Real Time Simulation of Truck Loads for Reliability Based Code Calibration

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Acknowledgements

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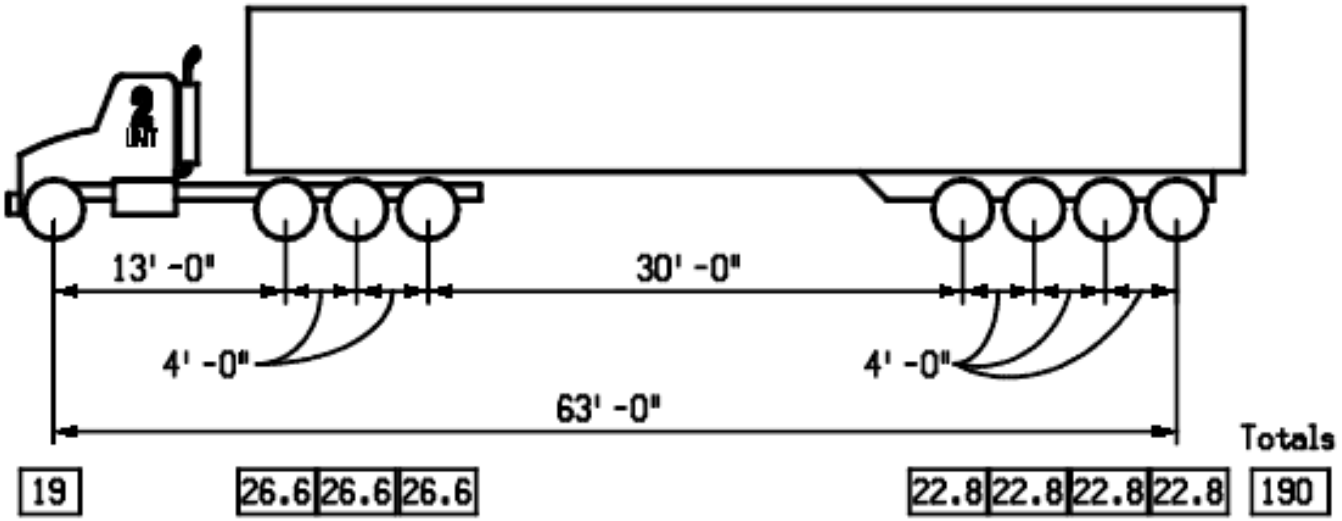
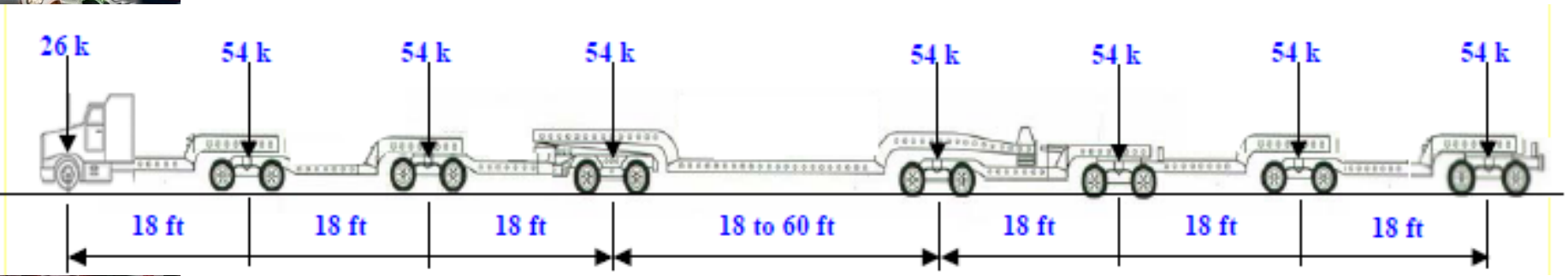
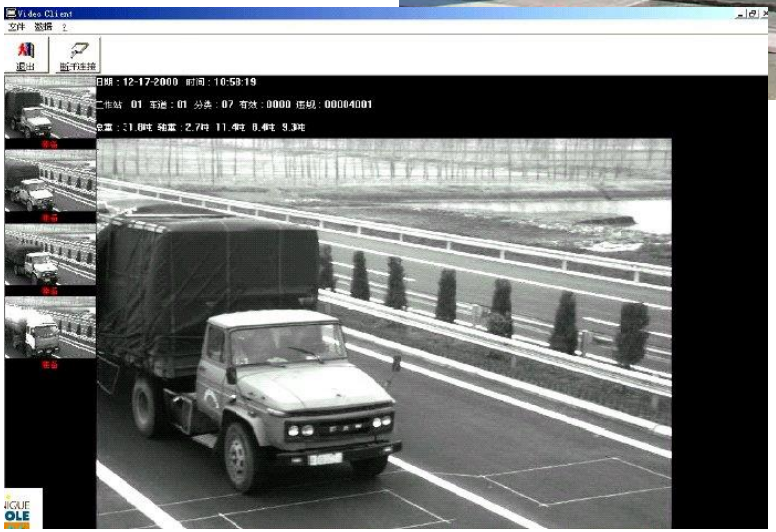
Powers


SUNBELT
SUNBELT
OVERSIZE LOAD


13' -0"
30' -0"
4' -0"
4' -0"
63' -0"
Totals
(kips)
19
26.6
26.6
26.6
22.8
22.8
22.8
22.8
190


26 k
54 k
54 k
54 k
54 k
54 k
54 k
54 k
18 ft
18 ft
18 ft
18 to 60 ft
18 ft
18 ft
18 ft

Sensors Recording Truck Weights



Typical Weigh-In-Motion (WIM) Record

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w26419759320604030009060029005079115056039046319063043044000000
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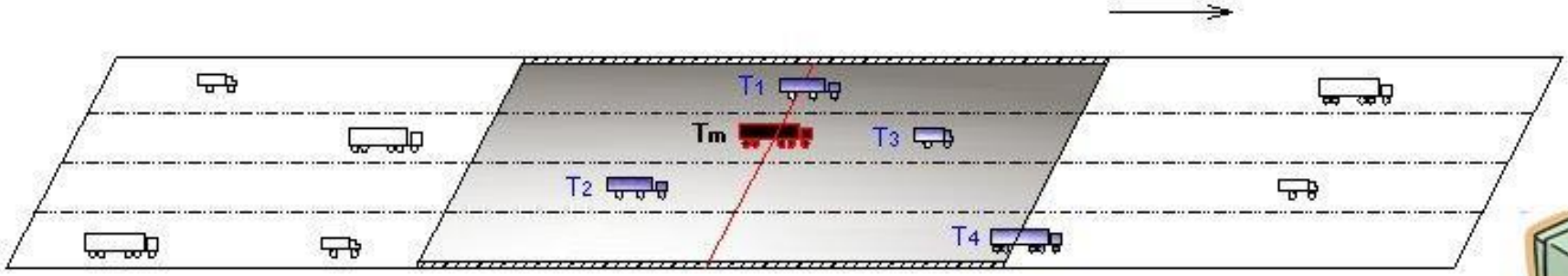
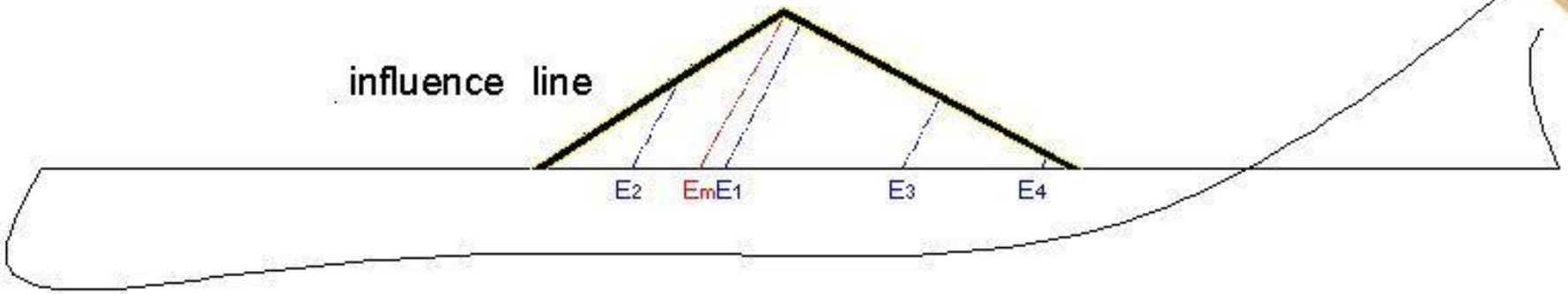
Real Time Simulation





Multiple Presence Factor (MPF) in Design Codes

Specifications	Edition Year	1 lane	2 lanes	3 lanes	4 lanes	5 lanes	6 lanes	7 lanes	8 lanes
AASHTO Standard Speicifcations for Highway Bridges	17th 2002	1.00	1.00	0.90	0.75	0.75	0.75	0.75	0.75
AASHTO LRFD Bridge Design Specifications	5th 2010	1.20	1.00	0.85	0.65	0.65	0.65	0.65	0.65
Australia AS5100.7 Bridge Design	2004	1.00	0.90	0.80	0.70	0.60	0.55	0.55	0.55
Canadian Highway Bridge Design Code	10th 2006	1.00	0.90	0.80	0.70	0.60	0.55	0.55	0.55
Chinese General Code for Design of Highway Bridge and Culverts JTG D60	2004	1.00 ~	1.00	0.78	0.67	0.60	0.55	0.52	0.50
Eurocode BS EN1991-2	2003	1.00	0.83	0.67	0.5*	0.40*	0.33*	0.29*	0.25*
Japanese Specifications for Roadway Bridge	2002	1.00	1.00	0.83	0.75	0.60*	0.50*	0.43*	0.38*






There has not been documentation for derivation of these MPFs, except for the AASHTO code.

The AASHTO code derivation was based on assumptions while no WIM data were available.

MPF should be a function of span length, truck traffic volume, and number of lanes available.






A New Approach to Deriving MPF

Use WIM data, simulating real load effect superimposed from different lanes.

$$\text{MPF} = \frac{\text{N-Lane Load Effect in Component}}{\text{One-Lane Load Effect in Component}} \frac{1}{N} = \frac{LE_{total}}{LE_{onelane}} \frac{1}{N}$$

Use the obtained real MPF values from different states and locations to derive MPF formulas for design and evaluation codes.

WIM data used:

California, Oregon, Michigan, and New York (only states with data of 0.01sec resolution).

