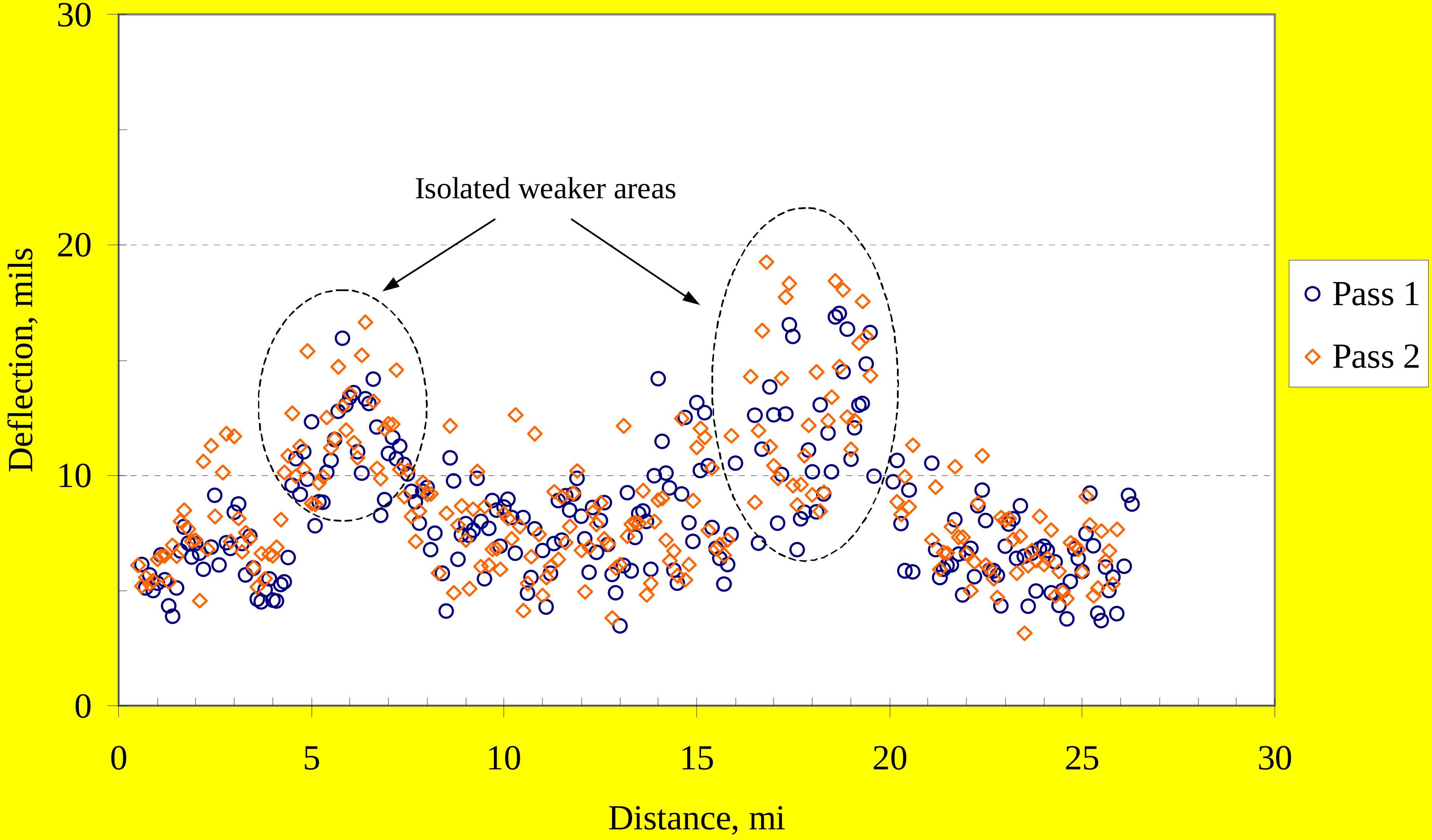
U.S. 15/29, Warrenton to Culpeper southbound



