INVESTIGATION OF BRIDGE DECK DETERIORATION

CAUSED BY DE-ICING CHEMICALS

By

Gary F. Demich
Bridge Condition Section
Washington State Department of Highways

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16. Abstract

Forty-eight bridge decks were investigated for deterioration using visual, mechanical, electrical and chemical techniques. Data from the various techniques and the techniques themselves were compared and evaluated, resulting in a data base for Washington's bridges and recommendations for efficient condition determinations.

Of the thirty-seven bridges for which all four types of inspection could be accomplished, twenty-nine were deteriorating as evidenced by delaminated concrete, and only two had non-deteriorating scores for all four techniques.

None of the investigative techniques used in the project have been shown able to predict deck deterioration problems six to eight years in advance, our desired time period for project planning.

The mechanical technique, commonly referred to as the "chain drag", is the method recommended for continued use by bridge inspection crews.

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ABSTRACT

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Of the thirty-seven bridges for which all four types of inspection could be accomplished, twenty-nine were deteriorating as evidenced by delaminated concrete, and only two had non-deteriorating scores for all four techniques.

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INTRODUCTION:

Salt, applied to prevent icing, is causing premature bridge deck deterioration. When de-icing salts reach the deck reinforcing steel, an electrolytic action begins causing the steel to corrode. As corrosive particles build up, they expand against the concrete cover, eventually exceeding the tensile strength of the concrete. Horizontal cracks then develop along the upper steel plane forming delaminated areas of concrete. Traffic impact causes the concrete above the fracture to spall out leaving a pothole in the deck and further exposing the reinforcing steel to deterioration.

The steel corrodes through an electrochemical process, forming a natural galvanic cell. Chloride ions dissolved in water form the electrolyte, and a portion of the steel becomes the anode and another portion the cathode, so that electrolytic action occurs along a bar.

Usually, galvanic cells are composed of two dissimilar metals immersed in a common electrolyte, but the same results may be obtained with two pieces of electrically connected metal in dissimilar electrolytes. In a bridge deck, different electrolytes may be due to different chloride ion concentrations, different amounts of available oxygen, etc., from one area of the deck to the next.

This corrosion process also creates repair problems in deteriorating decks. Removing "contaminated" concrete around an anodic section of reinforcing steel and placing new concrete will change the composition of the electrolyte in the repaired area, possibly making the new area cathodic to its surroundings. Corrosion may then begin in an adjacent area.

Bridge deck deterioration has accelerated so rapidly in Washington that visual techniques do not allow identification of decks requiring remedial action within the 6-year planning programs. Inspection techniques are needed which will indicate deck deterioration much sooner than previously.

OBJECTIVES:

Research by other States and the FHWA has established probable minimum chloride ion concentrations for initiating corrosion. Accepting those findings as valid, the primary objective of this investigation was to determine the existing condition of as many bridge decks as possible, at the same time confirming that de-icing salts were the probable cause of the apparently increasing rate of deterioration.

The secondary objectives were to evaluate the various inspection techniques used and the practical value of the information obtained from each; thereby being able to make recommendations concerning future investigations of Washington's highway bridges.

SCOPE AND LIMITATIONS

Forty-eight bridges, representing a cross-section of types, location and estimated levels of deterioration, were selected for study. The accepted technique for locating active corrosion, half-cell potential measurement, was performed on each bridge at rates varying from one reading per 32 square feet to one reading per 80 square feet. A chain-drag device was fabricated for locating delaminated areas, with 100% coverage of the deck easily realized. Four to twelve concrete samples were taken per bridge for chloride ion analysis, locations of the samples varying against high half-cell reading and delamination locations. A pachometer was ordered to measure the depth of concrete cover so the chloride ion concentration analysis could be on samples taken at the reinforcing steel level.

The wide spacings between half-cell readings and the small number of concrete samples tested were not expected to provide sufficient data for statistical analysis of any individual structure or any group. Means, standard deviations and percentages have proven to be misleading regarding the extent of deterioration of a bridge deck. To say that a bridge deck needs no maintenance because average values are below threshold values overlooks obvious isolated areas which are deteriorating.

The pachometer ordered to measure depth of the cover during the investigations was delayed in shipment so long that data gathering had to begin without it. The unit was unsatisfactory upon arrival, so all samples were taken at the assumed reinforcing steel location, one inch below the concrete surface.

Often only one lane of a structure was inventoried due to traffic control considerations.

CONCLUSIONS AND RECOMMENDATIONS

Visual inspection is an insufficient indicator of actual bridge deck condition. It is difficult to estimate the extent or seriousness of the problem, and by the time major defects are evident, immediate repair is often necessary. Appearance should still be considered for aesthetics and ride, but is not adequate for advance budgeting of specific deck repairs.

