Final Report
for
Iowa Department of Transportation
Project HR-504

Galvanized Bridge Deck Reinforcing

by
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TECHNICAL REPORT TITLE PAGE

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Construction Technology Laboratories, Inc. (CTL)

8. ABSTRACT

The deterioration of bridge decks due to steel corrosion is a problem encountered several years ago. This project, using galvanized reinforcement, began over twenty years ago. Since that time, epoxy coated reinforcement has become the specified material used in bridge decks.

The decks researched in this project are located on I-35 in Story County. They were constructed in 1967.

The results from the testing done on this project show that galvanizing protects steel from corrosion due to deicing salts, resulting in less/no concrete deterioration.

9. KEY WORDS	10. NO. OF PAGES
Galvanized reinforcement, Bridges, Corrosion, Reinforcing steel	59

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DISCLAIMER

INTRODUCTION

The corrosion of untreated reinforcing steel in bridge decks prompted this research over twenty years ago. At that time, untreated black steel was the primary reinforcement used. The corrosion of the untreated steel caused deterioration of the bridge decks. This was due to deicing salts penetrating the surface of the deck to the underlying steel. The steel would then corrode resulting in cracking and spalling of the concrete surrounding the steel in the bridge deck.

In this project galvanized reinforcement was used in part of the deck and compared to the conventional uncoated steel.

There were also some researchers who suggested that there would be adverse chemical reactions between the concrete and the galvanizing.

OBJECTIVE

The objective of this project was to determine the durability of a bridge deck constructed using galvanized reinforcing steel.

PROJECT DESCRIPTION

This project is located on I-35 over Long Dick Creek in Story County. There are two structures, one northbound and one southbound. The bridges are dual 193′-0 x 39′ pretensioned prestressed concrete bridges with three spans of 64′-1", 64′-10" and 64′-1".

Each deck incorporated both untreated and galvanized steel. The deck of the southbound lane contained both transverse and longitudinal rebar of galvanized steel. The galvanized rebar are located only in the south half of the bridge and only the top layer of steel is galvanized. Galvanized tie wires were used in this section. The deck of the northbound bridge contains galvanized rebar for transverse steel only. These galvanized rebars were placed in the south half of the deck and were placed as the top layer of reinforcing steel. The north half of the deck used all untreated rebar. Uncoated tie wires were used in this deck. The figures in Appendix A show the placement of steel in both bridges. The depth of cover of the concrete over the galvanized steel reinforcement ranged from 2 1/2" to 5" with an average of 3" depth.

MATERIALS

In these bridge decks, No. 5, 6 and 7 bars were used. The coating thickness was checked on the galvanized bars before construction. The results are in Table I.

TABLE I

Bar Size No.	Spelter oz./ft.^{2}
5	4.7
6	5.4
7	2.8

The galvanized coating thickness exceeds 1.2 oz./ft.^{2} required by ASTM A-123.

The concrete mix design consisted of a cement factor of 710 lbs./cu.yd. and a water cement ratio of .40 to .41. The entrained air content ranged from 5.2% to 6.2%. NCHRP Report 23 noted that the concrete placement must be carefully supervised since it did represent a potentially large variable. A pictorial diagram of the location of each truck load of concrete was kept to show where it was placed and the slump and air in each location. This diagram is in Appendix A.

CONSTRUCTION

All regular construction field procedures were followed. More loads were tested so the construction of the deck could be documented. Rain occurred during the placement on the south span of the northbound bridge. This was documented in case scaling would eventually occur. No scaling, however, did occur in this section.

TESTING

The Iowa DOT performed electrical potential testing, obtained cores for chloride determination and checked for delaminations every other year. Those results are shown in Appendix B. Construction Technology Laboratories (CTL) completed testing in 1975, 1982 and 1991. They measured electrical potentials and water soluble chloride ion contents of concrete at the depth of embedded steel reinforcement. They also inspected the concrete deterioration, did petrographic examination to determine concrete quality, and metallographic analysis of galvanized coating. These results are in Appendix C.

DISCUSSION OF RESULTS

The results of the tests performed on these bridge decks showed that galvanized reinforcement showed little evidence of corrosion. There was no direct correlation of concrete deterioration related to corrosion of embedded steel reinforcement. It is also possible that any corrosion that did occur could have occurred before or immediately after placement of concrete.

SUMMARY

Based on some researchers' findings in the past, it is believed that galvanized steel develops sacrificial expansion products resulting in concrete deterioration. This has not proven true in this instance. Recent research has not uncovered any significant long term problems with galvanized reinforcement. Galvanized steel was at a disadvantage at first because both mats had to be galvanized, while with epoxy, only the top layer of steel was required to be coated. Approximately 4 years ago epoxy coated steel was also required on both layers because of transverse cracking which allows deicing salt brine to reach the bottom layer. From this and other studies that have been completed, it appears galvanized reinforcement has proven to be an effective method of preventing corrosion in bridge decks.

CONCLUSIONS

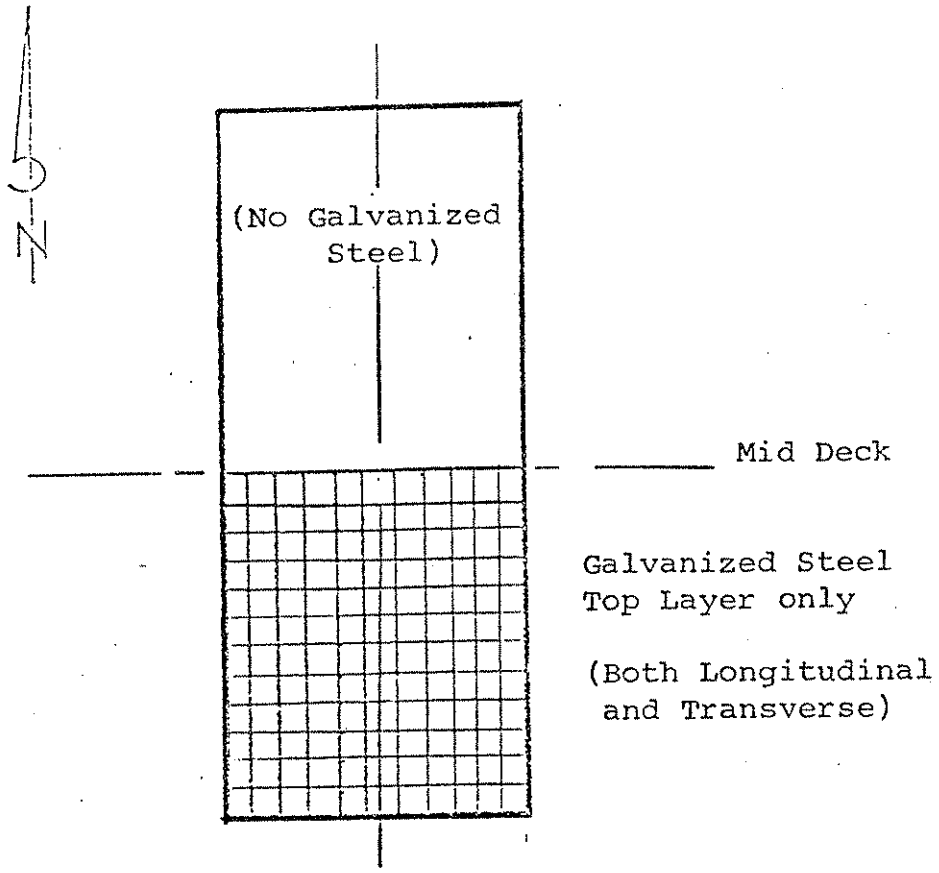
1. Galvanized reinforcement on this bridge provided satisfactory resistance to corrosion with a 2 1/2" or greater cover.

2. The galvanized reinforcement caused no problems on this bridge deck.

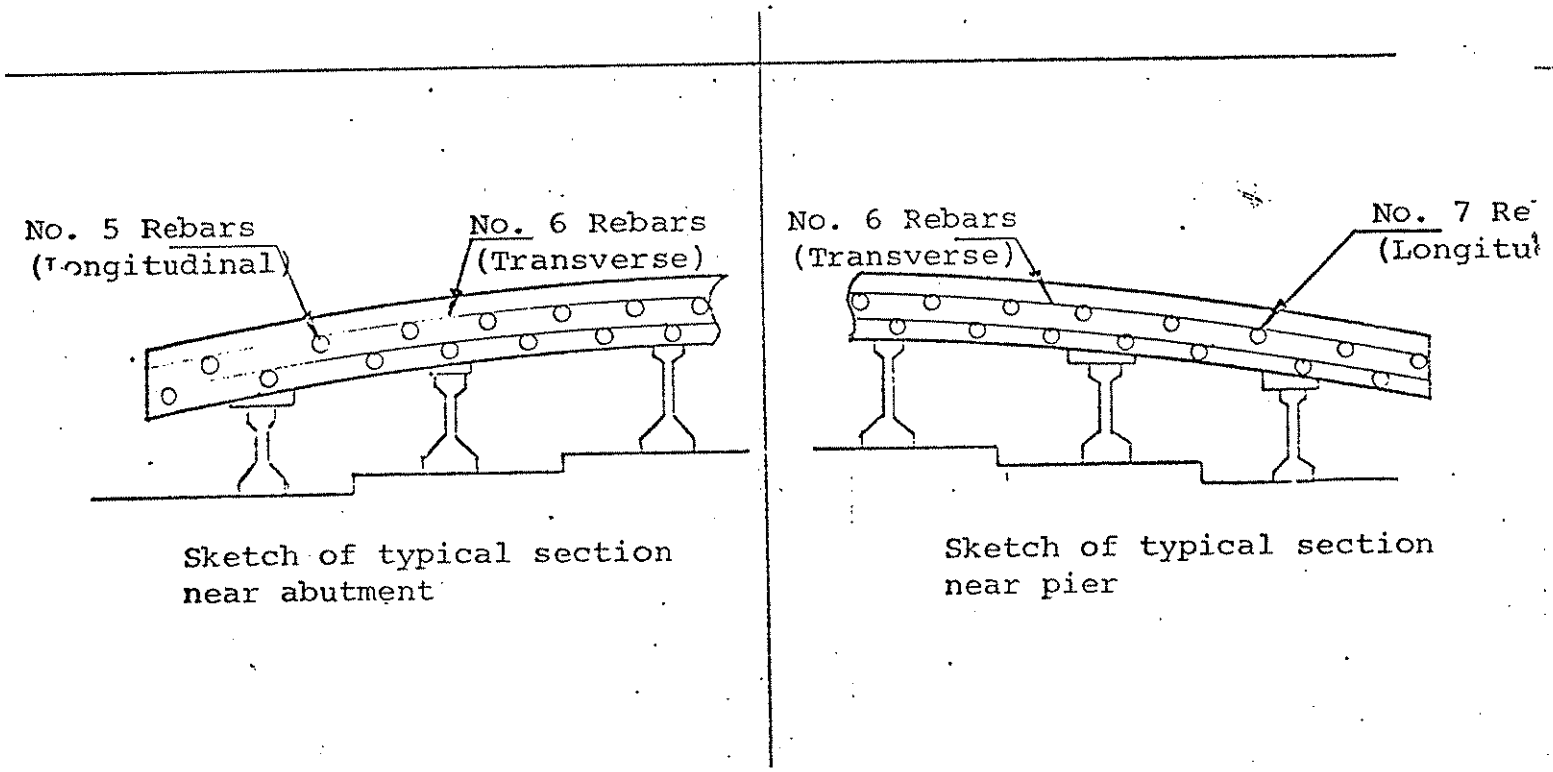
ACKNOWLEDGEMENT

The author wishes to express appreciation to Brian G. Stejskal of Construction Technology Laboratories and Dick Smith who has retired from the Iowa DOT for developing material used in this report.