U.S. 522, Culpeper to Sperryville northbound

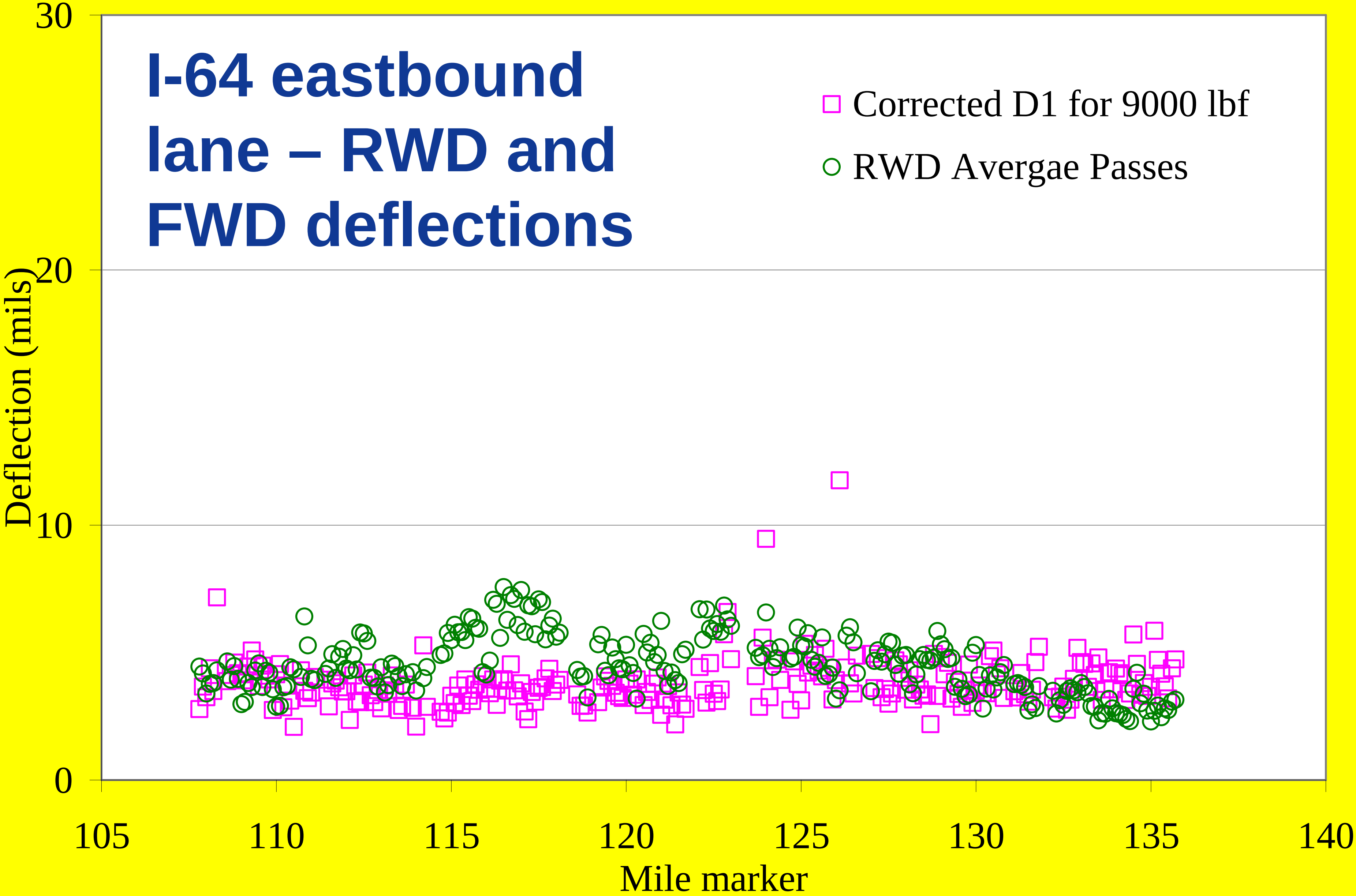


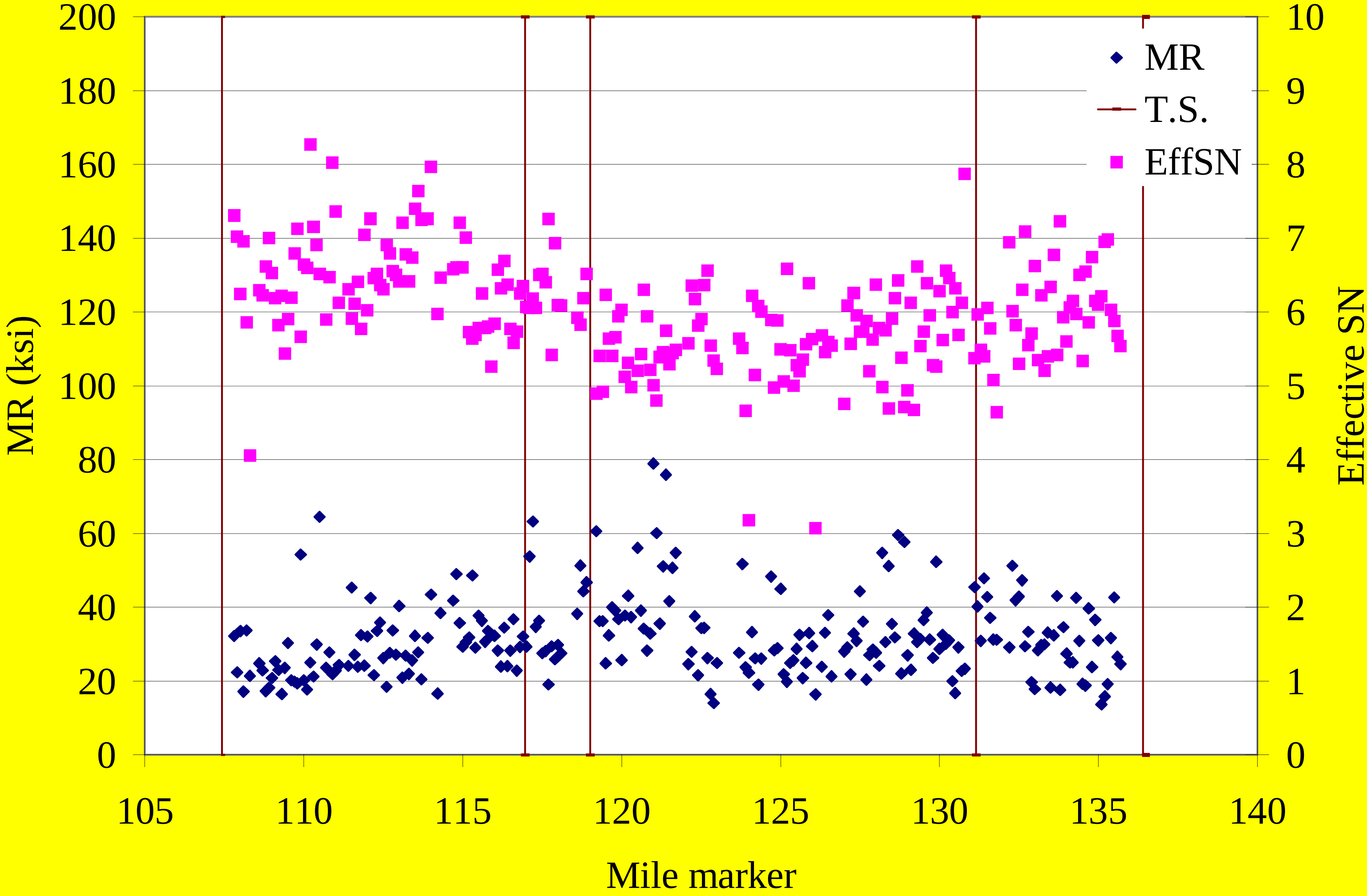
U.S. 211, Sperryville to Warrenton eastbound



