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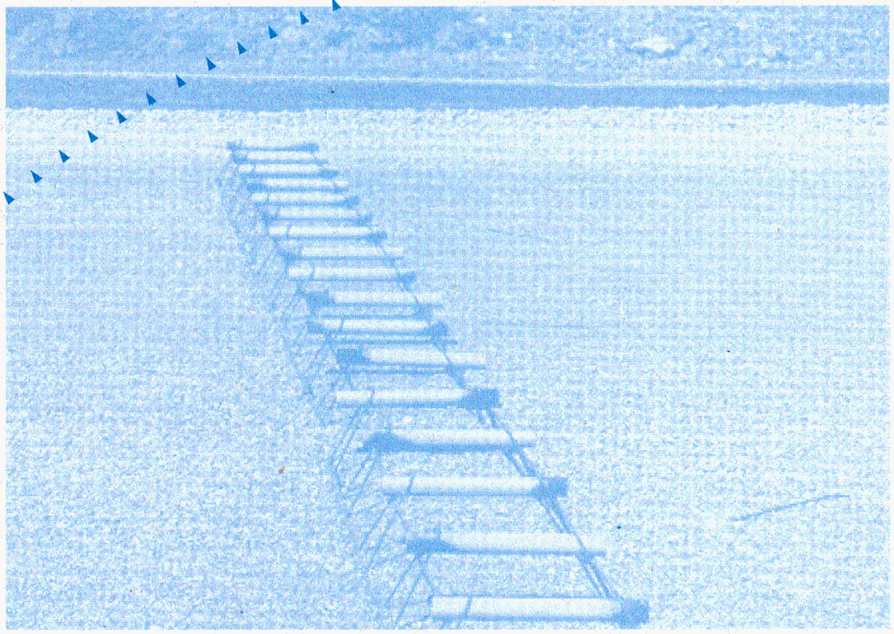

A Field Study of PCC Joint Misalignment Near Fergus Falls, Minnesota

MnROAD
Minnesota Road Research Section

A FIELD STUDY OF PCC JOINT MISALIGNMENT NEAR FERGUS FALLS, MINNESOTA

Final Report

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16. Abstract (Limit: 200 words)

This report highlights an investigation into concrete pavement performance problems caused by transverse joint misalignment on a segment of westbound Interstate 94 near Fergus Falls, Minnesota.

In 1986, heavy rain during construction resulted in transverse joint locations based on estimated sawing guide marks. The results of dowel bar alignment, faulting, and load transfer efficiency measurements all demonstrate that misaligned transverse joints in relationship to the dowel bar assemblies contributed to early faulting that a minimum dowel bar embedment length of 64 mm (2.5 in.) is needed to prevent significant faulting and maintain reasonable load transfer efficiency across a joint. However, construction alignment tolerances and long-term concrete stress reduction near the dowels warrant the use of embedment lengths longer than 64 mm (2.5 in.).

Since several of the joints investigated can be considered undoweled, accelerated faulting of these joints can be expected.

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Eric Embacher - Office of Materials and Road Research

Special thanks to Dan Frentress of the Concrete Pavement Association of Minnesota for his recollection of historical construction events related to this study.

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EXECUTIVE SUMMARY

It is well understood that the use of dowel bars increases the useful life of transverse joints in concrete pavements. Proper positioning of the dowel bars in a transverse joint is paramount to their effectiveness. This paper highlights an investigation into concrete pavement performance problems caused by insufficient dowel bar embedment that resulted from transverse joint misalignment.

This study was prompted by the observance of noticeable transverse joint faulting on a 120 m (400 ft) segment of westbound Interstate Highway 94 near Fergus Falls, Minnesota. The pavement consists of 241 mm (9.5 inches) of jointed reinforced concrete pavement (JRCP) resting on a dense graded aggregate base. When this pavement was constructed in 1986, heavy rain during construction resulted in transverse joint locations based on estimated sawing guide marks.

To determine if the cause of the premature joint faulting was related to misaligned transverse joints relative to the dowel bar assemblies, several field measurements and tests were conducted on December 2, 1998. Dowel bar alignment measurements were taken along fifteen selected transverse joints. Ten of selected joints were found to have dowel embedment lengths less than 51 mm (2 in). Of those ten, five had no dowels spanning the joint. Faulting measurements were taken at two locations along each selected joint. Several of the joints have faulting in excess of 6 mm (0.25 in), with the highest reading measured at 12.8 mm (0.50 in). The current load transfer efficiency (LTE) of the selected joints was determined from FWD testing. The LTE values found ranged from 30 to 87%.

This study found that significant early faulting is occurring when embedment lengths are less than 64 mm (2.5 in). Notification is made that the results are for a 12 year old pavement (35 year design life), and that the minimum embedment length requirement must be much greater than 64 mm to accommodate construction tolerances and provide long term strength. A comparison of embedment length and LTE revealed that higher embedment lengths result in higher LTE values, as expected. LTE values for the leave side of the slabs show more variability than for the corresponding approach side. A comparison of LTE and faulting also revealed expected results, with declines in LTE resulting in increased faulting.

The results of dowel bar alignment, faulting, and load transfer efficiency measurements all demonstrate that the early faulting behavior can be directly tied to misaligned transverse joints in relation to the dowel bar assemblies. Accelerated faulting of these joints can be expected, therefore the installation of retrofit dowel bars is recommended.

Introduction

It is well understood that the use of dowel bars increases the useful life of transverse joints in concrete pavements. Proper positioning of the dowel bars in a transverse joint is paramount to their effectiveness. Only with sufficient embedment length can a dowel bar transfer its stress to the surrounding concrete without causing damage. This paper highlights an investigation into concrete pavement performance problems caused by insufficient dowel bar embedment that resulted from transverse joint misalignment.

This study was prompted by the observance of noticeable transverse joint faulting on a 120 m (400 ft) segment of westbound Interstate Highway 94 near Fergus Falls, Minnesota. The pavement consists of 241 mm (9.5 inches) of jointed reinforced concrete pavement (JRCP) resting on a dense graded aggregate base. Transverse joint spacing is 8.2 m (27 ft) and panel widths are 4.0 m (13 ft) passing lane and 4.2 m (14 ft) driving lane. The dowel bars are 32 mm (1.25 in) in diameter, 381 mm (15 in) in length, and are epoxy coated. The transverse joints are skewed with a 1:6 ratio. Pavement design life was 35 years.

The less than satisfactory performance of the area investigated in this study is not particularly unexpected. When this pavement was constructed in 1986, weather related circumstances resulted in a sequence of events leading to a finished product of unknown quality. According to Dan Frentress of the Concrete Pavement Association of Minnesota, shortly following the placement of the concrete on the base layer, a heavy rainstorm removed a large number of guide markings used to saw the transverse joints over the dowel basket assemblies. The decision was made to estimate the location of the dowel assemblies in this area by measuring 8.2 m (27 ft) intervals from the first dowel assembly. The transverse joints were sawed based on those measurements.

To determine if the cause of the premature joint faulting was related to misaligned transverse joints relative to the dowel bar assemblies, several field measurements and tests were conducted on December 2, 1998. A rebar locating device was used to determine the position of several dowel bars within each transverse joint of interest. A Georgia Faultmeter device was used to measure the faulting in two places along each joint. Finally, a Falling Weight Deflectometer device was used to determine the current load transfer efficiency of each joint after 12 years of interstate highway traffic.

The following sections will describe the measurement methods and results obtained during this brief investigation.

Dowel Bar Alignment Measurements

Dowel bar alignment measurements were taken along fifteen selected driving lane transverse joints in the area under investigation. See Figure 1. A Proceq PROFOMETER 3 Rebar Locator was used to determine the lateral and longitudinal location of four to five of the twelve dowel bars in each joint. Dowel bars 1,2,10,11, and 12 were located; where dowel number 1 designates the dowel bar closest to the driving lane shoulder. The measurements are believed to be within ±13 mm (±0.5 in) of the actual location.

Based on the longitudinal measurements, dowel bar embedment lengths were determined. Table 1 clearly shows the large variation in embedment lengths found. Positive embedment values correlate to lengths on the approach panel side (see Figure 2). Figure 3 shows embedment lengths graphically. Note that embedment lengths greater than 356 mm (14 in) or less than zero are shown as zero on this graph.

Ten of the selected joints were found to have dowel embedment lengths less than or equal to 51 mm (2 in). Of those ten, five had no dowels spanning the joint. See Appendix A for copies of the field data collection sheets.

Faulting Measurements

Faulting (vertical stepping) measurements were taken at two locations along each selected joint. See Figure 1 for locations. A Georgia type faultmeter was used to obtain the measurements. See Table 2 for results. Several of the joints have faulting in excess of 6 mm (0.25 in), with the highest reading measured at 12.8 mm (0.50 in).

Load Transfer Measurements

The current load transfer efficiency of both the selected joints and several other joints nearby the area of study, was determined. A Dynatest Model 8000 Falling Weight Deflectometer (FWD) was used with the geophone sensors arranged as shown in Figure 4. Loading consisted of 3 drops at each load level of 26.7 kN, 40 kN, and 66.7 kN (6000, 9000, and 15000 lbs). Testing occurred from 11 AM to 2 PM, with pavement surface temperatures ranging from 2.8 to 10 °C (37 to 50 °F).

Load transfer efficiency (LTE) results from each of the load positions (see Figure 1) is presented in Table 3. LTE values were calculated using the method outlined in section 3.5.4 of the *AASHTO Guide for Design of Pavement Structures (1993)*[1].

The equation used was :

$$d_{je} = \frac{d_u}{d_l} \times 100$$

where d_{je} is the load transfer efficiency in percent, d_u is the deflection at the joint of the unloaded slab, and d_l is the deflection of the loaded slab.

The LTE values found ranged from 30 to 87%. Figures 5a and 5b show LTE versus joint number for dowel locations #1 and #12 respectively.

Comparison Study

Embedment Length versus Faulting

Figure 6 shows a comparison of dowel bar embedment length versus faulting for the selected joints. From the graph, it appears in this case that significant early faulting occurs when embedment lengths are less than 64 mm (2.5 in). The Minnesota Department of Transportation (Mn/DOT) considers faulting to be significant if it is greater than 6.4 mm (0.25 in) [2].

One must be careful not to immediately conclude that the minimum embedment length required is only 64 mm (2.5 in). Not only must there be tolerances for proper location of the dowels relative to the joint (during construction), but the results presented here are for a 12 year old pavement (relatively new). State-of-the-art design guides recommend an embedment length of 6 times the diameter of the dowel [190 mm (7.5 in) for this case] for adequate contribution to long term load transfer [3].

No significant difference in faulting behavior was observed between dowel #1 (near shoulder) and dowel #12 (near centerline) locations.

Embedment Length versus Load Transfer Efficiency

Table 4, and Figures 7a and 7b, show a comparison of embedment length and load transfer efficiency (LTE) for the selected joints. As observed in Figure 6, it appears an embedment length less than 64 mm (2.5 in) results in significantly lower (and more variable) LTE values. As in the previous comparison, caution must be taken in that this is only a 12 year old pavement. More importantly, LTE values can be strongly affected by the temperature and moisture gradients present at the time of FWD testing. Due to the lack of any instrumentation to measure these effects (other than surface and air temperatures obtained by the FWD machine), the values presented were not adjusted accordingly.

Figures 8a thru 8d demonstrate how the embedment length and LTE at each load position varies for each joint under investigation. Qualitatively, the behavior is as expected, with higher embedment lengths resulting in higher LTE values. LTE values for the leave side of the slabs (load positions 1 and 3) show more variability than the corresponding approach side.

Load Transfer Efficiency versus Faulting

Figures 9a and 9b show a comparison of LTE and faulting for the selected joints. As might be expected, declines in LTE result in increased faulting. Note that data points from what may be considered "undoweled" joints [less than 25 mm (1 in) embedment length] all exhibit significant faulting after only 12 years of traffic.

Summary

Due to the observance of significant early faulting on a small length of Interstate Highway 94 near Fergus Falls, Minnesota, a brief investigation was called for. The estimation of transverse joint sawing guide marks during construction was strongly suspected as the cause of this premature pavement performance problem.

The results of dowel bar alignment, faulting, and load transfer efficiency measurements all demonstrate that the early faulting behavior can be directly tied to misaligned transverse joints in relation to the dowel bar assemblies. Based on the 12 years of traffic experienced by this pavement, it appears that a minimum dowel bar embedment length of 64 mm (2.5 in) is needed to prevent significant faulting and maintain reasonable load transfer efficiency across a joint. However, construction alignment tolerances and long term concrete stress reduction near the dowels warrant the use of embedment lengths longer than 64 mm (2.5 in).

Since several of the joints investigated can be considered undoweled, the heavy truck traffic on this pavement will accelerate the faulting of these joints. To slow the degradation of the joints, one recommendation might be the installation of retrofit dowel bars. This could restore a good portion of the load transfer efficiency necessary for long term joint performance. The length of this distressed area makes it highly suitable as a test section for evaluating the effectiveness of retrofit dowel bars.

Dowels bars play a significant role in increasing the performance and life of transverse joints in concrete pavements. These load transverse devices can only function properly however, if they are accurately aligned within a joint. This brief investigation clearly demonstrates how simple mistakes during construction can quickly lead to pavement performance problems.

REFERENCES

1. *AASHTO Guide for Design of Pavement Structures 1993*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

2. *Minnesota Department of Transportation, Pavement Management Surface Rating Manual*, April 1991.

3. *A State-of-the-Art Report: Load Transfer Design and Benefits for Portland Cement Concrete Pavements*, Report Number 96-128-E1, ERES Consultants, Inc., 1998.

Joint #	Embedment Length[a] (on approach side, mm)					No dowels across joint
	Dowel #1 [b]	Dowel #2	Dowel #10	Dowel #11	Dowel #12	
13	89	108		89	89	
14	184	165		133	127	
15	-13	13		-38	-51	x
16	51	51	25	19		
18	-114	-102	-95	-95		x
19	64	38		19	32	
20	152	133		70	70	
21	-114	-114	-89	-89		x
24	44	38	25	19		
25	0	-6		44	32	x
26	108	108	89	102		
28	38	38		89	108	
29	19	19	44	38		
30	400	400				x
31	267		267			

Notes: a) Design embedment length = 190 mm
b) Dowel #1 located nearest to driving lane shoulder

Unit conversion: 25.4 mm = 1 inch

Table 1. Dowel bar embedment measurements

Joint #	Faulting Measurements (mm)		
	-3250 mm Offset [a]	-610 mm Offset	-305 mm Offset
13	0.3		0.1
14	0.4		0.2
15	10.8		5.3
16	12.8	7.4	
18	9	5.8	
19	5.6		1.5
20	0.8		0.7
21	11.3	7.2	
24	9.6	5.4	
25	11.3		6.9
26	0.07	1.1	
28	1.9		0.8
29	9.8	4.3	
30	3.6		
31	0.09	0.6	

Notes: a) Offset measured from centerline, toward driving lane shoulder.

Unit conversion: 25.4 mm = 1 inch

Table 2. Faulting measurements

Joint #	Average[a] Load Transfer Efficiency (%)			
	Load Position 0	Load Position 1	Load Position 2	Load Position 3
11	78	73	75	70
12	79	72	76	69
13	78	76	76	73
14	79	76	77	76
15	56	53	52	46
16	52	50	60	54
17	44	34	37	30
18	59	75	53	68
19	65	49	58	41
20	86	83	86	87
21	58	51		
22	60	54		
23	64	56		
24	67	57		
25	66	55		
26	84	79		
27	86	82		
28	73	76		
29	77	65		
30	63	82		
31	80	78		
33	87	83		
34	85	79		

Notes: a) Average of LTE from 40 kN and 66.7 kN loading levels combined.

Unit conversion: 1 kN = 225 lbs

Table 3. Load transfer efficiency testing results

a) Near Dowel #1

Joint #	Embedment Length[a] (mm)	LTE[b] (%)	
		Load Pos. 0	Load Pos. 1
13	98.5	78	76
14	174.5	79	76
15	0	56	53
16	51	52	50
18	0	59	75
19	51	65	49
20	142.5	86	83
21	0	58	51
24	41	67	57
25	0	66	55
26	108	84	79
28	38	73	76
29	19	77	65
30	0	63	82
31	76.5	80	78

Notes: a) Approach side, average of dowels #1 and #2.
b) Average of 40 kN & 66.7 kN loading level results.

b) Near Dowel #12

Joint #	Embedment Length[c] (mm)	LTE[d] (%)	
		Load Pos. 2	Load Pos. 3
13	89	76	73
14	130	77	76
15	0	52	46
16	22	60	54
18	0	53	68
19	25.5	58	41
20	70	86	87

Notes: c) Approach side, average of dowels #11 and #12.
d) Average of 40 kN & 66.7 kN loading level results.

Unit conversions: 25.4 mm = 1 inch; 1 kN = 225 lbs.