Appendix A
Steel Placement and Concrete Placement Test Results



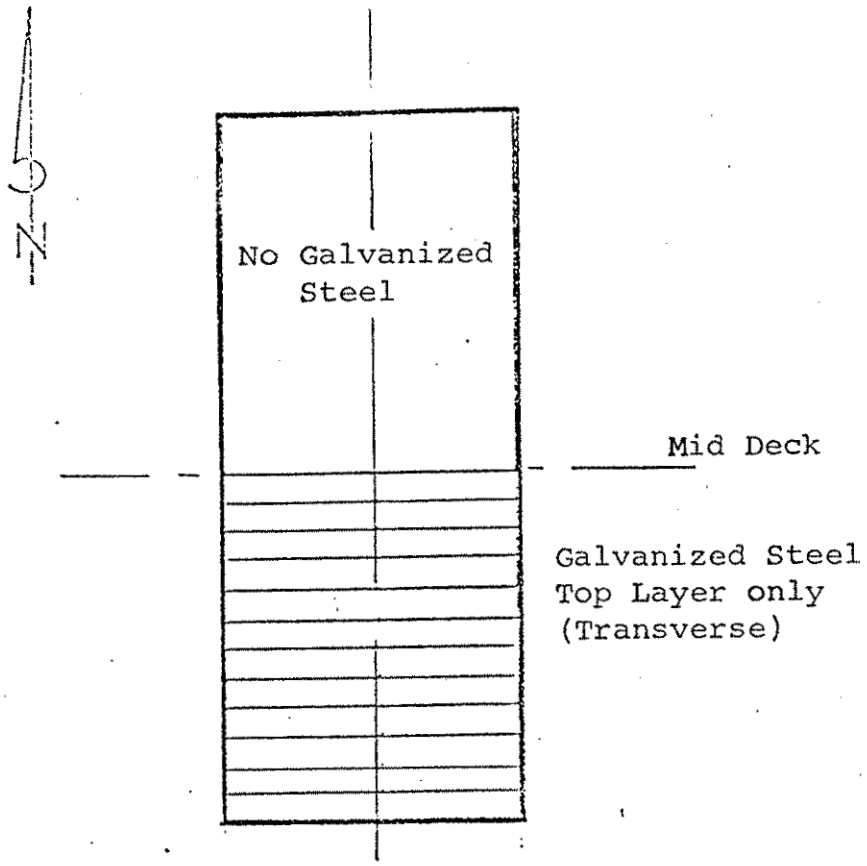
Plan View of Deck



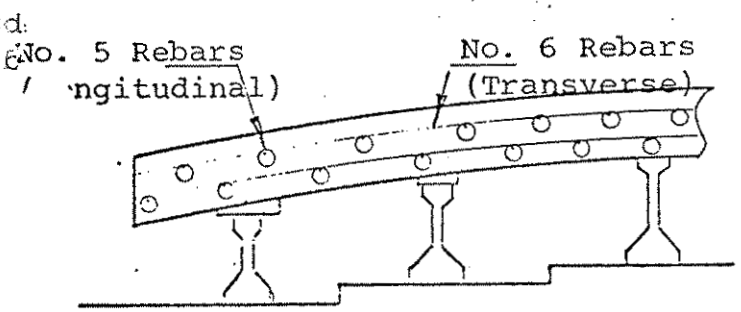
Sketch of typical section near abutment

Sketch of typical section near pier

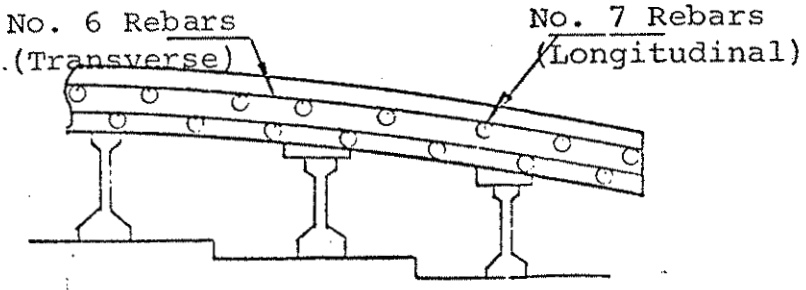
Deck - Southbound Lane
figure 2



Plan View of Deck



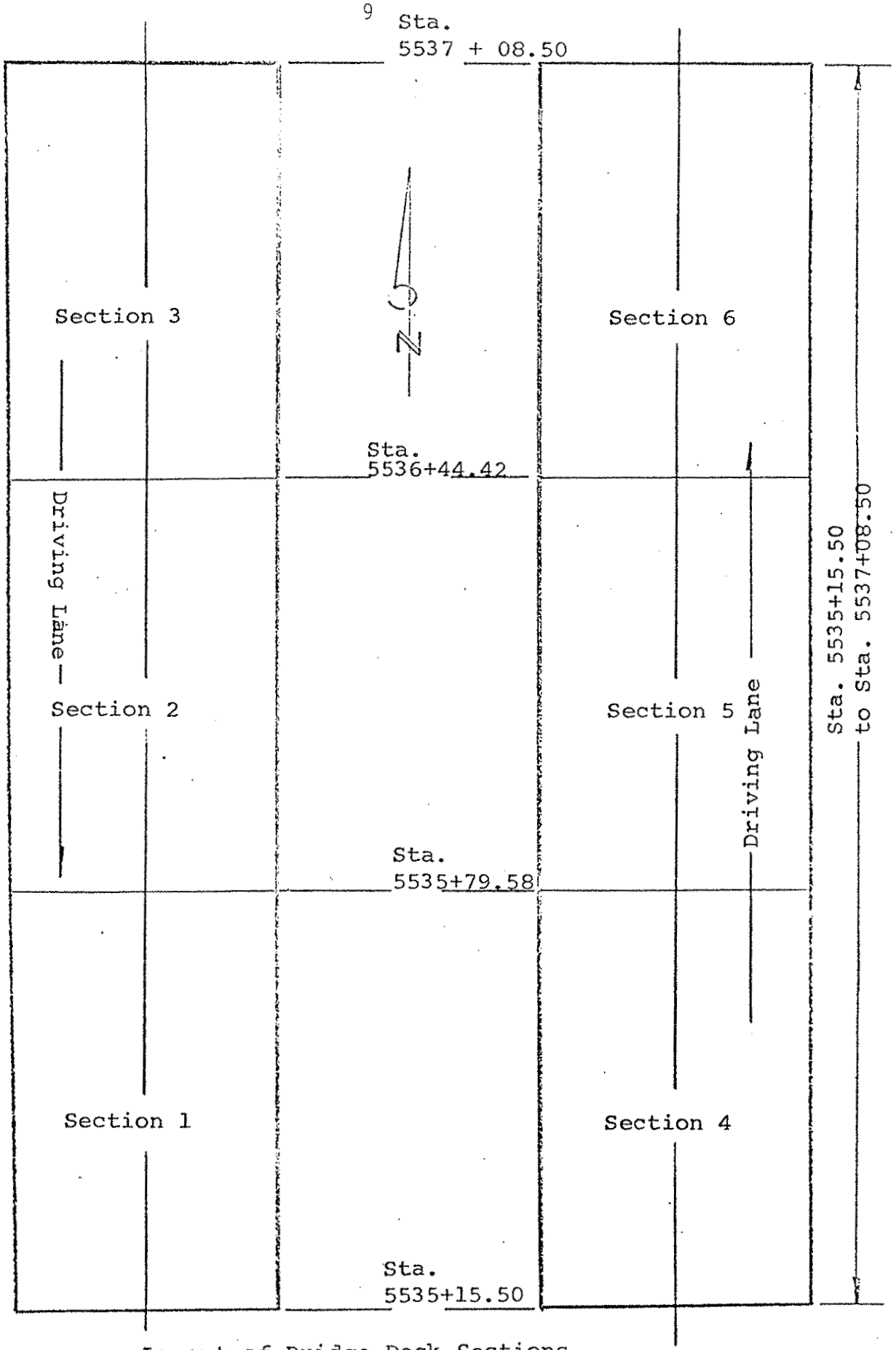
Sketch of typical section near abutment



Sketch of typical section near pier

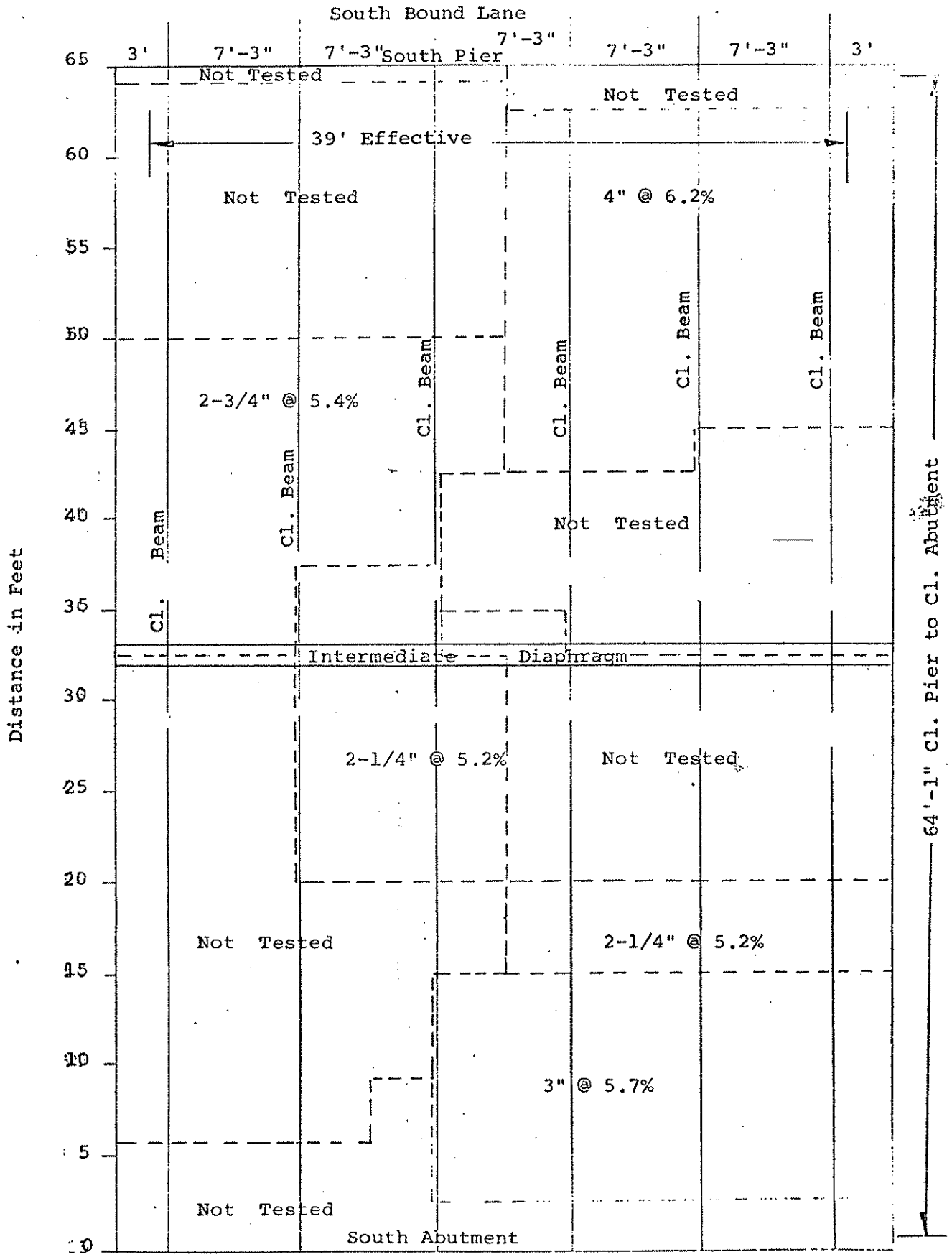
Deck - Northbound Lane

figure 3

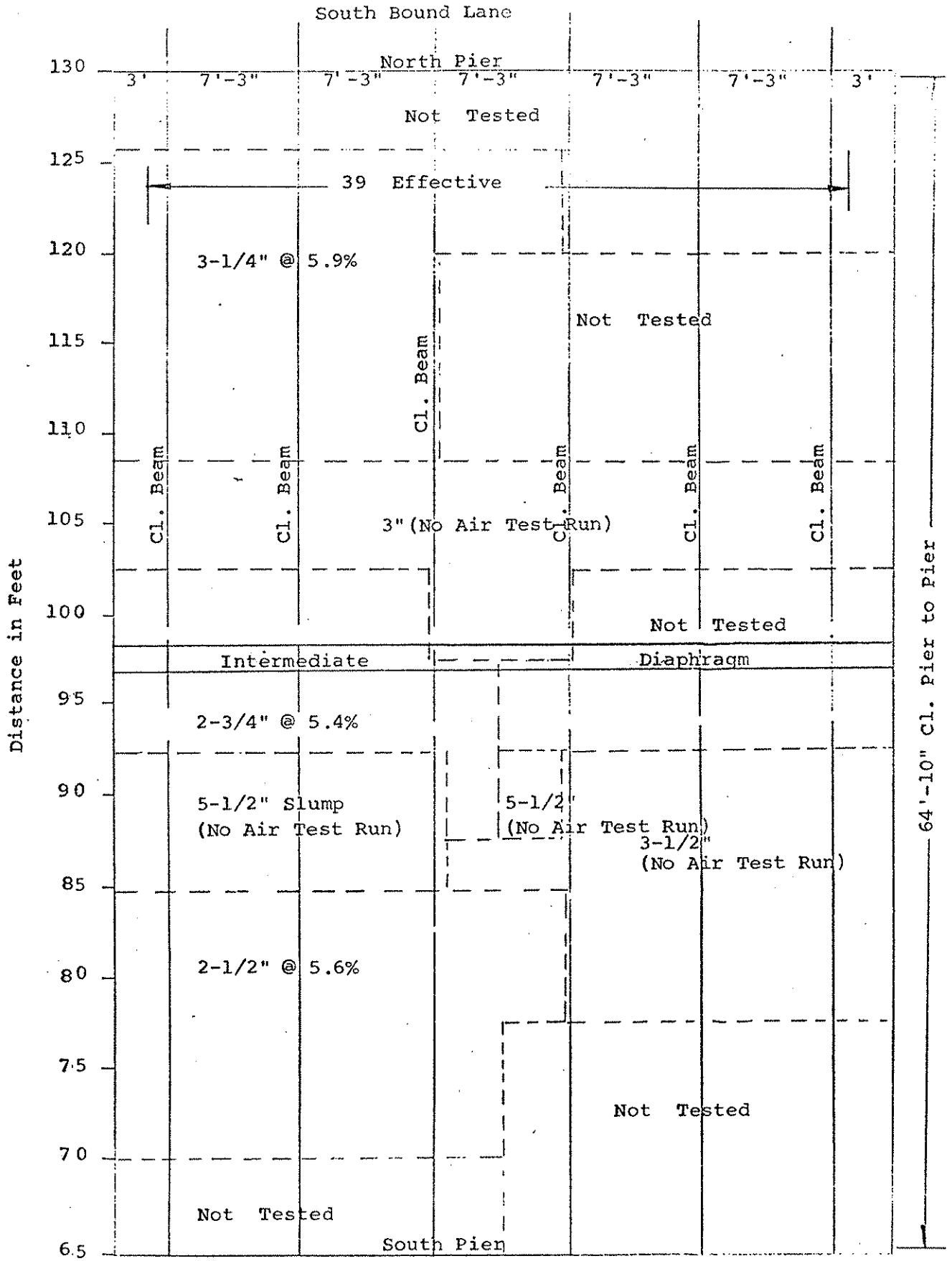


Layout of Bridge Deck Sections

Figure 4

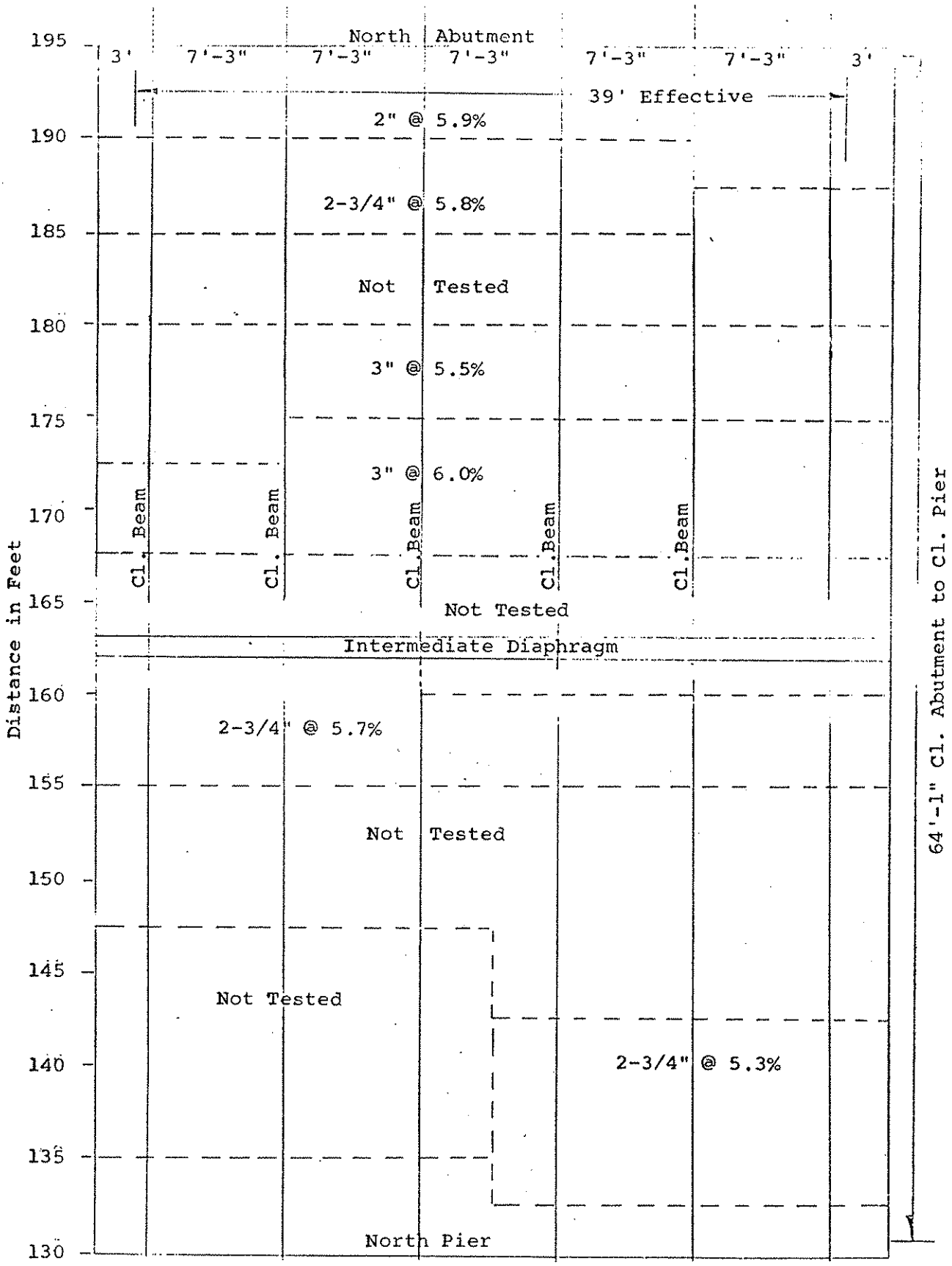


Section 1 - Slump & Air Content

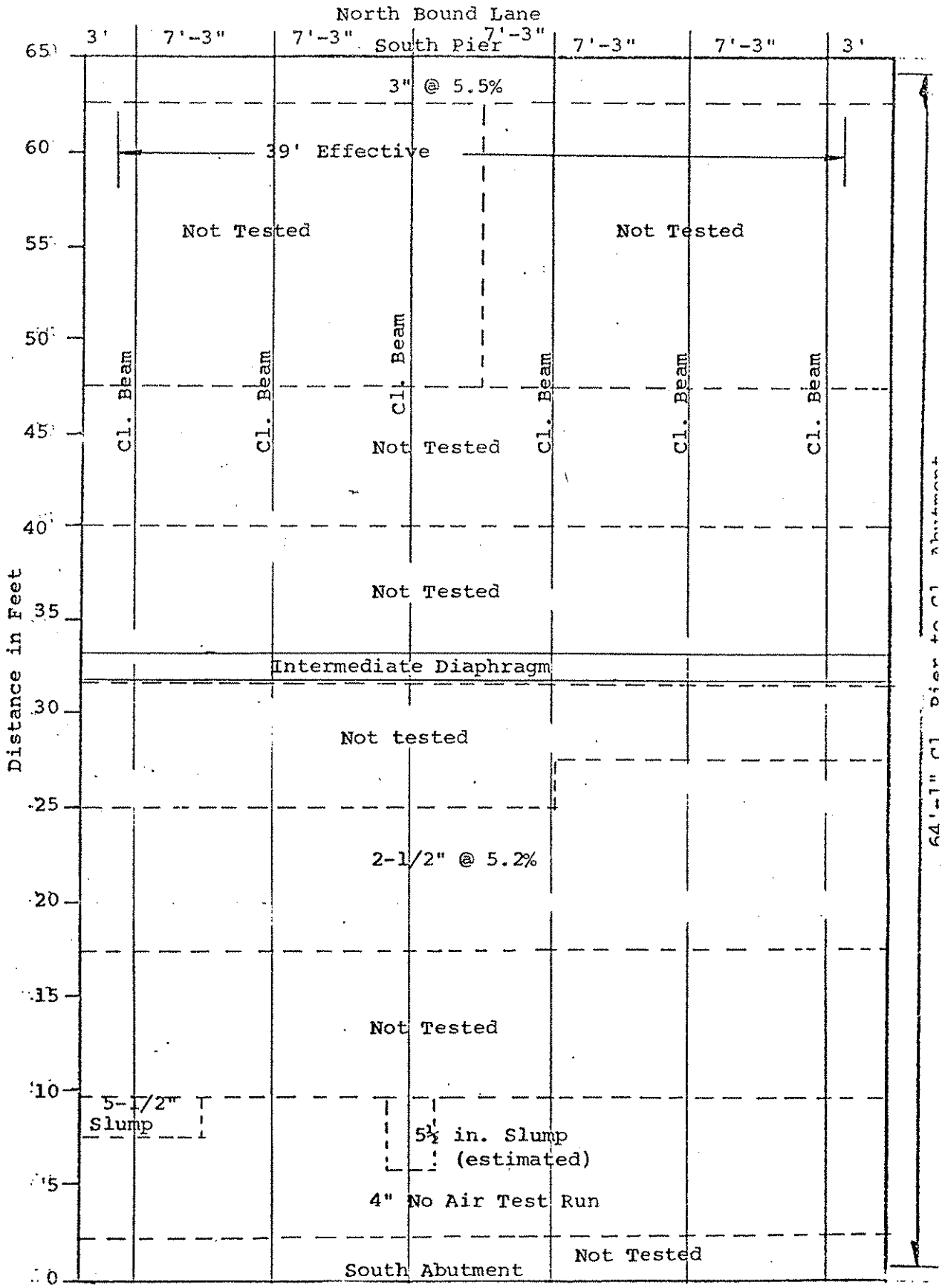


Section 2 Slump & Air Content

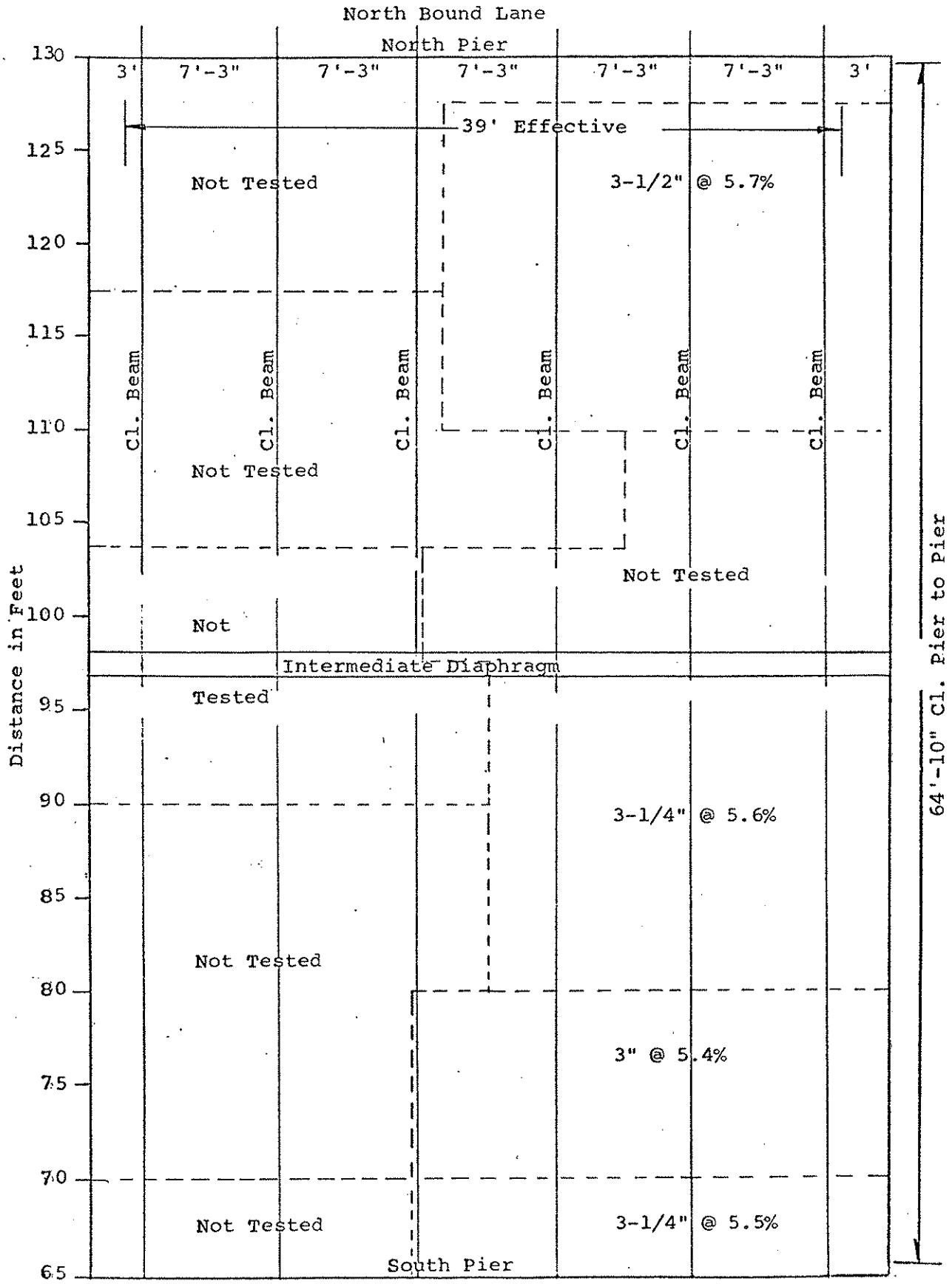
South Bound Lane



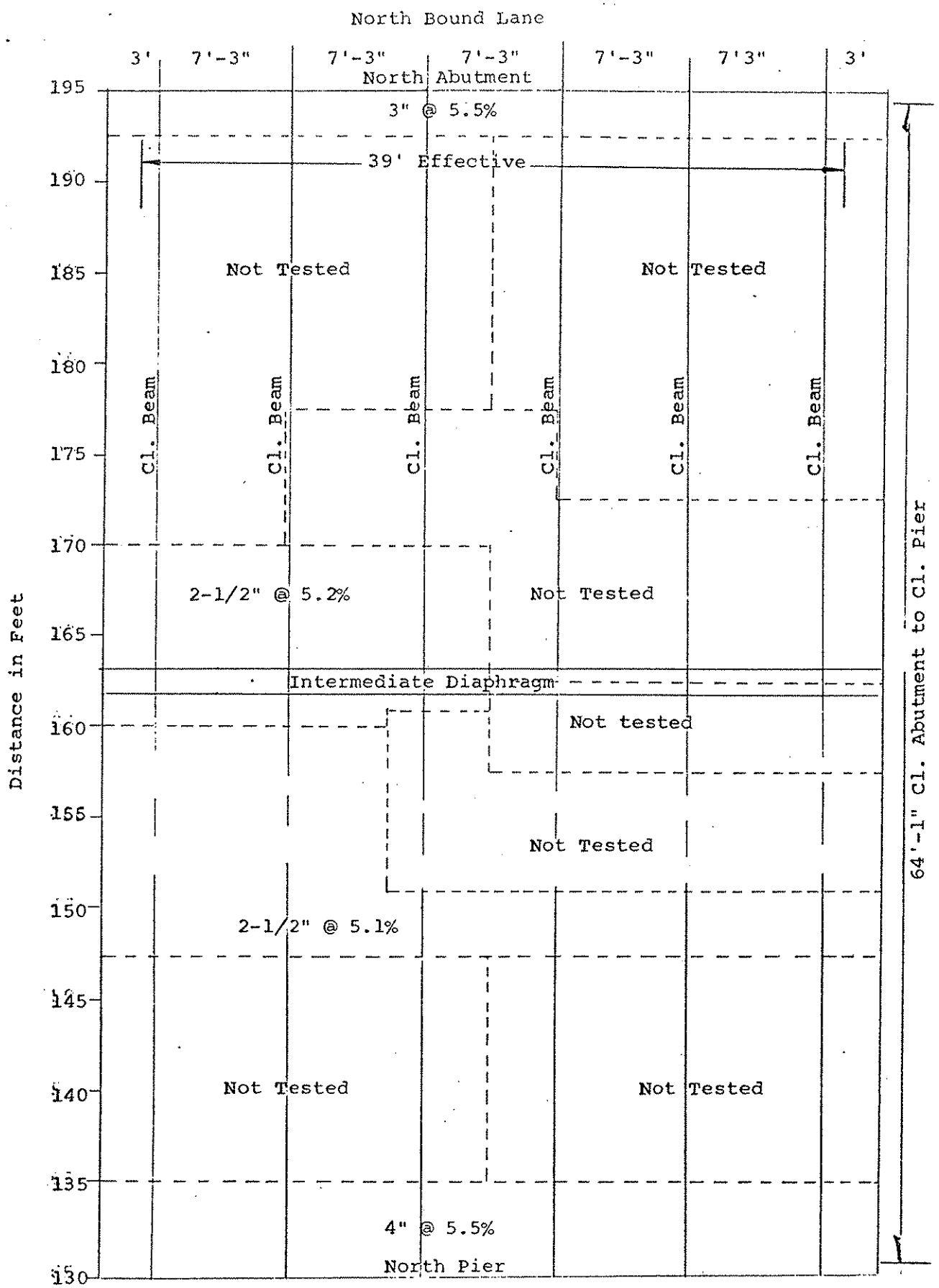
Section 3 - Slump & Air Content



Section 4 - Slump & Air Content



Section 5 Slump and Air Content



Section 6 - Slump and Air Content

Appendix B
Annual Test Results

Iowa DOT Project HR-504 IA-66-01

Galvanized Bridge Deck Reinforcing

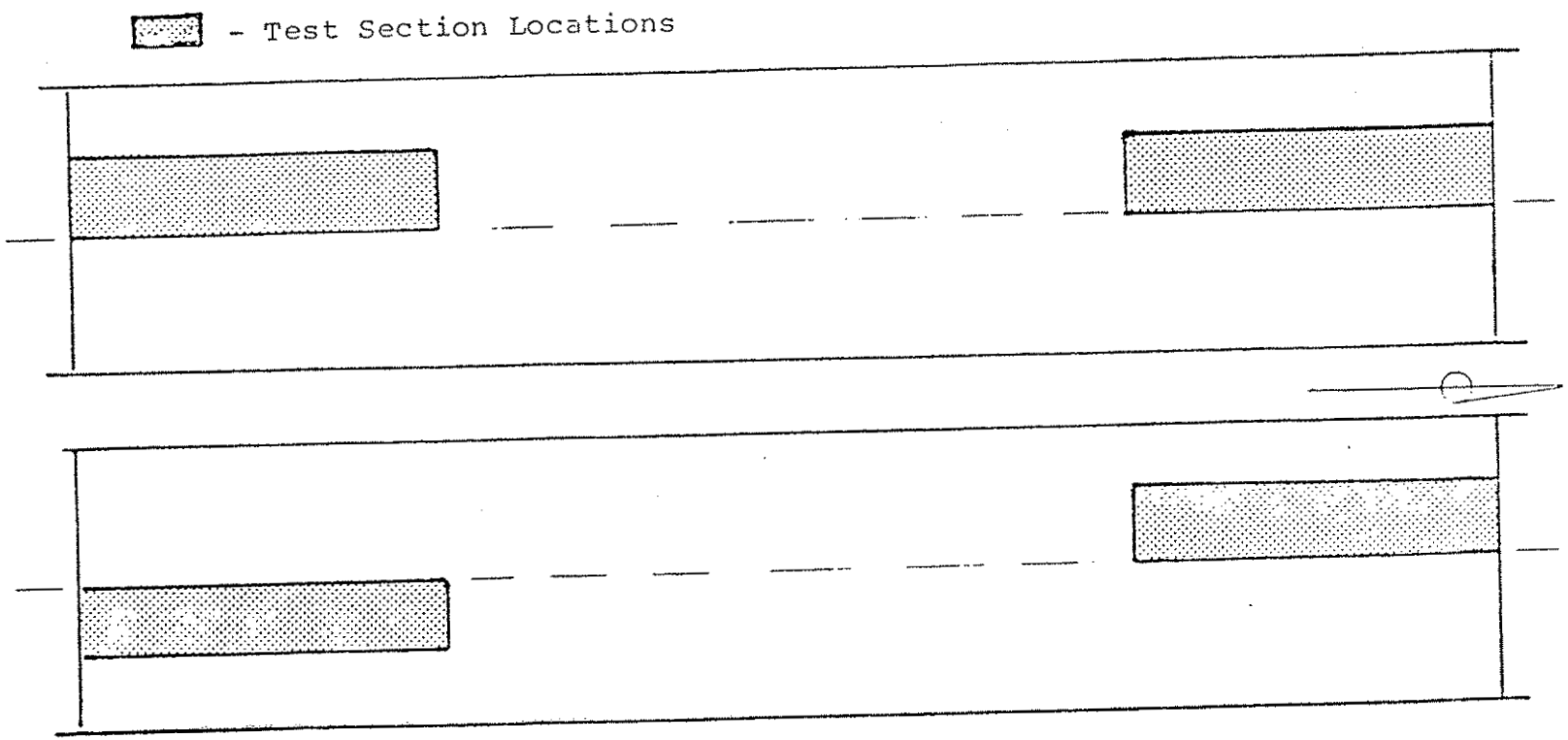
I-35 Northbound over Long Dick Creek
Delamination - Nil
Curbs badly deteriorated

I-35 Southbound over Long Dick Creek
2 sq. ft. Delaminated in shoulder area
5 sq. ft. Spalled in shoulder area

I-35 over Long Dick Creek
Story County

193' x 39' Dual Prestressed Concrete Beam Bridge
Constructed 1967

November 1977-All corrosion readings were less than 0.30 volt



Bridge: I-35 over Long Dick Creek - Story County

CHLORIDE CONTENT - LBS/CU. YD.

Year Sampled	Sample Depth (Inches) 0 - 0.75	0 - 1	0.75 - 1.5		1.5 - 2.25
1973					
S bound		3.86	-	-	1.78
		5.10	-	-	3.40
N bound		3.78	-	-	3.21
		3.40	-	-	1.40
1974					
S bound		2.46	-	-	0.96
		3.64	-	-	0.83
N bound		2.03	-	-	0.94
		1.30	-	-	0.88
1975					