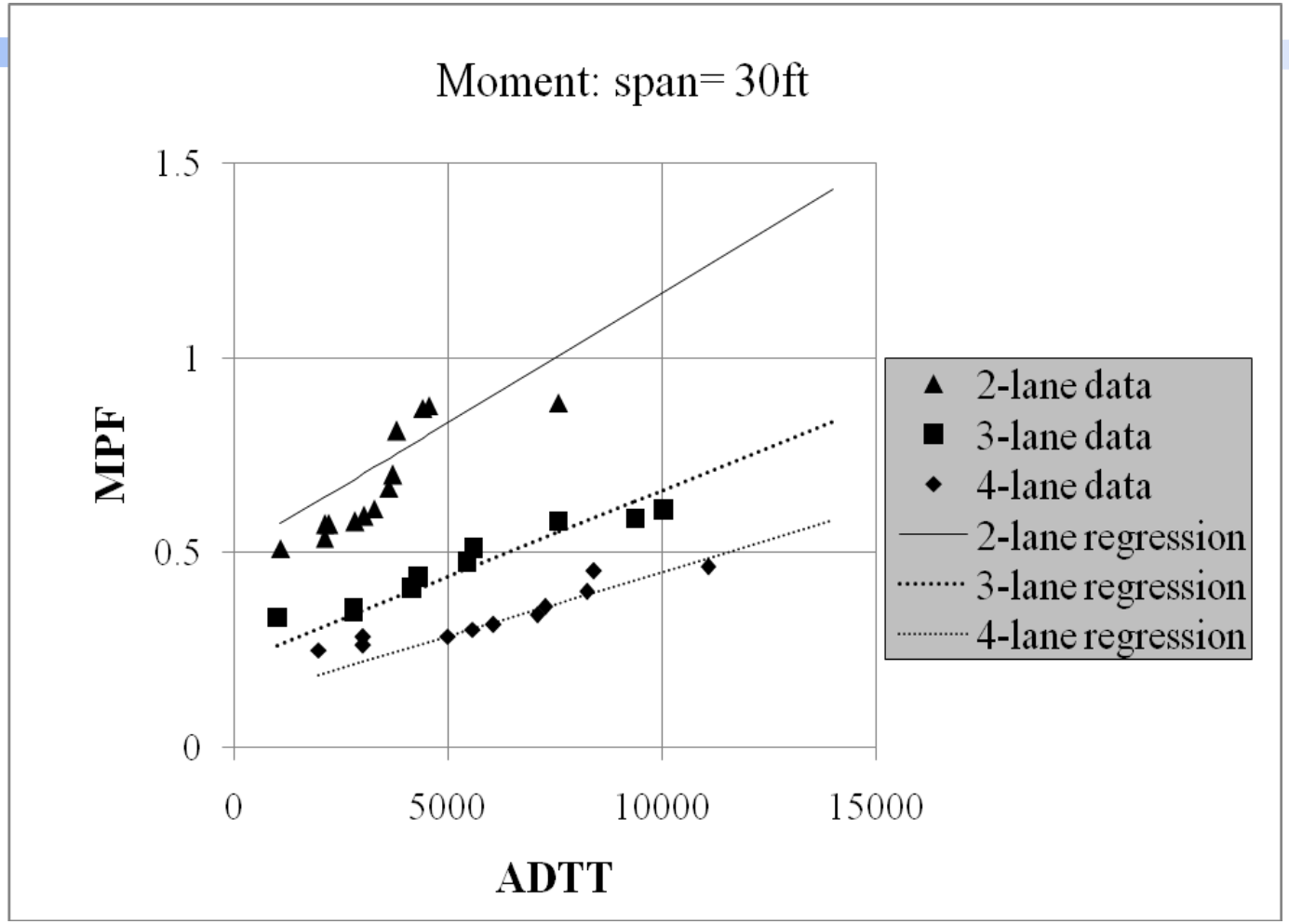
18,100,000 trucks, 161 months, 17 sites for 2-lane spans;

22,200,000 trucks, 137 months, 13 sites for 3-lane spans;

27,400,000 trucks, 138 months. 13 sites for 4-lane spans.

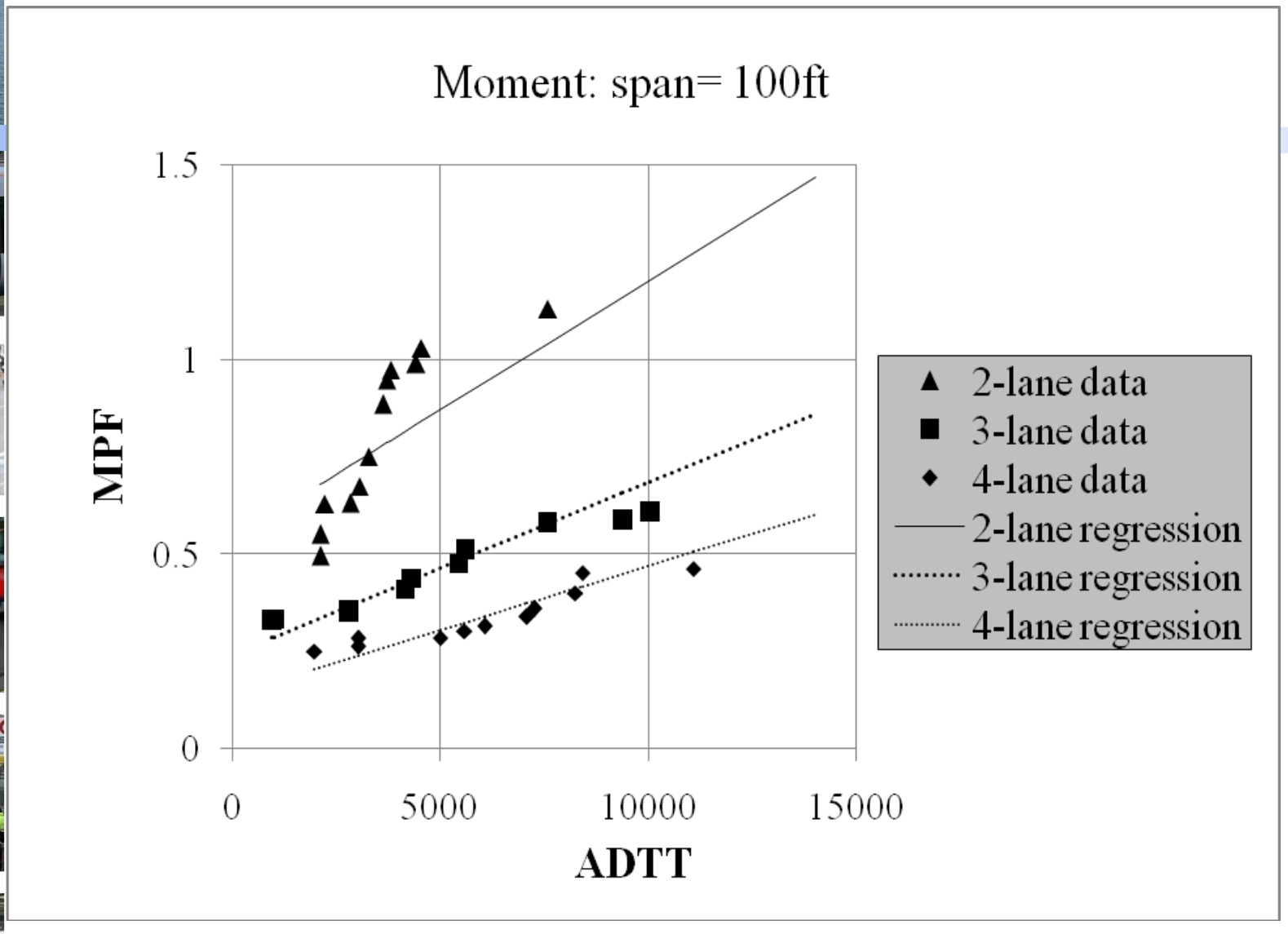






Moment: span= 30ft
1.5
1
0.5
0
MPF
0
5000
10000
15000
ADTT
2-lane data
3-lane data
4-lane data
2-lane regression
3-lane regression
4-lane regression

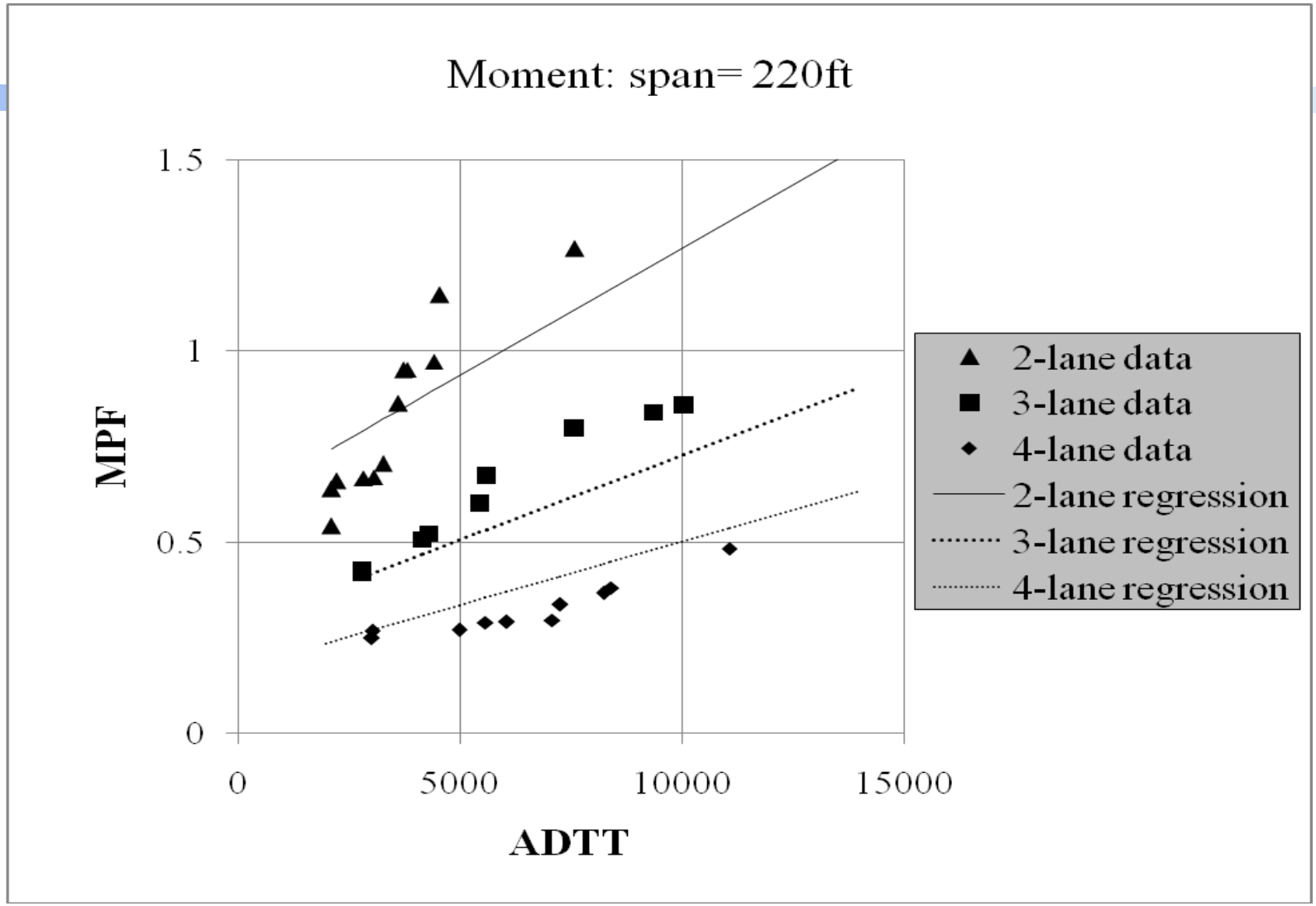






Moment: span= 100ft
1.5
1
0.5
0
MPF
0
5000
10000
15000
ADTT
2-lane data
3-lane data
4-lane data
2-lane regression
3-lane regression
4-lane regression