Table 4. Embedment Length versus Load Transfer Efficiency

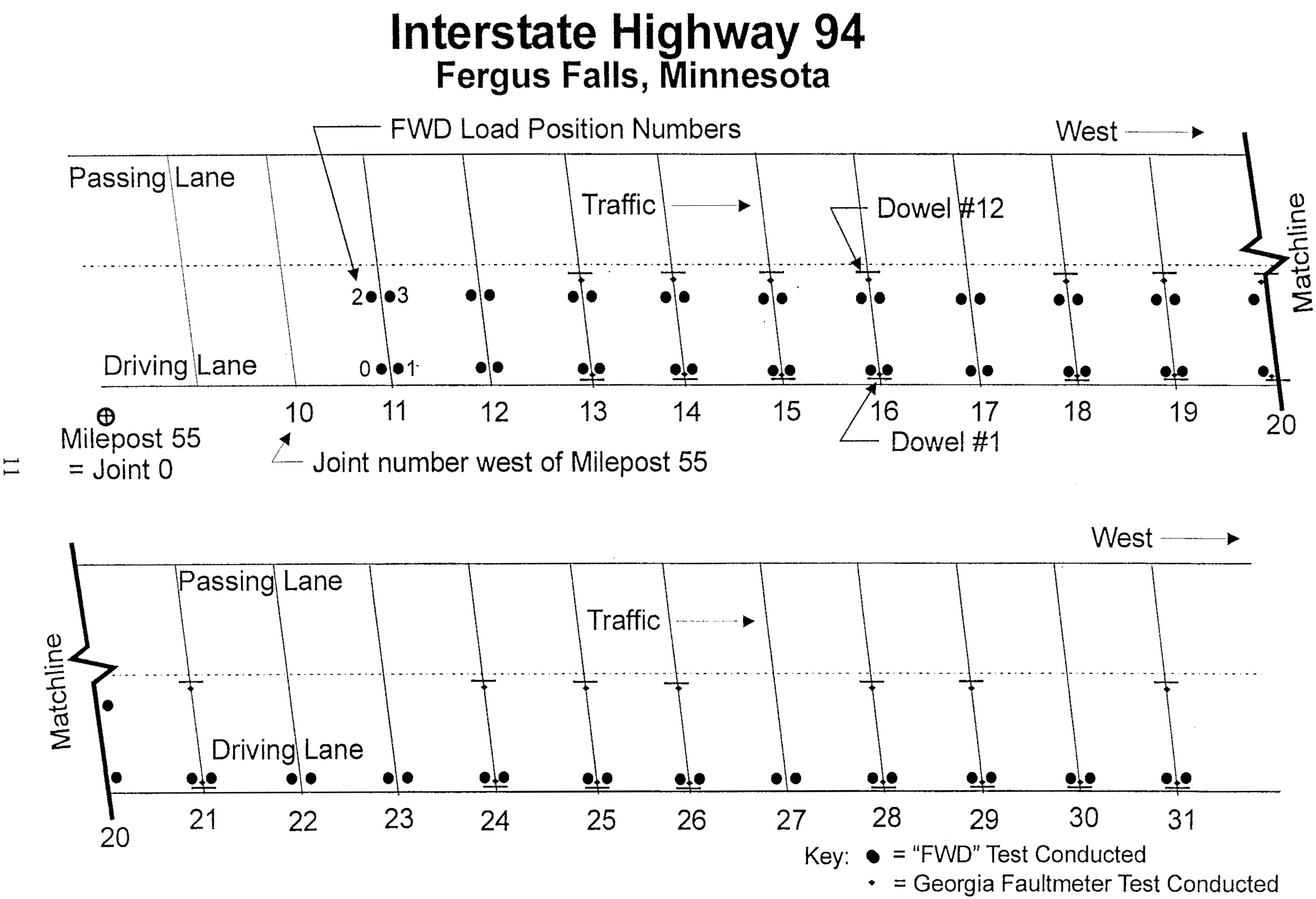
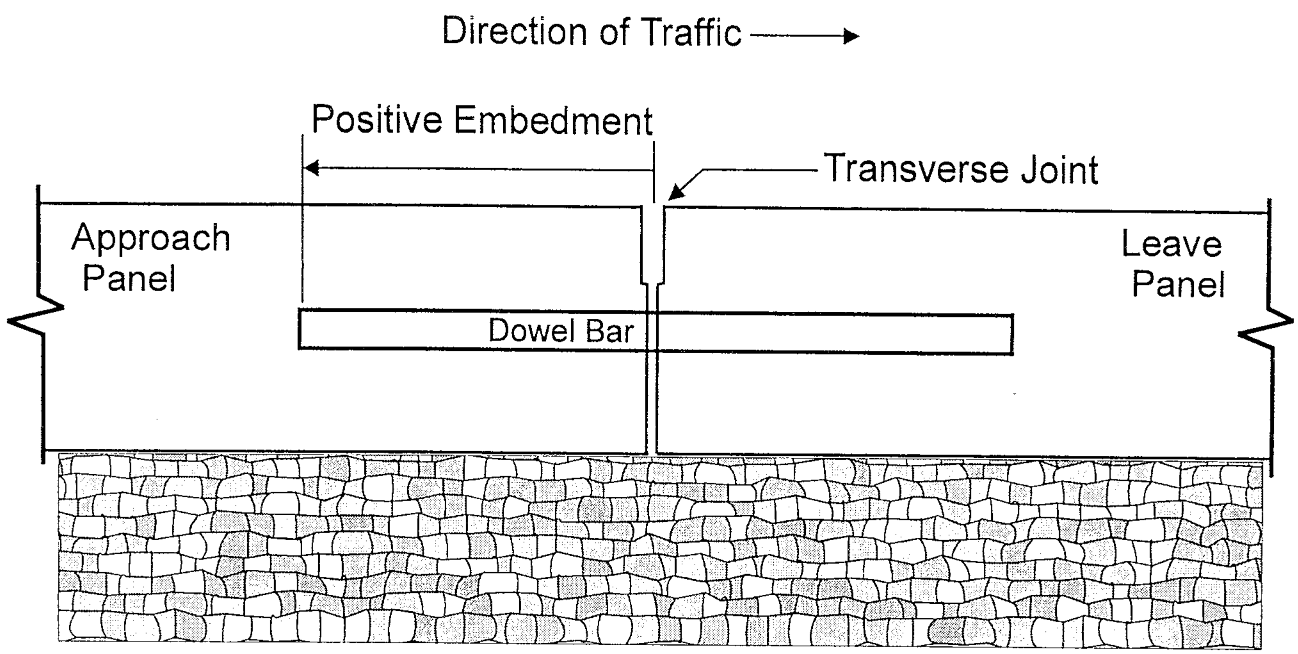
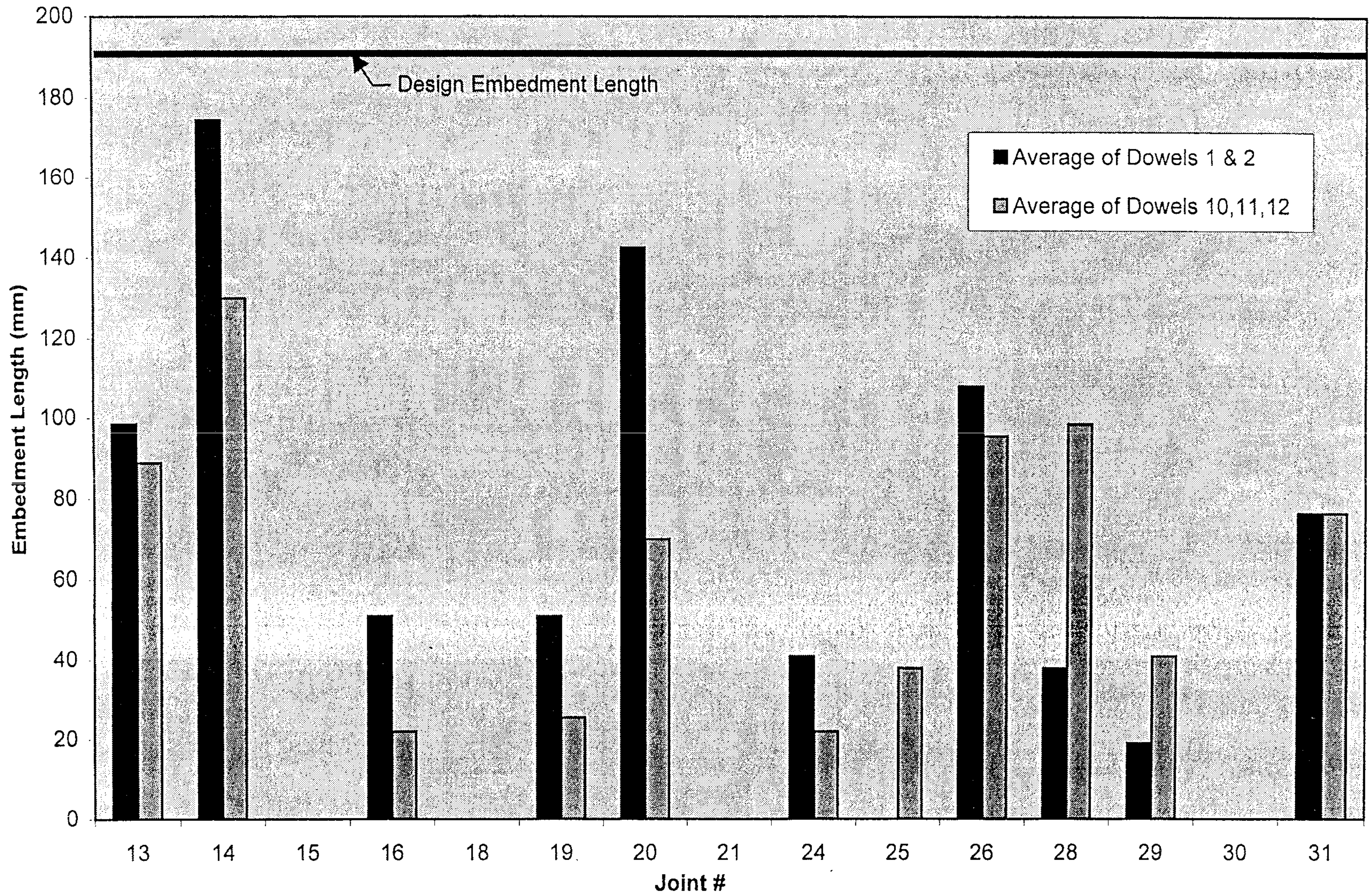


Figure 1. Test Site



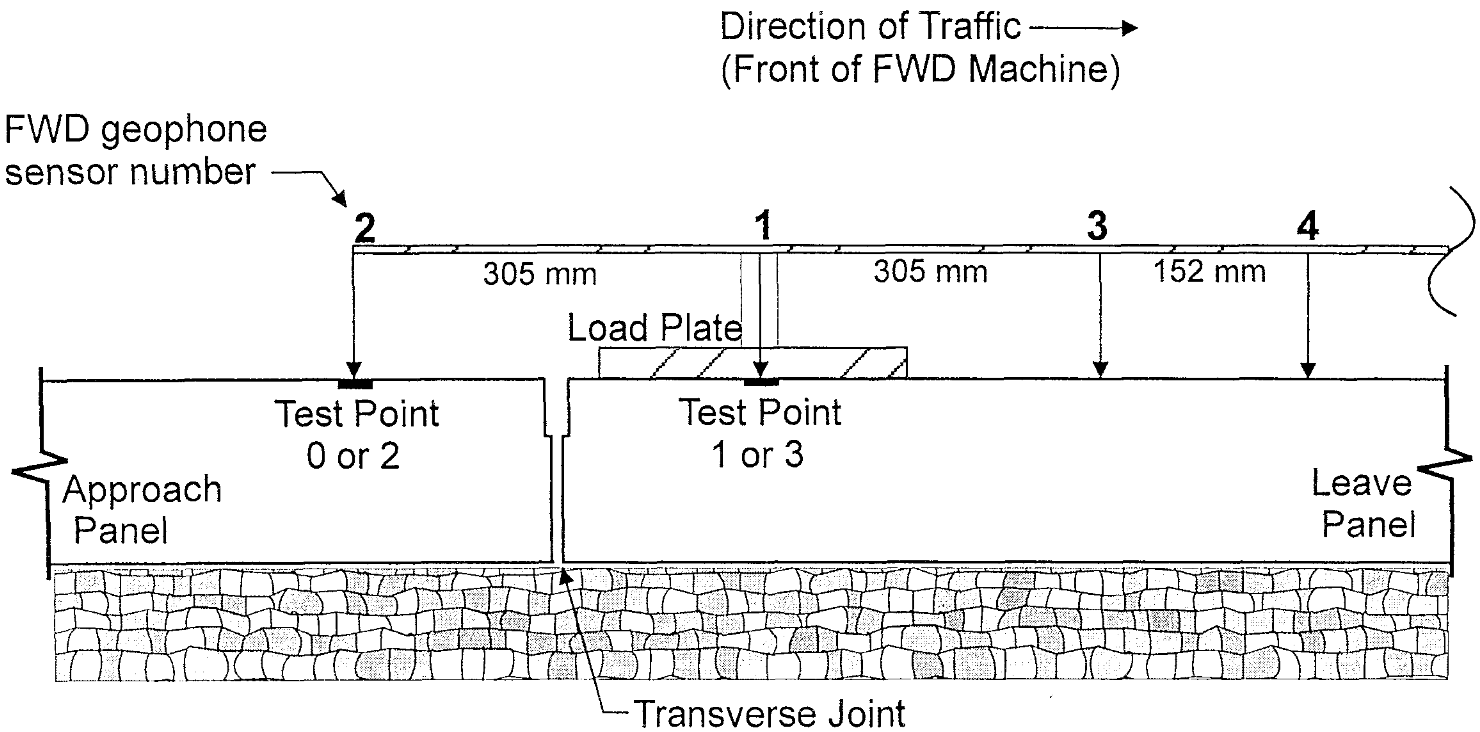
(Side view)

Figure 2. Embedment length notation



Note: Embedment lengths > 356 mm or < 0 are shown as zero on graph.

Figure 3. Dowel bar embedment lengths



(Side view)