S bound		2.1	-	-	0.5
		2.3	-	-	0.5
N bound		3.1	-	-	0.7
		2.4	-	-	0.6
1976					
S bound		5.2	-	-	0.5
		4.8	-	-	0.6
N bound		1.8	-	-	0.4
		8.3	-	-	0.5
1977					
S bound	7.45	-	0.48	-	0.33
	9.22	-	1.01	-	0.55
	9.53	-	2.15	-	0.52
	11.34	-	1.78	-	3.03
N bound	16.75	-	4.69	-	1.03
	5.18	-	1.03	-	0.70
	7.79	-	1.35	-	0.55
1979					
S bound	8.01	-	0.45	-	0.42
	11.00	-	0.87	-	0.45
N bound	8.28	-	1.97	-	0.42
	4.20	-	1.97	-	0.64

Bridge: I-35 over Long Dick Creek - Story County

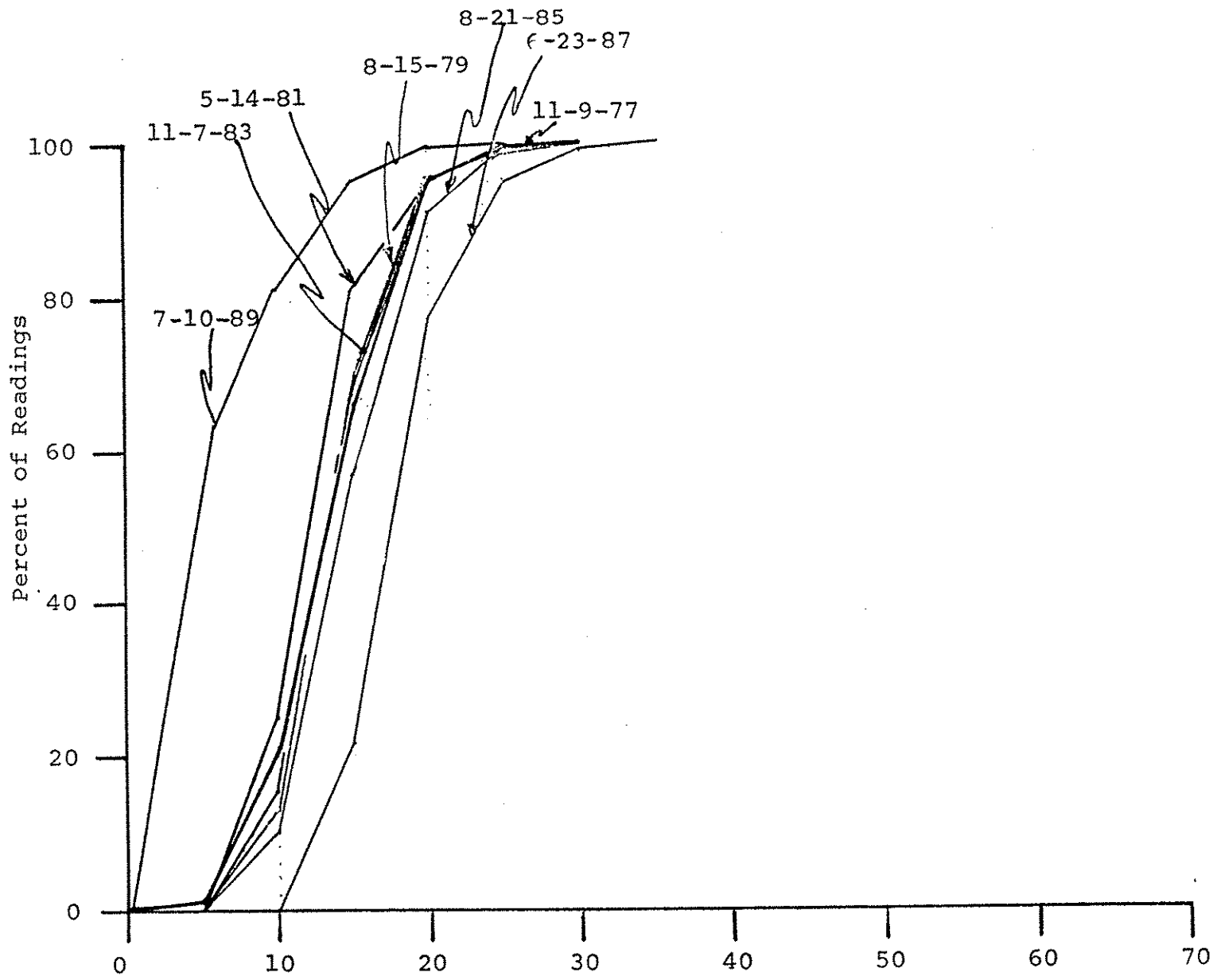
CHLORIDE CONTENT - LBS/CU. YD.

Year Sampled	Sample Depth (Inches) 0 - 0.75	0 - 1	0.75-1.5		1.5 - 2.25
1981					
S bound	13.19	-	8.35	-	0.56
	10.28	-	3.63	-	0.68
N bound	5.93	-	0.30	-	0.49
	5.07	-	0.95	-	0.30

Bridge: I-35 Northbound over Long Dick Creek

CHLORIDE CONTENT - LBS/CU. YD.

Year Sampled	Sample Depth (Inches) 0 - 0.5	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5
1983	11.87	4.95	1.13	0.34	0.42
	14.44	4.23	0.60	0.57	0.49
	9.68	2.95	1.40	0.53	0.38
	6.13	1.66	0.45	0.26	0.19
	7.11	1.06	0.38	0.30	0.53
	5.56	1.44	0.53	0.42	0.53
	5.86	0.15	0.30	0.30	0.30
1985	9.03	3.89	1.32	0.76	0.49
	10.09	0.64	2.19	0.71	0.49
	11.26	5.10	1.32	0.30	0.38
	11.23	3.33	0.91	1.78	0.76
	3.21	1.17	0.79	0.42	0.68
	4.23	1.06	0.72	0.68	0.45
1987	8.20	5.52	1.40	0.53	0.53
	4.91	1.66	0.87	0.64	0.45
	10.51	4.57	3.67	1.13	0.87
	5.03	2.15	1.74	1.51	1.51
	5.82	1.70	0.83	0.45	0.45
	4.61	0.49	0.57	0.45	0.57
	6.50	0.95	0.57	0.57	----
1989	13.08	6.16	3.67	1.40	0.76
	6.54	2.65	1.25	1.13	0.76
	15.76	11.72	8.69	4.80	0.38
	8.69	1.63	0.87	0.87	0.87
	10.47	2.65	1.51	0.87	0.76
	10.96	3.40	1.13	0.64	0.76

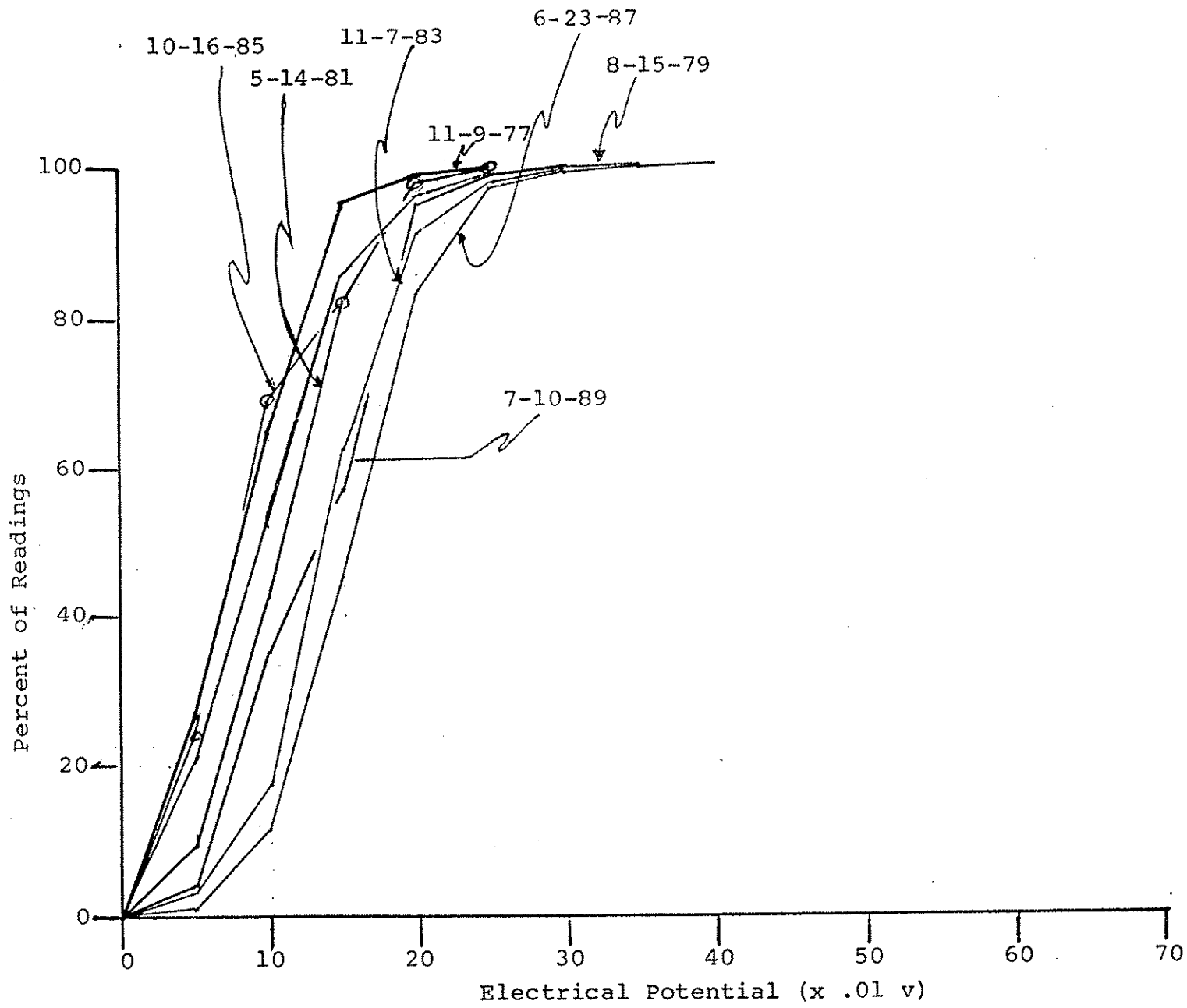


Electrical Potential (x .01 v)
I-35 Northbound over Long Dick Creek - Story County
Galvanized Steel in Part of Deck
Constructed in 1967

Bridge: I-35 Southbound over Long Dick Creek - Story County

CHLORIDE CONTENT - LBS/CU. YD.