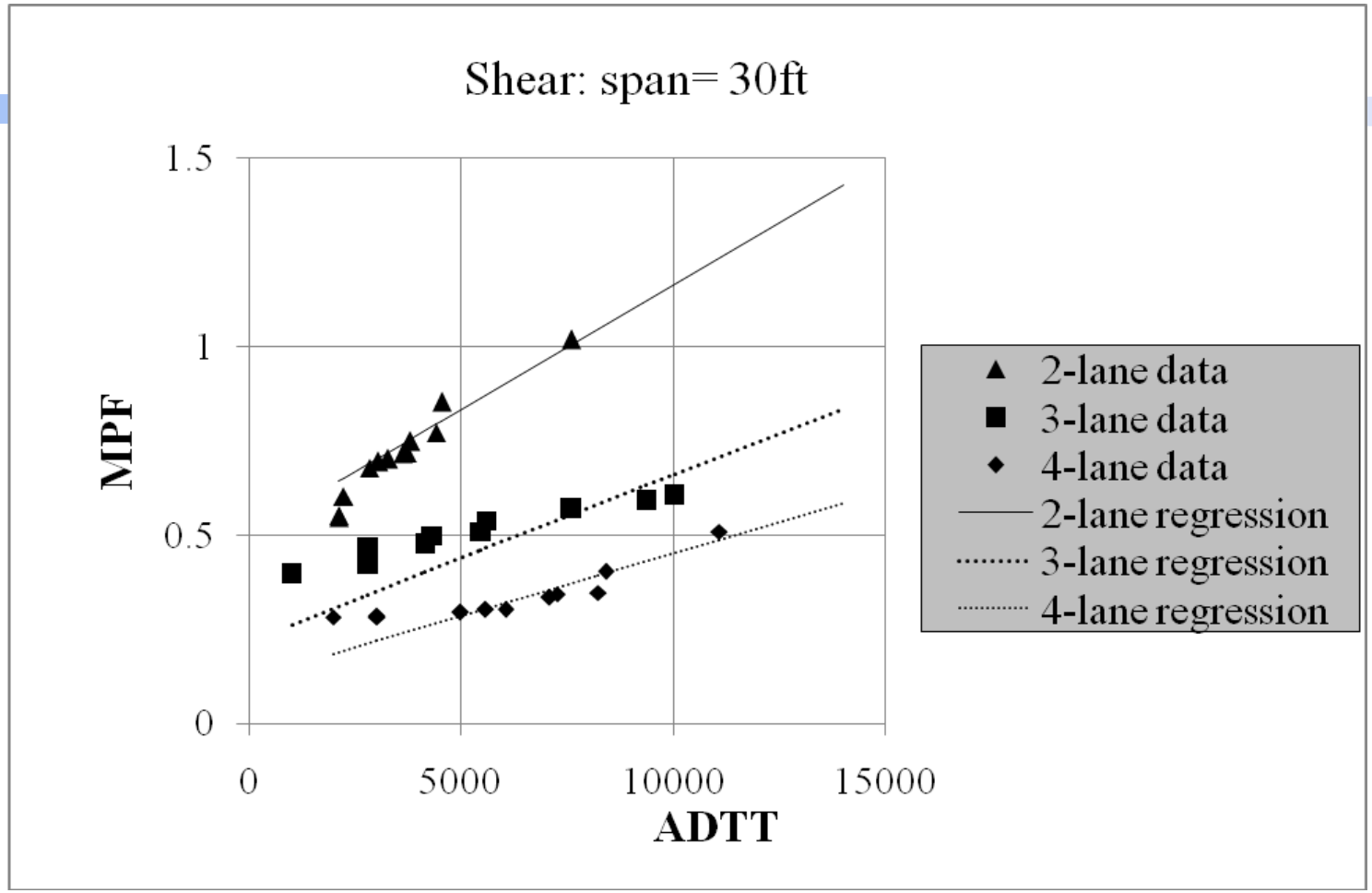






Moment: span= 220ft
1.5
1
0.5
0
MPF
0
5000
10000
15000
ADTT
2-lane data
3-lane data
4-lane data
2-lane regression
3-lane regression
4-lane regression

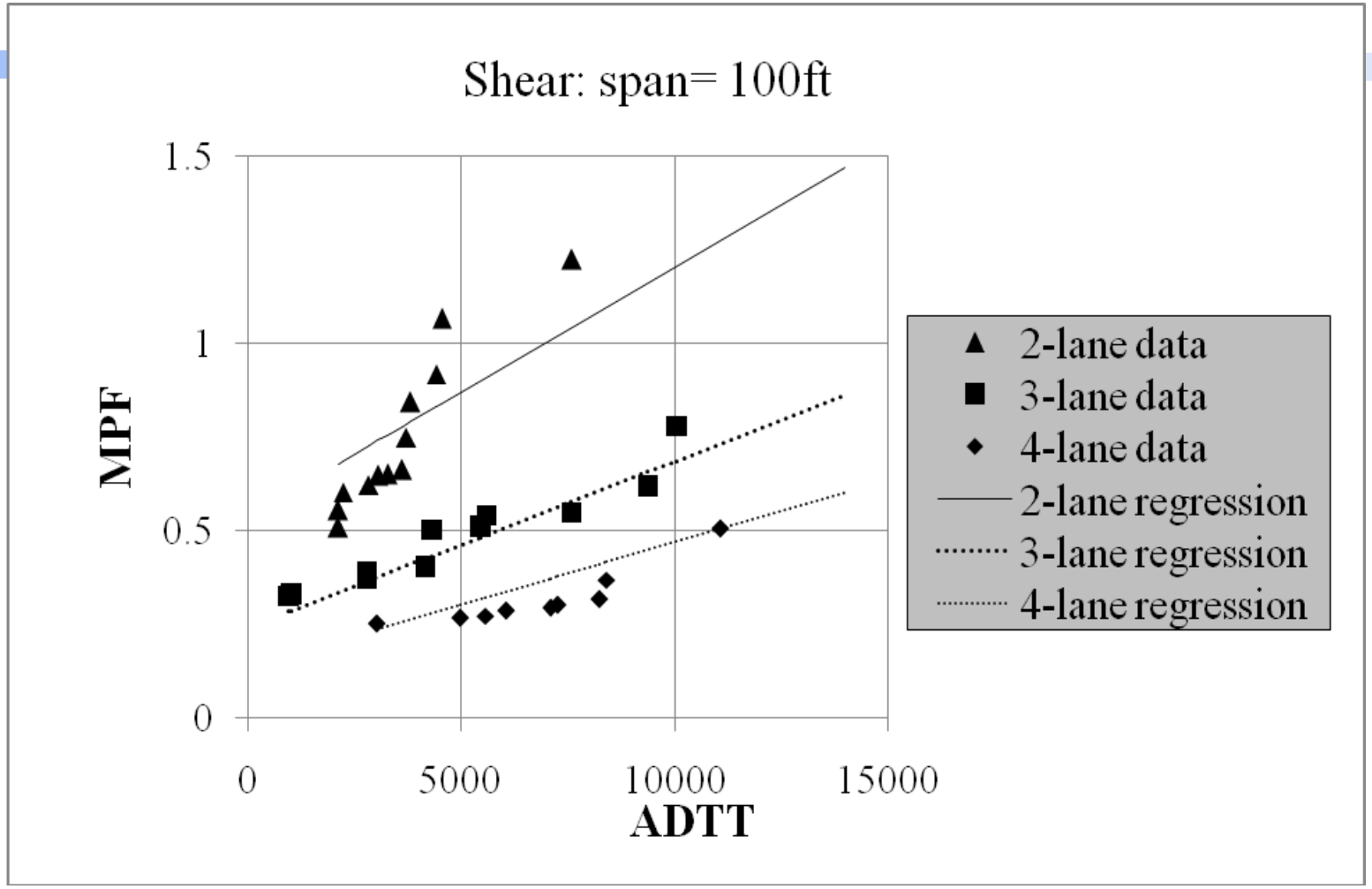






Shear: span= 30ft
MPF
1.5
1
0.5
0
0
5000
10000
15000
ADTT
2-lane data
3-lane data
4-lane data
2-lane regression
3-lane regression
4-lane regression