The chloride ion analysis tests performed during this project confirm that the State of Washington does have many bridge decks with sufficient chloride ion intrusion to cause deterioration. Because corrosion may be initiated as soon as the chloride ion exceeds a minimum value, the amount of chloride ion present is not indicative of the amount of or rate of deterioration.[12]

A minimum of ten samples is desirable for reasonably deducing the chloride content of an average bridge deck. Approximately six man-hours (not including traffic control) are required at the bridge site to obtain ten samples, with laboratory analysis presently costing $24 per sample.

Because chloride ion content is indicative only of the potential for chloride induced deterioration, and not of the actual rate of or amount of deterioration, the actual content is of little significance once the threshold line is crossed.[12] Chloride ion content does not presently dictate that a certain type of repair be used, and until further research establishes direct correlations or other need for determining this value, it is recommended that the State of Washington not perform this portion of the investigation on a continuing basis.

Half-cell potential measurements indicate the location of actively corroding reinforcing steel,(9,10) pointing out areas of a bridge deck that will eventually require repair. They provide the earliest indication of actual deterioration, and can, therefore, be an aid to budgeting future repairs. The rate or amount of deterioration cannot be ascertained from these measurements,(11) and no certain values have been agreed upon as requiring a certain type of repair for a bridge deck.

A maximum grid size of four feet is desirable for determining the general condition of a bridge deck with respect to half-cell potentials. Measuring and plotting half-cell potentials should average eight man-hours per bridge, not including traffic control.

Approximately six man-years would be required for measuring half-cell potentials of every concrete bridge deck on the State Highway System. This information is considered useful and desirable, but secondary to delamination detection, and the recommendation to continue or discontinue the measurements will have to include consideration of manpower availability and cost-benefit for the immediate future. If enough delaminated bridges are found to utilize all available monies, then the measurement of half-cell potential on non-delaminated structures might be of little value.

The amount of delamination present in a bridge deck is considered important because it is evidence of existing structural deterioration. The safe load capacity of a concrete slab is based upon its thickness and its bond with the reinforcing steel. With the thickness of the slab reduced by delamination, and the possible accompanying loss of bond, the safe load capacity of a bridge deck may be significantly reduced.

Regardless of the chloride ion content or the half-cell potential values, a delaminated bridge deck is of primary importance because of the structural considerations. Repair efforts and monies should be initially concentrated on returning delaminated bridge decks to their original capacity.

The location and extent of delaminations must be known for determining specific areas of a bridge deck requiring repair before the application of a suitable overlay. This information is, therefore, essential and necessarily obtained prior to repair, and it is recommended the State continue inventorying bridge decks for delaminations.

Approximately four man-years would be necessary for determining the extent of delaminated area on every concrete bridge deck on the State Highway System. The amount of time necessary for an individual bridge deck varies directly with the extent of delaminated area, with the average time requirement estimated to be four man-hours per bridge deck plus traffic control. This is for general size and location determinations, and not for specific outlining of exact areas. Such outlining is necessary only for actual repair work, and requires significantly more time.

It is observed that previous construction techniques did not provide sufficient cover for reinforcing steel. New specifications have been added recently to remedy this situation. It would be desirable to investigate recent projects, measuring actual cover provided to determine if further requirements are necessary.

No technique investigated in this project is capable of predicting bridge deck repair requirements six to eight years ahead. The data gathered here indicate an extensive problem exists, and it is assumed monetary considerations will dictate a repair-oriented solution rather than a preventive maintenance solution. For these reasons, the recommendation is that monies be budgeted for general bridge deck repair, and that specific bridges to receive repair be determined yearly based primarily on percentage of delaminated area.

FUTURE RESEARCH

A most desirable goal is that of accurately projecting the estimated life of a bridge deck known to be deteriorating. This would be extremely useful for budgeting purposes, and would allow an economic comparison of waterproof membrane versus cathodic protection versus eventual reconstruction.

SELECTION OF BRIDGES TO BE STUDIED

The initial selection of bridges for possible inclusion in this study was based on visual inspection of deck condition. Most bridges chosen had obvious scaling or spalling problems, with a few non-deteriorating decks used for comparison and control.

Two-man bridge inspection teams had, as a portion of their routine inspection, assigned numerical codes and written verbal descriptions on every state-owned bridge deck in Washington. The codes were sorted by depth of scaling and percentage of affected area, and bridges were selected or rejected based on verbal descriptions and location criteria.

Various climatic conditions were chosen, primarily by dividing Washington into its three geographical areas: wet Western, cold mountainous, and dry Eastern (see map-Appendix A).

Two-lane and multilane highway bridges were investigated, representing various bridge types and ages.

TYPES OF EXPERIMENTATION CONDUCTED

1. Visual Inspection:

All bridge decks in the study were visually appraised by a State bridge inspection team, for later comparison with data analysis. This was included primarily as a check on the accuracy of visual inspection as an indicator of deterioration.