Figure 4. FWD Geophone Arrangement Scheme

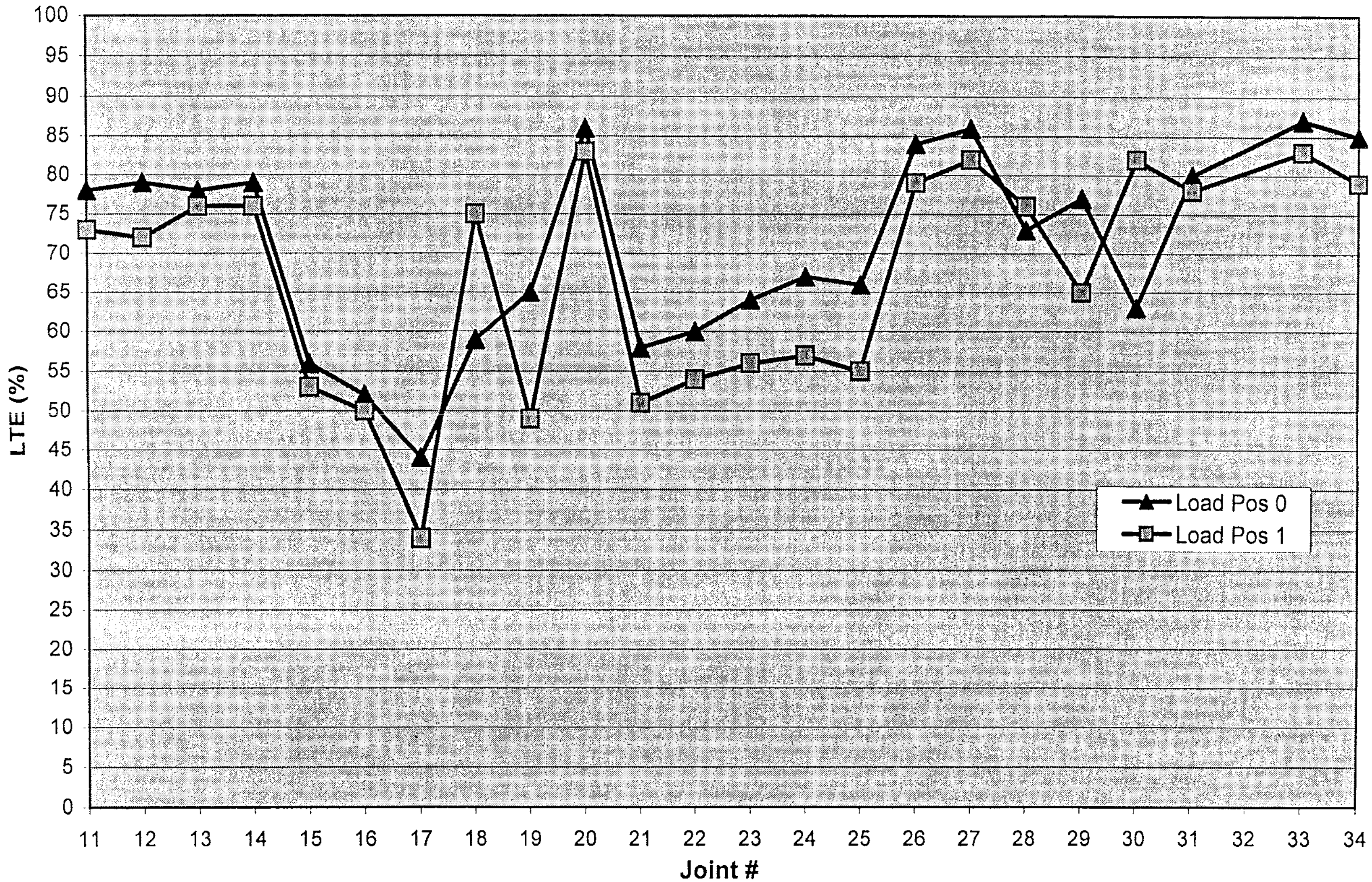


Figure 5a. Load Transfer Efficiency - Near Dowel #1

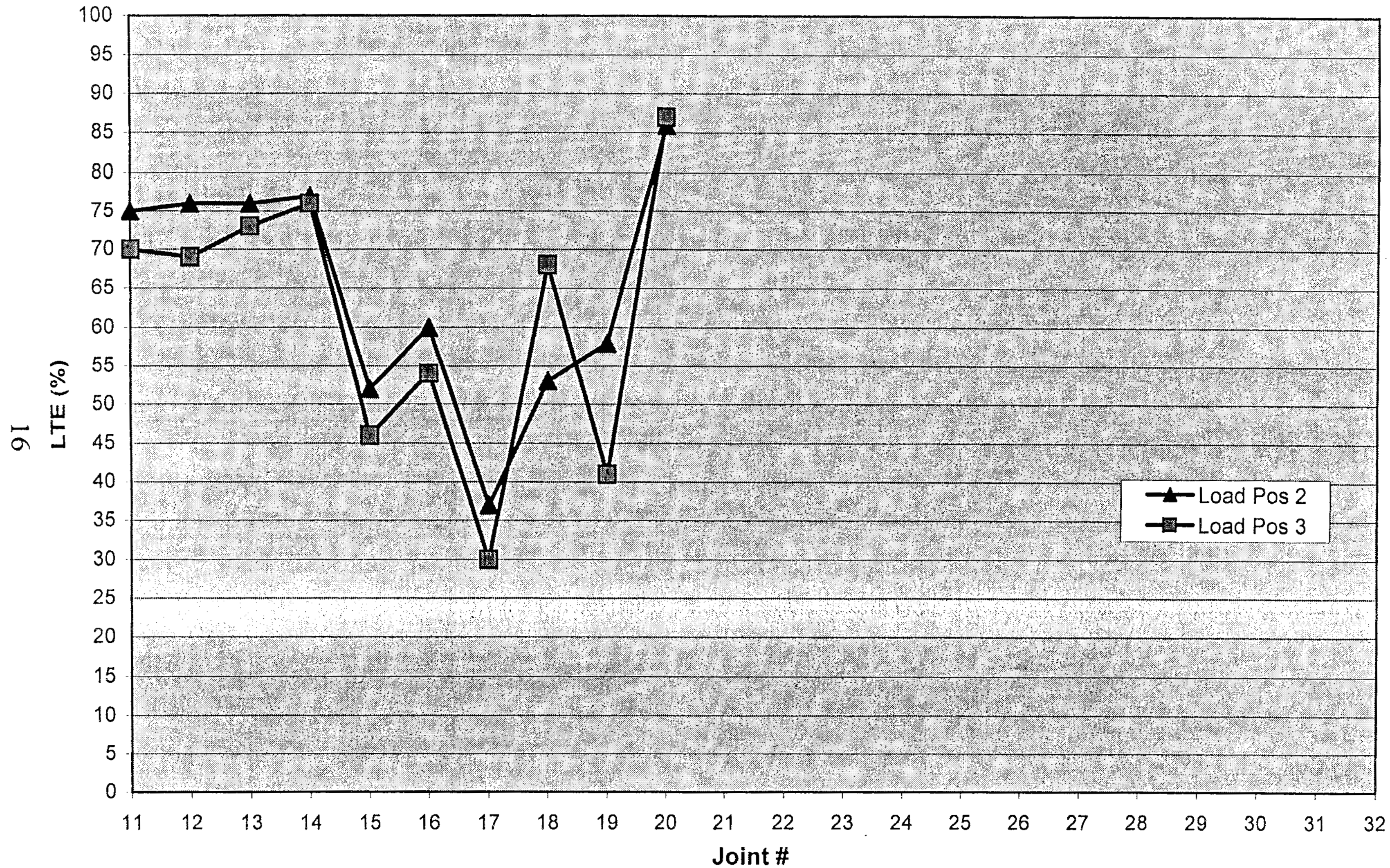


Figure 5b. Load Transfer Efficiency - Near Dowel #12

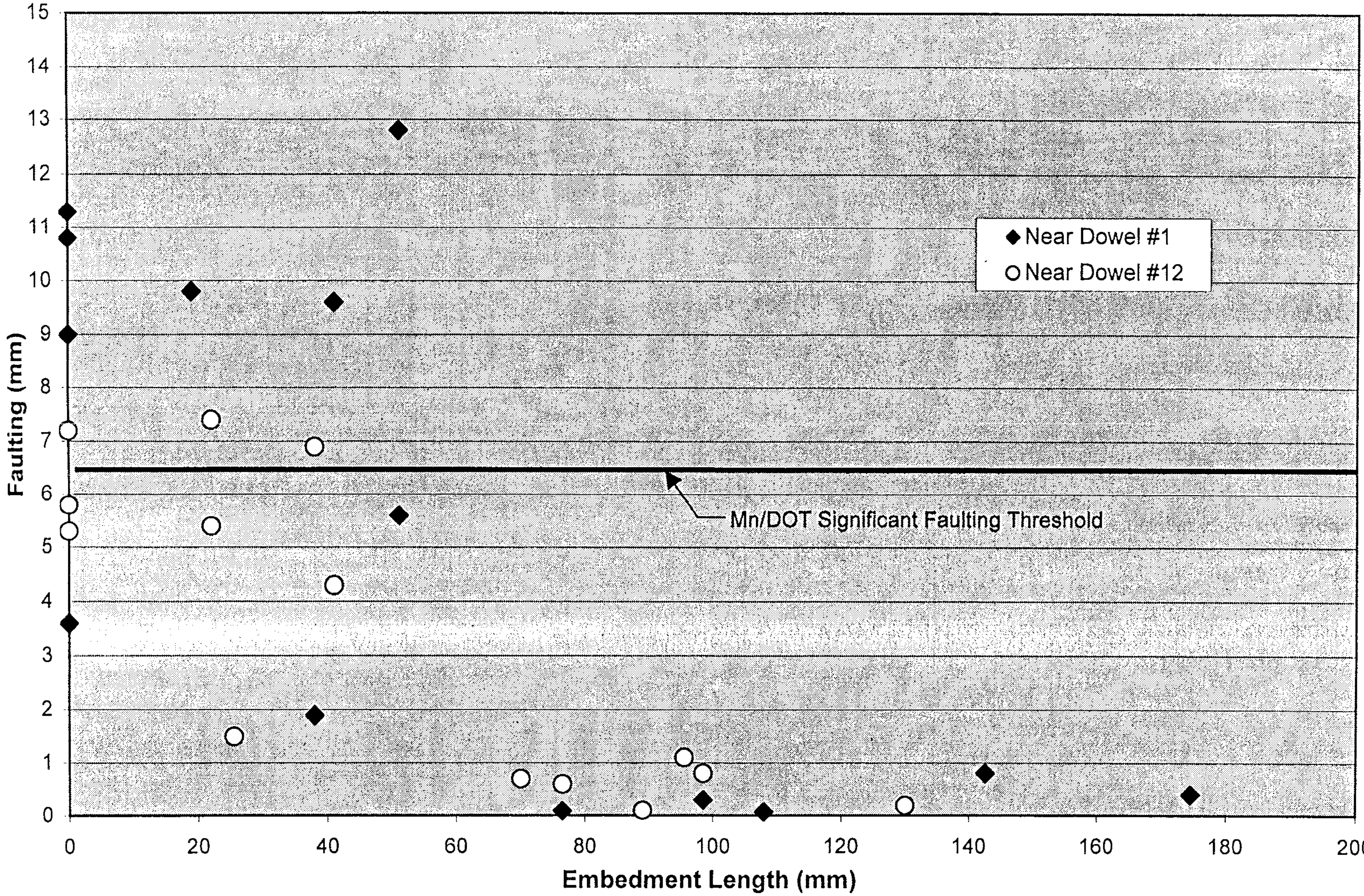


Figure 6. Embedment Length versus Joint Faulting

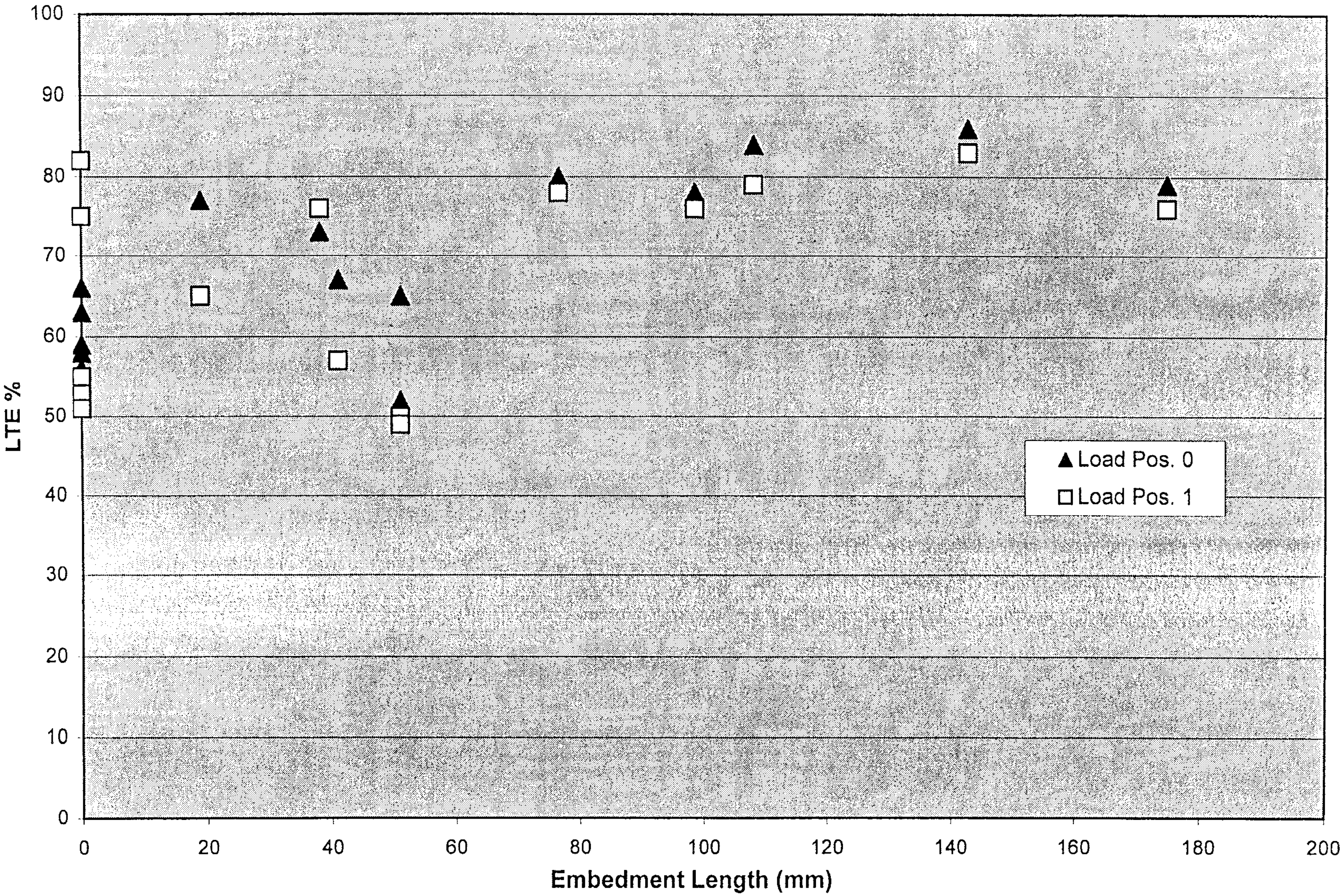


Figure 7a. Embedment length vs load transfer efficiency - Near Dowel #1

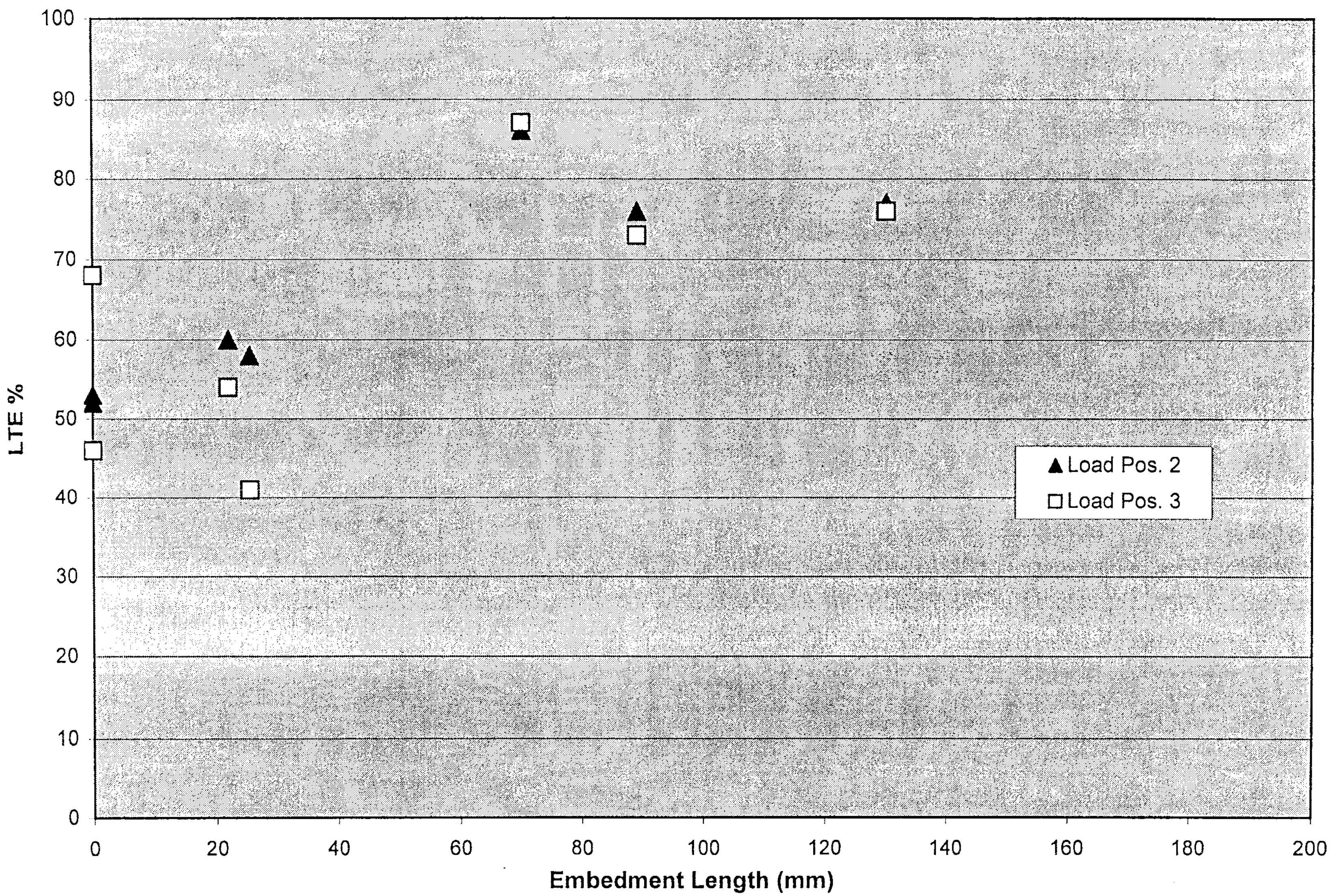


Figure 7b. Embedment length vs load transfer efficiency - Near Dowel #12

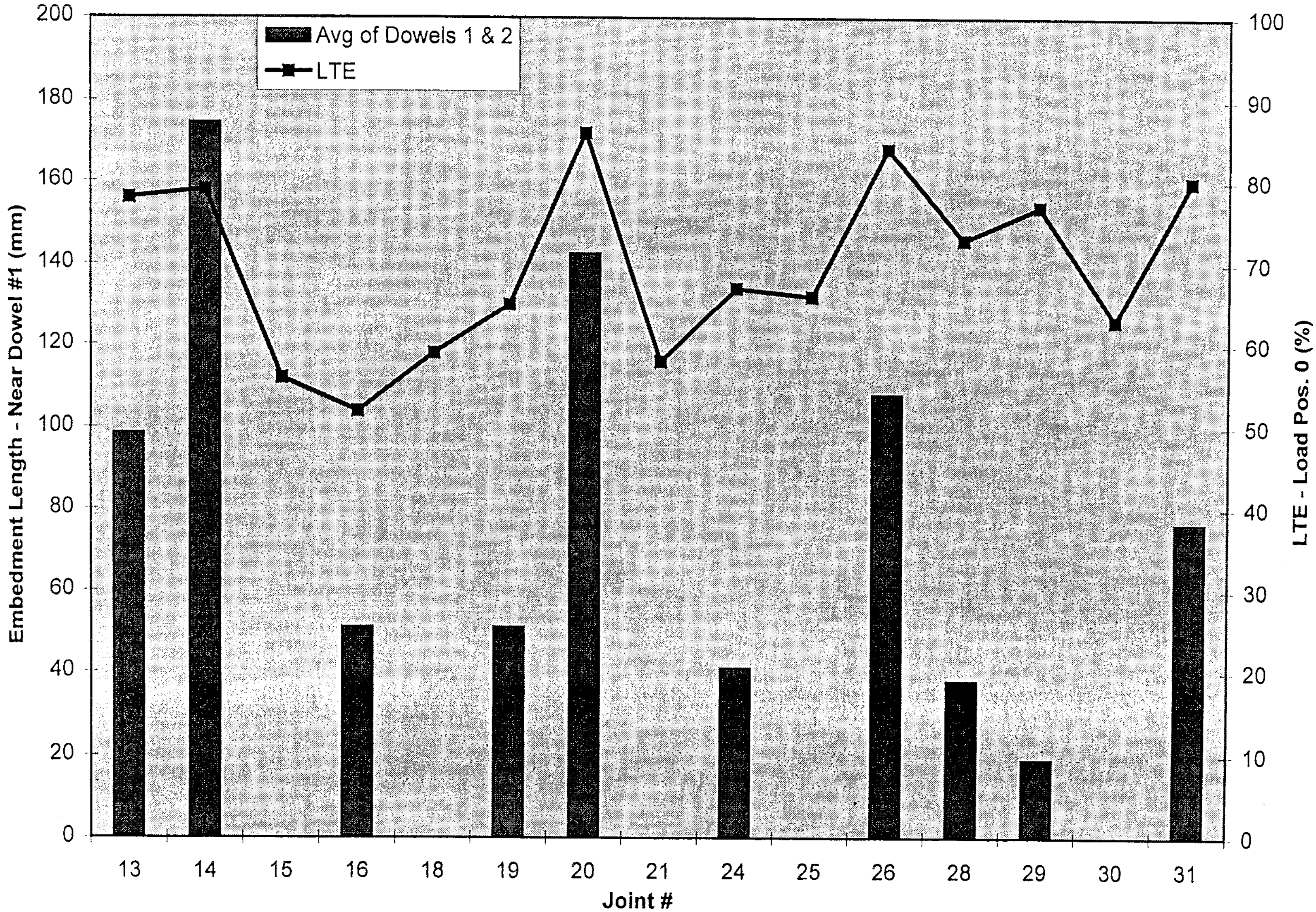


Figure 8a. Variation of embedment length and LTE for load position 0

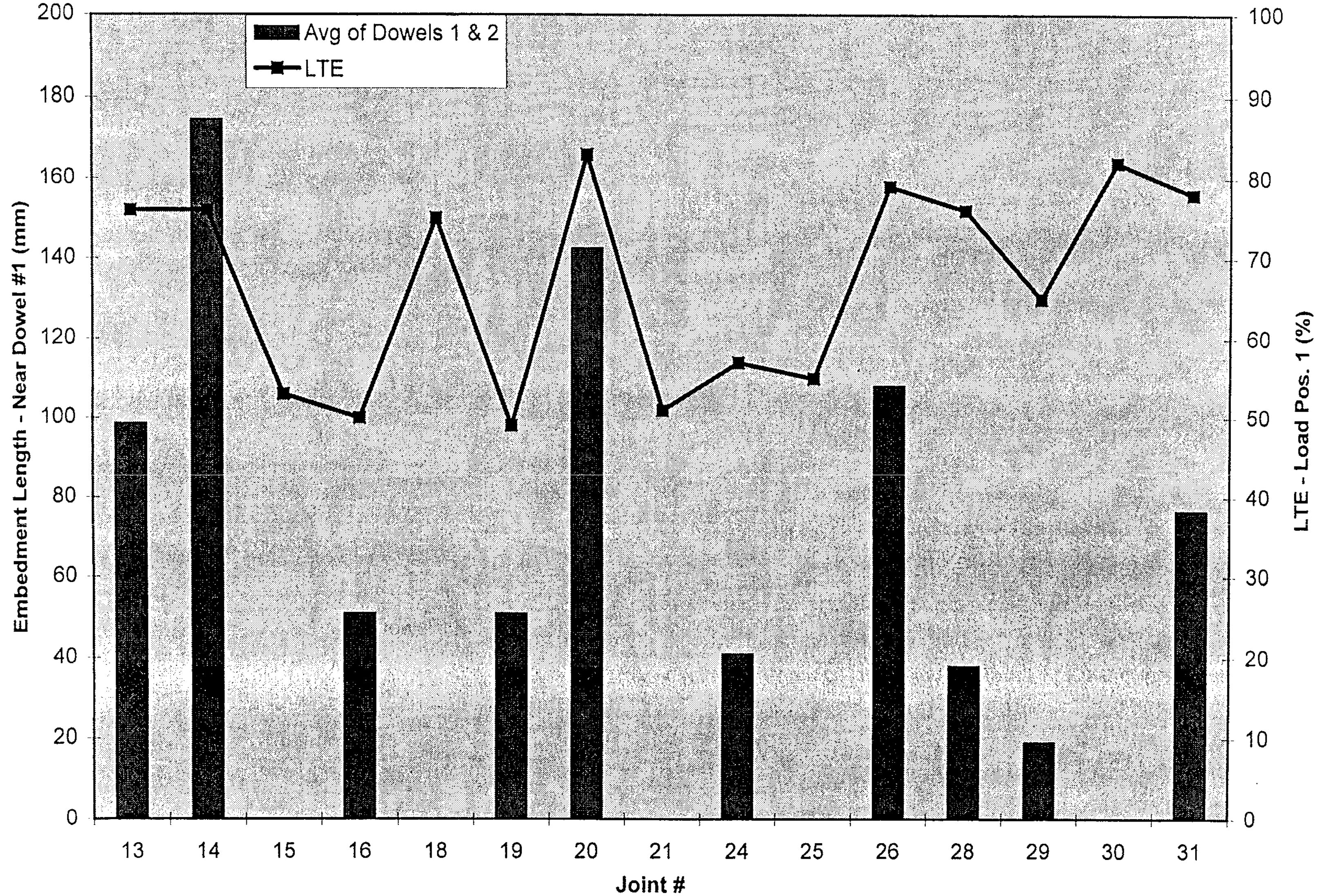


Figure 8b. Variation of embedment length and LTE for load position 1