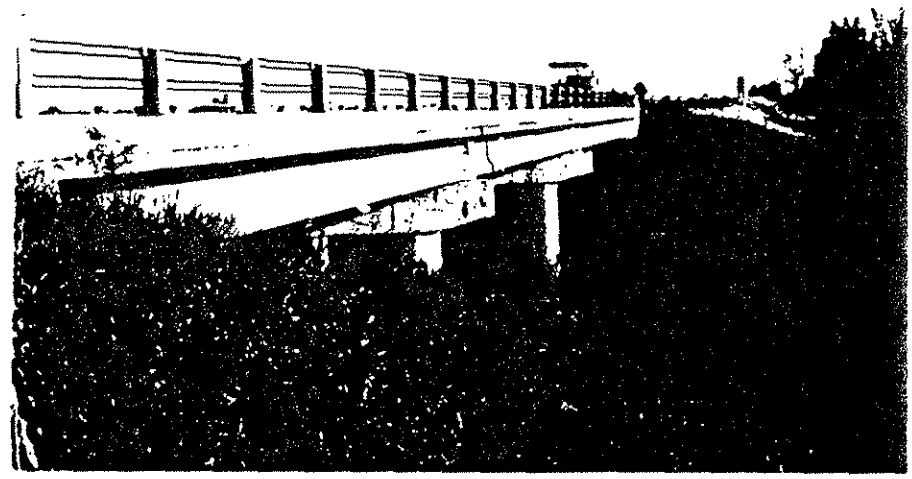
Year Sampled	Sample Depth (Inches) 0 - 0.5	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5
1983	13.23	6.54	1.51	0.45	0.76
	7.64	1.59	0.30	0.45	0.64
	14.33	11.60	2.61	0.26	0.26
	12.13	0.76	0.26	0.45	0.45
	13.95	3.36	0.60	0.23	0.30
	12.55	3.67	1.29	0.38	0.60
1985	8.51	2.76	0.68	0.57	0.53
	13.65	1.44	0.83	1.06	0.46
	7.52	2.72	0.83	0.64	0.60
	14.18	7.98	7.98	0.57	----
	26.99	14.82	9.19	2.72	0.64
	11.68	0.64	0.57	0.57	0.30
1987	10.09	3.97	1.02	0.49	0.68
	6.12	1.51	0.64	0.76	0.38
	10.77	0.91	0.23	0.83	0.49
	4.23	0.64	0.45	0.45	0.57
	15.08	3.78	0.45	0.30	0.87
	9.60	5.67	0.95	0.38	0.30
	11.64	1.44	0.83	0.38	0.45
	12.74	1.70	0.49	0.53	0.64



I-35 Southbound over Long Dick Creek - Story County
Galvanized Steel in Part of Bridge
Constructed in 1967

Appendix C
Construction Technology Laboratory Results

Section A.2: IOWA STRUCTURE



AMES BRIDGE:

Identification:

Two bridges on I-35 over Long Dick Creek (Story County) located near Ames, Iowa. The dual concrete decks service northbound and southbound traffic and are supported by two piers.

Year of Construction: 1967 Age: 24 years

Description:

The subject structure is a dual 3-span bridge which was previously inspected in 1981. All three spans of both decks were included for study. The bridge decks measure approximately 193 x 39 ft each and are composed of prestressed concrete beams spanning 64 to 65 ft. Reinforced concrete decks are constructed with both treated and galvanized steel reinforcing bars, as indicated on the next page.

Detail of Steel Reinforcement:

The north halves of both decks are constructed with untreated steel reinforcement in the longitudinal and transverse direction. The top mat in the south half of the concrete deck servicing southbound traffic contains galvanized longitudinal and transverse steel bars. Galvanized steel reinforcement is secured with galvanized steel wires. The top mat in the south half of the northbound deck contains galvanized transverse steel, and untreated longitudinal steel bars. Standard uncoated tie wires were used in this section of the bridge deck. The bottom steel reinforcing mats in both northbound and southbound decks are constructed with untreated steel bars.

Concrete Mix Design:

Cement Factor:	710 lbs/cu yd (7.55 bags/cu yd).
Water-to-Cement Ratio:	0.40 to 0.41 (4.5 to 4.6 gal/bag)
Air Content:	5.2 to 6.2%

Electrical Potentials:

Electrical potential survey results are presented in Figs. A.2.(a - f). Areas of similar potential are defined by equipotential lines at 100 millivolt intervals. Electrical potential measurements were recorded on a 5 ft. grid pattern.

Surface Defects:

Concrete deterioration in the form of cracking was observed on exposed deck surfaces. Concrete cracking oriented in the transverse direction is shown in Figs. A.2.(g - i). In some instances, cracks occur over embedded steel reinforcement.

Subsurface Delaminations:

Sounding of concrete decks indicated minor subsurface delaminations and small unbonded surfaces at isolated areas.

Chloride Analysis:

Water-soluble chloride content analysis of 12 concrete powder samples removed from the subject decks was performed. Tests were conducted in accordance with ASTM C 144 and analysis performed by potentiometric titration with silver nitrate. Results of tests are summarized in Table A.2.

Petrographic Examination:

Eight concrete core samples were removed from the concrete decks at locations designated as L-1, L-2, L-4, L-6, L-10, L-11, L13, and L-14. The location and description of core samples taken for study are presented in Table A.2. Petrographic examinations were performed on three of the cores (L-6, L-10, and L-14) to evaluate the condition and quality of concrete in respective deck slabs. Petrographic examainations were performed on the core samples in accordance with ASTM Designation C 856-83. Results of the examinations indicated the following:

Core Designation	Depth of Carbonation (inch)	Estimated Water/Cement Ratio	Air-Entrainment	Air Content
L-6	0.10	0.50 to 0.55	Air-Entrained	4 to 6%
L-10	0.10	0.45 to 0.50	Air-Entrained	3 to 5%
L-14	0.10	0.50 to 0.55	Air-Entrained	4 to 6%

Cores L-10 and L-14 exhibited vertical cracks and corrosion on steel reinforcement (reference Table A.2). In addition, microcracking was observed around chert and dolomitic chert, which are reactive fine aggregates that can cause internal concrete deterioration.

Metallographic Measurements:

Core L-6: Core sample contained a single reinforcing bar (No. 6) with a galvanized coating which averaged 3.8 mils thick. The coating structure consists of a blocky delta layer and a columnar growth of zeta crystals which are covered with a layer of pure zinc (eta layer). The smooth surface of the coating suggests that the sample has experienced only minimal corrosion attack.

Core L-10: Core sample shows a direct comparison between a coated bar (No. 5) and an uncoated steel bar (No. 6). The slightly ragged surface profile of the galvanized coating indicated that slight attack has taken place, although the coating still averages approximately 4.7 mils thick. The uncoated bar, which has a greater depth of concrete cover than the galvanized bar exhibits red rusting over almost half of its length.

Core L-14: Core sample contained two uncoated reinforcing bars(No. 5 and No. 6). Both of the bars appeared to be in good condition .

The following is a summary of the metallographic examination:

Core Designation	Bar Size	Depth of Concrete Cover (inches)	Galvanized Coating Thickness (mils)
L-6	No. 6	3	3.8
L-10	No. 5	3-1/4	4.7
	No. 6	4-7/8	(Uncoated)
L-14	No. 5	2-1/2	(Uncoated)
	No. 6	3-1/4	(Uncoated)

Table A.2: CONCRETE CORE AND POWDER SAMPLE SUMMARY

AMES BRIDGE, IOWA

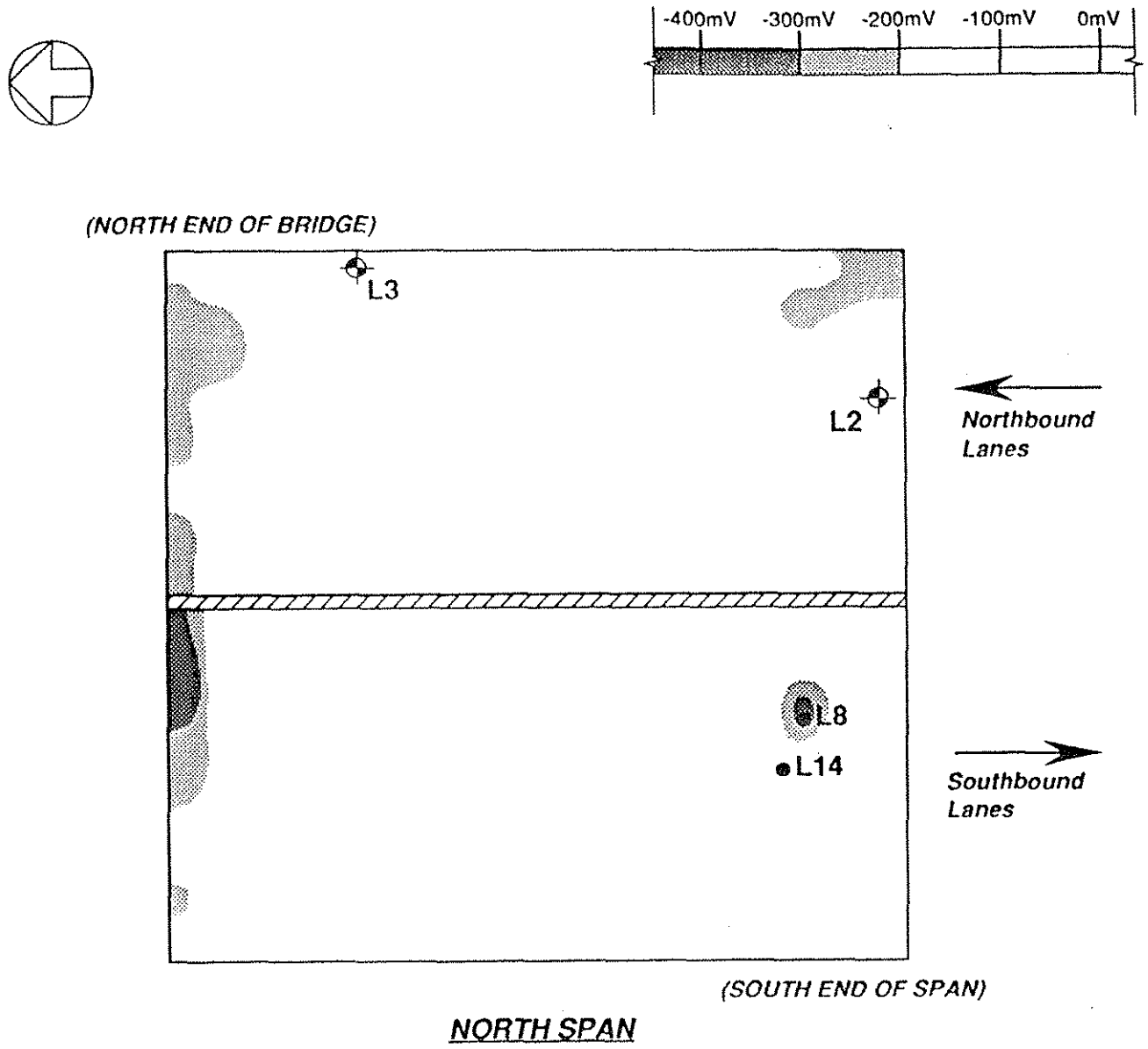
CONCRETE CORE DESCRIPTIONS:

CTL CORE DESIGNATION	LOCATION	STEEL REINFORCEMENT	DEPTH OF CONC. COVER (inches)	COMMENTS
L-6	SOUTH SPAN	No. 6 Bar	3"	No Corrosion Detected
	(N.B. LaneS)	No. 7 Bar	3-7/8"	(Same)
L-10	SOUTH SPAN	No. 6 Bar	3-1/4"	No Corrosion Detected
	(S.B. Lanes)	No. 7 Bar	4-7/8"	Crack, Corrosion Detected
L-13	MIDDLE SPAN	No. 7 Bar	2-5/8"	Crack, No Corrosion
	(S.B. Lanes)	No. 5 Bar	3-1/4"	No Corrosion Detected
L-14	NORTH SPAN	No. 6 Bar	2-1/2"	Light Corrosion Detected
	(S.B. Lanes)	No. 6 Bar	3-1/4"	(Same)

CHLORIDE ION TEST RESULTS:

CTL Powder Designation	SPAN (Lanes)	Depth of Powder Sample (inches)	Electro-Potential Readings (MV)	Water-Soluble Chloride Content
L1A	MIDDLE (N.B.)	2-1/4 to 2-3/4	170	0.257
L2	NORTH (N.B.)	2-1/4 to 2-3/4	135	0.057
L3A	NORTH (N.B.)	2-1/2 to 3	60	0.043
L4A	SOUTH (N.B.)	2-1/4 to 2-3/4	135	0.086
L5A	SOUTH (N.B.)	2-1/4 to 2-3/4	135	0.036
L6A	SOUTH (N.B.)	2-1/4 to 2-3/4	370	0.171
L7A	SOUTH (S.B.)	2-1/4 to 2-3/4	370	0.186
L8A	NORTH (S.B.)	2-1/4 to 2-3/4	360	0.343
L9A	SOUTH (S.B.)	2-1/4 to 2-3/4	300	0.193
L11	SOUTH (S.B.)	2-1/2 to 3	70	0.057
L12	SOUTH (S.B.)	1-1/2 to 2-1/4	120	0.714
L13	MIDDLE (S.B.)	2-1/4 to 2-3/4	60	0.121

* Based on an estimated cement content of 14% (by weight of cement)



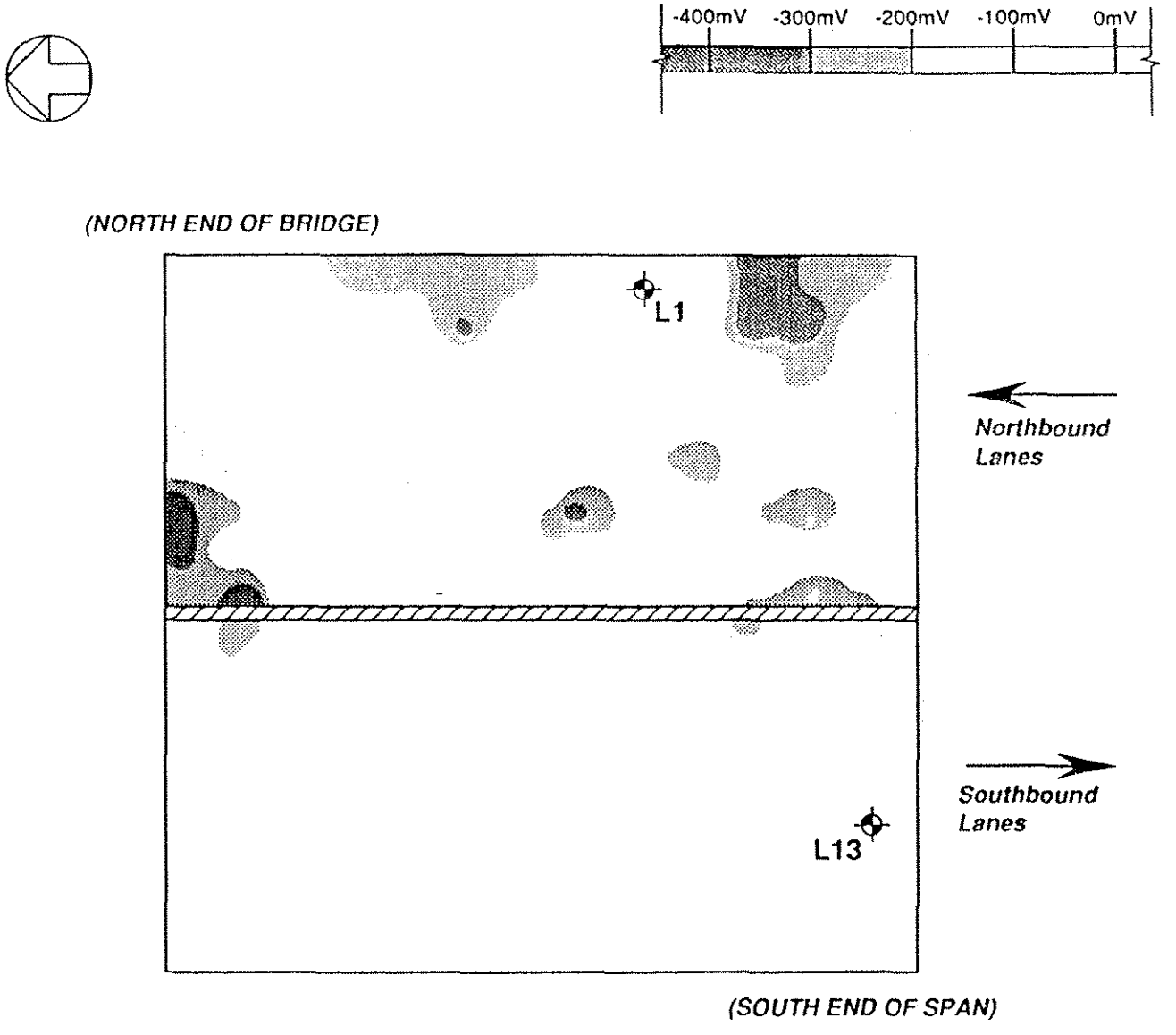
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(a)

CTL 050324

Construction Technology Laboratories, Inc.



MIDDLE SPAN

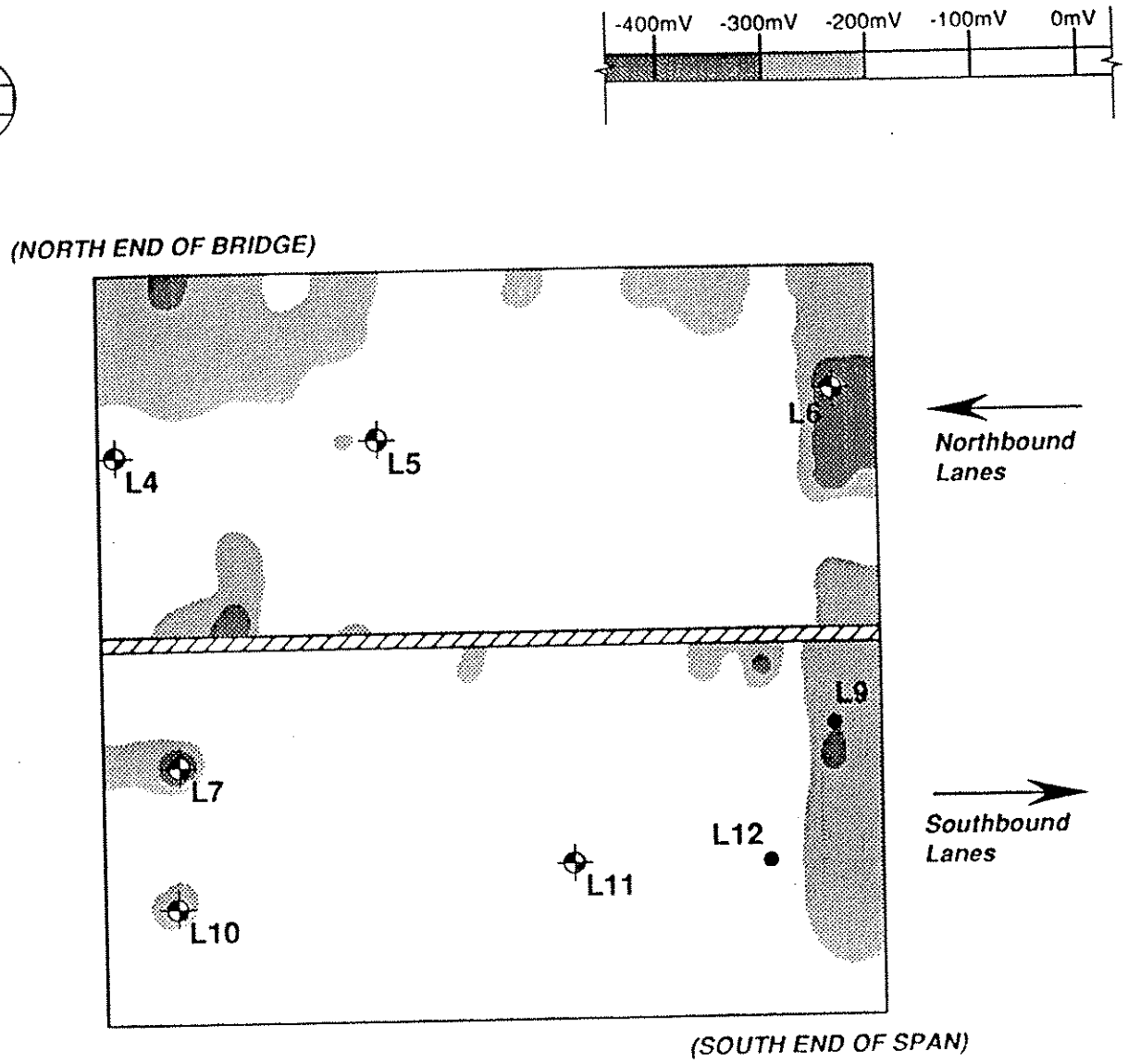
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(b)

CTL 050324

Construction Technology Laboratories, Inc.