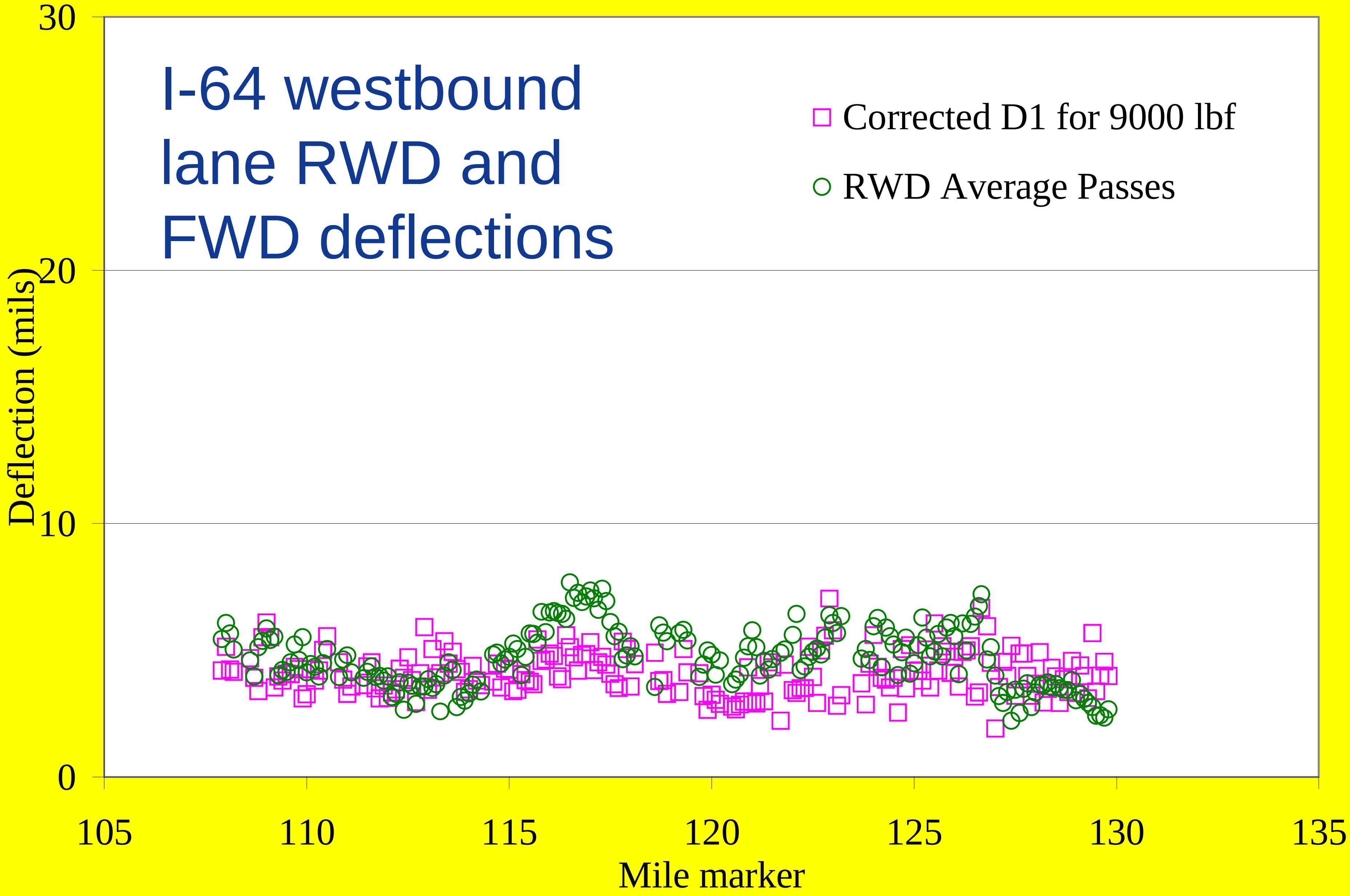
Comparisons between RWD & FWD

I-64 eastbound lane – RWD and FWD deflections

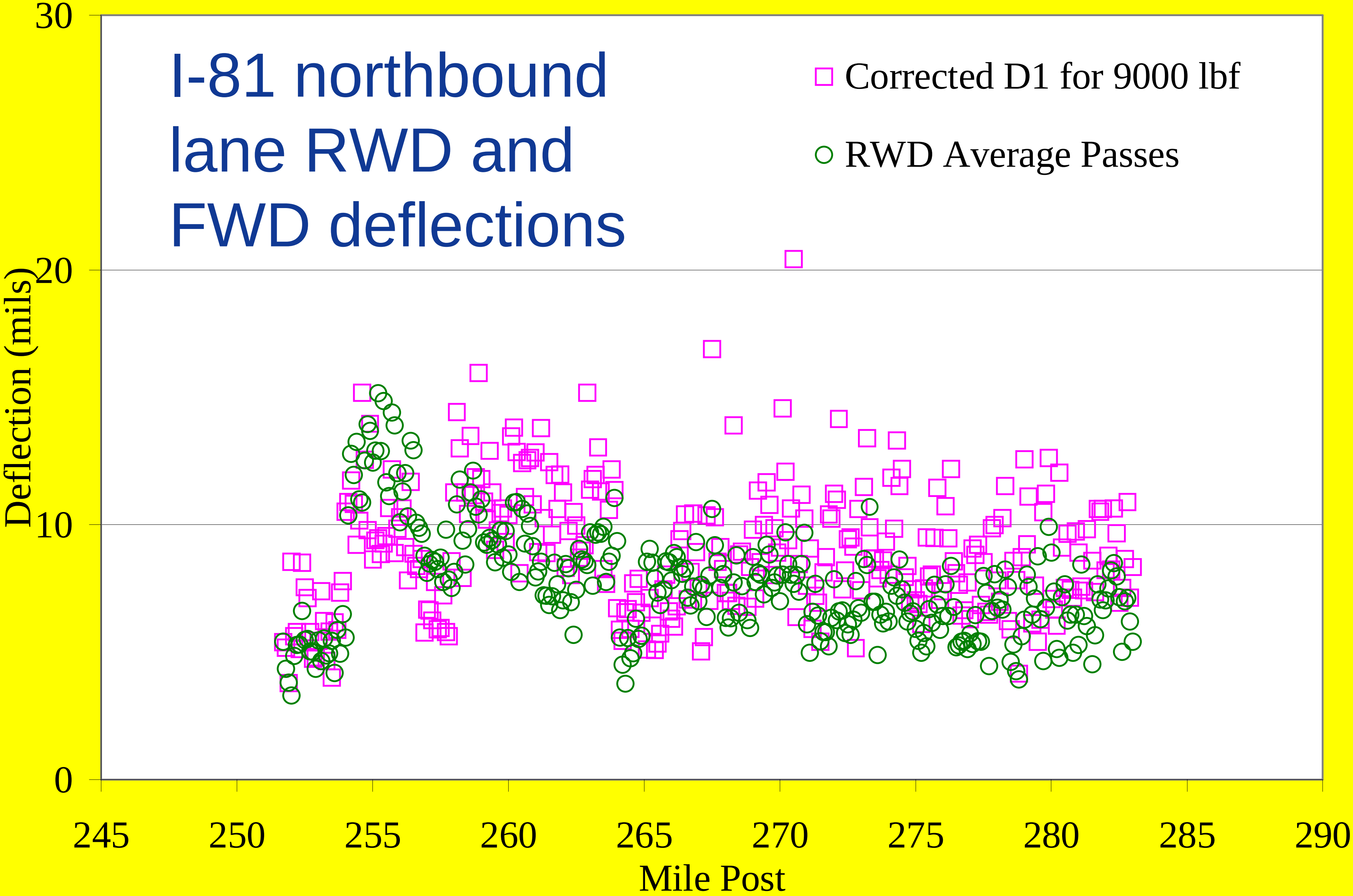


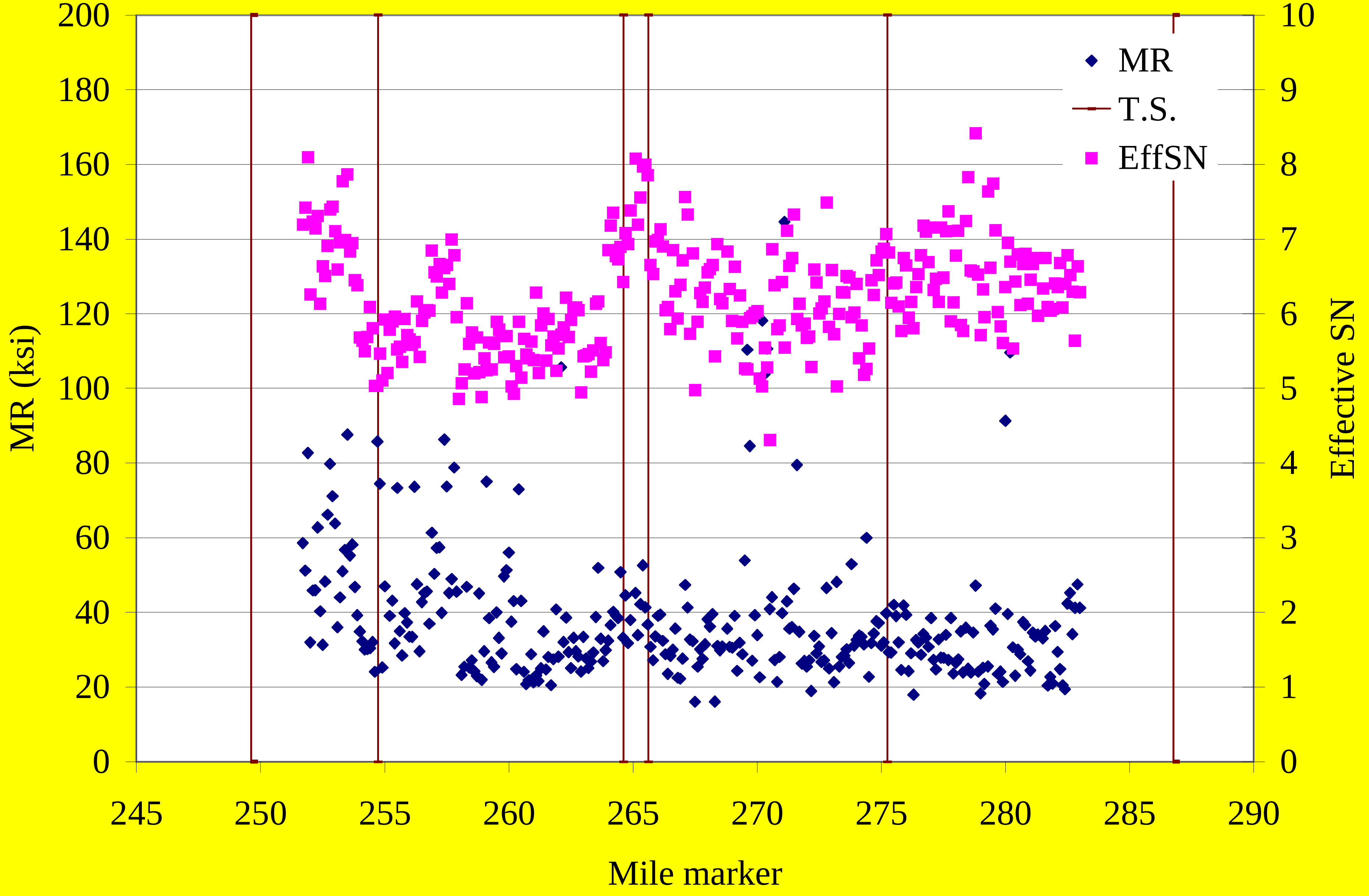