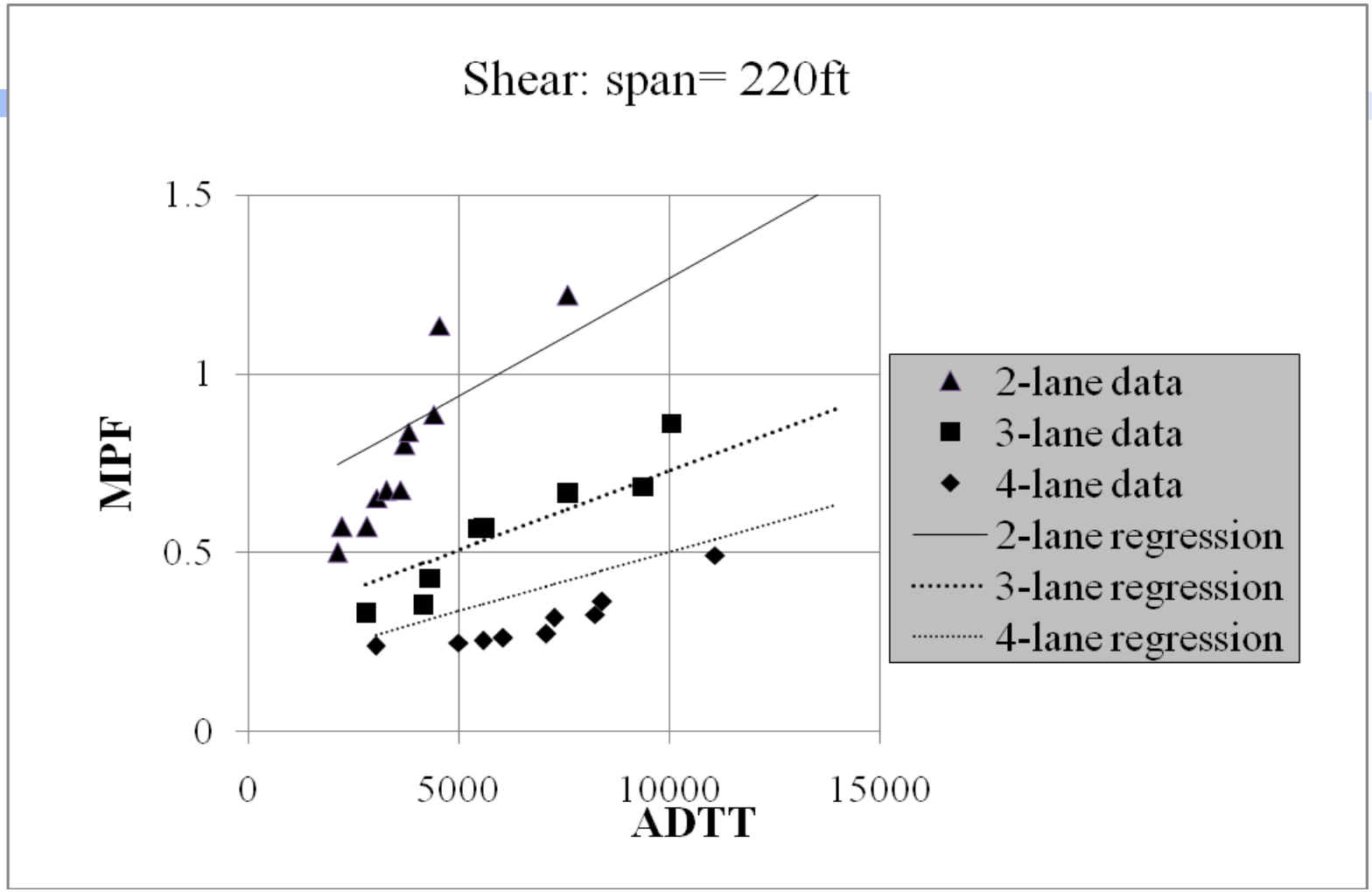






Shear: span= 100ft
MPF
1.5
1
0.5
0
0
5000
10000
15000
ADTT
2-lane data
3-lane data
4-lane data
2-lane regression
3-lane regression
4-lane regression



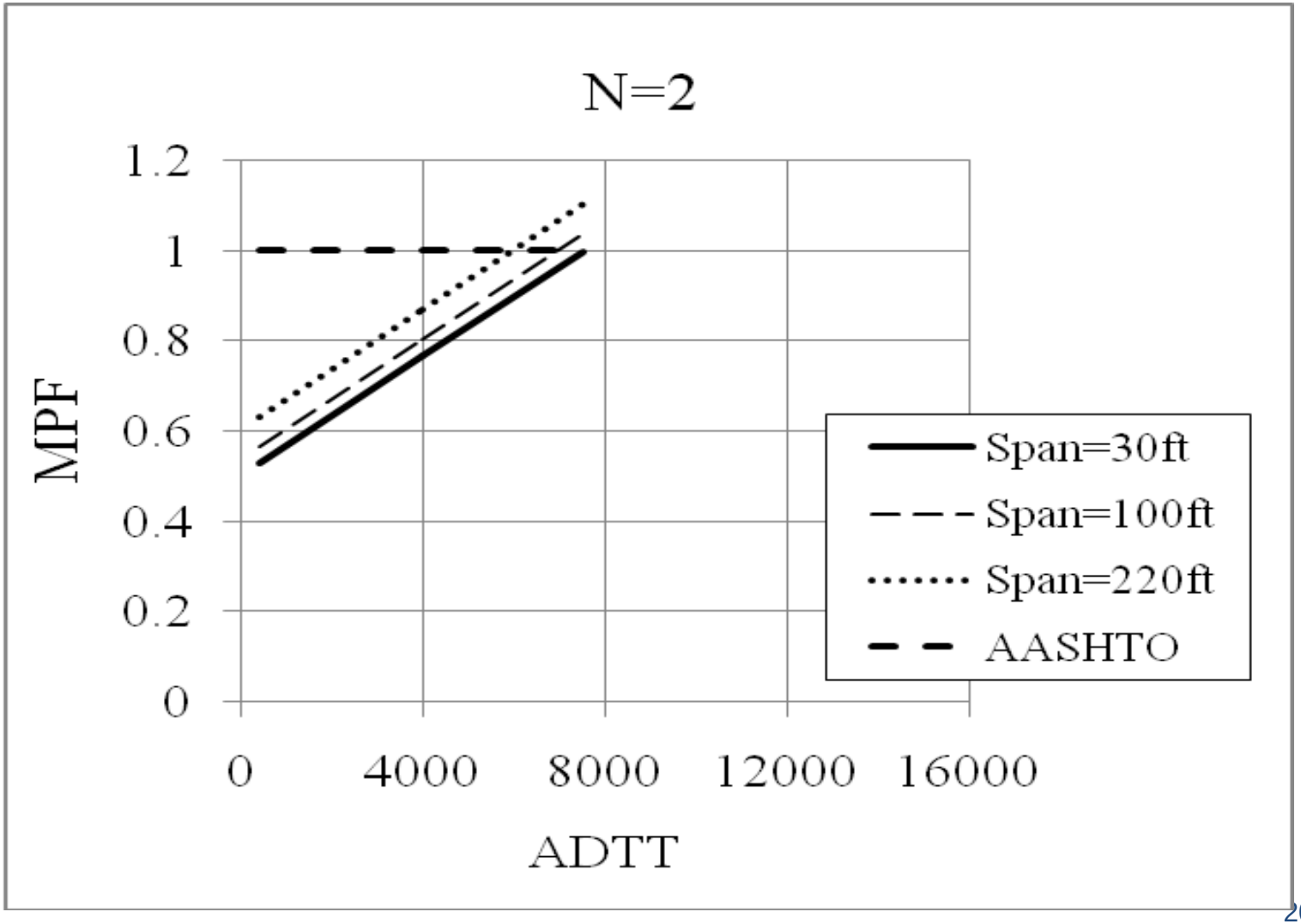


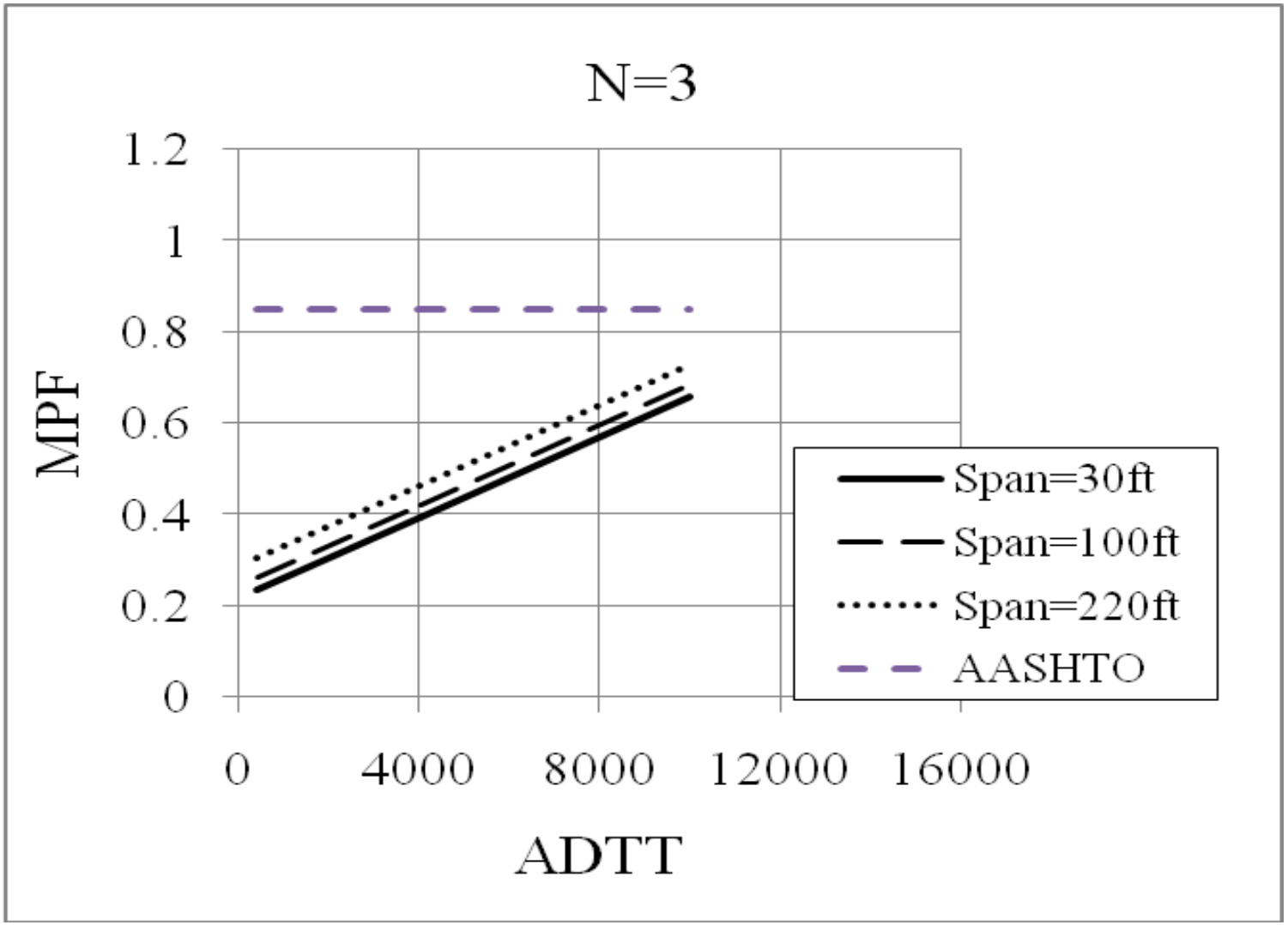


Shear: span= 220ft
1.5
1
0.5
0
MPF
0
5000
10000
15000
ADTT
2-lane data
3-lane data
4-lane data
2-lane regression
3-lane regression
4-lane regression