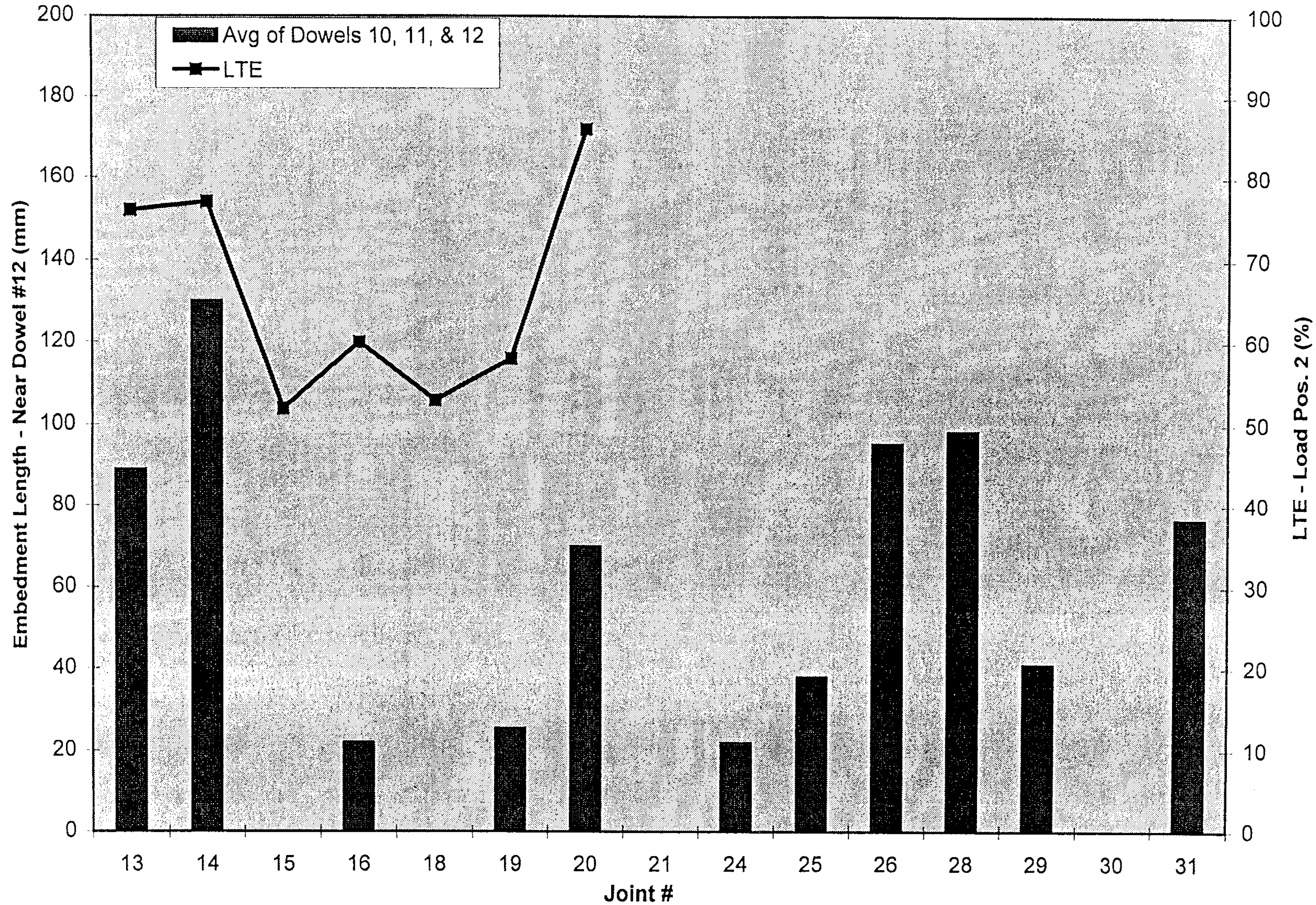


Figure 8c. Variation of embedment length and LTE for load position 2

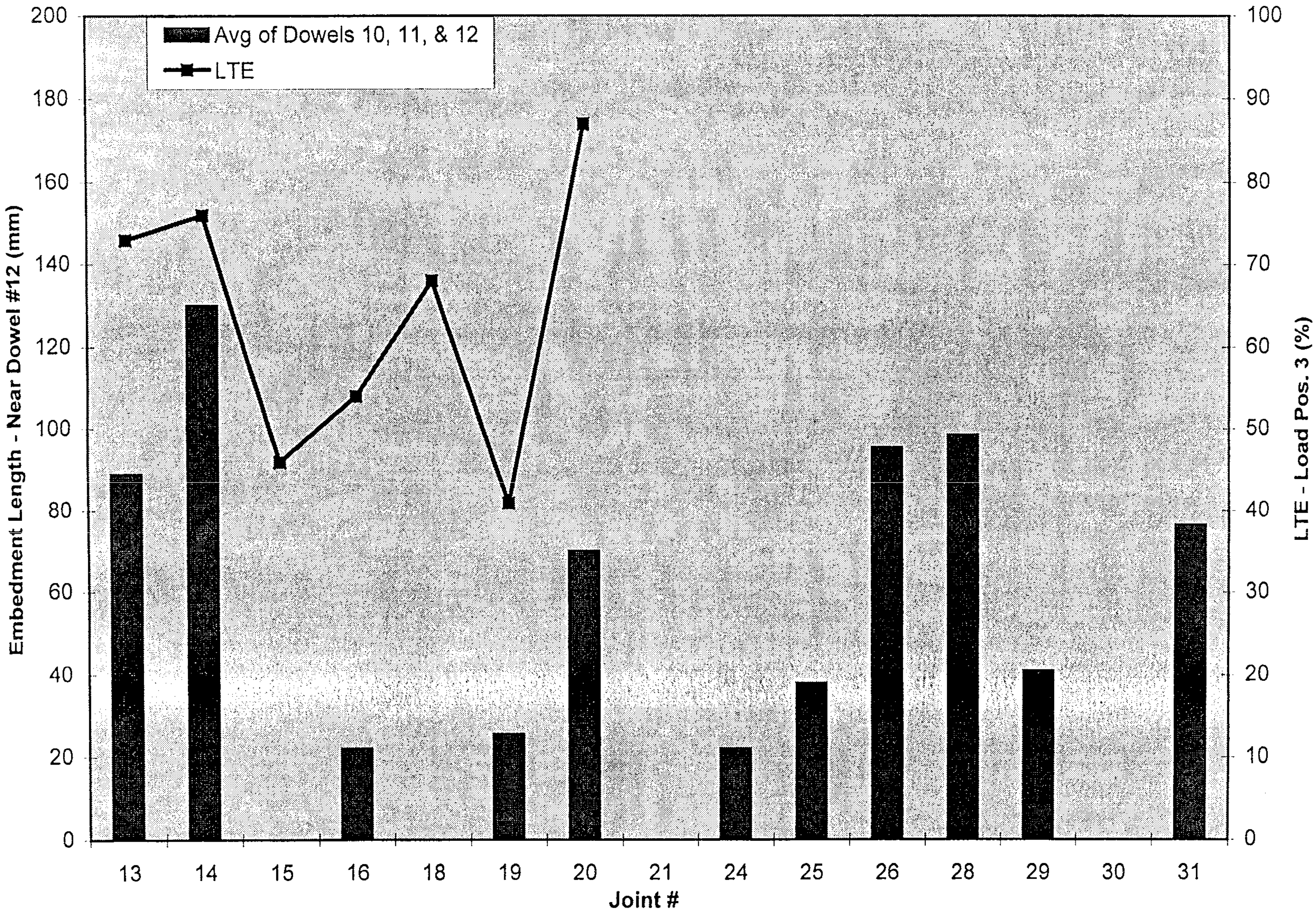


Figure 8d. Variation of embedment length and LTE for load position 3

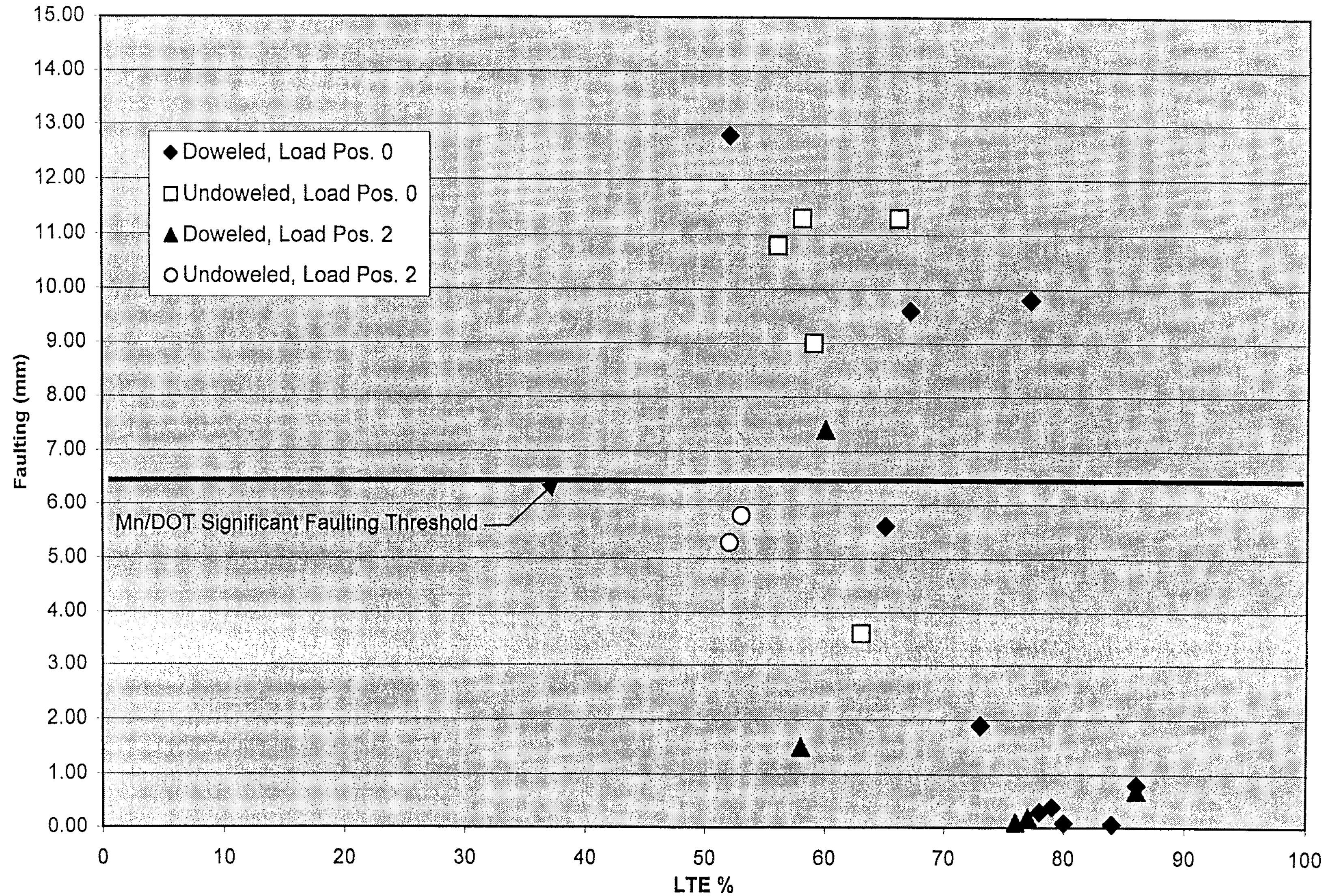


Figure 9a. LTE versus joint faulting - Approach panel side

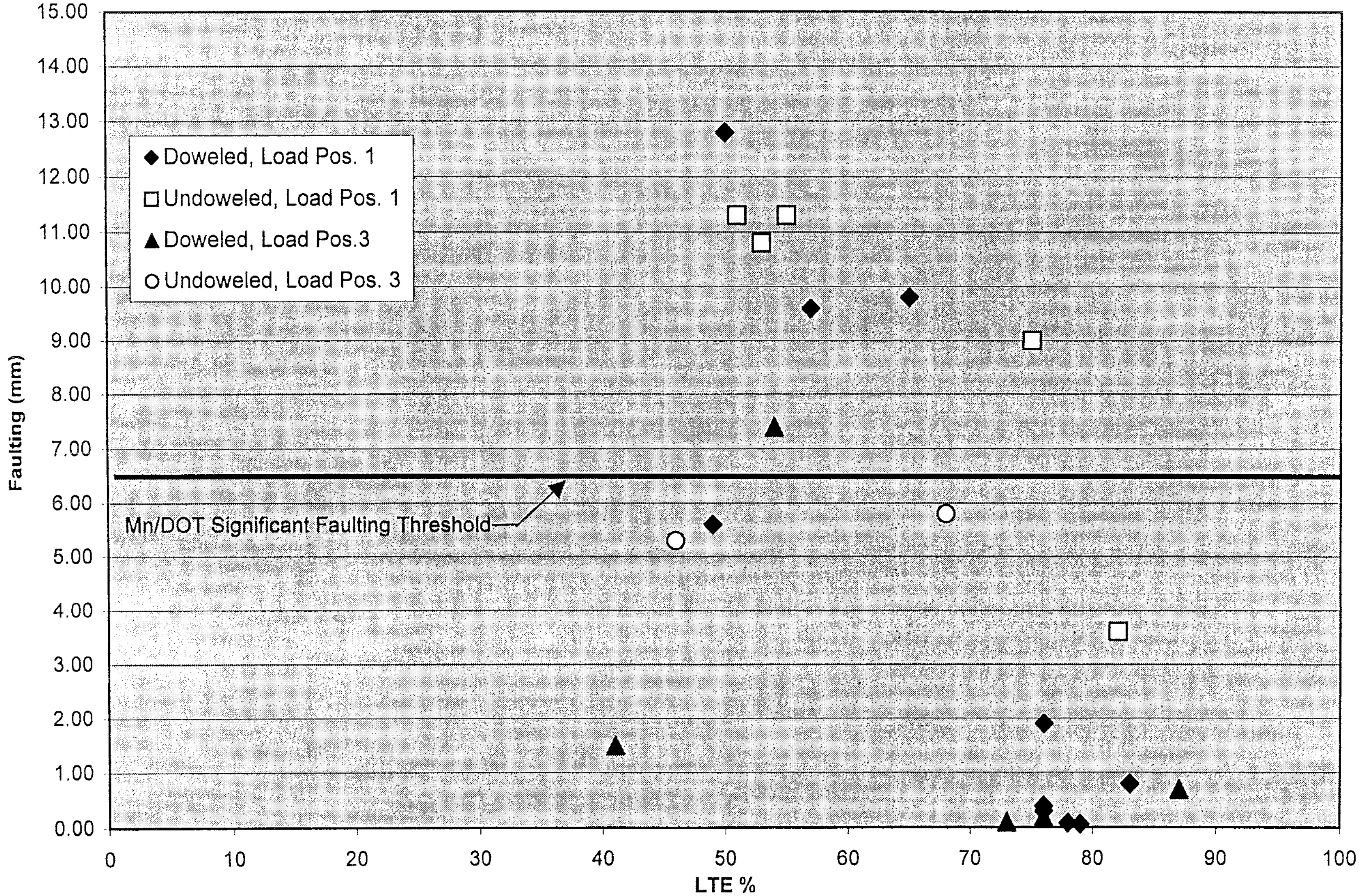
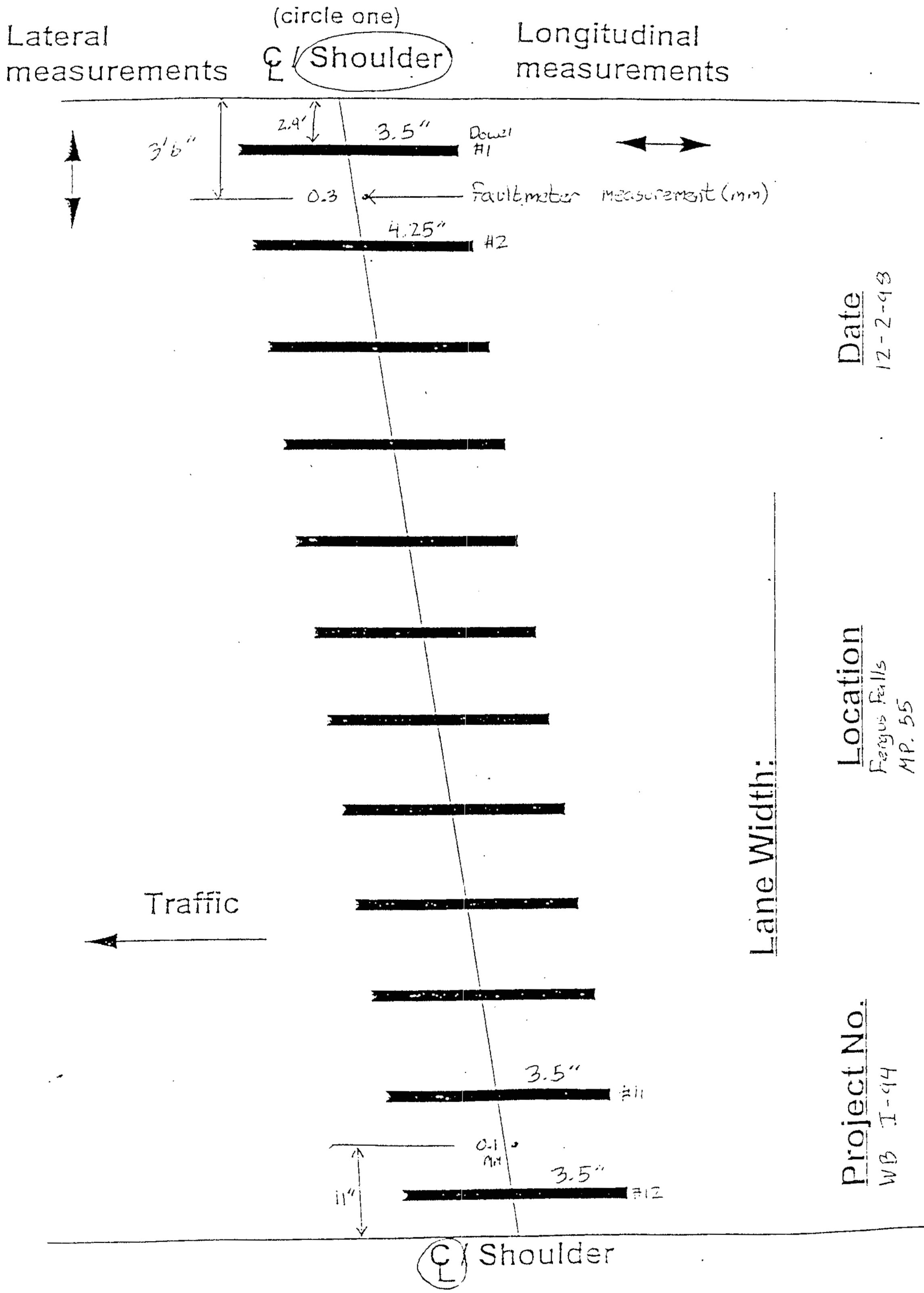


Figure 9b. LTE versus joint faulting - Leave panel side

APPENDIX A

FIELD DATA COLLECTION SHEETS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Longitudinal measurements
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12-2-93
Location
Fergus Falls
MP. 55
Jt. #13