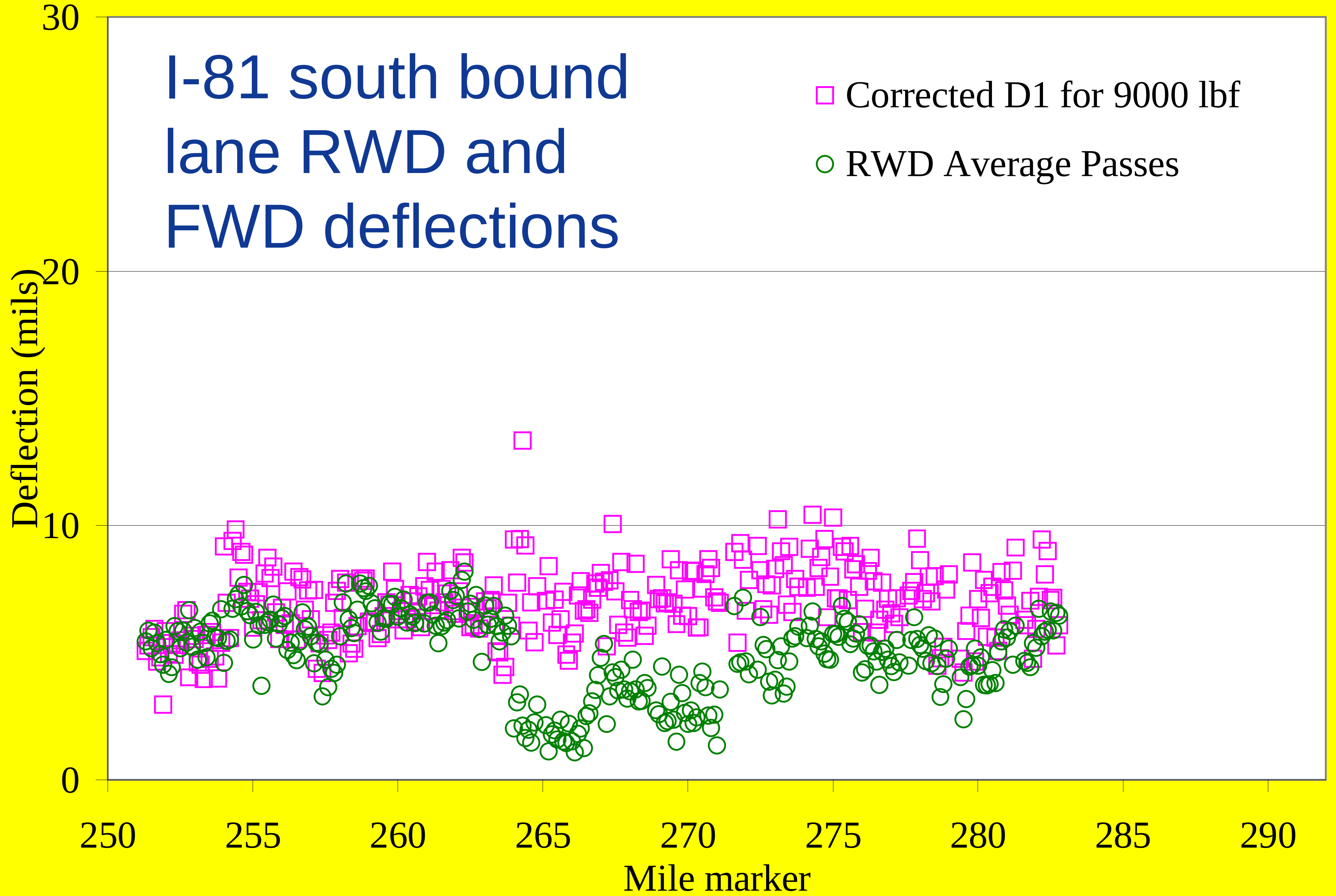
MR
T.S.
EffSN
MR (ksi)
Effective SN
Mile marker
200
180
160
140
120
100
80
60
40
20
0
10
9
8
7
6
5
4
3
2
1
0
105
110
115
120
125
130
135
140