SOUTH SPAN

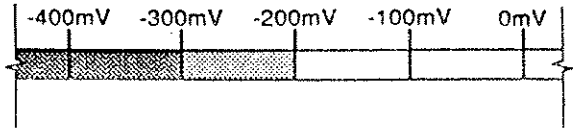
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(c)

CTL 050324

Construction Technology Laboratories, Inc.



(NORTH END OF BRIDGE)

191	153	198	60	48	70	94	157	107	199	175	184	225
242	204	123	105	93	194	146	149	128	123	133	284	180
264	207	119	108	83	147	123	125	115	184	128	108	161
253	100	144	103	137	158	129	123	125	151	121	165	137
261	137	114	78	77	103	99	78	114	112	69	140	112
184	150	119	97	126	114	98	127	125	109	119	108	138
212	173	155	142	94	96	120	111	125	130	112	94	154
217	184	133	124	136	113	157	106	105	85	75	77	186
313	167	94	59	27	30	72	91	80	58	43	249	88
364	101	110	85	38	54	45	105	67	59	75	110	75
323	85	100	102	72	78	100	120	46	21	43	363	172
258	80	71	48	41	52	80	83	87	21	80	129	17
300	113	83	72	46	100	84	116	87	82	97	140	87
177	50	20	20	1	35	84	132	40	48	90	145	28
218	100	7	3	15	45	42	15	12	30	66	96	70
150	40	10	10	13	11	12	17	2	35	34	110	115

Northbound Lanes

Southbound Lanes

(SOUTH END OF SPAN)

NORTH SPAN

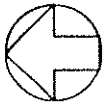
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

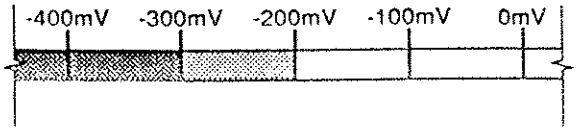
AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(d)

CTL 050324

Construction Technology Laboratories, Inc.





(NORTH END OF BRIDGE)

286	333	269	186	258	80	133	251	184	248	227	179	284
215	236	247	273	215	74	136	103	85	173	193	186	280
209	236	203	212	70	94	71	80	122	121	118	117	371
143	186	140	140	204	135	47	71	87	133	115	136	314
129	173	161	174	158	102	92	85	61	109	151	151	362
208	141	282	187	132	103	165	94	91	138	97	138	180
182	150	202	85	143	99	112	52	132	61	114	112	220
136	235	328	67	268	168	114	56	130	86	68	169	208
135	93	149	148	52	100	210	80	130	91	285	351	746
143	180	125	88	52	38	145	62	127	70	82	173	294
268	388	182	152	47	110	162	47	192	82	69	88	318
117	152	104	68	72	75	31	83	140	34	72	92	292
98	129	76	53	96	50	75	111	67	69	69	121	229
139	248	57	21	60	50	29	38	14	3	83	105	235
60	112	60	97	34	31	52	40	173	20	71	46	278
26	25	33	21	18	40	41	1	3	2	31	85	33

Northbound Lanes

Southbound Lanes

(SOUTH END OF SPAN)

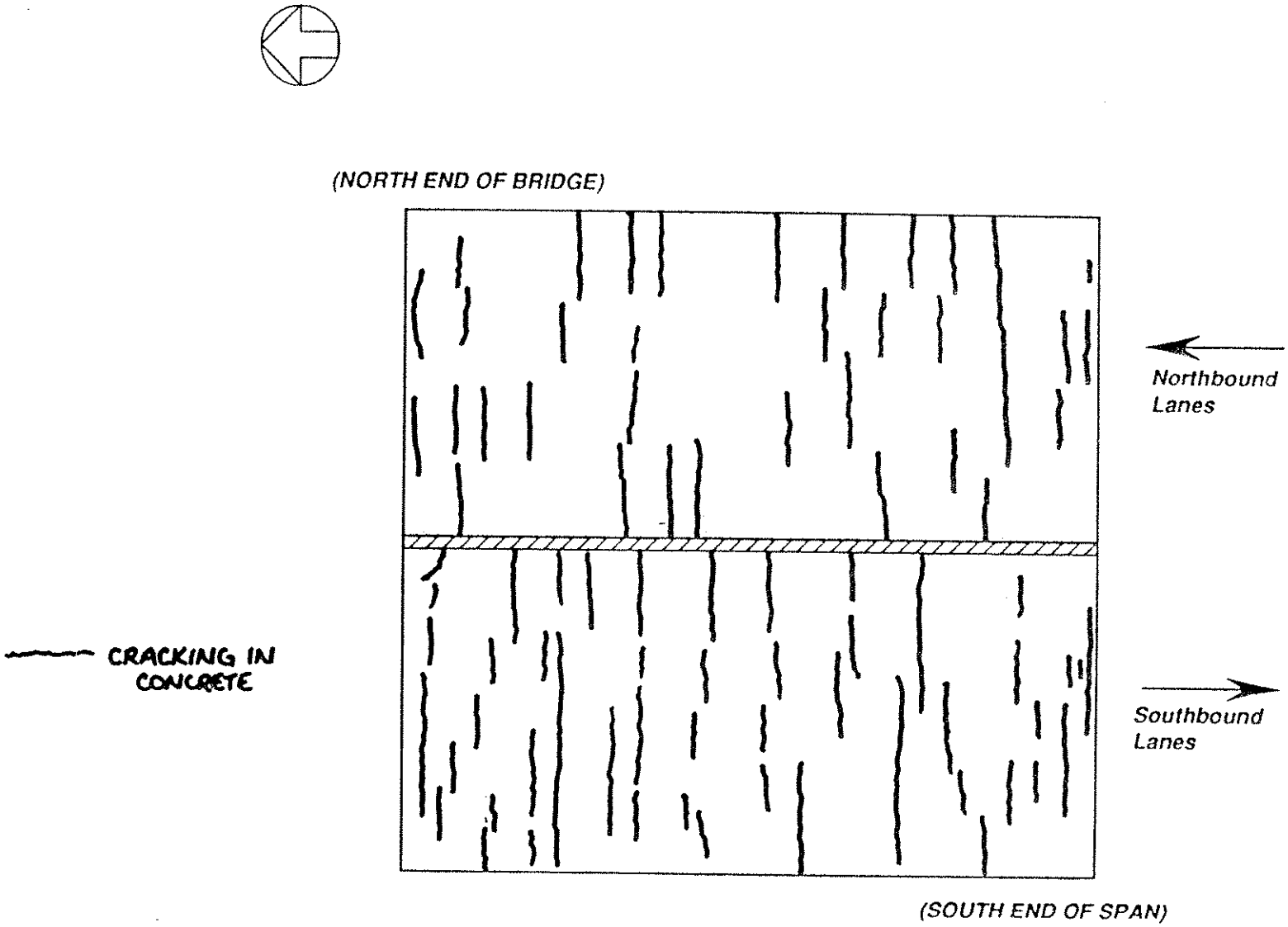
SOUTH SPAN

Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(f)

CTL 050324



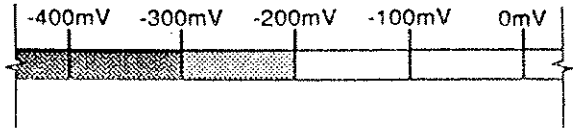
MIDDLE SPAN

Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(h)

CTL 050324



(NORTH END OF BRIDGE)

191	153	198	60	48	70	94	157	107	199	175	184	225
242	204	123	105	93	194	146	149	128	123	133	284	180
264	207	119	108	83	147	123	125	115	184	128	108	161
253	100	144	103	137	158	129	123	125	151	121	165	137
261	137	114	78	77	103	99	78	114	112	69	140	112
184	150	119	97	126	114	98	127	125	109	119	108	138
212	173	155	142	94	96	120	111	125	130	112	94	154
217	184	133	124	136	113	157	106	105	85	75	77	186
313	167	94	59	27	30	72	91	80	58	43	249	88
364	101	110	85	38	54	45	105	67	59	75	110	75
323	85	100	102	72	78	100	120	46	21	43	363	172
258	80	71	48	41	52	80	83	87	21	80	129	17
300	113	83	72	46	100	84	116	87	82	97	140	87
177	50	20	20	1	35	84	132	40	48	90	145	28
218	100	7	3	15	45	42	15	12	30	66	96	70
150	40	10	10	13	11	12	17	2	35	34	110	115

Northbound Lanes

Southbound Lanes

(SOUTH END OF SPAN)

NORTH SPAN

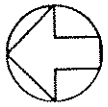
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

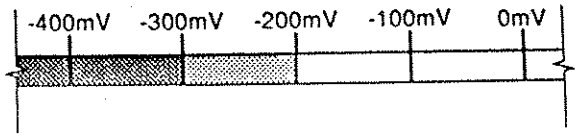
AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(d)

CTL 050324

Construction Technology Laboratories, Inc.





(NORTH END OF BRIDGE)

100	123	143	218	213	228	205	180	228	185	303	282	208
152	201	147	147	154	392	164	130	172	164	380	340	172
146	124	138	140	122	131	130	142	148	140	158	227	191
192	136	173	160	146	151	142	128	78	96	100	123	102
190	190	155	198	198	132	124	94	82	234	131	104	116
399	238	152	169	217	135	157	313	155	137	181	287	144
316	186	185	131	188	152	144	183	141	146	154	168	183
284	357	45	164	109	84	101	156	161	193	209	291	218
47	278	138	77	29	96	92	89	45	121	266	105	144
128	151	105	63	93	68	112	82	35	103	118	111	169
93	183	150	59	66	84	194	107	76	116	182	117	156
46	87	56	91	35	36	58	79	82	81	78	108	100
44	88	46	60	75	26	30	87	65	64	72	98	63
46	40	14	44	27	8	86	30	42	66	50	17	43
23	2	84	54	44	0	106	14	71	84	191	21	40
29	10	23	24	20	20	55	47	37	17	128	3	5

Northbound Lanes

Southbound Lanes

(SOUTH END OF SPAN)

MIDDLE SPAN

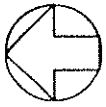
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

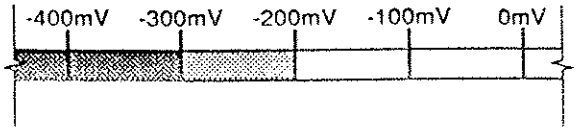
AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(e)

CTL 050324

Construction Technology Laboratories, Inc.





(NORTH END OF BRIDGE)

286	333	269	186	258	80	133	251	184	248	227	179	284
215	236	247	273	215	74	136	103	85	173	193	186	280
209	236	203	212	70	94	71	80	122	121	118	117	371
143	186	140	140	204	135	47	71	87	133	115	136	314
129	173	161	174	158	102	92	85	61	109	151	151	362
208	141	282	187	132	103	165	94	91	138	97	138	180
182	150	202	85	143	99	112	52	132	61	114	112	220
136	235	328	67	268	168	114	56	130	86	68	169	208
135	93	149	148	52	100	210	80	130	91	285	351	746
143	180	125	88	52	38	145	62	127	70	82	173	294
268	388	182	152	47	110	162	47	192	82	69	88	318
117	152	104	68	72	75	31	83	140	34	72	92	292
98	129	76	53	96	50	75	111	67	69	69	121	229
139	248	57	21	60	50	29	38	14	3	83	105	235
60	112	60	97	34	31	52	40	173	20	71	46	278
26	25	33	21	18	40	41	1	3	2	31	85	33

Northbound Lanes

Southbound Lanes

(SOUTH END OF SPAN)

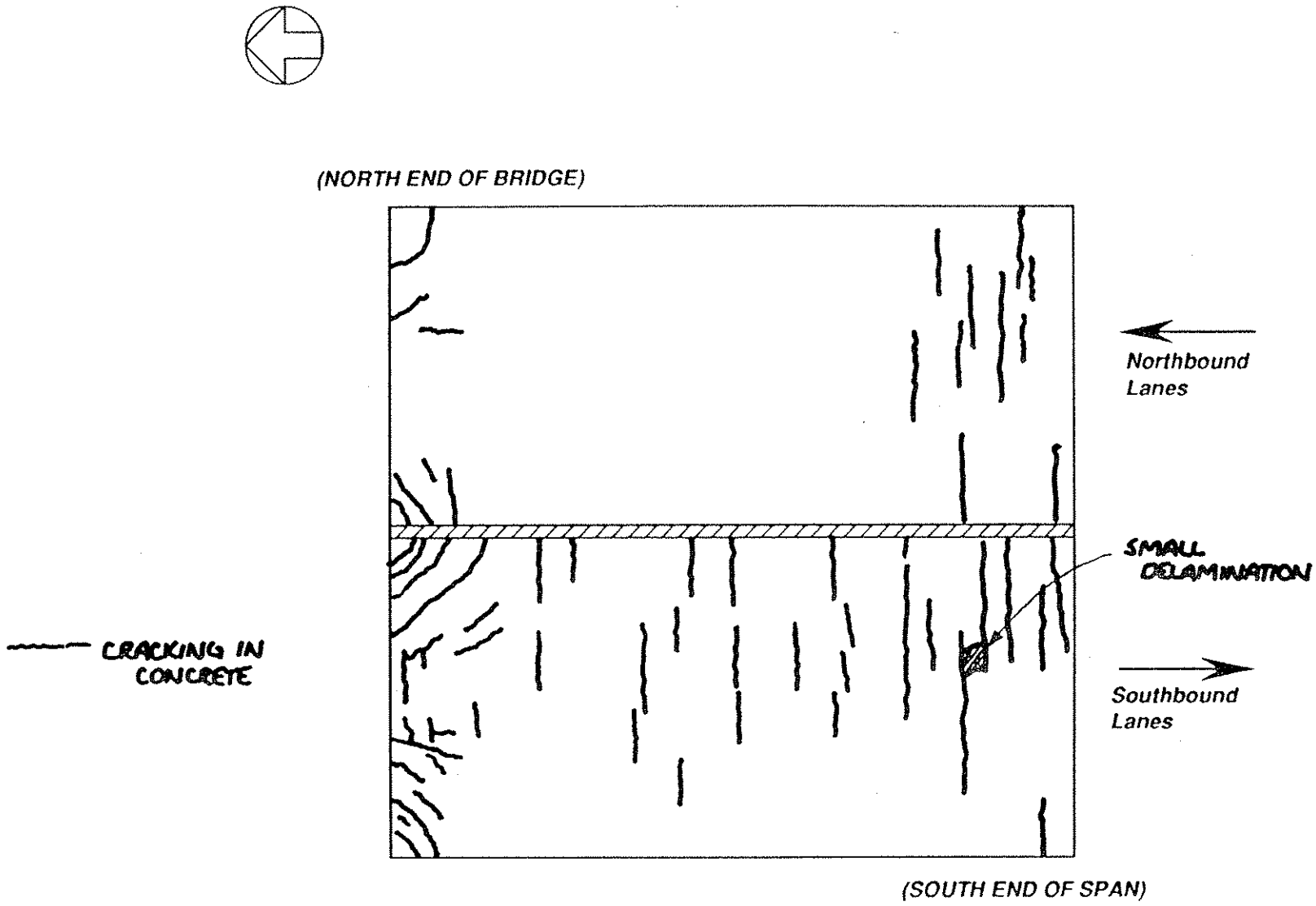
SOUTH SPAN

Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(f)

CTL 050324



NORTH SPAN

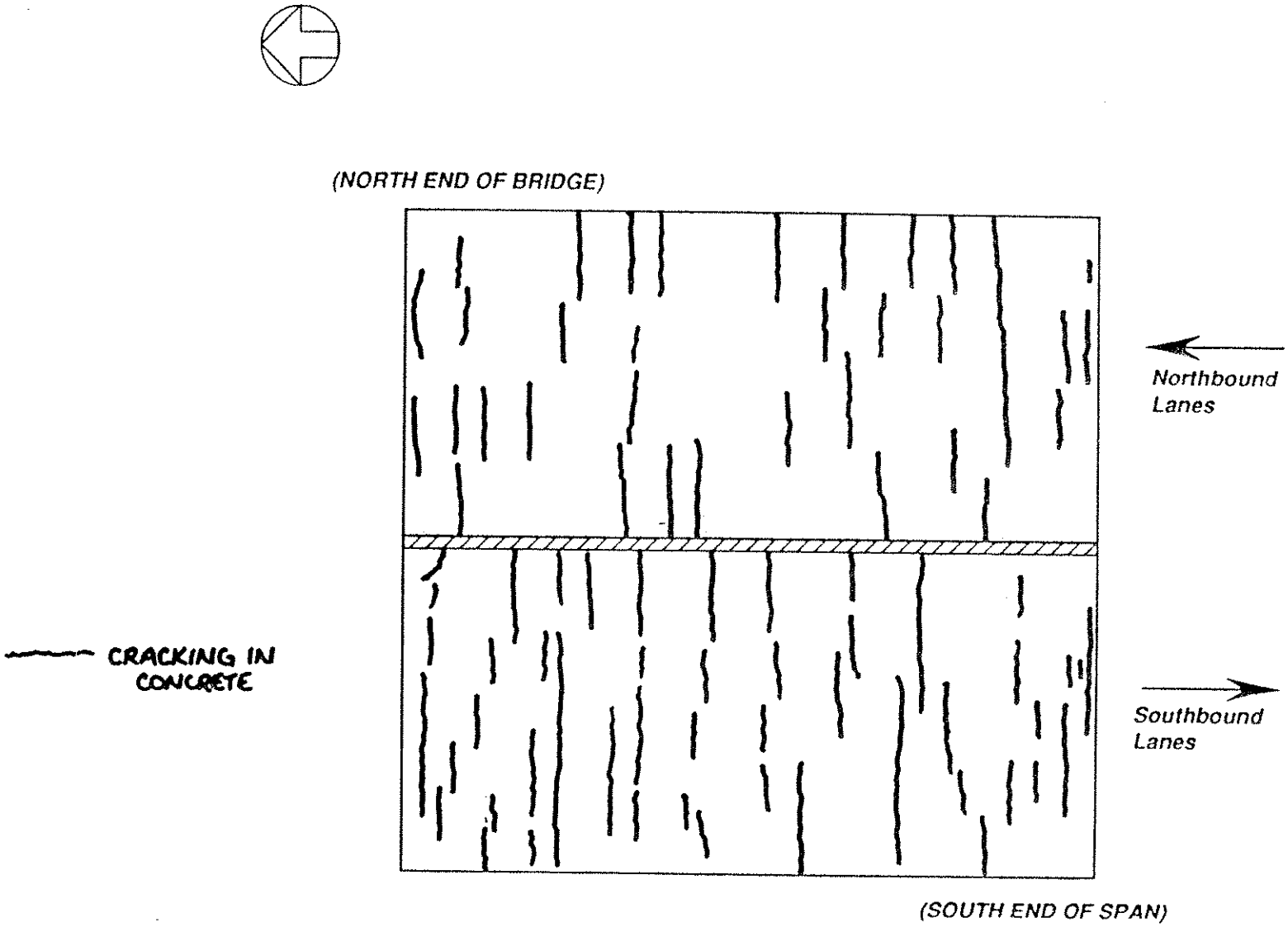
Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(g)

CTL 050324

Construction Technology Laboratories, Inc.