2. Delamination Detection:

All inventoried portions of each bridge studied were sounded using a chain drag device fabricated at a highway maintenance shop. The hand-pushed, wheeled device drags six 3/8" steel chains across the bridge deck, indicating the location of delaminated areas by a change in the pitch of the resultant sound. Solid areas result in a high pitched, ringing of steel-on-concrete sound, while delaminated areas result in a low pitched drummy sound. Using a hammer to tap the concrete proved to be misleading, and is not recommended.

The delaminated areas were outlined on the bridge deck with chalk, then accurately located on the data recording sheets for later comparison with the other types of investigation. Sample data recording sheets are presented as Appendices B-1 through B-3.

3. Corrosion Activity Measurement

Corroding reinforcing steel is due to an electrochemical process forming a natural galvanic cell. The potential across this cell at any given time may be measured using a voltmeter and a copper-copper sulfate electrode. The larger the magnitude of the (negative) volt reading, the greater the corrosion activity.

The inventoried portions of each bridge were divided into convenient sections and half-cell potentials were measured at consistent intervals. These measurements were accurately located on the data recording sheets (Appendices B-1 through B-3) for later comparison and evaluation.

4. Chloride Content Analysis:

Prepulverized samples of bridge deck concrete were taken by drilling 3/4" into the bridge deck with a rotary hammer, removing all dust with compressed air, and then drilling another 1/2" with the hammer. This resulted in a sample of concrete powder, already prepared for laboratory analysis and taken from an average depth of one inch below the deck surface.

The location of all samples was carefully recorded for later correlation with other types of investigation.

Samples selected for analysis were put into solution per FHWA Report No. FHWA-RD-72-12 and the chloride content determined by the Volhard method, described briefly in the following paragraph:

To a three-gram sample (weighed to the nearest milligram) of the pulverized concrete were added ten cc. water and five cc. nitric acid. When the cement had completely decomposed the sample was diluted to 50 ml. with hot water and boiled for one minute, then cooled to room temperature. Ten ml. 0.01 N silver nitrate was added, the mixture was agitated and one ml. Ferric ammonium sulfate indicator and two cc. nitrobenzene were added. The mixture was then diluted to 200 ml. and titrated with 0.01 N thiocyanate. The less thiocyanate required to reach an endpoint, the more chloride ion present. If 10 cc. thiocyanate were used without reaching an endpoint, no chloride ion was present.

Chlorides may be present in concrete in both free and combined forms. Only the free chlorides are considered available to promote reinforcing steel corrosion.[(3)] It is the amount of free chlorides present in a sample which is of interest in this type of investigation.

The Volhard method described above measures total chloride ion present, both free and combined. This was not considered detrimental, however, as new concrete samples and bridges less than one year old (where no salt had been used) showed a negligible chloride content. All chloride determined to be present in the samples tested in this investigation is considered to be available to promote corrosion.

TEST APPARATUS

1. Delamination Detector:

The delamination indicating device, referred to as the "chain drag" was a simple but very effective home-made tool. One-half inch diameter steel pipe was fabricated into a "T" shape, with wheels at the tips of the flanges. Six 3/8" steel chains were fastened to the flanges of the "T" at equal spaces.

Pushing the chain drag along a deck results in a readily discernable change in pitch when a delaminated area is encountered. Instead of the solid, ringing, steel-on-concrete sound of the bonded concrete, a very dull, hollow sound is heard. The boundaries of a delaminated area are easily defined with just two or three passes of the chain.

The chain drag located obviously deteriorating areas that were not detectable during visual inspection.

2. <u>Corrosion Detector</u>:

A corrosion activity measuring instrument was constructed using a three-foot long piece of 1-1/2 inch diameter plastic pipe with a sponge tip at the lower end. The pipe was filled with a copper sulfate solution and a connecting copper rod inserted through a rubber top plug down to the sponge to complete the "saturated copper-copper sulfate half-cell."

A second electrical connection was made to an exposed steel reinforcing bar and the potential measurements were made using a high input impedance electronic voltmeter.

3. Concrete Sampling:

A heavy duty rotary hammer, delivering 3750 blows and 700 revolutions per minute, was used with a one-inch diameter carbide tipped percussion bit for obtaining concrete samples.

A hole was drilled to 1/4 inch above the desired sample location and all dust removed using compressed air. An additional 1/2 inch of drilling yielded a pulverized sample of concrete from a specific location that was ready for laboratory analysis without further processing.

Initial sampling work utilized a diamond-tipped core-drilling machine, which yielded cylinders that had to be taken to the laboratory, sliced at the proper depth, and pulverized before analysis could begin. This technique was quickly abandoned for economic reasons.

4. Concrete Cover Measurements:

A pachometer was ordered to measure the depth of concrete covering the reinforcing steel. This was to provide a check on construction tolerances and to insure that the concrete samples would be checked for chloride ion content at the reinforcing steel level.

Arrival of the pachometer was delayed so long that data collection was begun without it. Samples were taken at assumed steel depths, and the pachometer was to be used later to document the depths and indicate which samples should be analyzed.