I-64 westbound lane RWD and FWD deflections
Corrected D1 for 9000 lbf
RWD Average Passes
Deflection (mils)
0
10
20
30
105
110
115
120
125
130
135
Mile marker

I-81 northbound lane RWD and FWD deflections

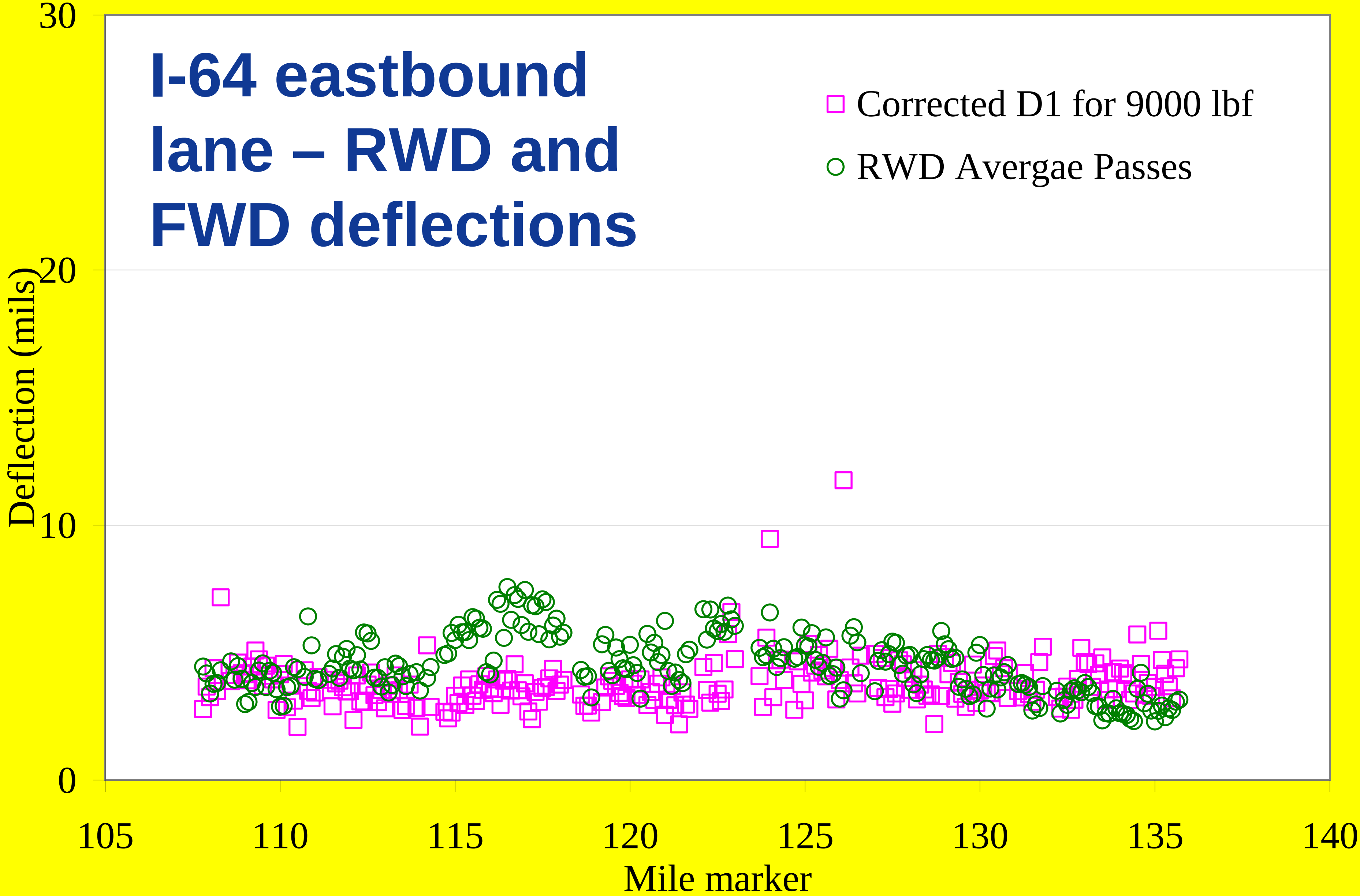



MR (ksi)
Effective SN
Mile marker
MR
T.S.
EffSN
0
20
40
60
80
100
120
140
160
180
200
0
1
2
3
4
5
6
7
8
9
10
245
250
255
260
265
270
275
280
285
290