Impact of Proposed MPF

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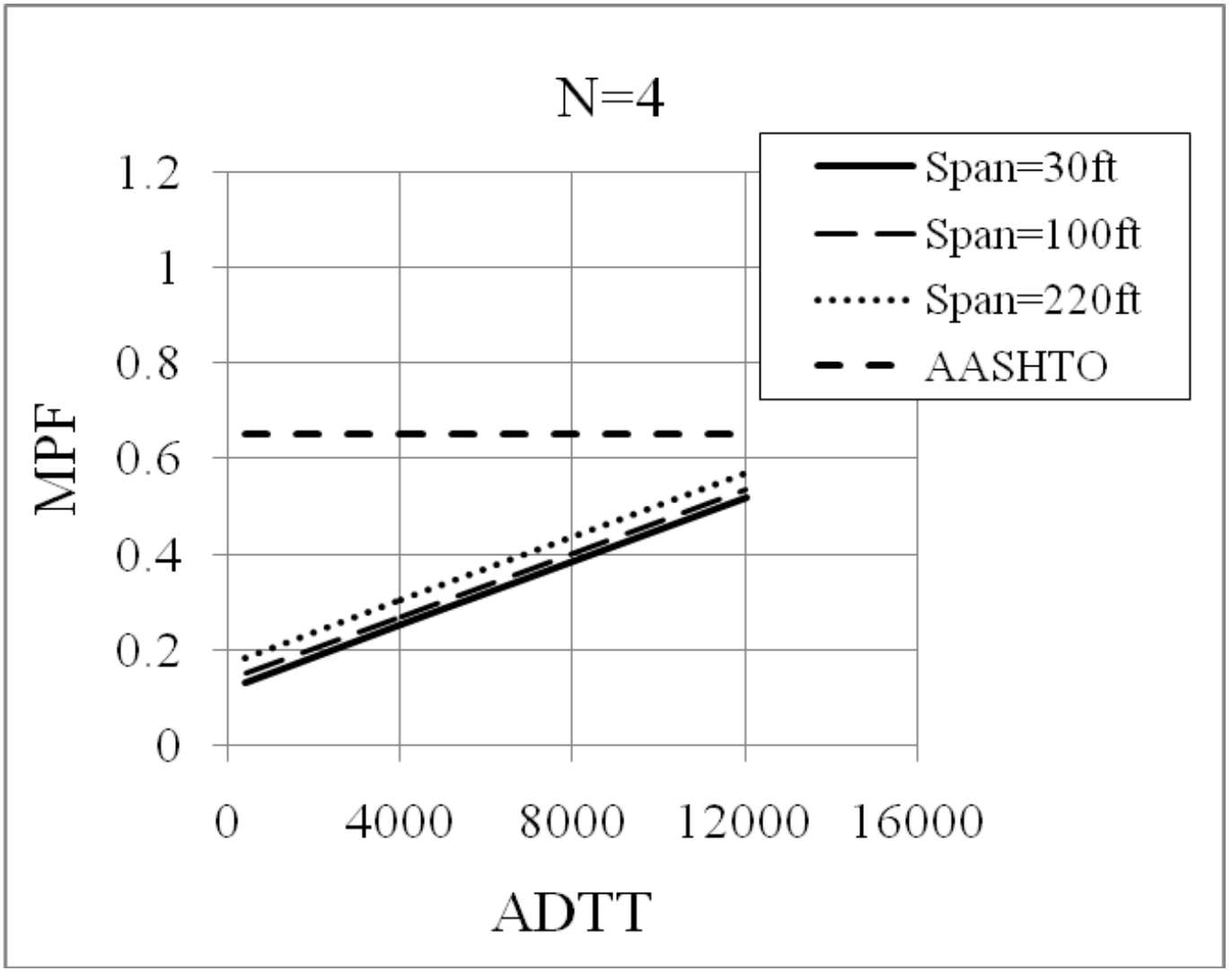
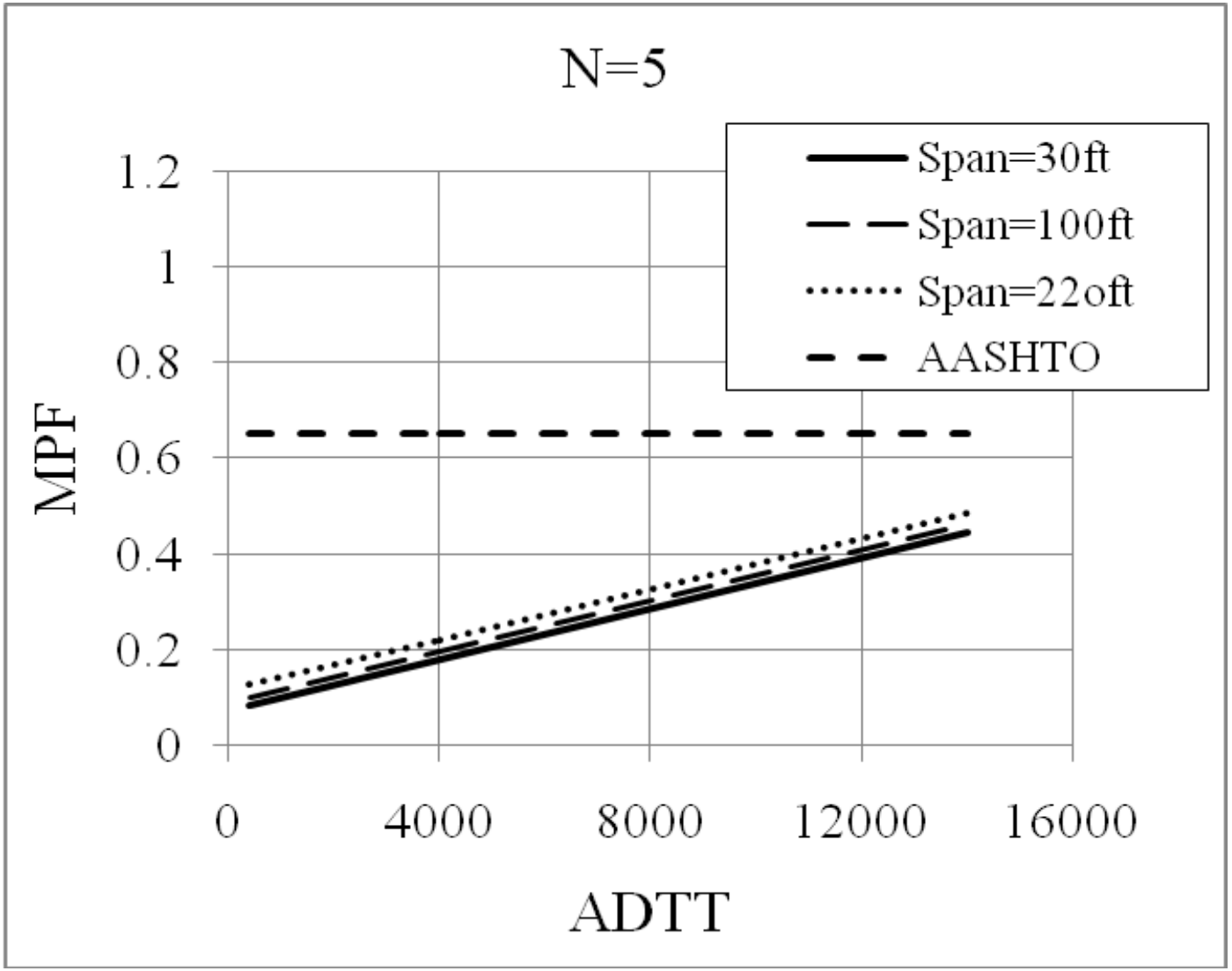
MPF
1.2
1
0.8
0.6
0.4
0.2
0
0
4000
8000
12000
16000
ADTT
Span=30ft
Span=100ft
Span=220ft
AASHTO







N=4
Span=30ft
Span=100ft
Span=220ft
AASHTO
MPF
1.2
1
0.8
0.6
0.4
0.2
0
0
4000
8000
12000
16000
ADTT


N=5
Span=30ft
Span=100ft
Span=22oft
AASHTO
MPF
1.2
1
0.8
0.6
0.4
0.2
0
0
4000
8000
12000
16000
ADTT






Conclusions

- Current MPF in bridge design and evaluation codes are over-conservative and extremely over-conservative for shorter spans.
- Proposed MPF to AASHTO based on span length, ADTT, and number of lanes available is more realistic and can save significant costs for strengthening existing bridge spans.

Thank you very much!

$$MPF_{fatigue} = \frac{0.988 + 6.87 \times 10^{-5}\ \text{span length} + 4.01 \times 10^{-6}\ ADTT + 1.07 \times 10^{-2} / N}{N} > \frac{1}{N}$$

An Important Issue in Calibration

Extreme/Future Load Projection/Prediction






Theory

$$f_N(x) = N F_1^{N-1}(x) f_1(x)$$

$$\mu_N = \int_{-\infty}^{\infty} x f_N(x) dx$$

$$\sigma_N^2 = \int_{-\infty}^{\infty} (x - \mu_N)^2 f_N(x) dx$$






Proposed Method:

Use more data for deriving f1(x) as an extreme value distribution

Analytically derive $f_N(x)$ as another extreme value distribution

$$f_N(x) = N F_1^{N-1}(x) f_1(x)$$

$$\mu_N = \int_{-\infty}^{\infty} x f_N(x) dx$$

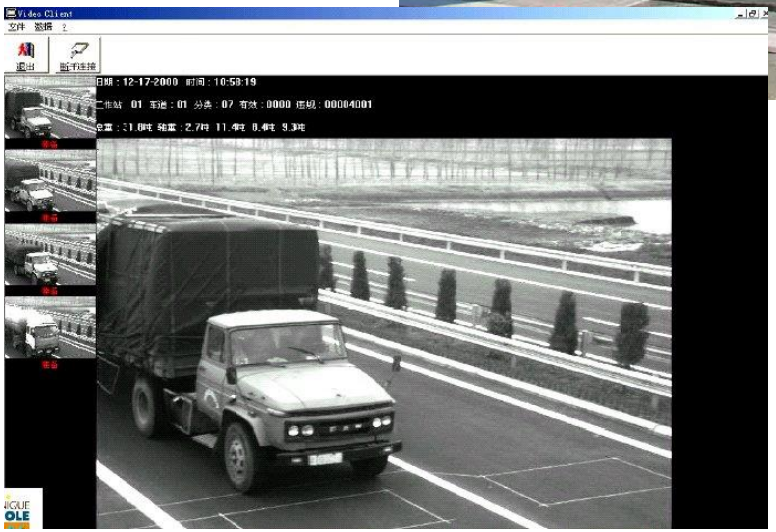
$$\sigma_N^2 = \int_{-\infty}^{\infty} (x - \mu_N)^2 f_N(x) dx$$

Evaluation














Errors (NCHRP 12-76 vs. Proposed)

Henan Province Station								
Load effect - Projection length	10m	15m	20m	25m	30m	40m	50m	70m
Shear (mean) - 1 month	59.5	74.5	81.0	84.2	85.5	86.0	86.1	85.9
Shear (mean) - 3 months	58.6	71.9	78.2	81.9	83.8	84.8	85.2	85.3
Moment (mean) - 1 month	51.9	56.5	63.4	72.8	77.1	81.8	84.1	85.6
Moment (mean) - 3 months	52.0	55.0	57.7	66.4	71.8	78.2	81.3	83.7
Shear (std) - 1 month	42.8	67.4	63.5	60.3	68.0	74.4	75.3	80.5
Shear (std) - 3 months	59.1	69.8	75.0	77.7	78.7	89.1	77.1	84.2
Moment (std) - 1 month	24.4	23.7	31.4	23.5	55.3	42.2	67.9	45.8
Moment (std) - 3 months	39.7	28.5	41.3	31.3	58.9	42.7	72.9	56.3

Henan Province Station								
Load effect - Projection length	10m	15m	20m	25m	30m	40m	50m	70m
Shear (mean) - 1 month	1.1	3.4	5.6	6.7	7.2	7.5	7.7	7.9
Shear (mean) - 3 months	0.2	1.2	3.1	4.6	5.3	5.9	6.3	6.7
Moment (mean) - 1 month	2.2	0.7	4.1	6.0	6.7	7.3	7.7	8.0
Moment (mean) - 3 months	0.2	0.2	0.9	2.3	3.5	4.8	5.5	6.2
Shear (std) - 1 month	14.0	10.8	15.4	17.4	14.1	11.0	10.2	6.7
Shear (std) - 3 months	4.1	9.5	9.4	8.5	8.7	3.4	9.3	4.8
Moment (std) - 1 month	28.9	12.3	12.1	15.9	7.4	12.6	9.3	16.2
Moment (std) - 3 months	14.8	8.0	4.2	9.0	5.0	12.2	6.1	8.5