When the pachometer did arrive, it was determined unsatisfactory and returned to the vendor. A separate "Concrete Reinforcing Cover Study" was conducted here by the FHWA during the course of this project, and their pachometer failed to give consistent readings due to reactive elements in the aggregates around Washington State. Because of the time required for delivery, and the erroneous belief that consistent measurements could not be made, no cover measuring device was reordered. It has since been determined that an initial calibration of the pachometer will negate the effect of the reactive aggregates.

5. Laboratory Equipment:

Using the pre-pulverized concrete samples simplified laboratory analysis procedures so that no special equipment was required. Chloride ion content determinations were made by qualified personnel at the State Materials Testing Laboratory.

DISCUSSION OF DATA

1. Percent Scaling and/or Spalling:

This is a visual estimation made by a bridge inspection team, and indicates a depth range and approximate amount of surface scaling and spalling. The letter codes are N, L, M, H and S for None, Light (0" to 1/4"), Medium (1/4" to 1/2"), Heavy (1/2" to 1") and Severe (over 1") depths, while the numerical code indicates the total percentage area involved. Thus, an S 30 indicates the worst spalling is over 1" deep, with approximately 30% of the bridge deck affected by some degree of scaling or spalling. A verbal description is included on the inspection reports to expand on this code.

Sorting the data by percent scaling, as is indicated when visual inspection only is used, results in no significant correlation in other values measured. (See Chart 1 at the end of this report.) Some consideration must be given to aesthetics and ride, making visual appearance an item of concern, but it is not a sufficient indicator of actual extent of deterioration.

2. Exposed Reinforcing Steel:

Previous studies have shown the extent of deterioration to be related directly to the amount of chloride ion present at the level of the reinforcing steel. Concentration is approximately described by a Log_{10} equation using depth of concrete cover over the reinforcing steel.[10] Any shallow reinforcing steel has been subject to relatively high chloride ion concentrations, and subsequently, a higher rate of deterioration.

Improper construction techniques have resulted in shallow concrete cover on a surprisingly high number of bridge decks, contributing directly to early deterioration. For the non-overlayed bridges in this project:

DECK CODE	MAX. SCALE DEPTH	NUMBER OF BRIDGES	
		SOME RE-STEEL EXPOSED	NO RE-STEEL EXPOSED
S	Over 1"	4	0
H	1"	9	9
M	1/2"	4	6
L	1/4"	0	1
N	0"	2	4

TABLE 1 - DEPTH OF EXPOSED REINFORCING STEEL

Table 1 shows that all four non-overlayed bridges with more than one inch deep scaling had reinforcing bars exposed, while nine of eighteen bridges with one-half inch to one-inch deep scaling showed bars. Four bridges had less than one-half inch cover before scaling began, and two bridges had reinforcing bars exposed with no scaling at all.

Combining Table 1 above with Chart 1 at the end of the report results in the observation that the incidence of improper construction techniques, resulting in insufficient concrete cover, has apparently increased recently. Eight of the fifteen bridges which had less than one inch of cover are less than ten years old, and four of the six bridges with less than one-half inch of cover are six years old or less.

Washington State's bridges were specified to have a minimum concrete cover of 1-1/2" (recently changed to 2"). It is apparent that this specification has not been met in many instances, and that the assumed level for collecting chloride samples (1" down) may have resulted in samples which contained less chloride ion than was present at the level of the steel.

3. <u>Chloride Samples Tested</u>:

The number of samples tested is generally indicative of the size of the bridge deck, larger decks having had more samples taken. Economic considerations dictated the total number of samples which could be analyzed in the Laboratory. Chloride ion concentration analysis was performed on 176 of the 280 samples taken from the 48 bridges in this project, the purpose of this investigation being to examine as many bridge decks as possible, and not to examine, in depth, any particular deck.

4. <u>Chloride Ion Concentration Levels</u>:

As mentioned earlier, other research indicates that a bridge deck can support active galvanic corrosion when its chloride ion content exceeds 1.3 lbs. of chloride per cubic yard of concrete.(3,4) It may be considered "chloride free" when the concentration is less than 0.6 lbs. per cubic yard,(10) and is a candidate for future problems when the concentration of chloride ions is between those values.

Chart 2, sorted by highest chloride ion sample, shows readily that 21 bridges had at least one sample above 1.3 lbs. per cubic yard, and 3 others were within .04 lbs. per cubic yard of that level. Of 48 bridge decks sampled at random locations, 50% had areas containing enough chloride to initiate corrosion. Another 14.6% were in the "potential problem" range, while 35.4% could be considered "chloride free." Note that "chloride free" is not synonymous with "deterioration free," as is discussed in the following paragraphs.

Measuring the choride ion concentration of new bridge decks has indicated that the contamination does occur after construction. Significant chloride ion concentrations were not found in new concrete.