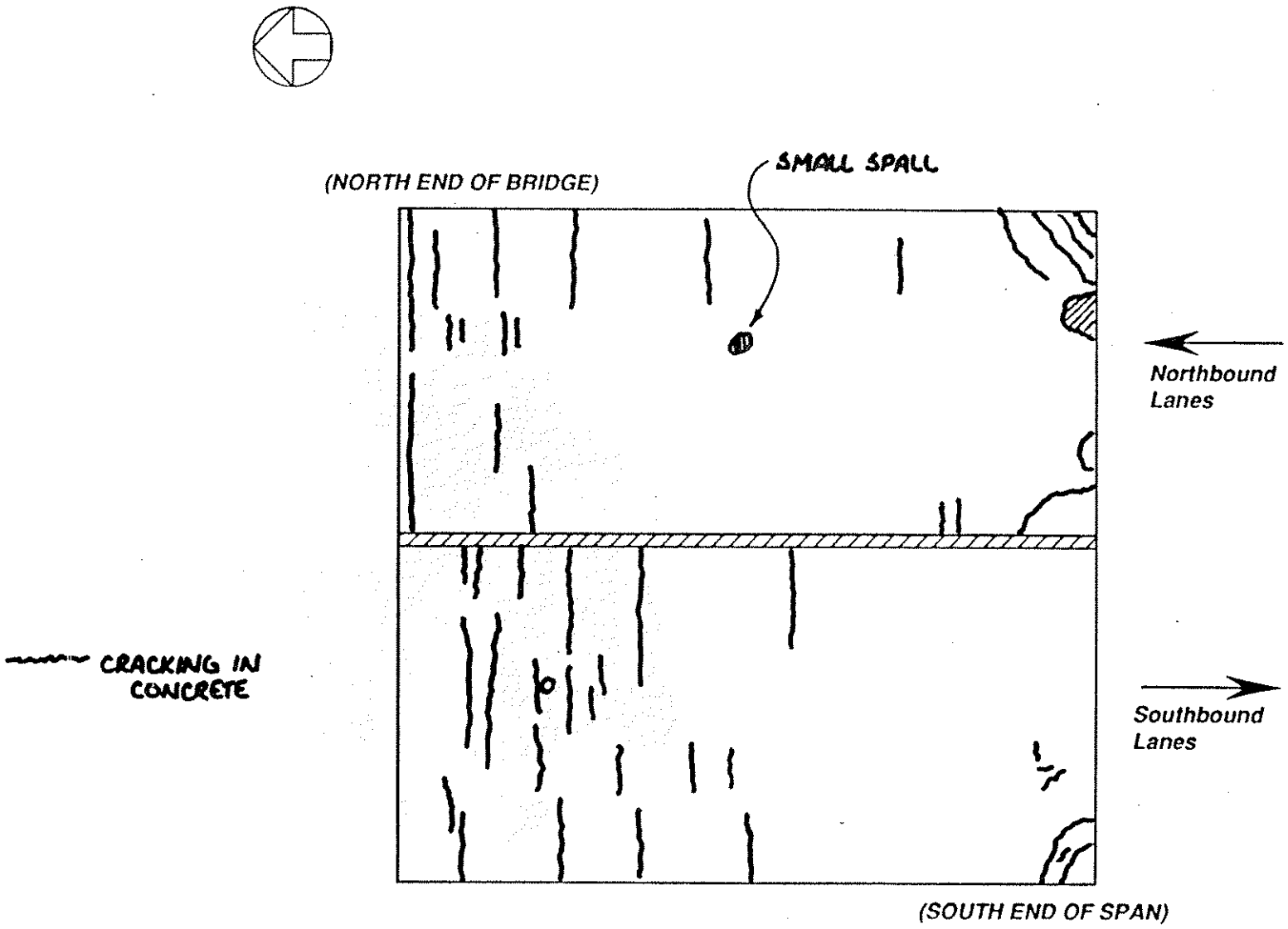
MIDDLE SPAN

Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(h)

CTL 050324



SOUTH SPAN

Iowa Department of Transportation
AMES, IOWA (Story County)
DISTRICT 3

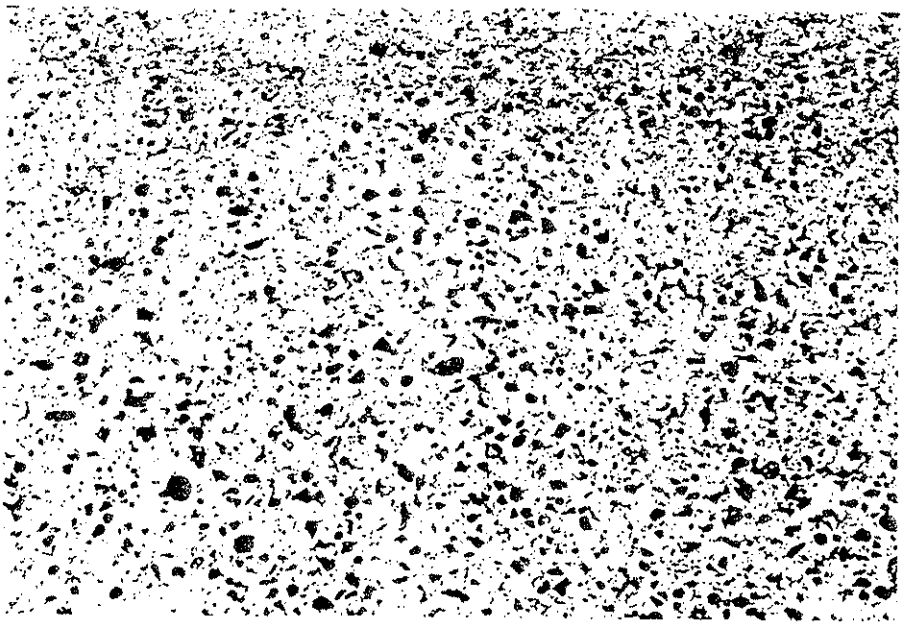
AMES BRIDGE
(I-35 over Long Dick Creek)

FIG A.2(i)

CTL 050324

Construction Technology Laboratories, Inc.

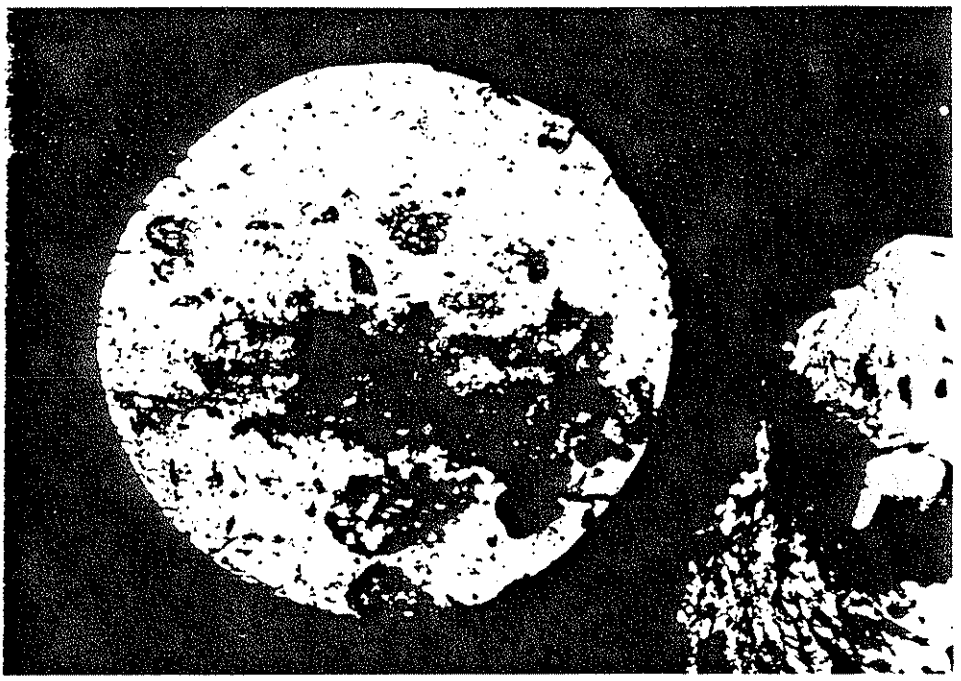
AMES BRIDGE

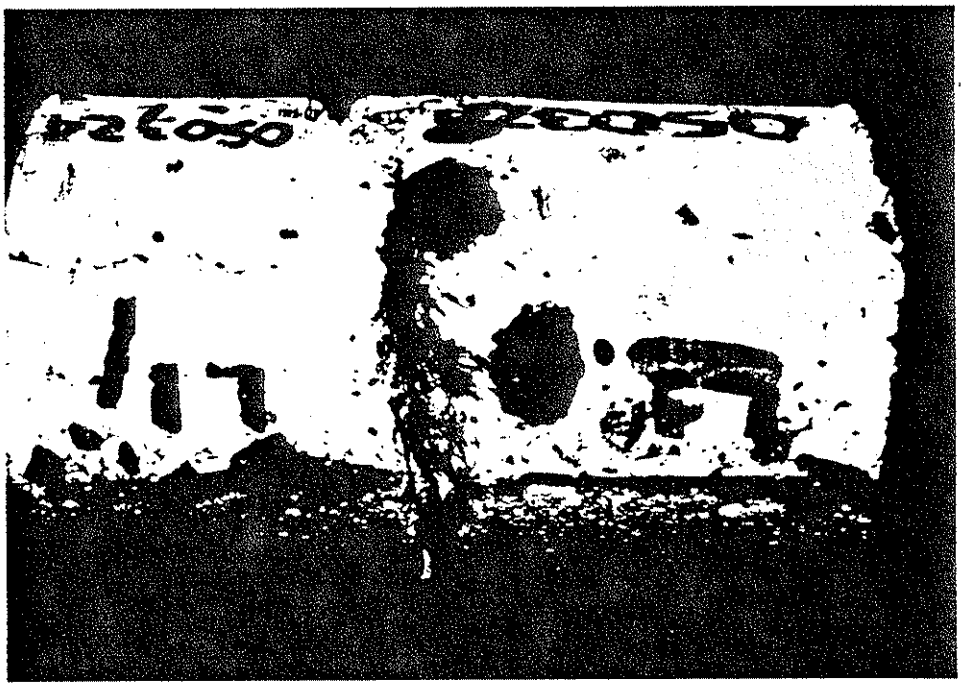


PHOTOS A.2(a & b):

Representative Conditions of Bridge Deck Wearing Surface (Note areas of concrete deterioration and ashalt patch shown in Photo b)

AMES BRIDGE





PHOTOS A.2(c & d):

Close-up Views of Core Sample L-1 Note that the water-soluble chloride ion content in powder sample L-1A was 0.257 (by weight of cement), at a depth of approximately 2-1/2-in. Potential survey results indicated a reading of -170 mv in adjacent concrete.

AMES BRIDGE

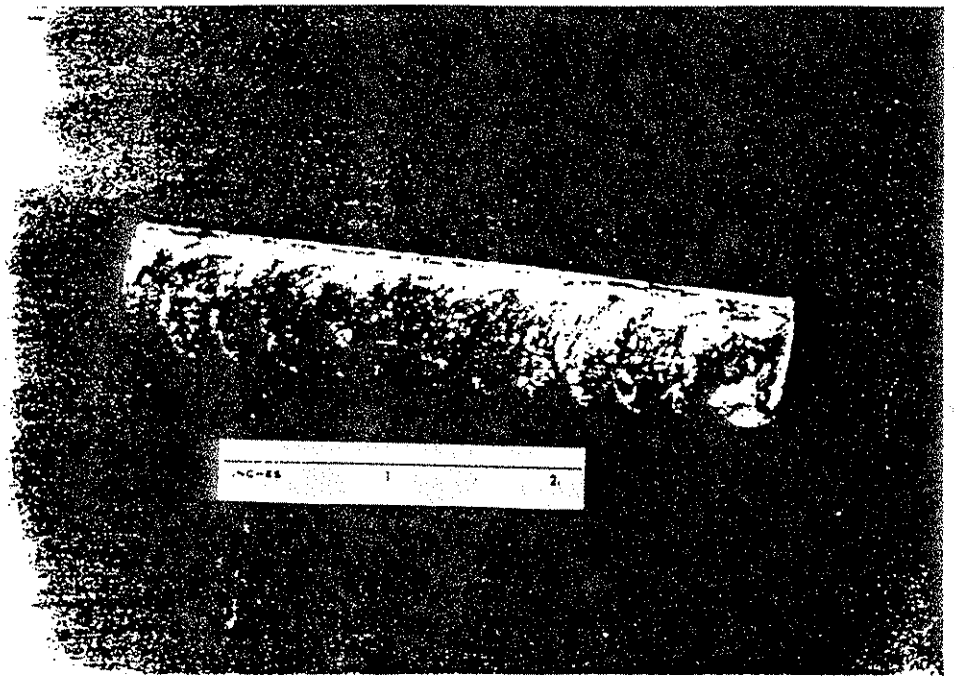


PHOTO A.2(e):
Steel samples removed from Core Sample L-6.

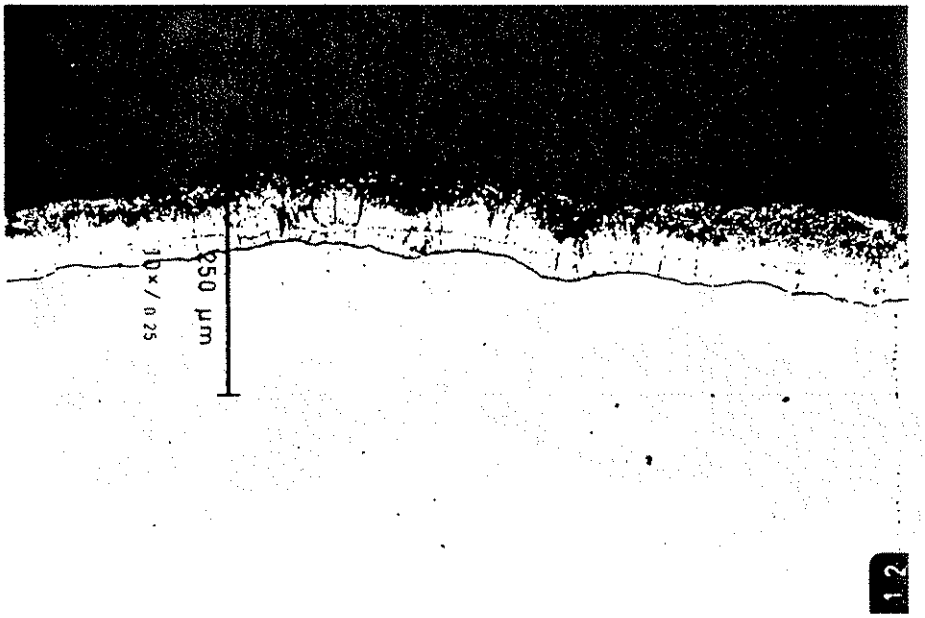


PHOTO A.2(f):
Magnification of No. 6 Bar removed from Core Sample L-6 (galvanized coating thickness of 3.8 mils).

AMES BRIDGE

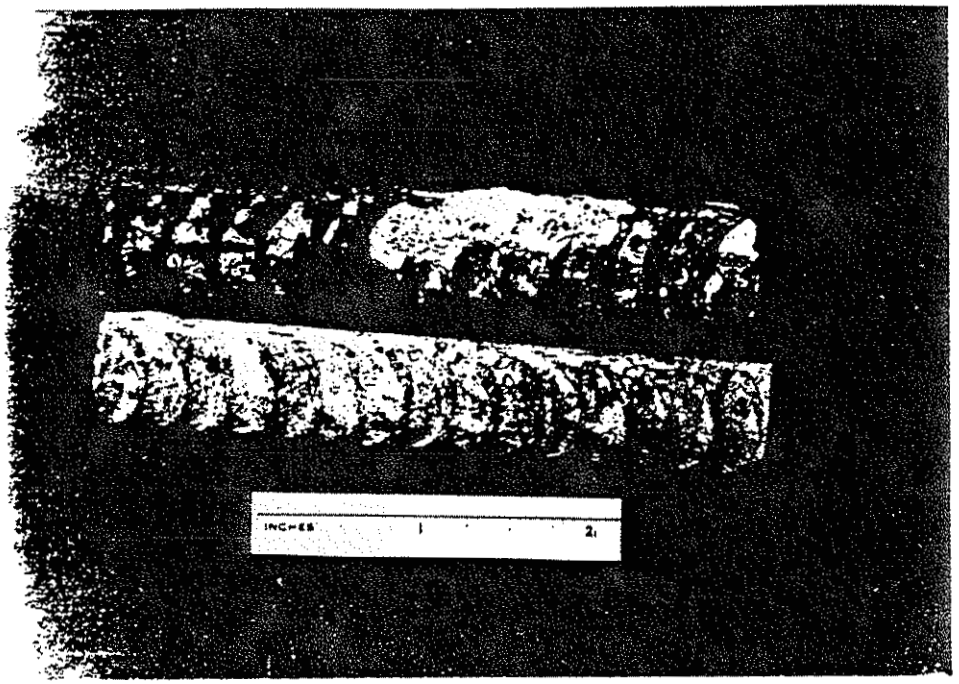


PHOTO A.2(g):
Steel samples removed from Core Sample L-10.

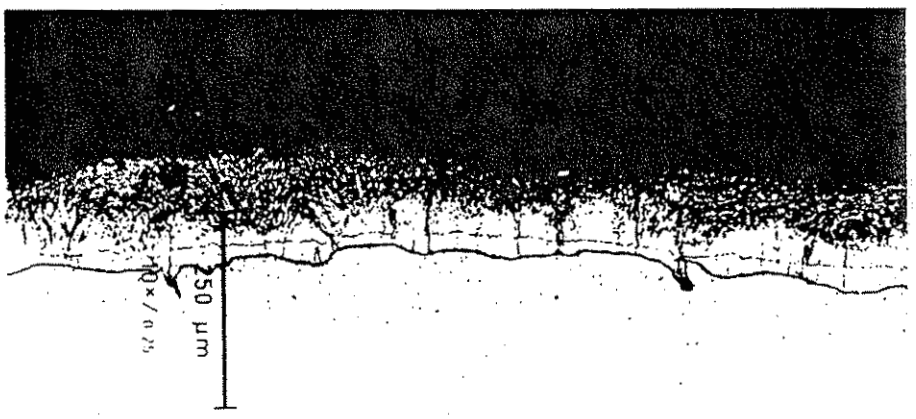


PHOTO A.2(h):
Magnification of No. 5 Bar removed from Core Sample L-10 (galvanized coating thickness of 4.7 mils).