Errors (NCHRP 12-76 vs. Proposed)

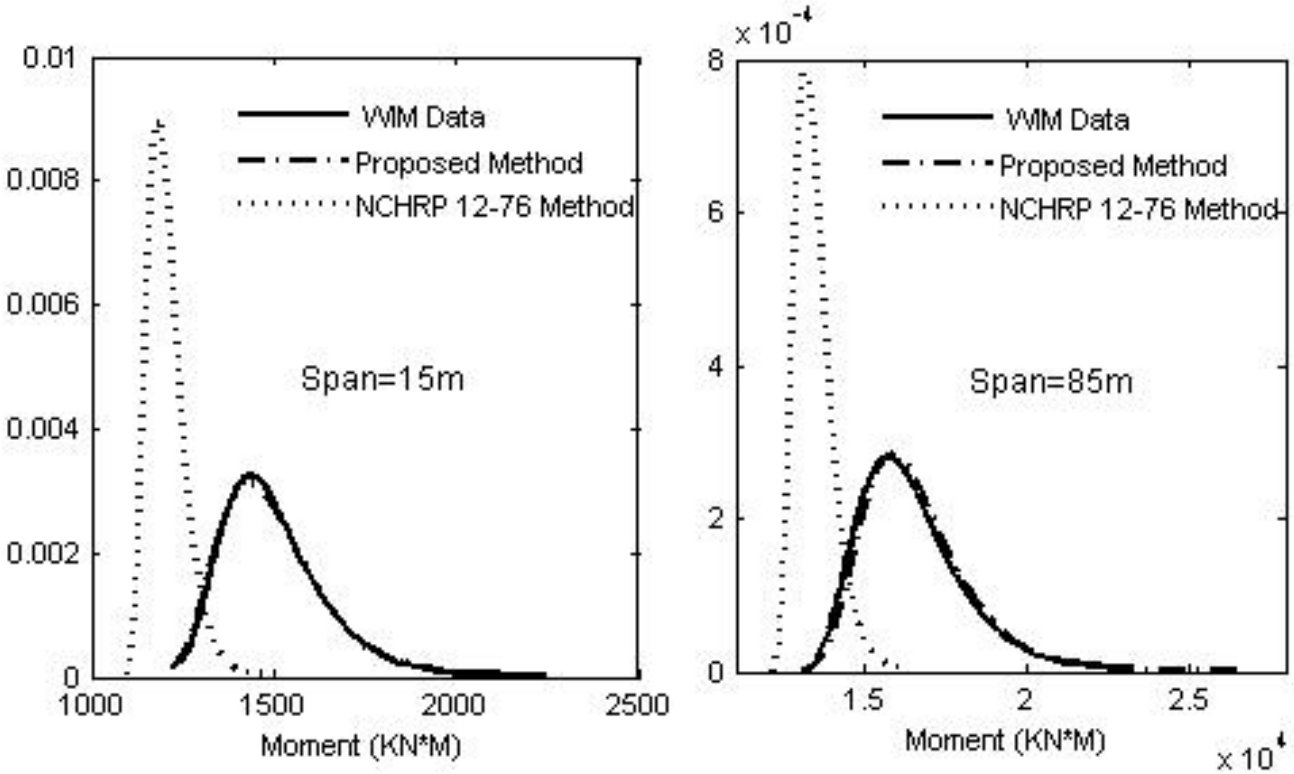
Jiangxi Province Station									
Load effect - Projection length		10m	15m	20m	25m	30m	40m	50m	70m
Shear (mean) - 1 month		83.6	87.6	84.7	83.9	82.9	81.9	80.9	79.7
Shear (mean) - 3 months		83.4	88.9	85.2	84	83.5	82.8	82.5	82.3
Moment (mean) - 1 month		72.6	74.5	81.7	83.1	82.3	81.4	80.9	79.8
Moment (mean) - 3 months		70.6	74.8	86.4	86.6	84.3	82.5	82.3	82.0
Shear (std) - 1 month		69.2	63.7	62.2	55.2	48.7	50.8	50.8	58.6
Shear (std) - 3 months		75.9	80.0	68.1	65.2	62.0	88.6	80.3	70.2
Moment (std) - 1 month		50.3	65.1	78.7	74.0	65.0	64.4	57.8	47.7
Moment (std) - 3 months		60.4	76.0	82.8	87.8	77.3	91.8	72.1	88.7

Jiangxi Province Station									
Load effect - Projection length		10m	15m	20m	25m	30m	40m	50m	70m
Shear (mean) - 1 month		1.9	1.7	1.6	1.8	1.7	1.6	1.3	0.9
Shear (mean) - 3 months		1.5	1.9	1.6	1.9	2.2	2.3	2.5	2.7
Moment (mean) - 1 month		0.5	1.1	2.2	1.0	0.7	0.0	0.4	0.4
Moment (mean) - 3 months		0.4	1.2	0.3	0.4	0.2	0.5	1.2	1.7
Shear (std) - 1 month		10.4	17.5	13.1	14.3	16.5	12.5	12.6	6.6
Shear (std) - 3 months		4.0	9.3	9.9	8.7	9.0	9.4	4.6	0.2
Moment (std) - 1 month		9.3	9.4	6.1	11.2	13.6	7.9	12.0	15.7
Moment (std) - 3 months		6.7	3.4	4.0	4.1	7.1	7.5	4.1	7.7