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Project No.
WB I-94
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#11
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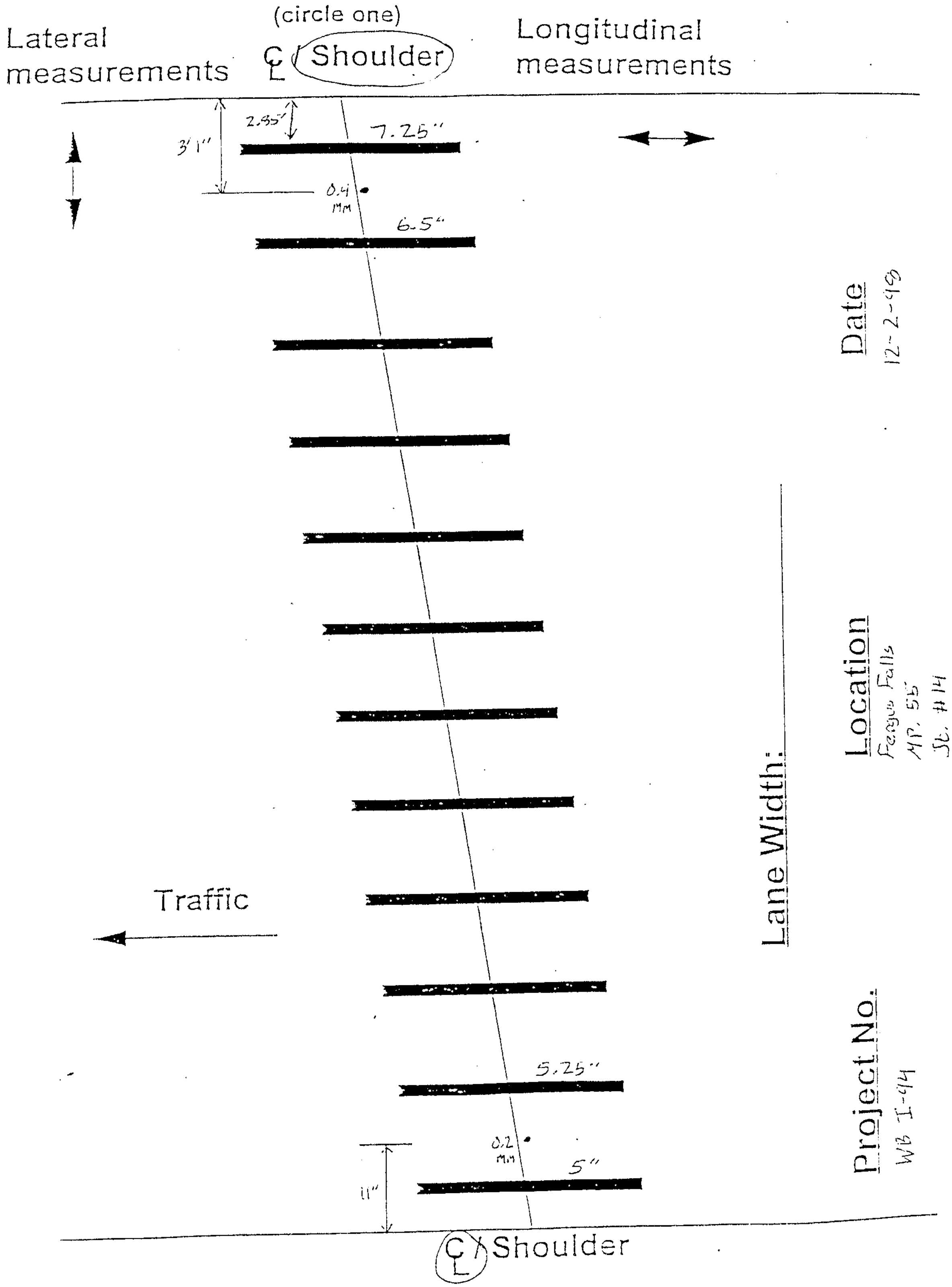
3.5"
#12
11"
CL / Shoulder



Lateral measurements
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CL / Shoulder
Longitudinal measurements
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7.25"
0.4 mm
6.5"
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12-2-99
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Fergus Falls
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St. #14
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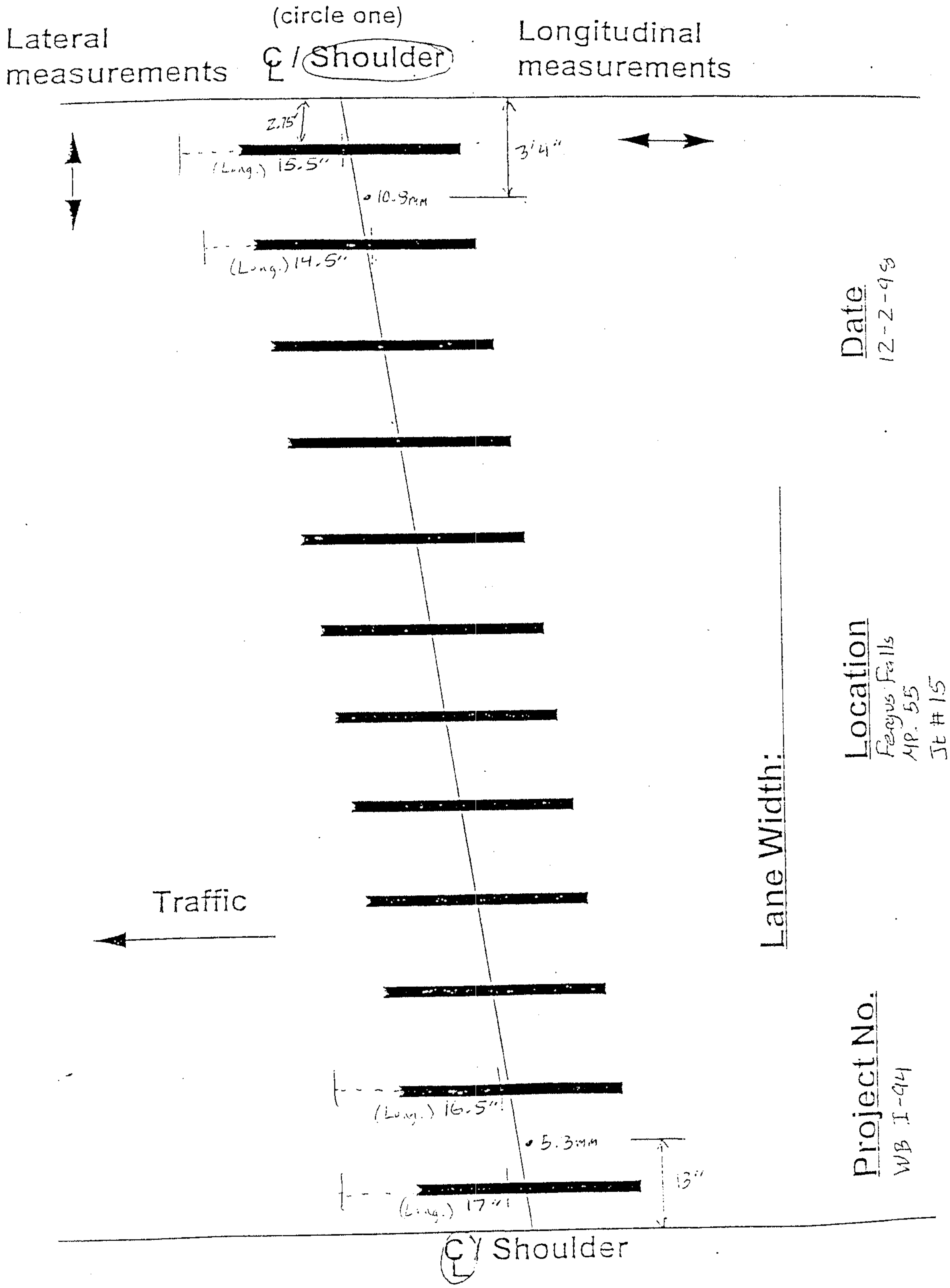
Traffic
Project No.
WB I-94
5.25"
0.2 mm
5"
11"
CL / Shoulder