5. <u>Half-Cell Potentials</u>:

Even the most reliable indicator of active corrosion, half-cell potential, does not yield foolproof results. An indefinite range exists between -0.20 volts and -0.35 volts, with active corrosion possible at -0.20 volts [3] and probable at -0.35 volts. [3,4] For the following discussion a dividing line between corrosion and non-corrosion was placed at -0.25 volts. [10]

Chart 3, sorted by percentage of half-cell readings "above" -0.25 volts, indicates corrosion probably occurring in 27 of the 37 bridges (73.0%) for which those readings were taken. It appears that once corrosion begins, it becomes generalized rapidly. Of the 27 probably corroding bridges, 22 have more than 10% of the readings indicating corrosion, 19 have more than 20% indicating corrosion, and 8 have more than 50%. This is compared to 10 bridges indicating no corrosion present.

Comparing Chart 2 with Chart 3, it is evident that chloride ion concentration values are not a good indicator of existing deterioration for the number of samples taken. Eight of the twelve half-cell-measured bridges which could be considered "chloride free" had half-cell values indicating probable corrosion activity, with three having more than 50% of the values so indicating. The half-cell potentials of three bridges with at least one sample above 1.3 pounds chloride ion per cubic yard of concrete indicate no corrosion occurring.

Local areas on many bridges show good correlation between high half-cell values, high chloride ion concentrations, and delaminated areas. (See Appendices B-1, B-2, and B-3.) General conclusions regarding the entire deck could not, however, be reached by merely comparing values. Exact locations within a specific deck had to be known before attempts at correlation approached success.

6. <u>Percent Delaminated Area</u>:

This is the best indicator of the present condition of an existing structure. Perhaps corrosion has temporarily slowed, or perhaps the delamination is not due to chlorides in a particular bridge. Half-cell measurements and chloride ion analysis could indicate "no problems." Checking for delaminations will indicate any problems this bridge may have had previously, and gives the best insight into the actual structural condition of the deck.

Chart 4, sorted by percent delaminated area, is the best indicator of relative conditions of the bridge decks in this project. The first five bridges on this chart averaged 11% delaminated area, yet three showed 1% or less visual deterioration, and another only 5%. The bridge with extensive visual deterioration was already scheduled for deck repair and overlay when this project began. Assuming an arbitrary guideline of 10% scaling required an overlay recommendation, only six of the worst fifteen bridge decks checked would be repaired. This underscores the insufficiency of visual inspection alone.

Chart 4 does not allow optimism concerning bridge deck conditions in Washington. Of the 37 bridges for which half-cell potentials, chloride ion analysis, and delamination determinations were made, only eight had no delaminations. Of those eight, four had half-cell potentials indicating probable corrosion, and two others have chloride ion concentrations capable of supporting corrosion. Only two bridges investigated had low chlorides, low half-cell potential and no delamination, and they are parallel structures in a mild climatic region, and are just eight to nine years old.

Six of the twleve "control" bridges (1% or less visual deterioration) were among the worst twelve delaminated bridges, five of them in the worst seven. The sample used in this project indicates greater than 50% of the bridge decks in Washington may be delaminated.

7. <u>Average Annual Rainfall</u>:

This statistic indicates the total moisture available to each structure, but does not consider local drainage conditions, evaporation rates, etc.

The only apparent correlation occurs on Chart 4, sorted by percent delaminated area. It is interesting to note that the worst 15 delaminated bridges have less than 20 inches or more than 80 inches per year, and that the better bridges are almost exclusively between 30 inches and 40 inches per year.

The high and low precipitation rates are associated with mountainous and eastern regions in most cases, thereby indicating greater temperature extremes, heavier salt usage and more pounding by tire chains and snow removal equipment than on bridges with moderate rates.

Average rainfall comparisons do indicate definite relationships between bridge deck condition and climatalogical data, but because both high and low extremes are deteriorating, the actual amount of water available as precipitation has little significance.

8. <u>Average Daily Traffic</u>:

No correlation was found between average daily traffic and deterioration as measured by any of the techniques used in this investigation.

9. <u>Age</u>:

Many persons have noticed what they thought to be an inverse relationship between age and deterioration, pointing to old bridge decks in good condition and to new bridge decks in obviously poor condition. Such examples tend to stand out, but are by no means general. No correlation between age and amount of deterioration was found during this investigation.

10. <u>Salt Usage</u>:

Several inquiries regarding salt usage by maintenance crews were made. Nearly all areas of the state where salt is used are salted selectively, depending upon individual conditions. A bridge may be salted several times relative to other portions of the roadway, or vice-versa.

Verbal inquiries to the maintenance men who actually do the sanding resulted in the conclusion that significant estimates could not be made.