California State Data - Moment

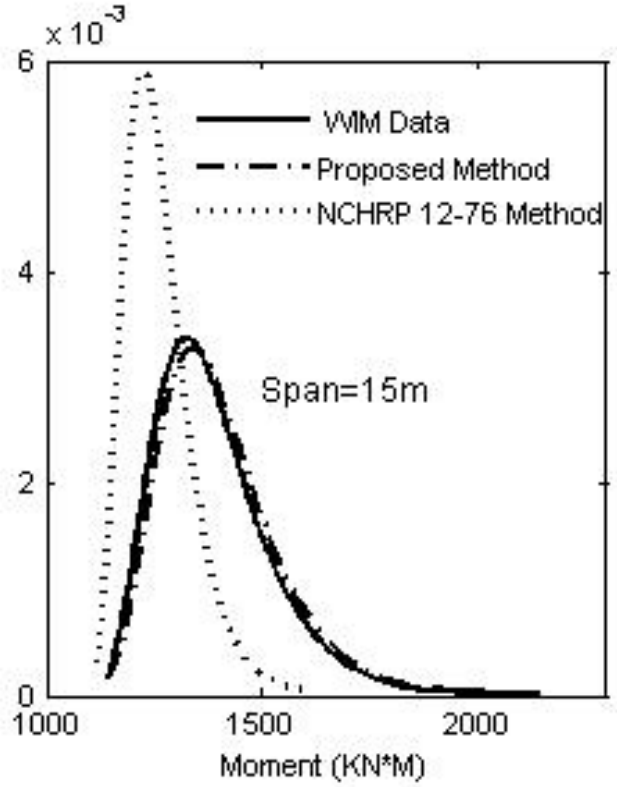


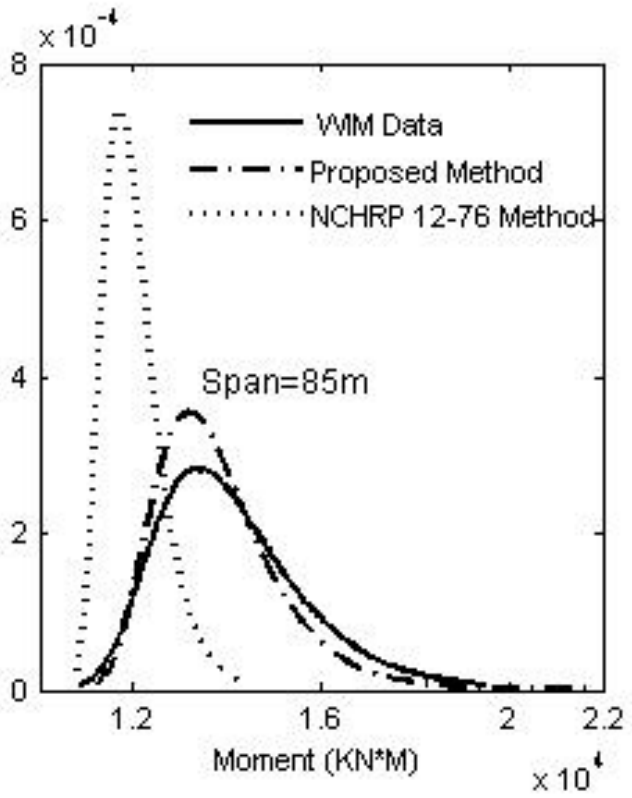
CA






New York State Data - Moment



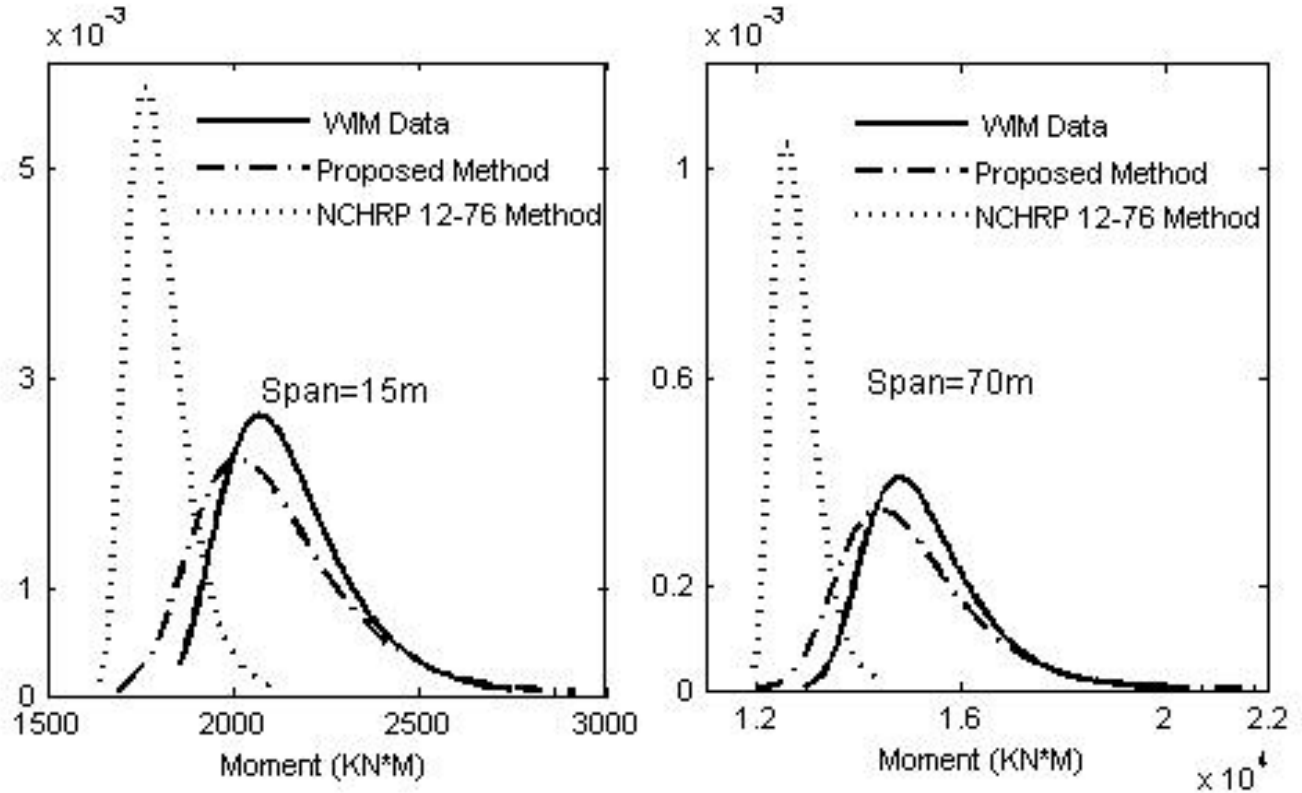


NY






HeNan Province Data - Moment

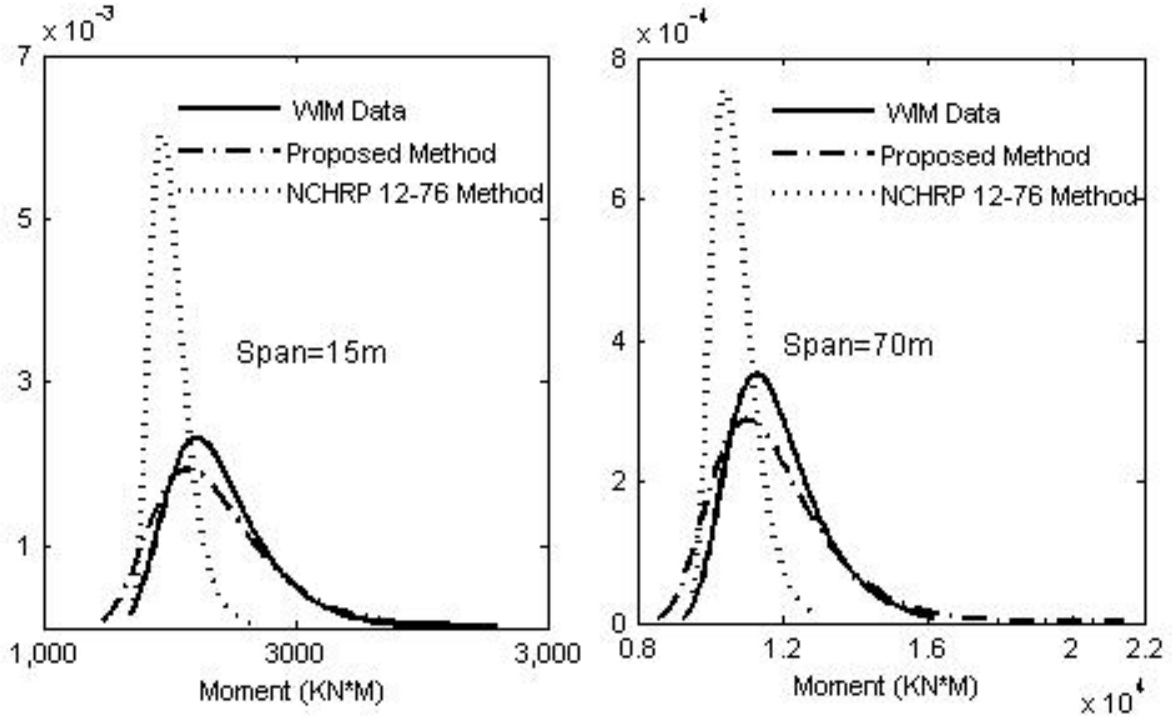


Henan






JiangXi Province Data - Moment

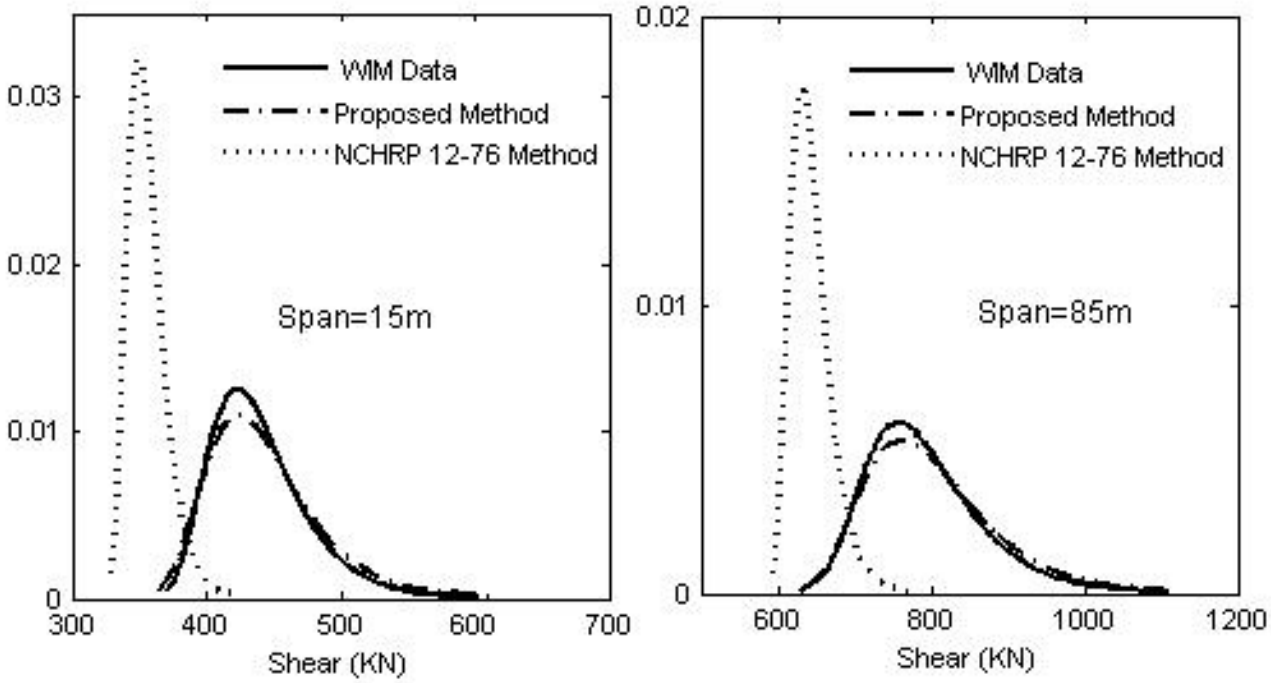


Jiangxi






California State Data - Shear

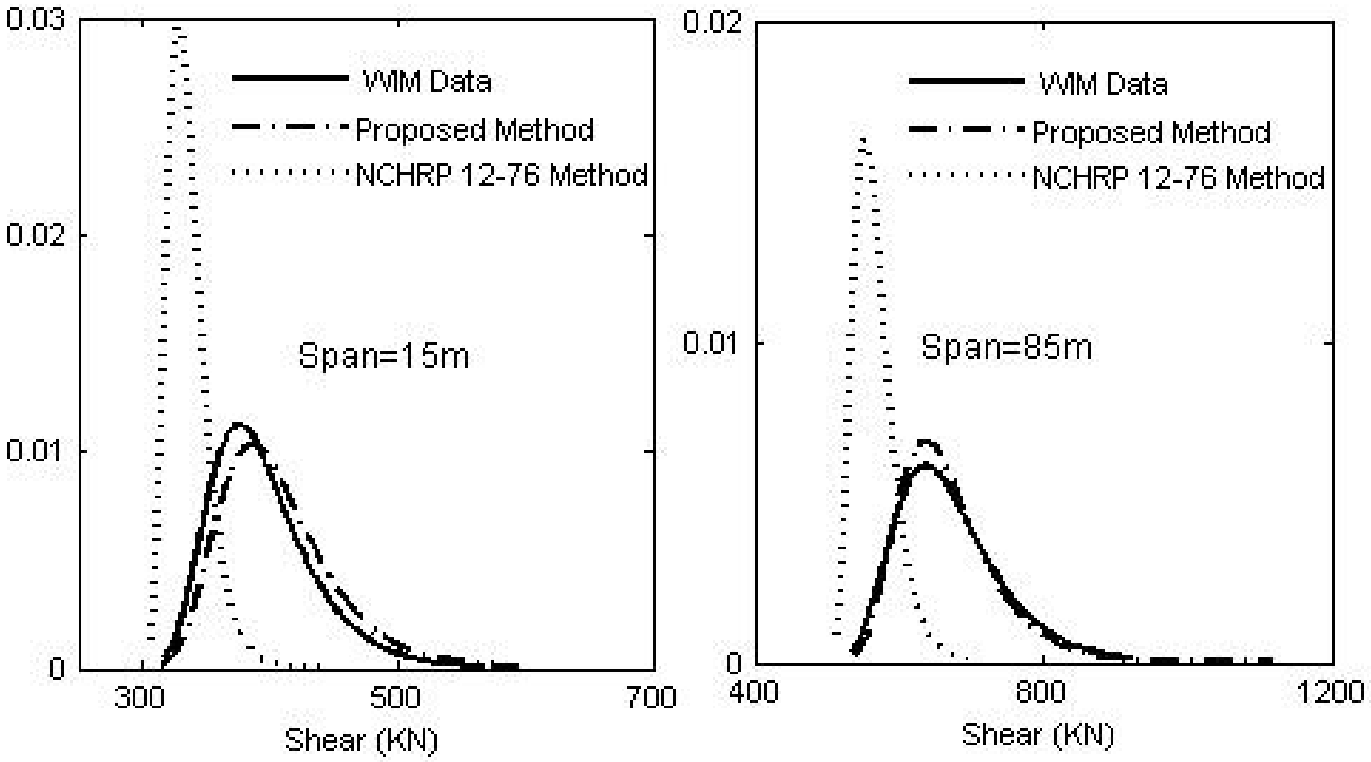


CA






New York State Data - Shear

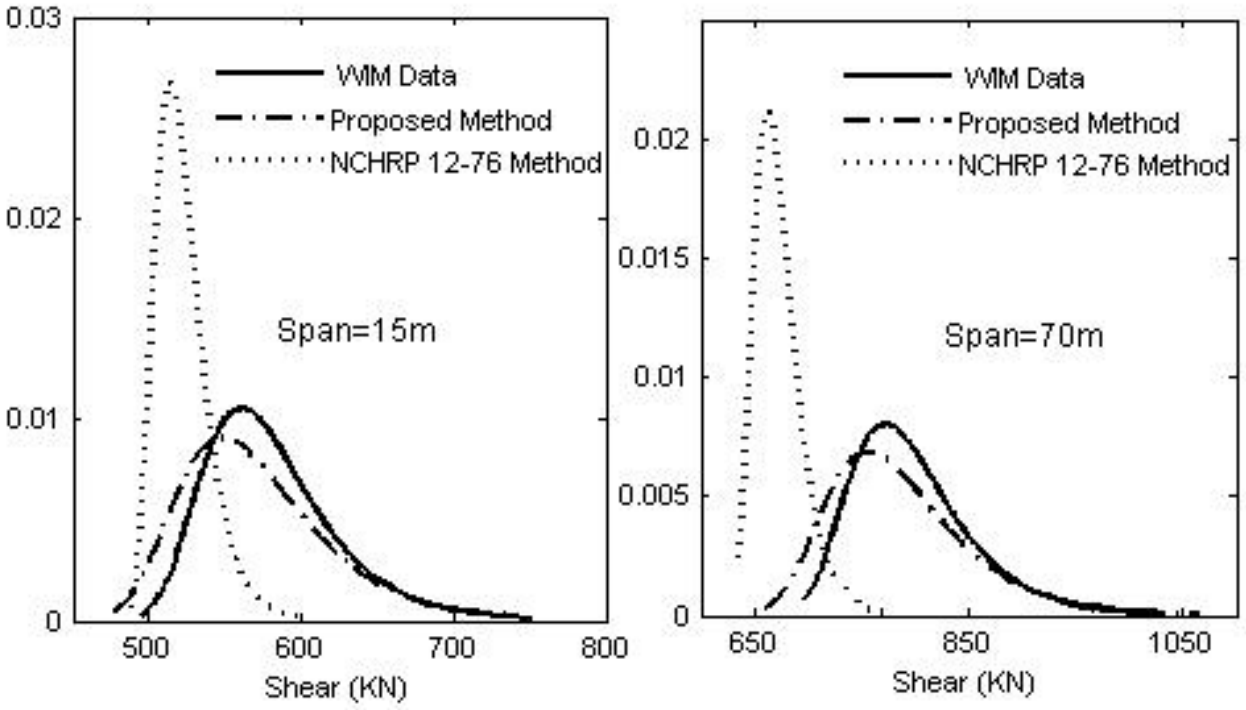


Ny






HeNan Province Data - Shear

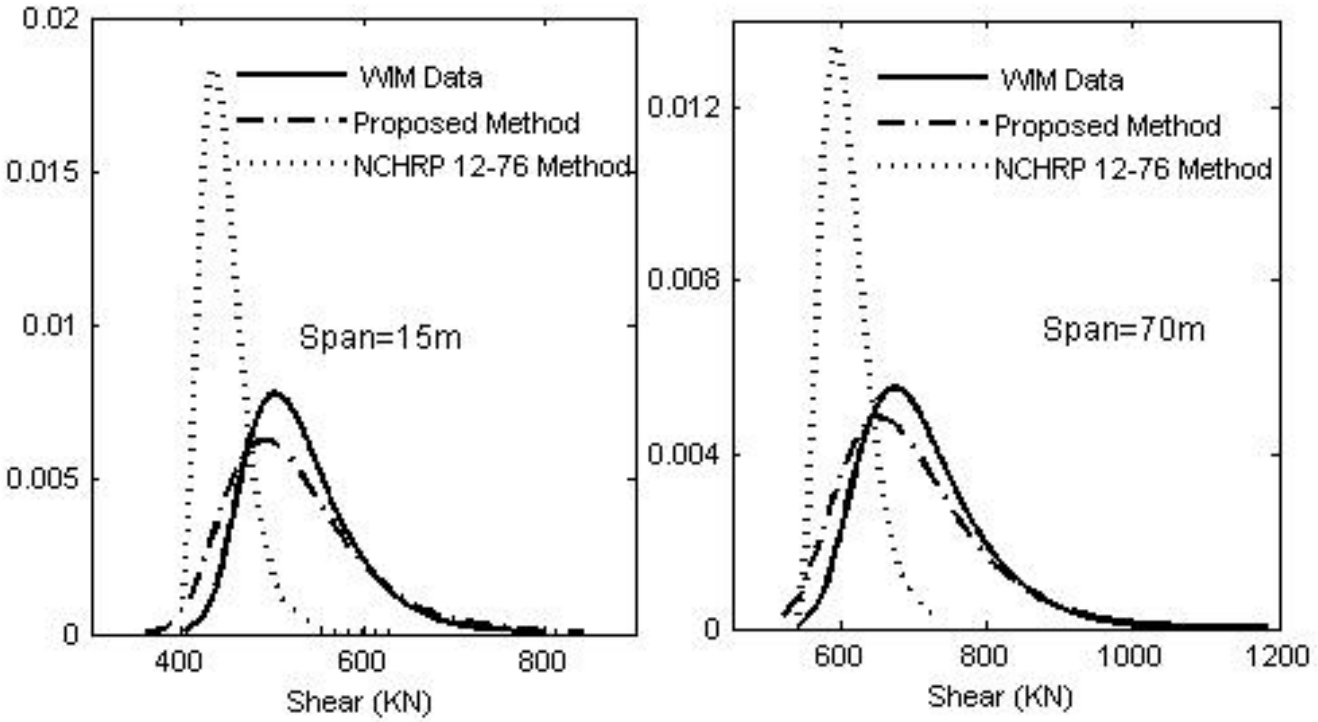


Henan






JiangXi Province Data - Shear



Jiangxi






Evaluation by User

(Integration by Monte Carlo simulation)

$$E(\mu_N) = \int_{-\infty}^{+\infty} (\mu_1 + \frac{\ln N}{\alpha_1}) f_1(x) dx$$

$$V(\mu_N) = \int_{-\infty}^{+\infty} [\mu_1 + \frac{\ln(N)}{\alpha_1} - E(\mu_N)]^2 f_1(x) dx$$

$$E(\sigma_N{}^2) = \int_{-\infty}^{+\infty} (\frac{\pi}{\sqrt{6}a_1})^2 f_1(x) dx$$

$$V(\sigma_N{}^2) = \int_{-\infty}^{+\infty} [(\frac{\pi}{\sqrt{6}\alpha_1})^2 - E(\sigma_N{}^2)]^2 f_1(x) dx$$






HeNan Province Data - Moment

span length		15m	25m	30m	40m	50m	70m	Average
1 month MU_N (N=4)	Error (%)	1.86	0.13	1.58	0.22	2.61	1.82	1.37
	Error Upper Bound (%)	5.73	4.13	4.32	4.82	4.35	3.69	4.50
1 month SIGMA_N(N=4)	Error (%)	18.83	17.02	17.51	17.68	18.34	17.81	17.87
	Error Upper Bound (%)	30.56	26.68	25.79	23.91	19.10	19.24	24.21
5 month MU_N (N=20)	Error (%)	1.18	0.87	2.24	1.87	2.50	2.58	1.87
	Error Upper Bound (%)	7.71	5.60	7.48	8.63	7.10	8.19	7.45
5 month SIGMA_N(N=20)	Error (%)	40.83	6.57	11.95	5.52	14.24	14.61	15.62
	Error Upper Bound (%)	23.20	17.74	22.30	26.18	23.07	24.46	22.83
12 month MU_N(N=48)	Error (%)	3.48	2.69	2.47	2.75	3.68	3.35	3.07
	Error Upper Bound (%)	9.77	5.88	4.85	9.49	6.77	8.07	7.47






HeNan Province Data - Shear

span length		15m	25m	30m	40m	50m	70m	Average
1 month MU_N (N=4)	Error (%)	1.52	1.11	1.67	1.81	1.60	1.35	1.51