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C/L / Shoulder
Longitudinal measurements
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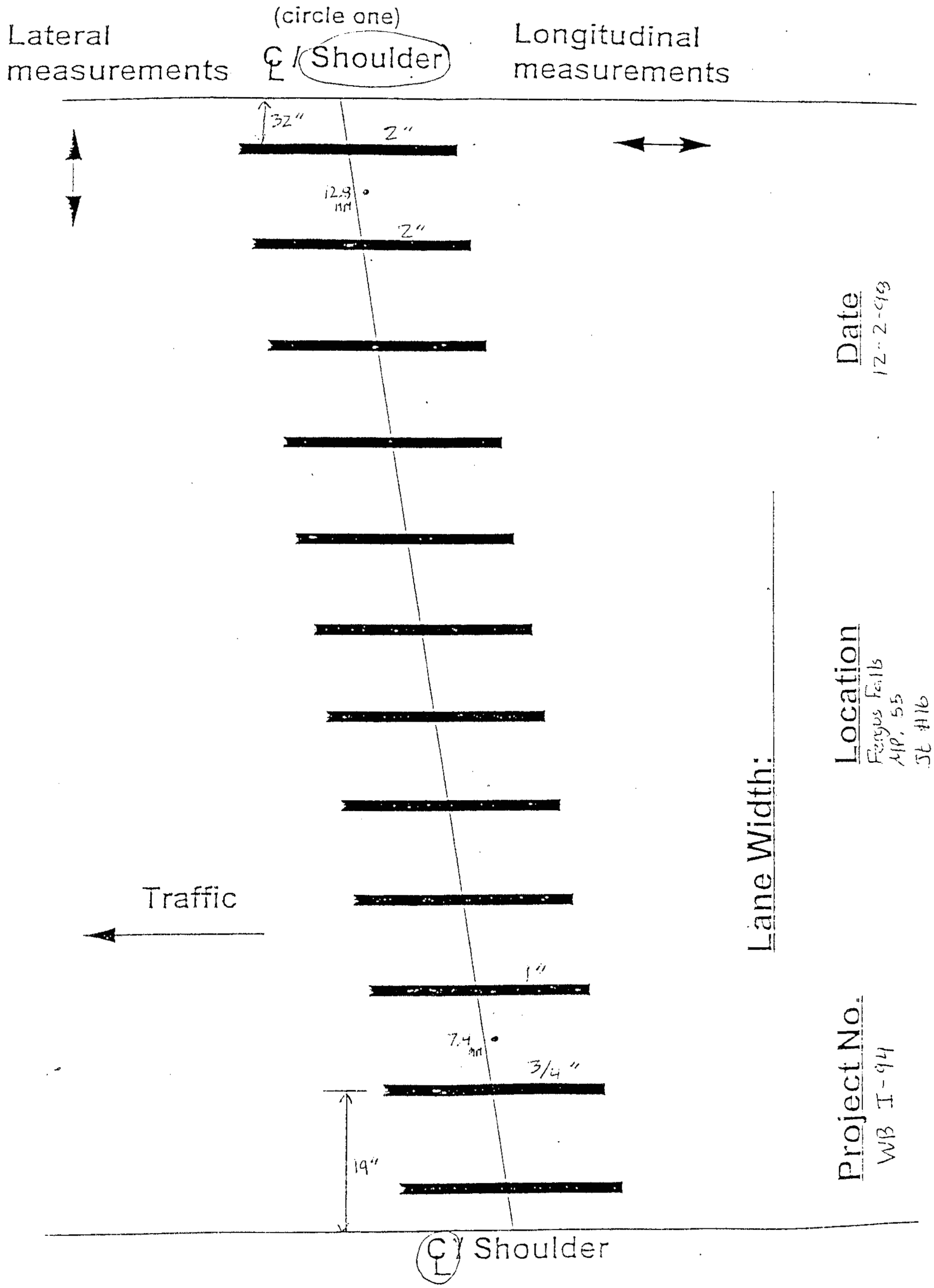
C/L / Shoulder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Date
Location
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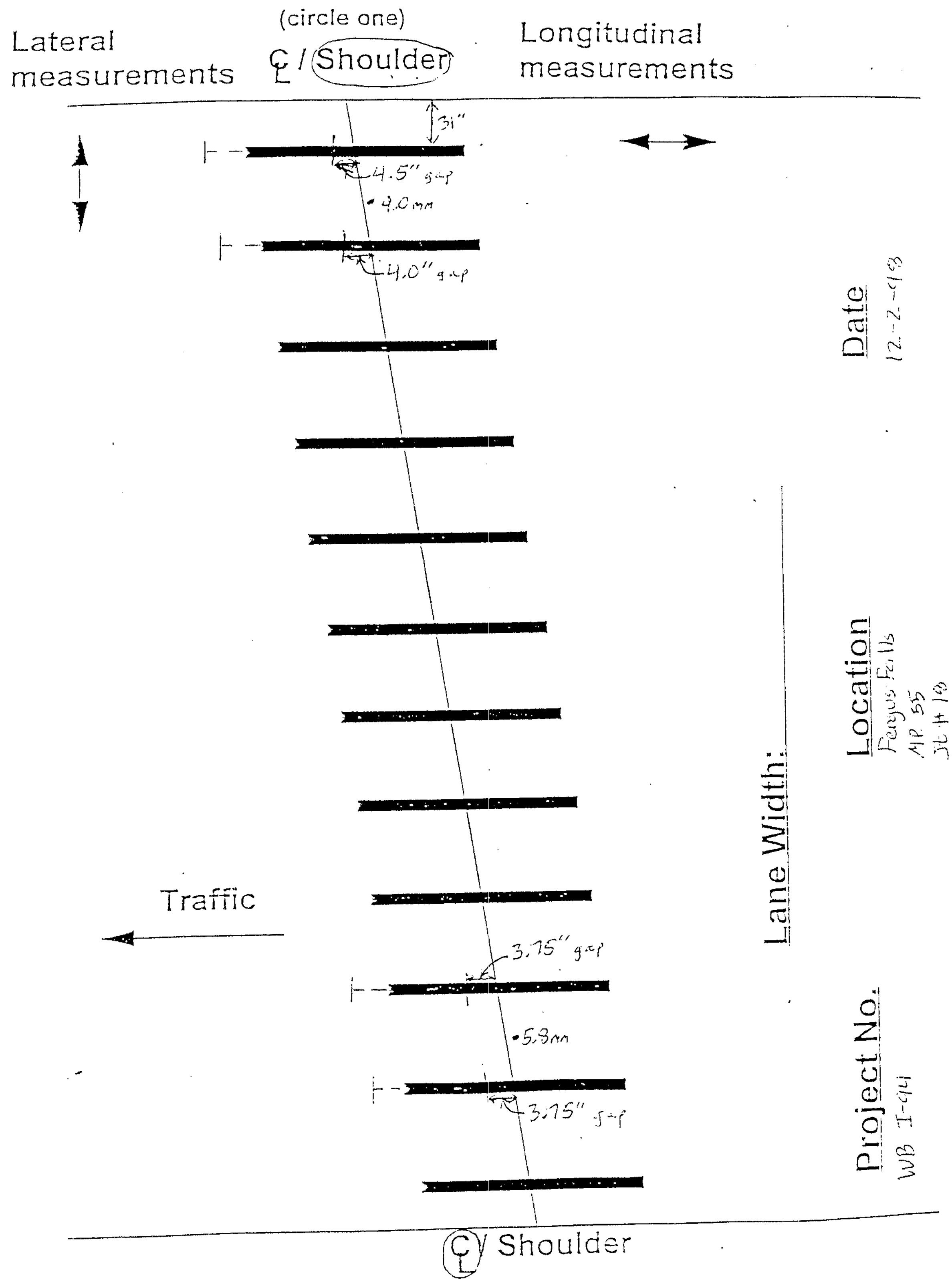
WB I-94
CL / Shoulder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C/L / Shoulder
Longitudinal measurements
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4.0" gap
Date
Location
Lane Width:
Project No.
WB I-94
Traffic
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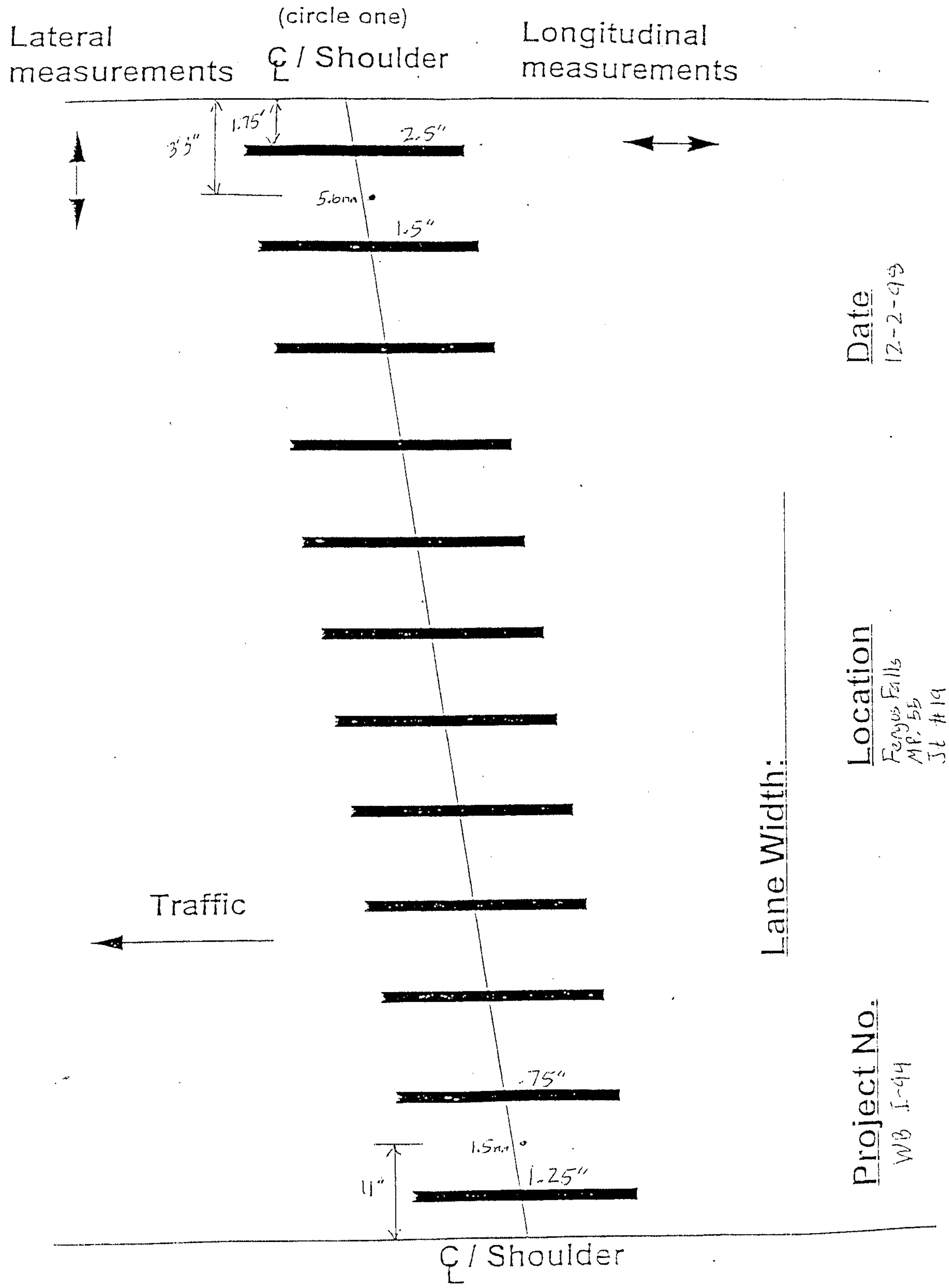
3.75" gap
C/L / Shoulder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CL / Shoulder