Presentation of Pertinent Data

BRIDGE NUMBER	DECK APPEARANCE: PERCENT SCALING	DECK APPEARANCE: EXPOSED RE-STEEL	CHLORIDE ION ANALYSIS: SAMPLES TESTED	>1.3 LB/YD³	<1.3; ≥0.6 LB/YD³	<0.6 LB/YD³	HIGH Cl⁻ VALUE	AVG. Cl⁻ VALUE	(-) HALF CELL POTENTIALS: "HIGH" VALUE	AVG. VALUE	% "ABOVE" 0.25	PERCENT DELAM. AREA	AVERAGE ANNUAL RAINFALL	AVERAGE DAILY TRAFFIC	AGE (YEARS)
5/440 W	M 80	YES	4	4			2.52	2.11	.44	.12	13.6	0.5	35	19,300	9
90/106 A	H 75	YES	3	1		2	2.16	.71	1.04	.71	100.0	9.7	100	6,700	15
395/542	M 75	NO	3		2	1	1.28	.78	.40	.23	26.7	1.8	17	1,950	34
527/120	H 50	SURFACED	3		2	1	1.29	.82	SURFACED AT TIME OF PROJECT				35	9,400	12
153/24	H 50	NO	2			2	.39	.27					20	7,600	52
153/17	H 50	YES	2			2	.32	.18	.22	.12	0	3.5	20	860	36
153/20	H 50	NO	3			3	.05	.02	.19	.11	0	2.5	20	860	40
5/650 W	H 30	SURFACED	5	2	3		2.31	1.51	SURFACED AT TIME OF PROJECT				35	16,800	21
20/636	H 20	NO	3		1	2	.72	.24	.47	.24	33.3	0	15	2,700	44
90/106 S	H 20	NO	2			2	.30	.27	.47	.27	62.7	2.0	100	6,750	19
153/10	H 20	YES	3			3	.18	.05	.33	.17	7.3	0.8	15	840	36
5/593 E	S 15	YES	7		3	4	.75	.49	.19	.04	0	1.3	40	30,800	15
90/535	S 10	YES	3	2	1		2.10	1.54	.32	.12	7.0	5.0	20	11,900	36
162/22	S 10	SURFACED	2			2	.27	.18	SURFACED AT TIME OF PROJECT				47	1,750	39
12/254	H 10	NO	2			2	.11	.07	.42	.29	22.0	6.2	90	1,270	41
153/16	H 10	NO	3			3	.05	.01	.19	.05	0	2.3	20	860	36
90/40	S 7	YES	6	2	1	3	1.92	.98	SURFACED AT TIME OF PROJECT				35	55,000	36
2/7 E-S	M 5	NO	6	5		1	2.81	1.81	.46	.24	37.4	1.4	35	23,700	19
9/132	M 5	NO	2	2			1.53	1,75	.47	.29	23.2	0	40	3,400	51
31/36	H 5	YES	3	1	1	1	1.59	.89	.56	.35	51.5	2.1	30	1,080	25
5/709	S 5	YES	4	2		2	1.53	.81	.30	.09	2.3	1.0	33	23,300	46
90/25	M 5	YES	5		1	4	1.11	.47	.36	.13	9.4	0.6	35	55,000	35
169/8	H 5	NO	3		2	1	.86	.57	.45	.22	28.6	PATCHED	50	3,100	43
101/105	H 5	NO	4			4	.30	.23	.37	.14	12.7	2.3	100	4,600	45
123/2	M 5	NO	2			2	.15	.14	.34	.24	52.6	16.5	80	360	40
12/317	H 5	NO	2			2	.08	.04	.45	.21	70.0	0	30	1,600	42
90/545	H 2	SURFACED	5	4		1	2.01	1.56	SURFACED AT TIME OF PROJECT				20	32,300	8
530/120	M 2	NO	2	1		1	1.74	1.05	.07	.04	0	0	70	4,600	51
5/710	H 2	YES	3	1	2		1.31	1.01	.18	.02	0	0.4	33	23,300	21
90/104	H 2	YES	2		2		1.26	1.10	.47	.22	28.8	1.2	110	13,500	6
2/250	H 1	YES	4	3	1		3.45	1.91	.63	.42	92.8	6.4	10	27,000	25
90/99	M 1	YES	5	2	1	2	1.91	.98	.59	.39	95.8	6.3	120	13,300	6
12/915	H 1	YES	4	1	2	1	1.64	.87	.56	.21	32.4	0.2	13	24,600	36
90/568	M 1	NO	2	2			1.55	1.45	.47	.23	25.0	8.2	20	40,000	18
90/510 S	H 1	YES	3	1	1	1	1.38	.94	.73	.53	100.0	8.9	19	6,750	9
405/18 E	L 1	NO	8		3	5	1.05	.55	.31	.06	0	0.1	40	27,550	13
90/101	M 1	YES	2		1	1	.63	.44	.46	.23	26.4	2.9	115	13,500	6
90/569	N 0	NO	2	1		1	1.59	1.07	.49	.32	37.5	11.8	20	40,000	18
405/18 W	N 0	NO	8	2	3	3	1.50	.72	.16	.03					
90/562 S	N 0	YES	3		2	1	.96	.65	.42	.20	14.1	3.3	20	19,900	5
5/536 W	N 0	NO	3			3	.15	.06	.02	.16	0	0	35	56,700	9
153/10	N 0	YES	4			4	.15	.04	.30	.11	1.3	0	10	1,600	5
5/536 E	N 0	NO	3	3		3	.09	.05	.05	.02	0	0	35	56,700	8
104/5	NO TRAFFIC	NO	5	2		2	2.83	1.56	NOT MEASURED (MAINT. DECK)				(32)	NONE	14
2/7 S	SURFACED	SURFACAD	3	2	1		1.76	1.49	SURFACED AT TIME OF PROJECT				35	23,700	39
2/7 N	SURFACED	SURFACED	8				.39	.13	SURFACED WHEN BUILT-NO MEMBR.				35	23,700	39
3/118	NEW	NO DATA	5				.08	.05	NOT MEASURED				50	NEW BR.	1
16/5 E	NEW	NO DATA	5				.03	.02	NOT MEASURED				45	NEW BR.	1