	Error Upper Bound (%)	3.72	3.85	3.52	3.69	2.86	3.53	3.53
1 month SIGMA_N(N=4)	Error (%)	16.13	17.25	16.71	17.76	17.78	17.16	17.13
	Error Upper Bound (%)	20.38	21.07	18.97	21.66	19.21	23.27	20.76
5 month MU_N (N=20)	Error (%)	1.82	1.59	1.70	2.69	1.72	1.59	1.85
	Error Upper Bound (%)	4.76	5.57	5.37	5.64	6.37	6.33	5.67
5 month SIGMA_N(N=20)	Error (%)	21.99	13.03	21.21	20.95	14.37	20.66	18.70
	Error Upper Bound (%)	21.58	22.51	19.01	22.71	23.78	24.22	22.30
12 month MU_N(N=48)	Error (%)	3.79	3.78	3.28	3.07	3.08	3.24	3.37
	Error Upper Bound (%)	7.39	6.04	7.65	7.08	6.64	6.54	6.89






JiangXi Province Data - Moment

span length		15m	25m	30m	40m	50m	70m	Average
1 month MU_N (N=4)	Error (%)	1.03	1.48	1.20	1.31	1.13	1.03	1.20
	Error Upper Bound (%)	5.43	4.94	5.85	4.82	7.31	4.37	5.45
1 month SIGMA_N(N=4)	Error (%)	19.41	19.37	20.08	21.82	23.15	22.66	21.08
	Error Upper Bound (%)	17.30	15.19	17.54	16.68	17.91	15.81	16.74
5 month MU_N (N=20)	Error (%)	1.09	2.34	1.81	0.83	1.38	1.28	1.45
	Error Upper Bound (%)	7.32	6.26	5.94	4.92	11.29	7.31	7.17
5 month SIGMA_N(N=20)	Error (%)	25.65	24.88	22.44	25.43	25.39	25.35	24.86
	Error Upper Bound (%)	17.37	20.09	17.75	17.07	21.41	17.51	18.53
12 month MU_N(N=48)	Error (%)	3.56	3.41	3.29	3.80	3.60	3.55	3.53
	Error Upper Bound (%)	8.41	6.79	6.96	4.30	11.26	8.06	7.63






JiangXi Province Data - Shear

span length		15m	25m	30m	40m	50m	70m	Average
1 month MU_N (N=4)	Error (%)	1.09	1.99	2.16	1.46	2.66	2.01	1.90
	Error Upper Bound (%)	6.60	6.32	6.58	6.40	6.00	5.71	6.27
1 month SIGMA_N(N=4)	Error (%)	24.11	15.94	12.16	15.84	14.12	14.43	16.10
	Error Upper Bound (%)	18.79	18.78	21.89	16.64	20.57	20.08	19.46
5 month MU_N (N=20)	Error (%)	2.23	2.91	2.60	2.04	3.98	2.29	2.67
	Error Upper Bound (%)	7.91	7.47	6.66	7.93	6.55	7.66	7.36
5 month SIGMA_N(N=20)	Error (%)	24.29	14.42	14.97	18.26	16.90	16.48	17.55
	Error Upper Bound (%)	21.02	18.79	22.08	16.99	20.82	21.69	20.23
12 month MU_N(N=48)	Error (%)	4.54	3.83	3.47	4.65	4.27	4.09	4.14
	Error Upper Bound (%)	9.10	7.52	8.68	8.49	7.43	7.73	8.16