Longitudinal measurements
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3'5"
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1.5mm
1.25"
11"
Traffic
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12-2-99
Location
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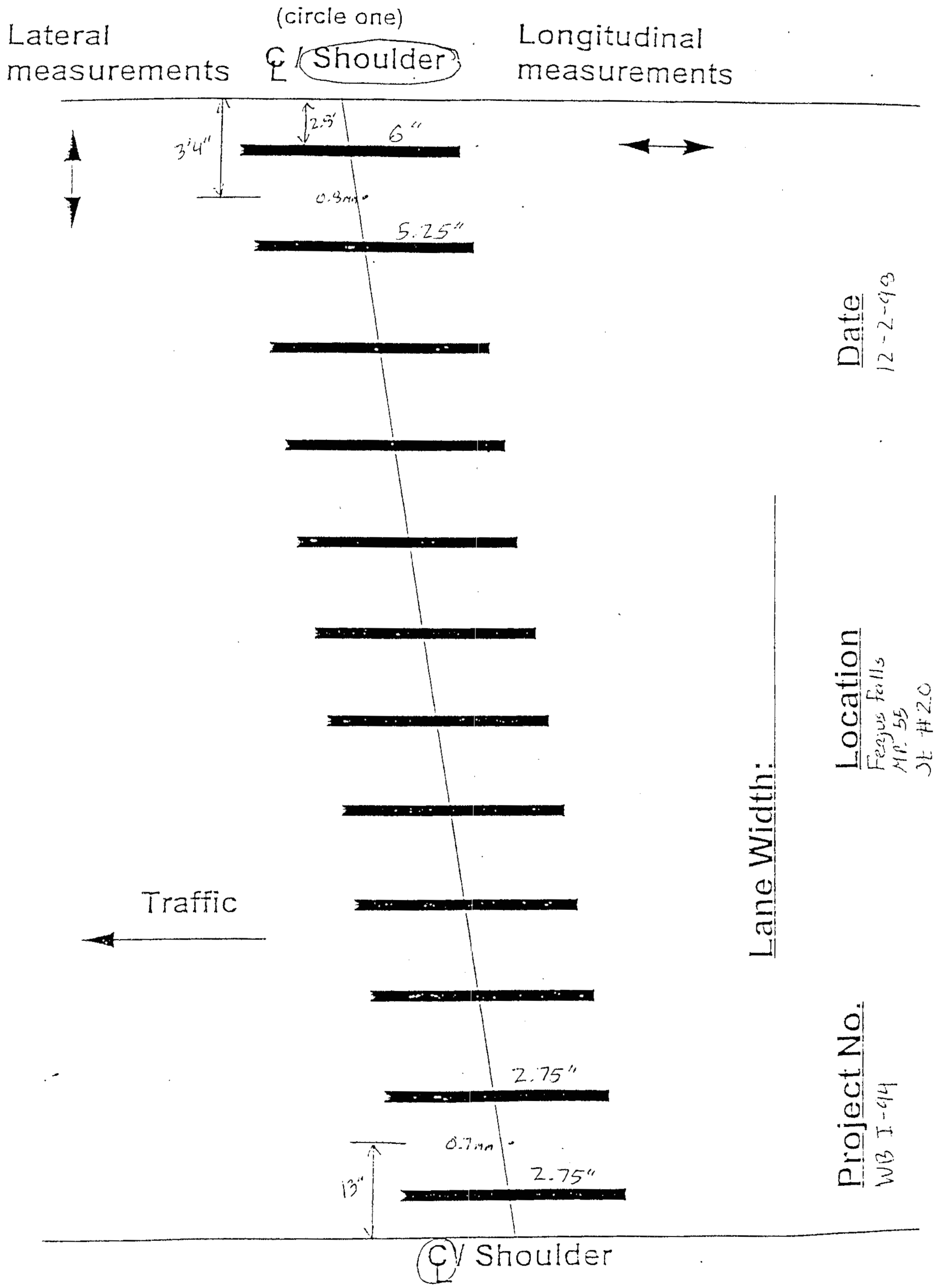
CL / Shoulder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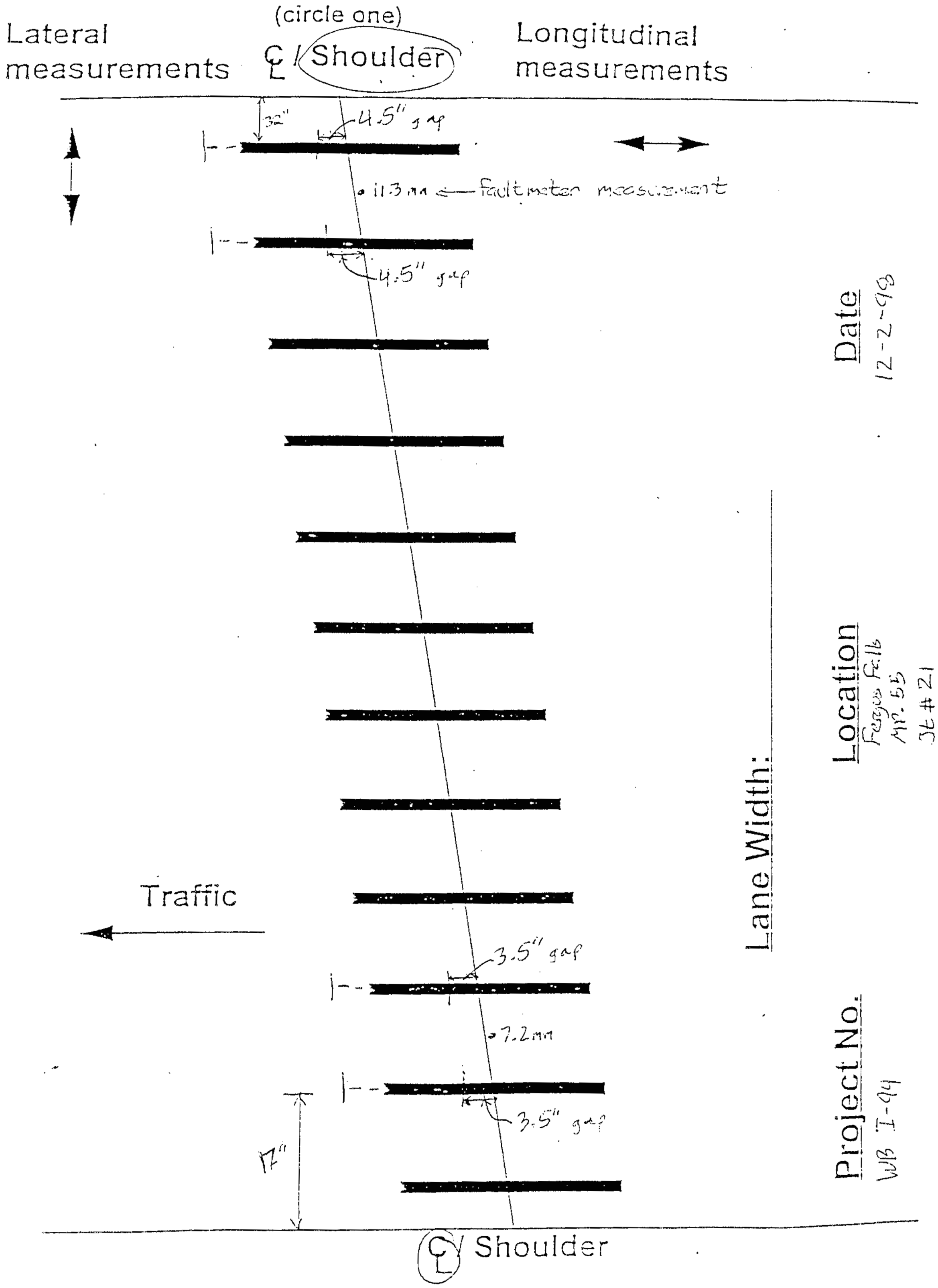
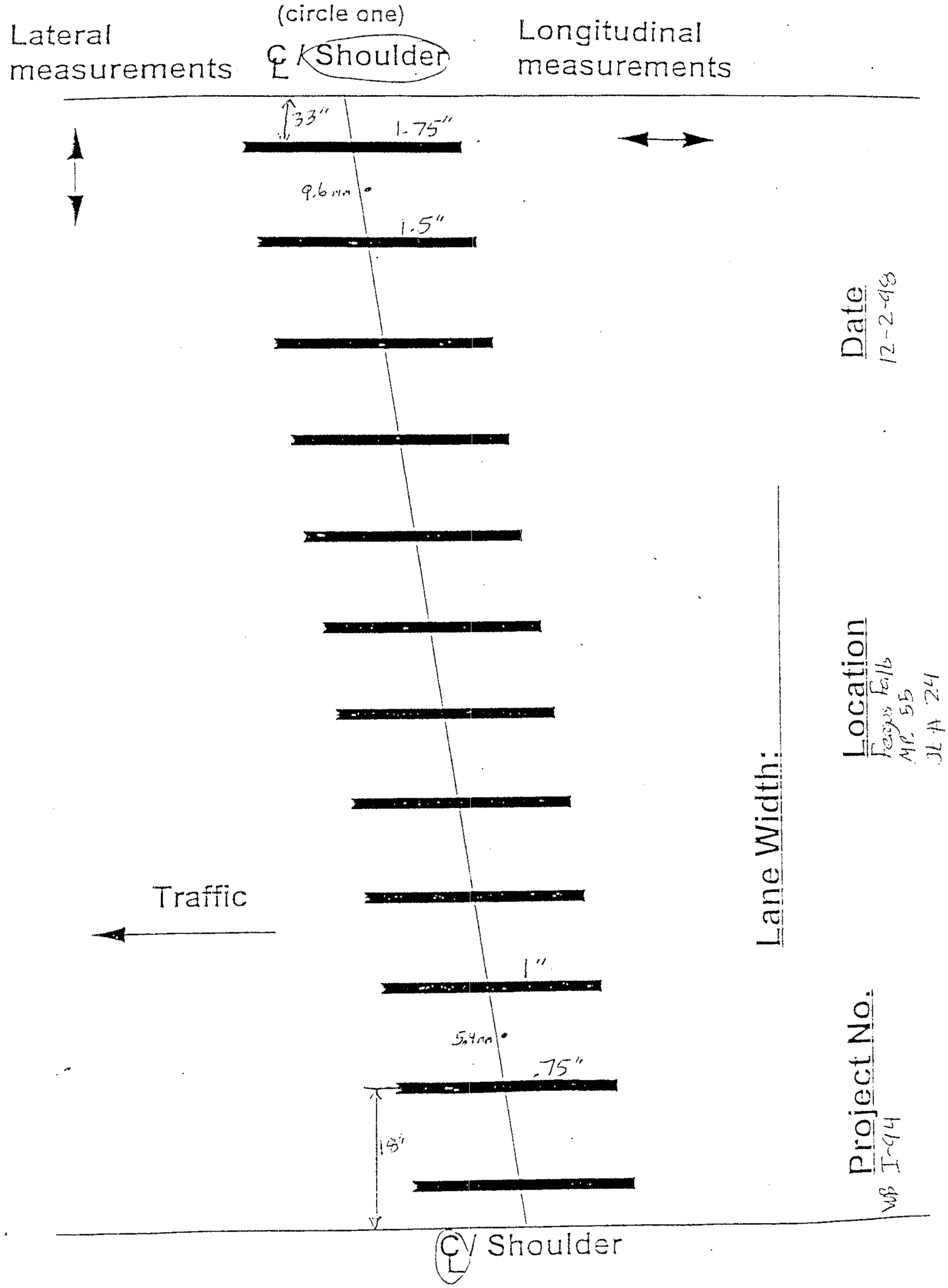
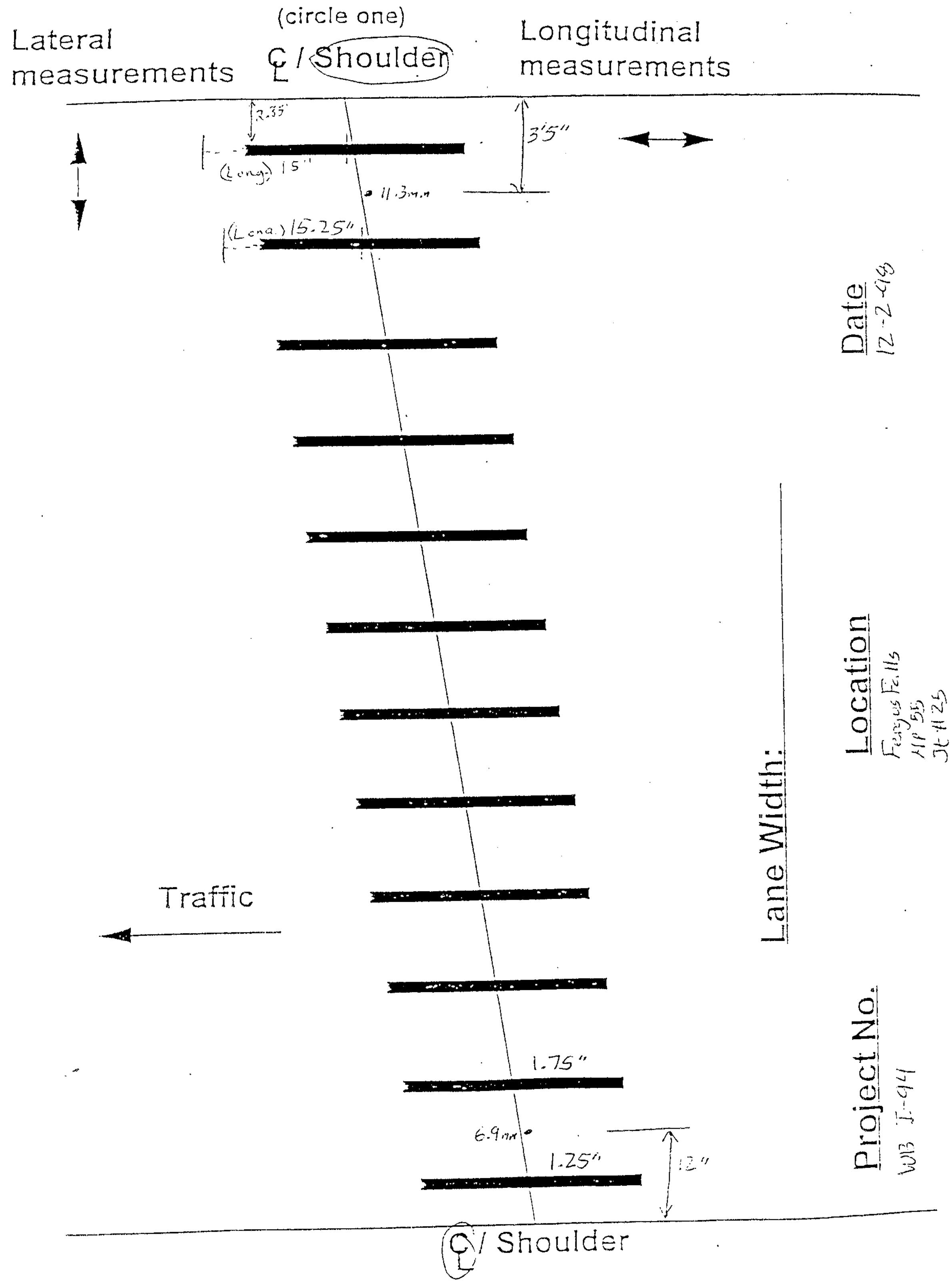
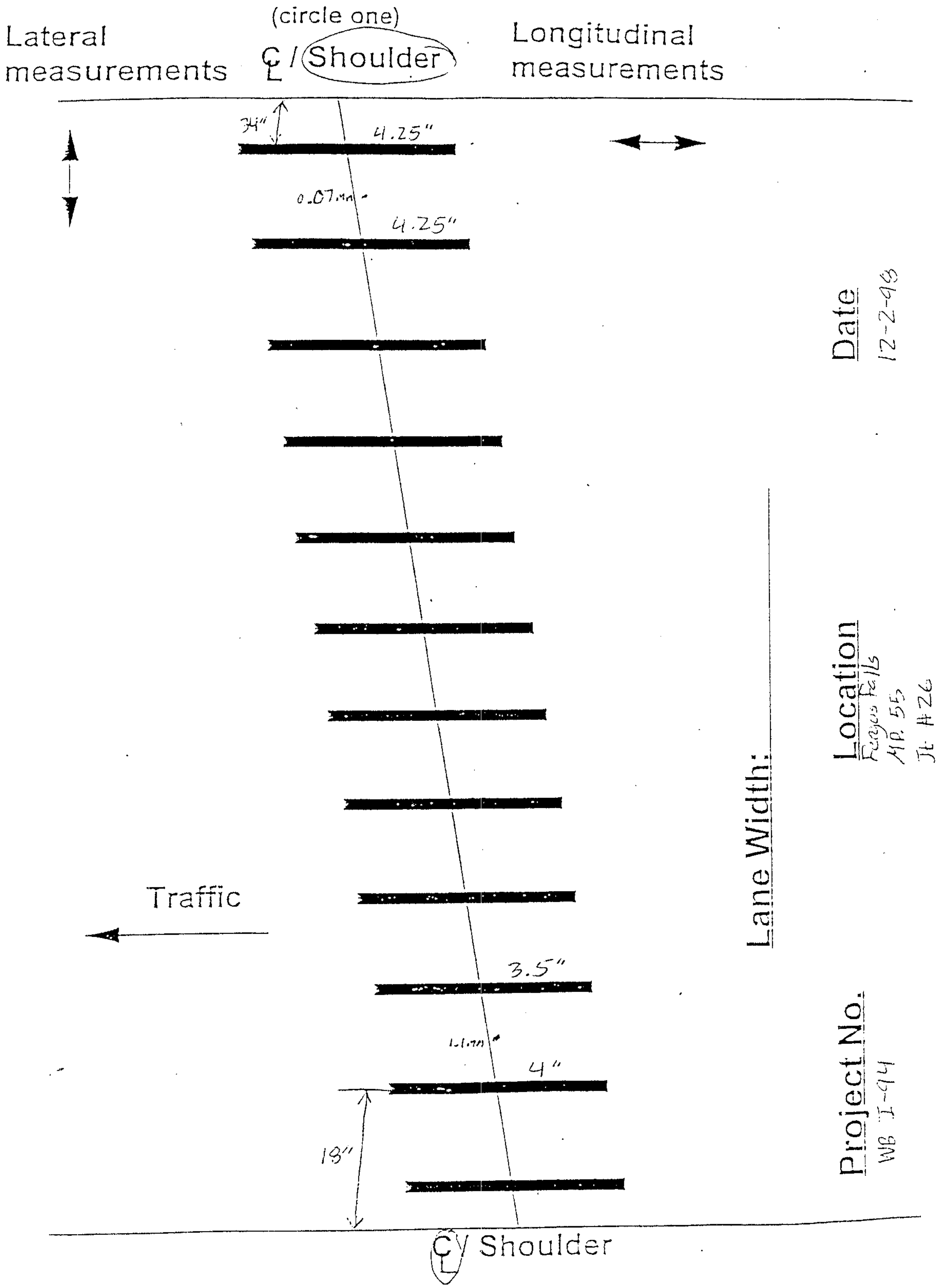
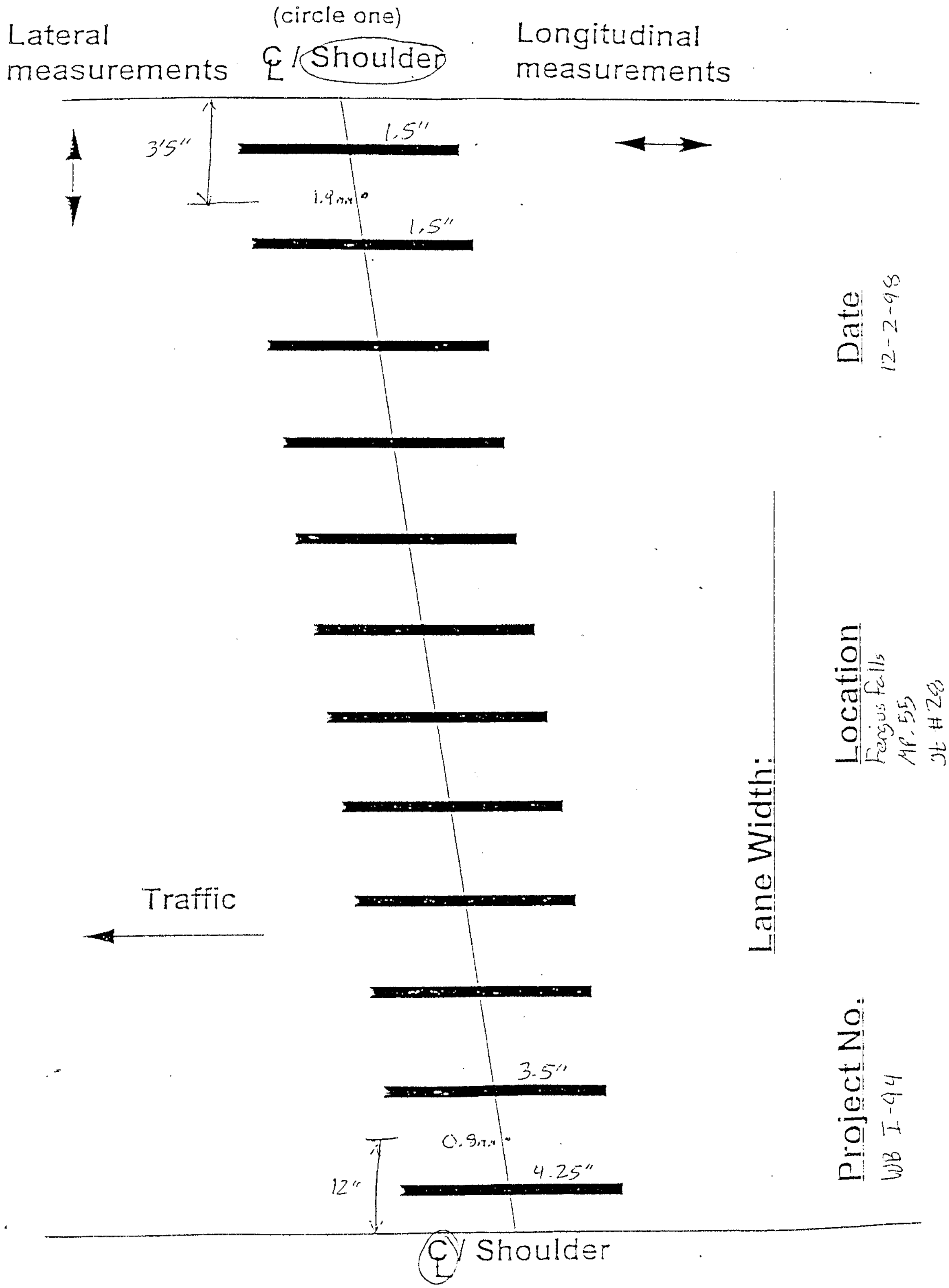
Lateral measurements
℄ / Shoulder
Longitudinal measurements
2.5'
3'4"
6"
0.8mm
5.25"
Traffic
2.75"
0.7mm
2.75"
13"
℄ / Shoulder
Date
12-2-93
Location
Fergus Falls
MP 55
Jt #20
Lane Width:
Project No.
WB I-94