CHART 1 - PROJECT DATA BY PERCENT SCALING

BRIDGE NUMBER	DECK APPEARANCE: PERCENT SCALING	DECK APPEARANCE: EXPOSED RE-STEEL	CHLORIDE ION ANALYSIS: SAMPLES TESTED	>1.3 LB/YD³	≤1.3; ≥0.6 LB/YD³	<0.6 LB/YD³	HIGH Cl⁻ VALUE	AVG. Cl⁻ VALUE	(-) HALF CELL POTENTIALS: "HIGH" VALUE	AVG. VALUE	% "ABOVE" 0.25	PERCENT DELAM. AREA	AVERAGE ANNUAL RAINFALL	AVERAGE DAILY TRAFFIC	AGE (YEARS)
2/250	H 1	YES	4	3	1		3.45	1.91	.63	.42	92.8	6.4	10	27,000	25
104/5	NO TRAFFIC	NO	5	3		2	2.83	1.56	NOT MEASURED (MAINT. DECK)				(32)	NONE	14
5/640 W	M 80	YES	4	4			2.82	2.11	.44	.12	13.6	0.5	35	19,300	9
2/7 E-S	M 5	NO	6	5		1	2.81	1.81	.46	.24	27.4	1.4	35	23,700	19
5/650 W	H 30	SURFACED	5	2	3		2.31	1.51	SURFACED AT TIME OF PROJECT				35	16,800	21
90/106 A	H 75	YES	3	1		2	2.16	.71	1.05	.71	100.0	9.7	100	6,750	15
90/595	S 10	YES	3	2	1		2.10	1.54	.32	.12	7.0	5.0	20	11,900	36
90/545	H 2	SURFACED	5	4		1	2.01	1.56	SURFACED AT TIME OF PROJECT				20	32,300	8
90/40	S 7	YES	6	2	1	3	1.92	.98					35	55,000	36
90/99	M 1	YES	5	2	1	2	1.91	.98	.59	.39	95.8	6.3	120	13,300	6
9/132	M 5	NO	2	2			1.83	1.25	.47	.29	23.2	0	40	3,400	51
2/7 S	SURFACED	SURFACED	3	2	1		1.76	1.49	SURFACED AT TIME OF PROJECT				35	23,700	39
530/120	M 2	NO	2	1		1	1.74	1.05	.07	.04	0	0	70	4,600	51
12/915	H 1	YES	4	1	2	1	1.64	.87	.56	.21	32.4	0.2	13	24,600	36
31/36	H 5	YES	3	1	1	1	1.59	.89	.56	.35	51.5	2.1	30	1,080	25
90/[illegible]	N 0	NO	2	1		1	1.59	1.07	.49	.32	37.5	11.8	20	40,000	18
90/[illegible]	M1	NO	2	2			1.55	1.45	.47	.23	25.0	8.2	20	40,000	18
5/709	S 5	YES	4	2		2	1.53	.81	.30	.09	2.3	1.0	33	23,300	46
405/16 W	N 0	NO	8	2	3	3	1.50	.72	.16	.03	0	0	40	27,550	13
90/510 S	H 1	YES	3	1	1	1	1.38	.94	.73	.53	100.0	8.9	19	6,750	9
5/710	H 2	YES	3	1	2		1.31	1.01	.18	.02	0	0.4	33	23,300	21
527/120	H 50	SURFACED	3		2	1	1.29	.82	SURFACED AT TIME OF PROJECT				35	9,400	12
395/542	M 75	NO	3		2	1	1.28	.78	.40	.23	26.7	1.8	17	1,950	34
90/104	H 2	YES	2		2		1.26	1.10	.47	.22	28.8	1.2	110	13,500	6
90/25	M 5	YES	5		1	4	1.11	.47	.36	.13	9.4	0.6	35	55,000	35
405/12E	L 1	NO	8		3	5	1.05	.55	.21	.06	0	0.1	40	27,550	13
90/562 S	NO	YES	3		2	1	.96	.65	.42	.20	14.1	3.3	20	19,900	5
169/8	H 5	NO	3		2	1	.86	.57	.45	.22	28.6	PATCHED	50	3,100	43
5/508 E	S 15	YES	7		3	4	.75	.49	.19	.04	0	1.3	40	30,800	15
20/636	H 20	NO	3		2		.72	.24	.47	.24	33.3	0	15	2,700	44
90/101	M 1	YES	2		1	1	.63	.44	.46	.23	26.4	2.9	115	13.500	6
2/7 N	SURFACED	SURFACED	8			8	.39	.13	SURFACED WHEN BUILT-NO MEMBR.				35	23,700	8
195/24	H 50	NO	2			2	.39	.27	SURFACED AT TIME OF PROJECT				20	7,600	52
153/17	H 50	YES	2			2	.32	.18	.22	.12	0	3.5	20	860	36
90/106 S	H 20	NO	2			2	.30	.27	.47	.27	62.7	2.0	100	6,750	19
101/105	H 5	NO	4			4	.30	.23	.37	.14	12.7	2.3	100	4,100	45
162/22	S 10	SURFACED	2			2	.27	.18	SURFACED AT TIME OF PROJECT				49	1,750	39
153/10	H 20	YES	3			3	.18	.05	.33	.17	7.3	0.8	15	840	35
5/536 E	N 0	NO	3			3	.15	.06	.16	.02	0	0	35	56,700	9
123/2	M 5	NO	2			2	.15	.14	.34	.24	52.6	16.5	80	360	40
173/10	N 0	YES	4			4	.15	.04	.30	.11	1.3	0	10	1,600	5
12/128	H 10	NO	2			2	.11	.07	.42	.29	22.0	6.2	90	1,270	41
5/5[illegible]6 W	N 0	NO	3			3	.09	.05	.06	.02	0	0	35	56,700	8
12/[illegible]7	H 5	NO	2			2	.08	.04	.45	.21	70.0	0	30	1,600	42
3/118	NEW	NO DATA	5			5	.08	.05	NOT MEASURED					NEW BR.	1
153/16	H 10	NO	3			3	.05	.01	.19	.05	0	2.3	20	860	36
153/20	H 50	NO	3			3	.05	.02	.19	.11	0	2.5	20	860	40
15/5 E	NEW	NO DATA	5			5	.03	.02	NOT MEASURED				45	NEW BR.	1