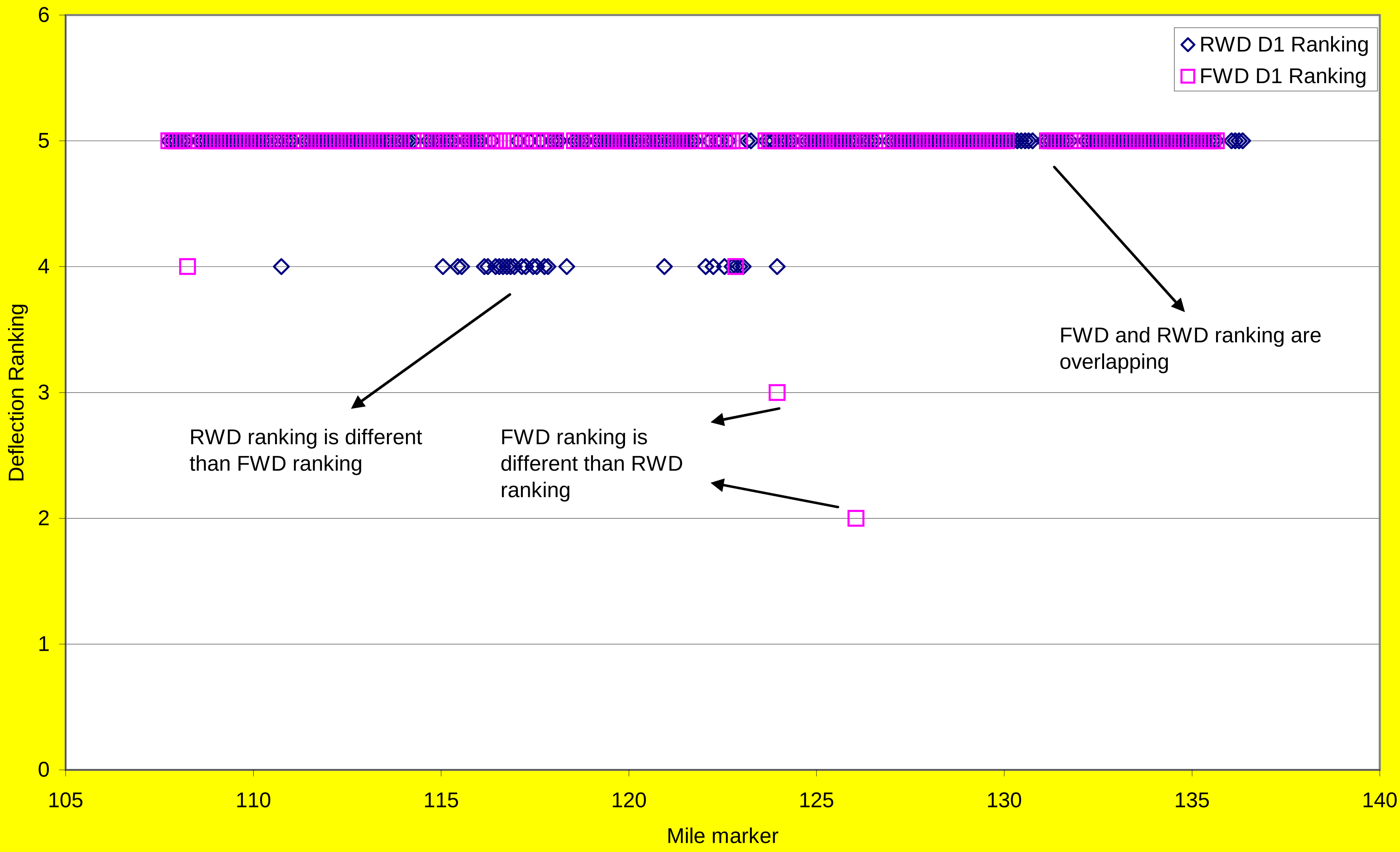


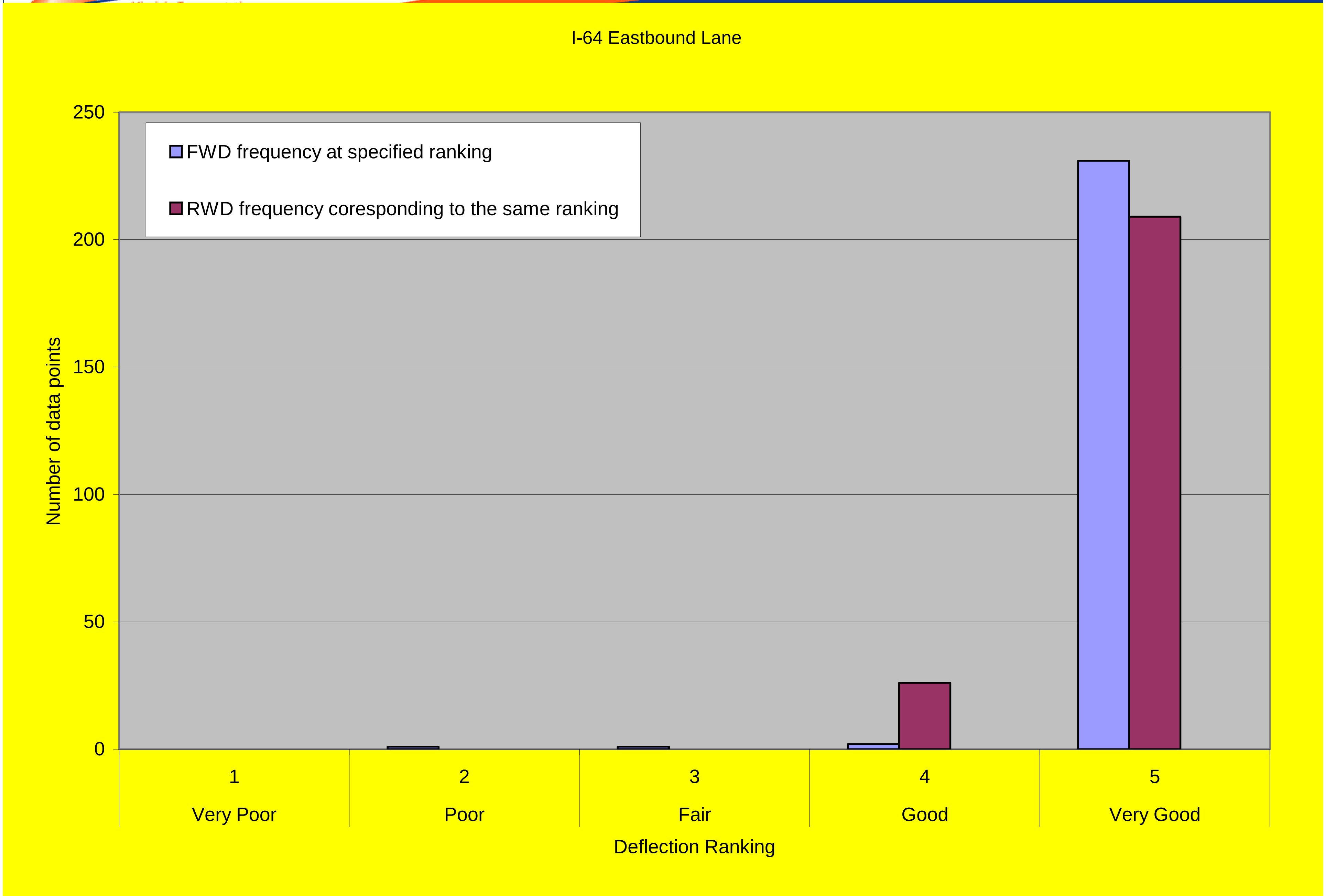
I-81 south bound lane RWD and FWD deflections
Corrected D1 for 9000 lbf
RWD Average Passes
Deflection (mils)
0
10
20
30
250
255
260
265
270
275
280
285
290
Mile marker