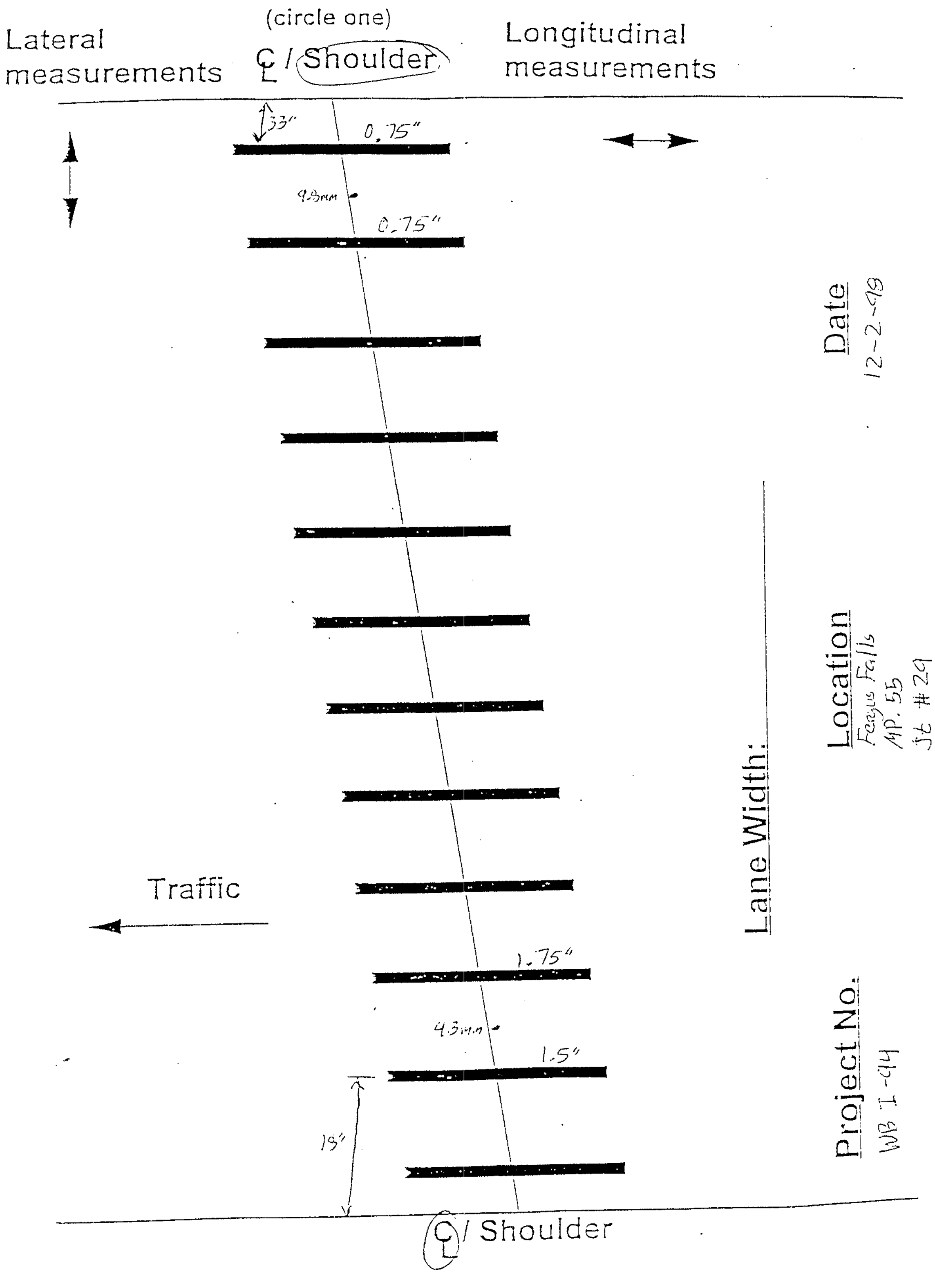

Lateral measurements
(circle one)
CL / Shoulder
Longitudinal measurements
32"
4.5" gap
11.3 mm ← faultmeter measurement
4.5" gap
Date
12-2-98
Location
Fergus Falls
MP. 55
Jt # 21
Lane Width:
Traffic
3.5" gap
7.2 mm
3.5" gap
17"
Project No.
WB I-94
CL / Shoulder

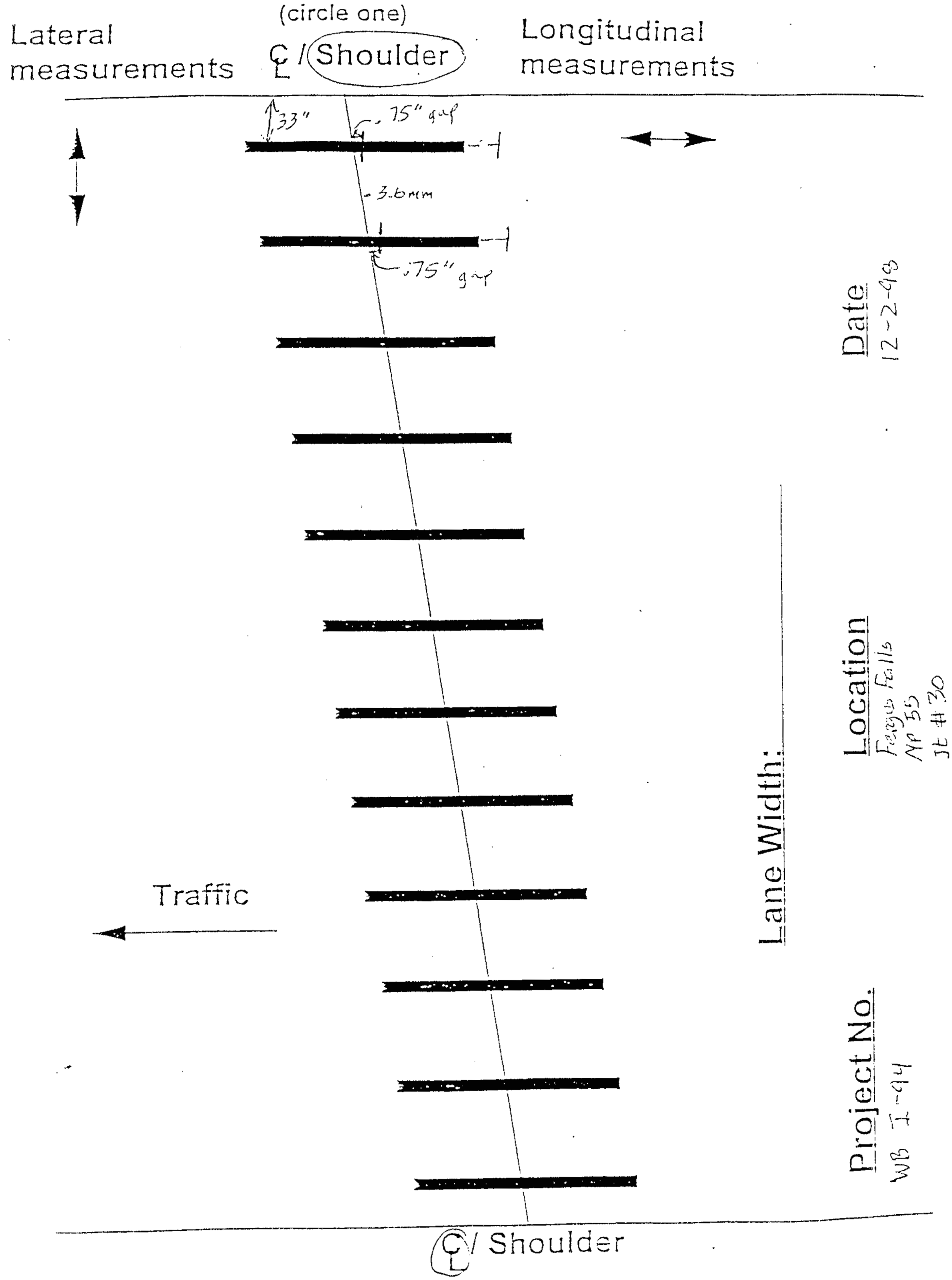

(circle one)
Lateral measurements
CL / Shoulder
Longitudinal measurements
33"
1.75"
9.6 mm
1.5"
Date
12-2-98
Lane Width:
Location
MP 55
Traffic
1"
5.4mm
.75"
Project No.
WB I-94
CL / Shoulder

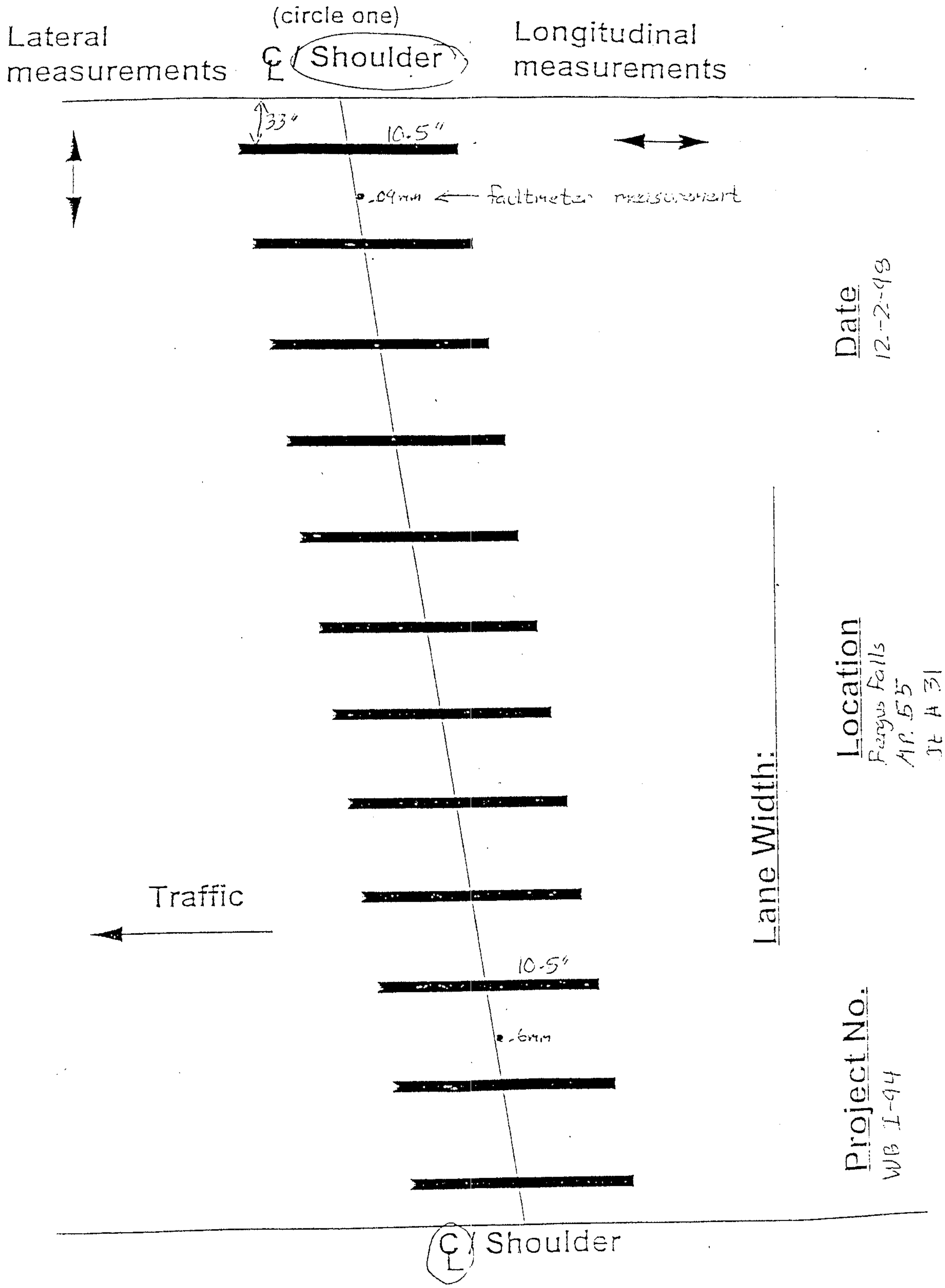

(circle one)
Lateral measurements
CL / Shoulder
Longitudinal measurements
2.35"
3'5"
(Long.) 15"
11.3mm
(Long.) 15.25"
Date
12-2-98
Location
Fergus Falls
MP 55
Jt 4125
Lane Width:
Traffic
Project No.
WB I-94
1.75"
6.9mm
1.25"
12"
CL / Shoulder


Lateral measurements
(circle one)
CL / Shoulder
Longitudinal measurements
34"
4.25"
0.07mm
4.25"
Traffic
3.5"
1.1mm
4"
18"
CL / Shoulder
Date
12-2-98
Location
Fergus Falls
MP 55
Jt #26
Lane Width:
Project No.
WB I-94


Lateral measurements
(circle one)
CL / Shoulder
Longitudinal measurements
3'5"
1.5"
1.9mm
1.5"
3.5"
0.5mm
4.25"
12"
Traffic
CL / Shoulder
Lane Width:
Date
12-2-98
Location
Fergus Falls
MP 55
Jt #20
Project No.
WB I-94


Lateral measurements
(circle one)
C/L / Shoulder
Longitudinal measurements
33"
0.75"
9.3mm
0.75"
Date
12-2-98
Location
Fergus Falls
MP. 55
Jt #29
Lane Width:
Traffic
1.75"
4.3mm
1.5"
19"
Project No.
WB I-94
C/L / Shoulder


Lateral measurements
(circle one)
℄ / Shoulder
Longitudinal measurements
33"
.75" gap
3.6mm
.75" gap
Traffic
Date
12-2-98
Location
Fergus Falls
MP 55
Jt #30
Lane Width:
Project No.
WB I-94
℄ / Shoulder



Lateral measurements
(circle one)
CL / Shoulder
Longitudinal measurements
33"
10.5"
.09mm ← faultmeter measurement
Date
12-2-98
Lane Width:
Location
Fergus Falls
MP 55
Jt # 31
Traffic
10.5"
.6mm
Project No.
WB I-94
CL / Shoulder

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