AMES BRIDGE

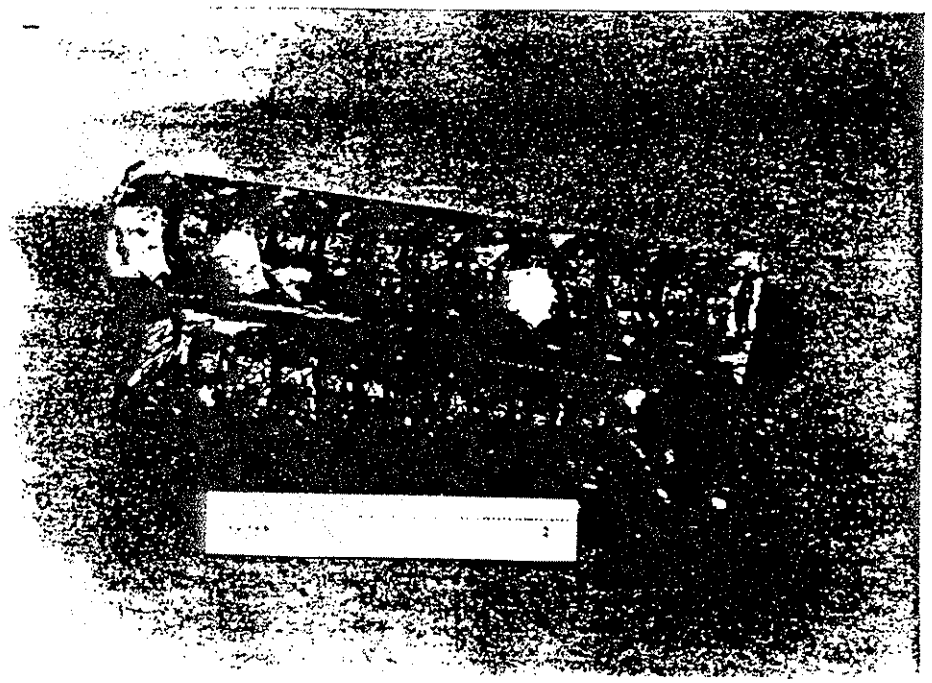


PHOTO A.2(i):
Steel samples removed from Core Sample L-14.

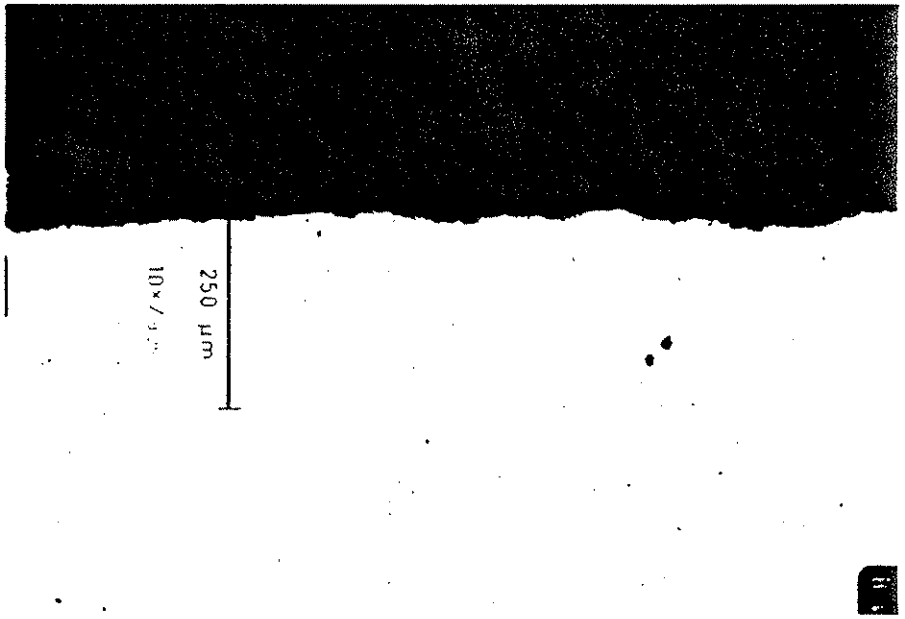


PHOTO A.2(j):
Magnification of No. 6 Bar removed from Core Sample L-14 (steel reinforcement is uncoated).

CTL

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 154070
CLIENT: International Lead Zinc Research Organization
STRUCTURE: Bridge Deck
LOCATION: Ames, Iowa

DATE: January 22, 1992
PROBLEM: Quality Evaluation
EXAMINED BY: L. Powers-Couche

SAMPLE:

Identification: L6.

Dimensions: Diameter = 4.0 in.; Length = 4.0 to 5.0 in.

Top Surface: Abraded surface with exposed coarse aggregate. Aggregate particles are polished and stand out in relief against softer paste.

Bottom Surface: Broken surface fractured around aggregate.

Cracks, Joints, Large Voids: Many areas of underconsolidation. The largest underconsolidated area is 1.5 in. long and 2.0 in. wide.

Reinforcement: No. 6 rebar is located 3.0 in from top surface.

AGGREGATES (A)

Coarse (C): Siliceous and calcareous gravel consisting of granite, limestone, chert, altered volcanic rock (hematitic and silicified), and schist.

Fine (F): Siliceous and calcareous sand consisting of quartzite, quartz, limestone, chert, feldspar, schist, hornblende, granite, graywacke, and hematite-cemented sandstone.

Gradation & Top Size: Evenly graded to a top size of 0.7 in.

Shape & Distribution: CA is rounded to subangular, equidimensional to elongate, and somewhat nonuniformly distributed. FA is rounded to subangular, equidimensional, and uniformly distributed.

PASTE

Color: Medium gray.

Hardness: Moderately hard.

Luster: Subvitreous.

Calcium Hydroxide*: 7 to 10% uniformly distributed small crystals.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 8 to 12% uniformly distributed UPC's and relics.

Depth of Carbonation: 0.1 in. from top surface.

Air Content: 4 to 6% uniformly distributed, small, spherical air voids and irregularly shaped, larger (up to 0.5 in.) paste-lined, entrapped air voids.

Fly Ash*: None observed.

Paste-Aggregate Bond: Moderately tight. The concrete breaks around the smooth, hard coarse aggregates.

Secondary Deposits: Inwardly-pointing ettringite needles line or fill voids.

*percent by volume of paste

Microcracking: No significant microcracks are observed.

ESTIMATED WATER-CEMENT RATIO: 0.50 to 0.55.

MISCELLANEOUS: Chert particles have dark rims, however, no other evidence of alkali-silica reaction is observed. The paste is carbonated around limestone particles and around some larger air voids.

CTL

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 154070
CLIENT: International Lead Zinc Research Organization
STRUCTURE: Bridge Deck
LOCATION: Ames, Iowa

DATE: January 22, 1992
PROBLEM: Quality Evaluation
EXAMINED BY: L. Powers-Couche

SAMPLE:

Identification: L10.

Dimensions: Diameter = 4.0 in.; Length = 6.5 in.

Top Surface: Abraded surface with coarse aggregates exposed. Aggregates are polished and stand out in relief against softer paste.

Bottom Surface: Irregular, broken surface fractured through aggregates.

Cracks, Joints, Large Voids: The concrete is generally well consolidated with no visible joints and few voids larger than 0.2 in. Two major vertical cracks which mostly pass around aggregates pass lengthwise through the core.

Reinforcement: No. 5 rebar is located 3.2 in. from the top surface. No 6 rebar is 5.0 in. for the top and is corroded.

AGGREGATES (A)

Coarse (C): Siliceous and calcareous gravel consisting of granite, limestone, chert, altered volcanic rock (hematitic and silicified), and schist.

Fine (F): Siliceous and calcareous sand consisting of quartzite, quartz, limestone, chert, feldspar, schist, hornblende, granite, graywacke, and hematite-cemented sandstone.

Gradation & Top Size: Evenly graded to a top size of 0.7 in.

Shape & Distribution: CA is rounded to subangular, equidimensional to elongate, and somewhat nonuniformly distributed. FA is rounded to subangular, equidimensional, and uniformly distributed.

PASTE

Color: Medium gray.

Hardness: Moderately hard.

Luster: Subvitreous.

Calcium Hydroxide*: 6 to 8% uniformly distributed small crystals and patches. Calcium hydroxide lines voids and partially coats aggregates.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 10 to 15% uniformly distributed UPC's and relics.

Depth of Carbonation: 0.1 in. from top surface.

Air Content: 3 to 5% uniformly distributed, small, spherical air voids.

Fly Ash*: None observed.

Paste-Aggregate Bond: Moderately tight.

Secondary Deposits: Blades of calcium hydroxide and ettringite needles line or fill voids.

*percent by volume of paste

Microcracking: Microcracks occur around reactive chert particles. Other cracks are randomly oriented and pass through aggregates. Adjacent paste is carbonated.

ESTIMATED WATER-CEMENT RATIO: 0.45 to 0.50.

MISCELLANEOUS: Dark rims occur around chert and dolomitic chert. Adjacent paste is cloudy and isotropic. Curved cracks following the outline of the aggregate are also observed. Gel is seen in one crack and in several voids.

PETROGRAPHIC EXAMINATION OF HARDENED CONCRETE, ASTM C 856

CTL PROJECT NO.: 154070
CLIENT: International Lead Zinc Research Organization
STRUCTURE: Bridge Deck
LOCATION: Ames, Iowa

DATE: January 22, 1992
PROBLEM: Quality Evaluation
EXAMINED BY: L. Powers-Couche

SAMPLE:

Identification: L14.

Dimensions: Diameter = 4.0 in.; Length = 5.6 in.

Top Surface: Moderately abraded surface with coarse aggregates exposed and polished.

Bottom Surface: Broken surface fractured through aggregates.

Cracks, Joints, Large Voids: Generally well consolidated with no visible joints. Some underconsolidation occurs around rebar. Air voids are typically smaller than 0.15 in. One side of the core intersected a vertical crack from the top of the core to a depth of 3 in. The crack passes through several coarse aggregate particles.

Reinforcement: Corroded No. 6 rebar is located 2.5 in. from top of core, and corroded No. 5 or 6 rebar located 3.3 in. from top.

AGGREGATES (A)

Coarse (C): Siliceous and calcareous gravel consisting of granite, limestone, chert, altered volcanic rock (hematitic and silicified), and schist.

Fine (F): Siliceous and calcareous sand consisting of quartzite, quartz, limestone, chert, feldspar, schist, hornblende, granite, graywacke, and hematite-cemented sandstone.

Gradation & Top Size: Evenly graded to a top size of 0.7 in.

Shape & Distribution: CA is rounded to subangular, equidimensional to elongate, and somewhat nonuniformly distributed. FA is rounded to subangular, equidimensional, and uniformly distributed.

PASTE

Color: Medium gray.

Hardness: Moderately hard.

Luster: Subvitreous.

Calcium Hydroxide*: 7 to 10% uniformly distributed small crystals.

Unhydrated Portland Cement Clinker Particles (UPC's)*: 8 to 12% uniformly distributed UPC's and relics.

Depth of Carbonation: 0.1 in. from top surface.

Air Content: 4 to 6% uniformly distributed, small, spherical air voids and irregularly shaped, larger (up to 0.5 in.) paste-lined, entrapped air voids.

Fly Ash*: None observed.

Paste-Aggregate Bond: Moderately tight. The concrete breaks around the smooth, hard coarse aggregates.

*percent by volume of paste

CTL

Secondary Deposits: Blades of calcium hydroxide and ettringite needles line or fill voids.

Microcracking: Microcracks occur around reactive chert particles. Other cracks are randomly oriented and pass through aggregates. Adjacent paste is carbonated.

ESTIMATED WATER-CEMENT RATIO: 0.50 to 0.55.

MISCELLANEOUS: Dark rims occur around chert and dolomitic chert. Adjacent paste is cloudy and isotropic. Curved cracks following the outline of the aggregate are also observed. Gel is seen in one crack and in several voids.

Table B.2(a): CONCRETE POWDER SAMPLE SUMMARY (1975 CTL Report)

AMES BRIDGE, IOWA

CTL Powder Designation	Electro-Potential Readings (-MV)	Water-Soluble Chloride Content (lbs/cu yd concrete)	Water-Soluble Chloride Content (by weight of concrete)	Water-Soluble Chloride Content* (by weight of cement)
SF2				
0" TO 1/4"	N.A.	13.80	0.352	2.518
3/4" TO 1"	N.A.	3.60	0.092	0.657
1-1/2" TO 1-3/4"	N.A.	0.70	0.018	0.128
SF3				
0" TO 1/4"	N.A.	14.50	0.370	2.646
3/4" TO 1"	N.A.	1.40	0.036	0.255
1-1/2" TO 1-3/4"	N.A.	0.70	0.018	0.128
SF5				
0" TO 1/4"	N.A.	4.30	0.110	0.785
3/4" TO 1"	N.A.	1.60	0.041	0.292
1-1/2" TO 1-3/4"	N.A.	0.70	0.018	0.128
NG1				
0" TO 1/4"	N.A.	4.20	0.107	0.766
3/4" TO 1"	N.A.	1.40	0.036	0.255
1-1/2" TO 1-3/4"	N.A.	0.50	0.013	0.091
NG3				
0" TO 1/4"	N.A.	9.00	0.230	1.642
3/4" TO 1"	N.A.	1.30	0.033	0.237
1-1/2" TO 1-3/4"	N.A.	0.50	0.013	0.091
NG5				
0" TO 1/4"	N.A.	3.50	0.089	0.639
3/4" TO 1"	N.A.	1.40	0.036	0.255
1-1/2" TO 1-3/4"	N.A.	0.70	0.018	0.128
NN2				
0" TO 1/4"	N.A.	10.70	0.273	1.952
3/4" TO 1"	N.A.	7.90	0.202	1.441
1-1/2" TO 1-3/4"	N.A.	0.40	0.010	0.073
NN4				
0" TO 1/4"	N.A.	4.20	0.107	0.766
3/4" TO 1"	N.A.	0.80	0.020	0.146
1-1/2" TO 1-3/4"	N.A.	0.40	0.010	0.073
NN5				
0" TO 1/4"	N.A.	2.30	0.059	0.420
3/4" TO 1"	N.A.	0.60	0.015	0.109

* Based on an estimated cement content of [illegible] (by weight of cement)

TABLE 8 - RESULTS OF CHLORIDE ANALYSES

Depth at Which Sample Was Taken	Lbs. Cl^-/cu. yd. of Concrete at Location Indicated								
	SF2	SF3	SF5	NG1	NG3	NG5	NN2	NN4	NN5
0 - 1/4"	13.8	14.5	4.3	4.2	9.0	3.5	10.7	4.2	2.3
3/4" - 1"	3.6	1.4	1.6	1.4	1.3	1.4	7.9	0.8	0.6
1-1/2" - 1-3/4"	0.7	0.7	0.7	0.5	0.5	0.7	0.4	0.4	0.4
2-1/4" - 2-1/2"	0.6*	0.7*	0.4*	0.6	0.5*	0.3*	0.7*	0.4*	0.2*
3" - 3-1/4"	0.6	0.5	0.5	-*	-	-	0.4	0.3	0.2

*Denotes level of top steel at location indicated.

TABLE 9 - RESULTS OF pH MEASUREMENTS

Depth at Which Sample Was Taken	pH at Location Indicated								
	SF2	SF3	SF5	NG1	NG3	NG5	NN2	NN4	NN5
0 - 1/4"	12.3	12.1	12.4	12.2	12.2	12.4	12.2	12.3	12.3
3/4" - 1"	12.4	11.8	12.0	12.1	12.1	12.1	12.0	12.1	12.2
1-1/2" - 1-3/4"	11.9	11.8	11.8	12.0	12.0	12.1	9.2	12.1	12.0
2-1/4" - 2/1/2"	11.2*	11.7*	11.8*	12.0	12.0*	12.1*	11.8*	12.0*	12.0*
3" - 3-1/4"	11.3	11.8	11.9	-*	-	-	11.7	11.7	11.5

*Denotes level of top steel at location indicated.