I-64 eastbound lane – RWD and FWD deflections



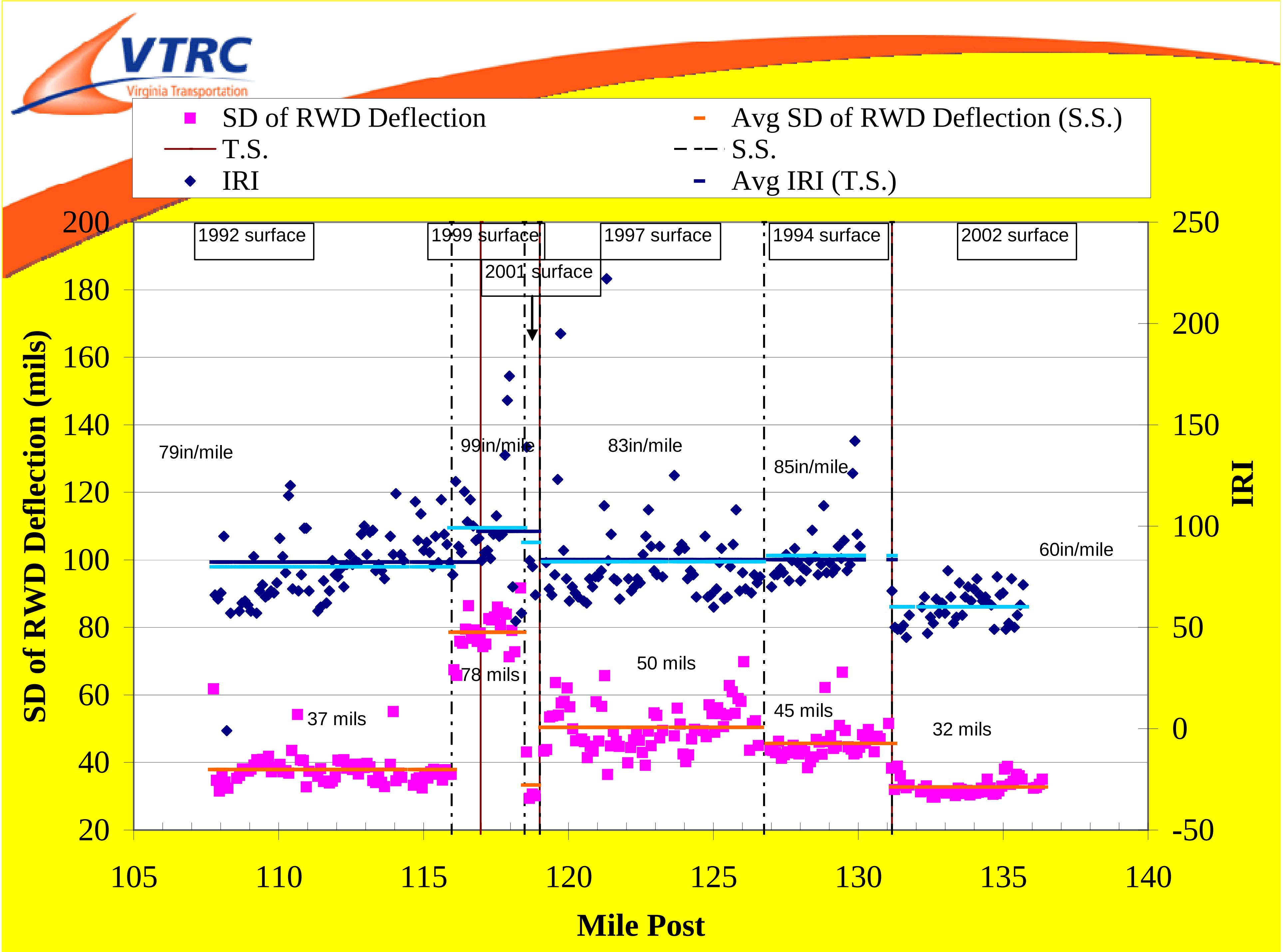
I-64 Eastbound

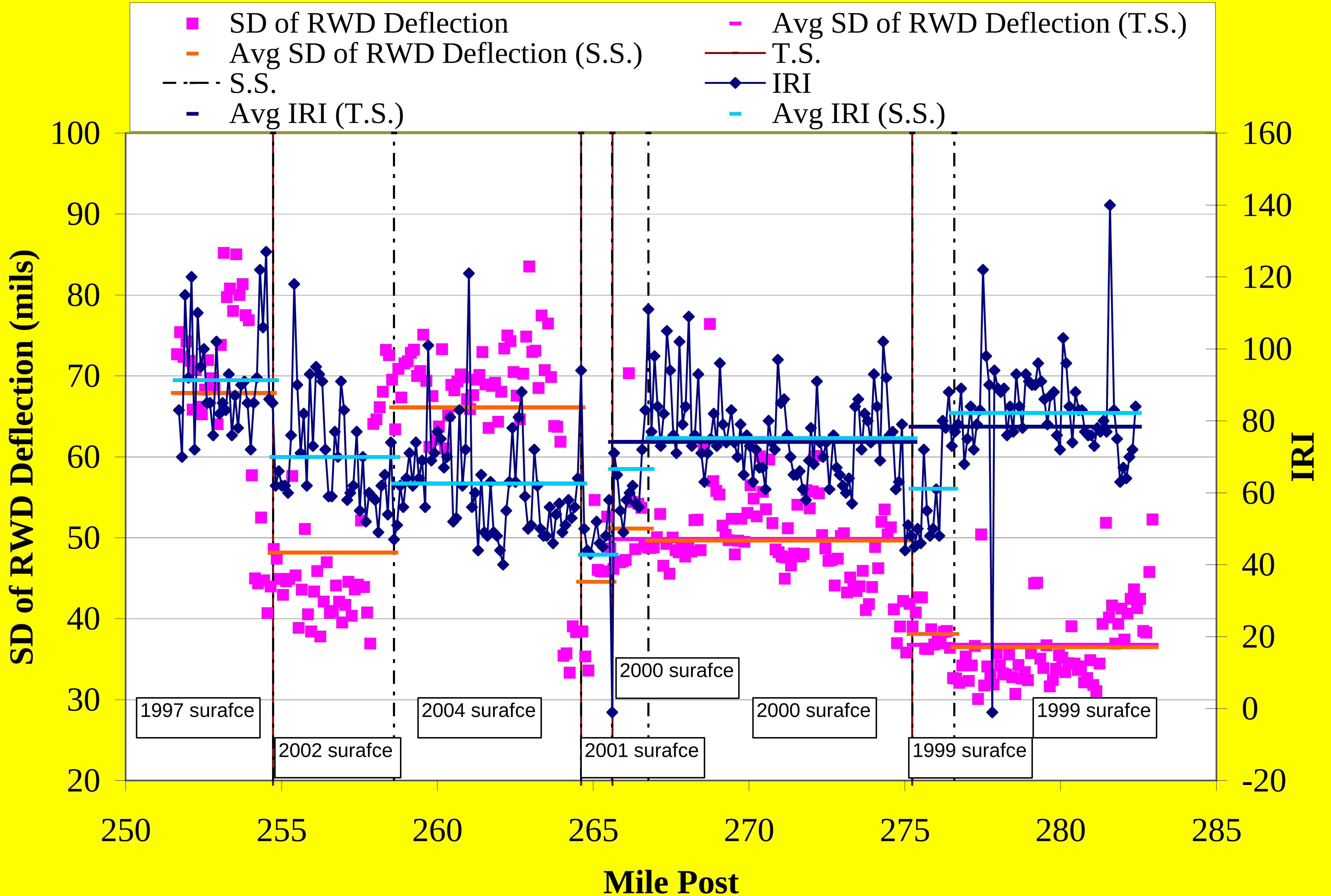




I-64 Eastbound Lane
FWD frequency at specified ranking
RWD frequency coresponding to the same ranking
250
200
150
100
50
0
Number of data points
1
Very Poor
2
Poor
3
Fair
4
Good
5
Very Good
Deflection Ranking

Correlation between surface characteristics (IRI) and measured RWD SD of deflection


VTRC
Virginia Transportation
SD of RWD Deflection
Avg SD of RWD Deflection (S.S.)
T.S.
S.S.
IRI
Avg IRI (T.S.)
1992 surface
1999 surface
2001 surface
1997 surface
1994 surface
2002 surface
79in/mile
99in/mile
83in/mile
85in/mile
60in/mile
37 mils
78 mils
50 mils
45 mils
32 mils
SD of RWD Deflection (mils)
IRI
Mile Post
200
180
160
140
120
100
80
60
40
20
250
200
150
100
50
0
-50
105
110
115
120
125
130
135
140



SD of RWD Deflection
Avg SD of RWD Deflection (T.S.)
Avg SD of RWD Deflection (S.S.)
T.S.
S.S.
IRI
Avg IRI (T.S.)
Avg IRI (S.S.)
SD of RWD Deflection (mils)
IRI
Mile Post
1997 surafce
2002 surafce
2004 surafce
2001 surafce
2000 surafce
2000 surafce
1999 surafce
1999 surafce
100
90
80
70
60
50
40
30
20
160
140
120
100
80
60
40
20
0
-20
250
255
260
265
270
275
280
285

- The RWD provides continuous deflection profile that represents an average of more than 65,000 points every 10th of a mile. This deflection can be used to screen the pavement conditions on the network level.
- The RWD deflection results appear reasonable and are consistent with the expected conditions of the three pavement sites tested. Interstate pavement sections that typically thicker structures showed a lower and less variable deflection as measured by the RWD. Pavement sections from the primary network, having a reduced thickness and potential higher variability, resulted in a higher and more variable deflection as measured by the RWD.

- The RWD deflection results are highly impacted by the surface conditions manifested by the surface distresses and roughness as well as with the HMA surface type and age.
- Qualitative deflection rankings (low, medium, or high) measured by the RWD appeared to consistently match those produced by the FWD. This indicates that the RWD is suitable for network-level pavement structural characterization and can identify sections that require additional project-level testing (such as those performed by the FWD).

- As compared to the FWD deflection measurements, the RWD deflection measurements indicate that:
- Deflections that are less than or equal 8 mils reflect good to excellent structural conditions,
- Deflections that are greater than 8 mils and less than 14 mils, reflect fair to good structural conditions, and
- Deflections that are greater than 14 mils, reflect poor to very poor conditions.

- FWD deflection results allow for better estimates of the in-situ structural conditions (effective structural number and in-situ subgrade resilient modulus) on both the project and the network level. These results are a better representation of the in-situ pavement conditions and are more useful for use as direct input into pavement design for rehabilitation purposes. However, the RWD is more suitable for network-level analysis due to the speed at which measurements can be conducted.
- FWD deflection, basin parameters and structural conditions can be used to develop structural indices on the network level. These indices correlates reasonably with the existing distresses and pavement roughness of the pavement sites tested

- FWD deflection, basin parameters and structural conditions can be used to develop structural indices on the network level. These indices correlates reasonably with the existing distresses and pavement roughness of the pavement sites tested
- The RWD technology is not a replacement for the FWD deflection testing on the network level. However, RWD can be used as an effective evaluation tool on the network level before typical FWD testing and subsequent detailed pavement evaluation. Thus, RWD can results in reducing the cost of FWD data collection on the network level.

Questions

VTRC

Virginia Transportation
Research Council