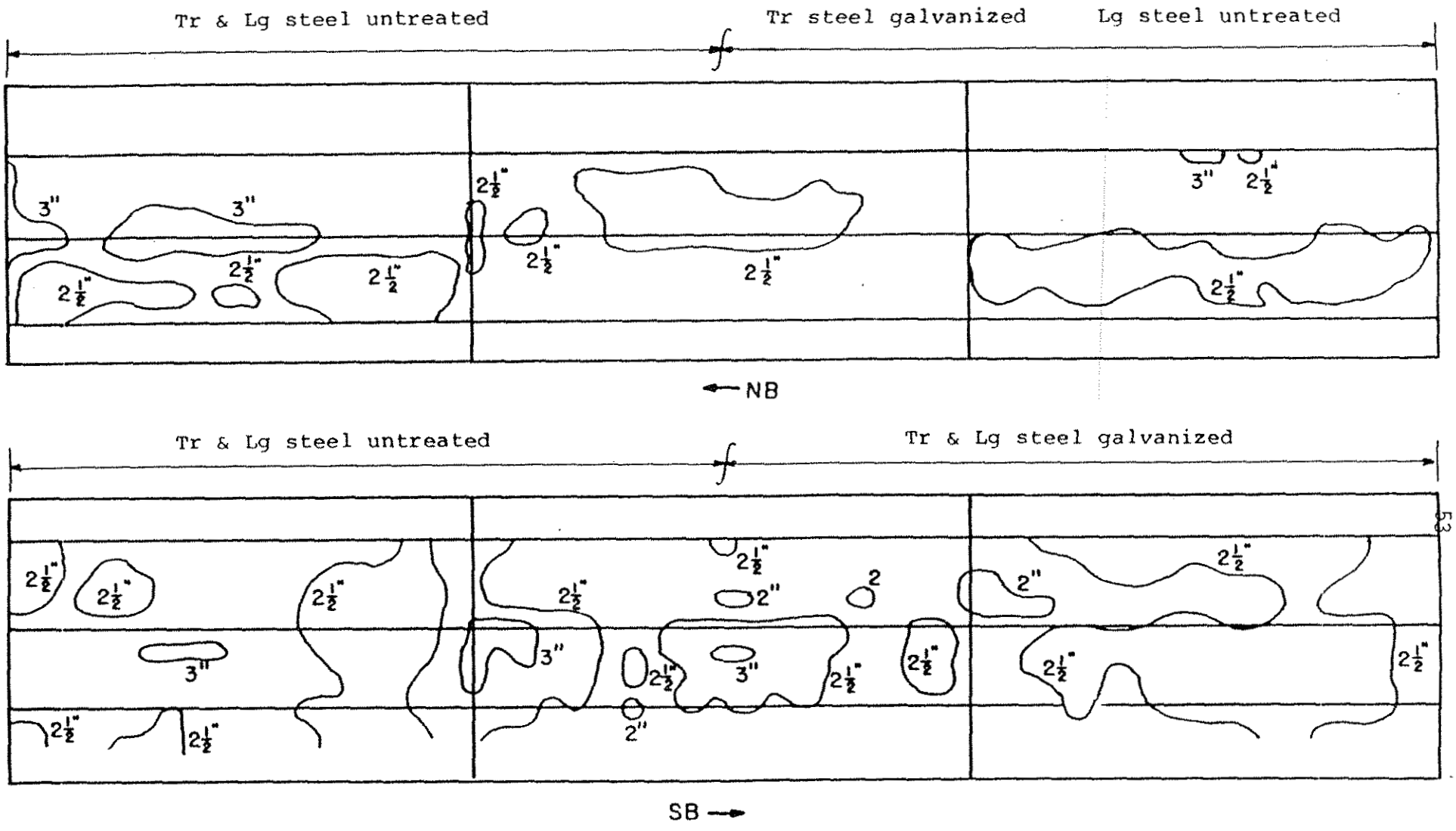
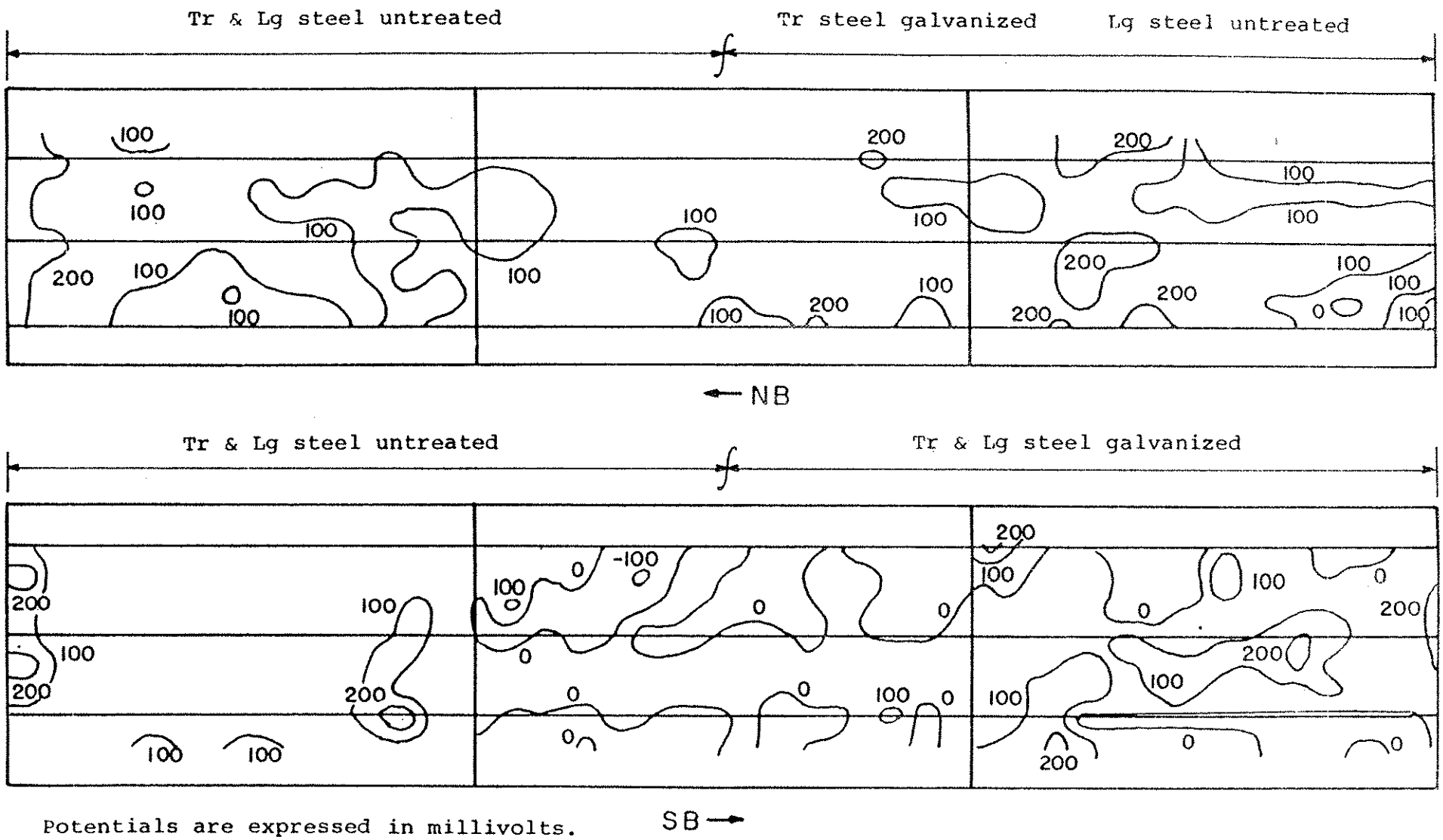
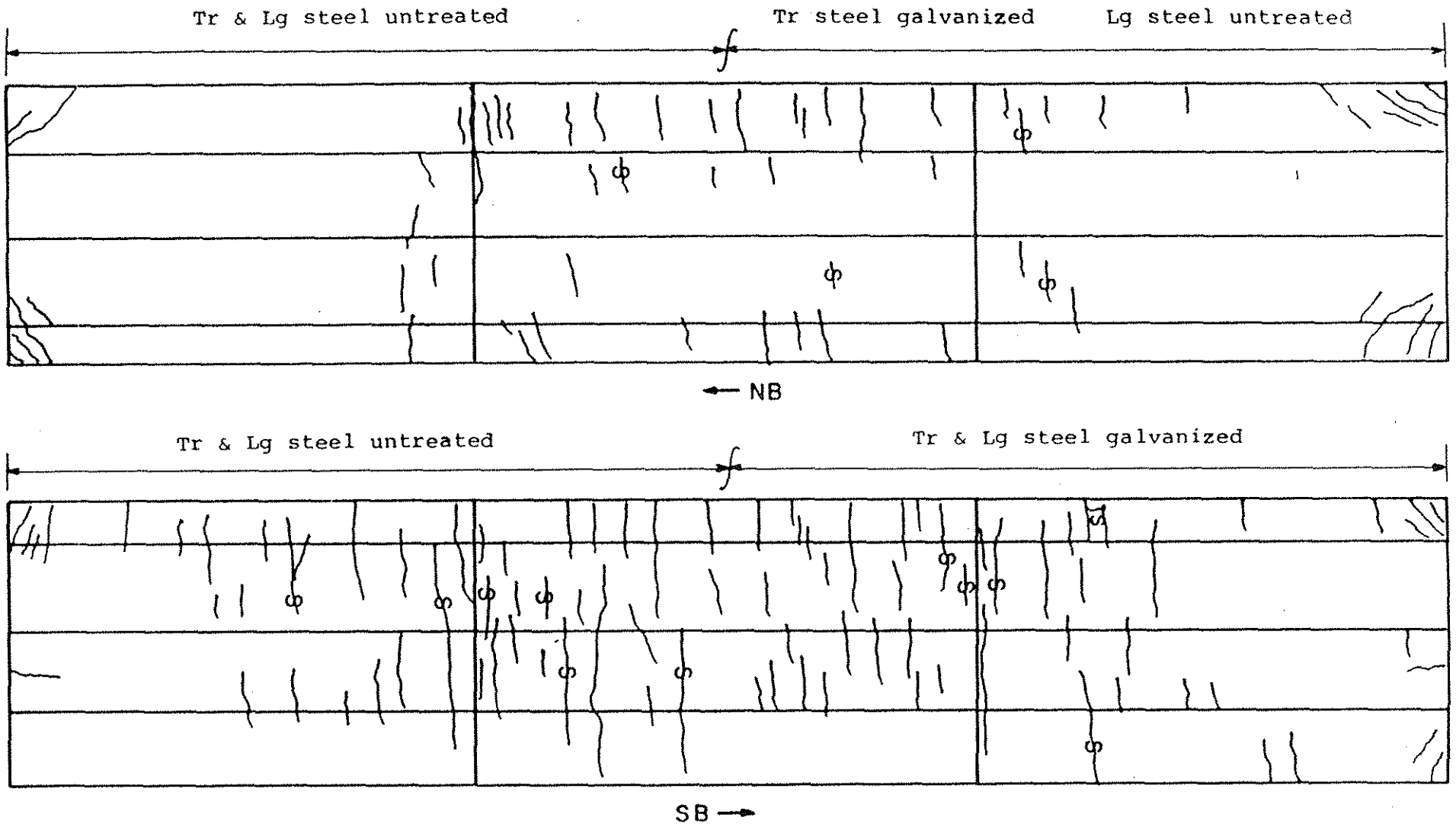


Fig. 21 - Diagram showing cover over top transverse reinforcing bars.



Potentials are expressed in millivolts.

Fig. 22 - Diagram of distribution of electrical potentials in top mat of reinforcing steel.



ϕ- Denotes crack directly over top reinforcing bar.

Crack

Fig. 23 - Diagram showing locations of cracks visible at wearing surface.

Table B.2(b): CONCRETE POWDER SAMPLE SUMMARY (1982 CTL Report)

AMES BRIDGE, IOWA

CTL Powder Designation		Electro-Potential Readings (-MV)	Water-Soluble Chloride Content (lbs/cu yd concrete)	Water-Soluble Chloride Content (by weight of concrete)	Water-Soluble Chloride Content* (by weight of cement)
LD-1	M	90	1.44	0.037	**0.263**
LD-2	M	370	0.56	0.014	**0.102**
LD-3	N	100	0.64	0.016	**0.117**
LD-4	S	350	0.88	0.022	**0.161**
LD-5	S	120	0.92	0.023	**0.168**
LD-6	S	120	0.44	0.011	**0.080**
LD-7	S	240	0.20	0.005	**0.036**
LD-8	S	40	0.96	0.025	**0.175**
LD-9	M	10	0.92	0.023	**0.168**
LD-10	S	110	0.64	0.016	**0.117**
LD-11	S	150	0.56	0.014	**0.102**
LD-12	S	70	0.76	0.019	**0.139**
LD-13	M	80	0.40	0.010	**0.073**
LD-14	N	100	0.40	0.010	**0.073**
LD-15	N	100	0.92	0.023	**0.168**

* Based on an estimated cement content of 14% (by weight of cement)

Table 1 - Results of Chloride and Metallographic Measurements

Sample No.	Sample Depth, in.	Steel Mat	Potential-Volts	Cl^- content lbs/cu yd	Average Coating Thickness Remaining Mils *
LD-1	2-1/4 - 2-3/4	Untreated	-0.09	1.44	-
LD-2	2 - 2-1/2	Untreated	-0.37	0.56	-
LD-3	2 - 2-1/2	Untreated	-0.10	0.64	-
LD-4	2-1/4 - 2-3/4	Galv. & Untr.	-0.35	0.88	7.7
LD-5	2-3/4 - 3-1/4	Galv. & Untr.	-0.12	0.92	5.8
LD-6	2-1/2 - 3	Galv. & Untr.	-0.12	0.44	5.7
LD-7	2 - 2-1/2	Galvanized	-0.24	0.20	-
LD-8	2 - 2-1/2	Galvanized	-0.04	0.96	-
LD-9	2-3/4 - 3-1/4	Galvanized	-0.01	0.92	-
LD-10	2 - 2-1/2	Galvanized	-0.11	0.64	-
LD-11	2-1/4 - 2-3/4	Galvanized	-0.15	0.56	5.4
LD-12	2-3/4 - 3-1/4	Galvanized	+0.07	0.76	-
LD-13	2 - 2-1/2	Galvanized	-0.08	0.40	6.1
LD-14	2-1/2 - 3	Untreated	-0.10	0.40	-
LD-15	2-1/4 - 2-3/4	Untreated	-0.10	0.92	-

*Based on average of 10 readings

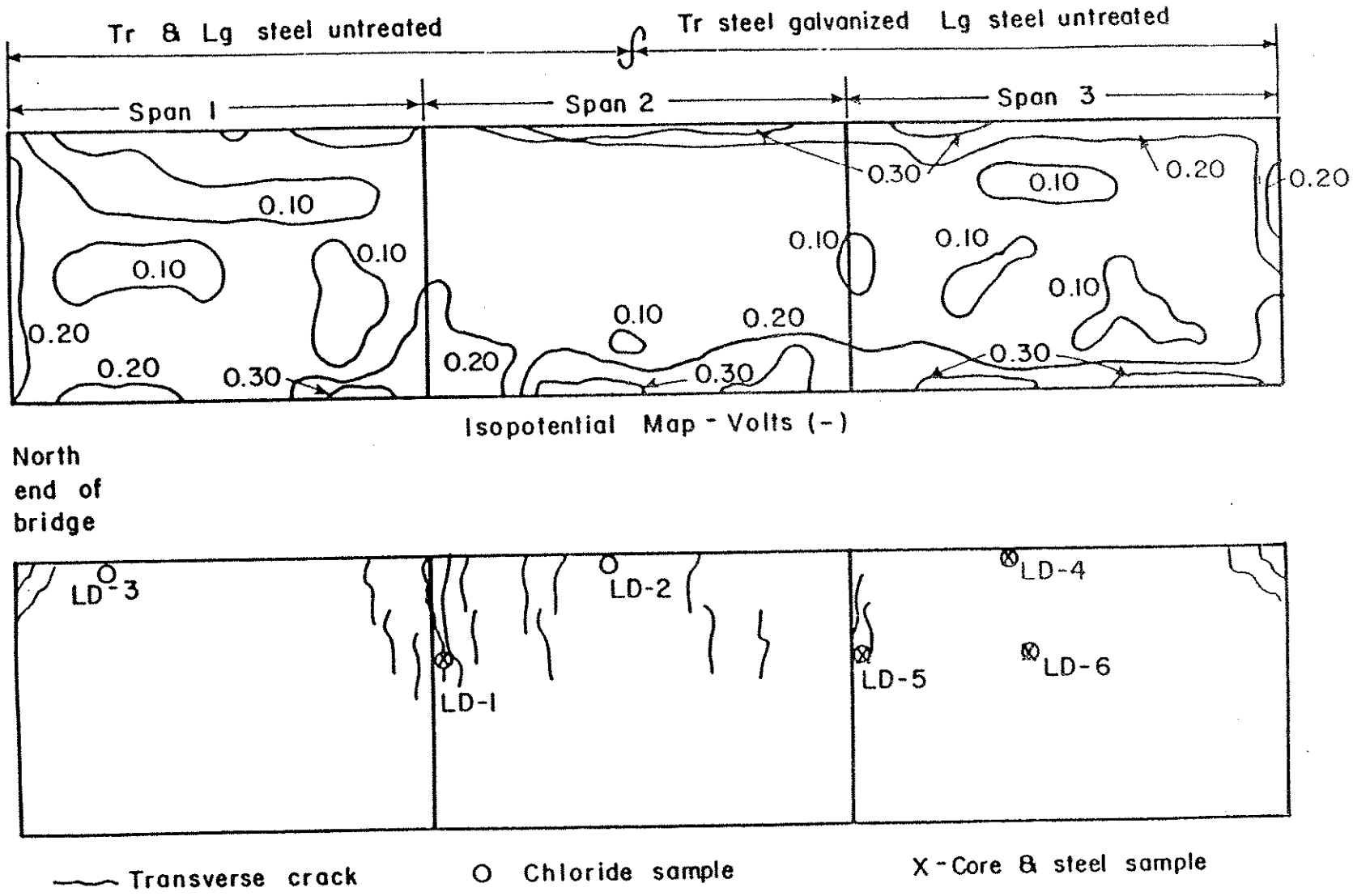


Fig. 1 Diagrams of Ames Bridge for Northbound Traffic Showing Results of Potential Measurements, Crack Survey, and Locations of Test Samples.

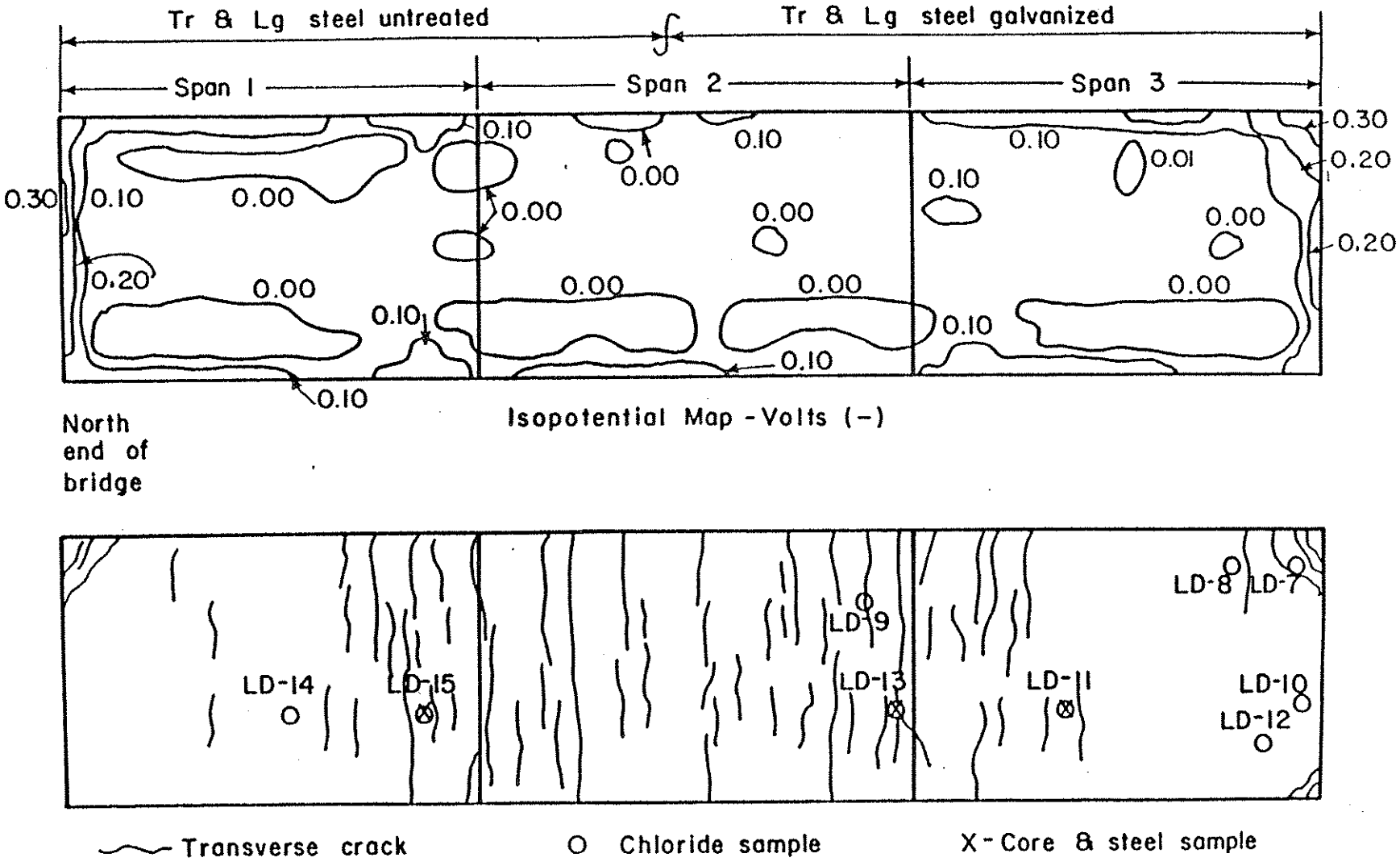


Fig. 2 Diagrams of Ames Bridge for Southbound Traffic Showing Results of Potential Measurements, Crack Survey, and Locations of Test Samples.