CHART 2 - PROJECT DATA BY HIGH CHLORIDE ION SAMPLE

BRIDGE NUMBER	DECK APPEARANCE: PERCENT SCALING	DECK APPEARANCE: EXPOSED RE-STEEL	CHLORIDE ION ANALYSIS: SAMPLES TESTED	>1.3 LB/YD³	≤1.3; ≥0.6 LB/YD³	<0.6 LB/YD³	HIGH Cl⁻ VALUE	AVG. Cl⁻ VALUE	(-) HALF CELL POTENTIALS: "HIGH" VALUE	AVG. VALUE	% "ABOVE" 0.25	PERCENT DELAM. AREA	AVERAGE ANNUAL RAINFALL	AVERAGE DAILY TRAFFIC	AGE (YEARS)
90/105 A	H 75	YES	3	1		2	2.16	.71	1.05	.71	100.0	9.7	100	6,750	15
90/510 S	H 1	YES	3	1	1	1	1.38	.94	.73	.53	100.0	8.9	19	6,750	9
90/99	M 1	YES	5	2	1	2	1.91	.98	.59	.39	95.8	6.3	120	13,300	6
2/250	H 1	YES	4	3	1		3.45	1.91	.63	.42	92.8	6.4	10	27,000	25
12/317	H 5	NO	2			2	.08	.04	.45	.21	70.0	0	30	1,600	42
90/106 S	H 20	NO	2			2	.30	.27	.47	.27	62.7	2.0	100	6,750	19
123/1	M 5	NO	2			2	.15	.14	.34	.24	52.6	16.5	80	360	40
31/36	H 5	YES	3	1	1	1	1.59	.89	.56	.35	51.5	2.1	30	1,080	25
90/569	N 0	NO	2	1		1	1.59	1.07	.49	.32	37.5	11.8	20	40,000	18
2/7 E-S	M 5	NO	6	5		1	2.81	1.81	.46	.24	37.4	1.4	35	23,700	19
20/638	H 20	NO	3		1	2	.72	.24	.47	.24	33.3	0	15	2,700	44
12/313	H 1	YES	4	1	2	1	1.64	.87	.56	.21	32.4	0.2	13	24,600	36
90/104	H 2	YES	2		2		1.26	1.10	.47	.22	28.8	1.2	110	13,500	6
169/8	H 5	NO	3		2	1	.86	.57	.45	.22	28.6	PATCHED	50	3,100	43
395/542	M 75	NO	3		2	1	1.28	.78	.40	.23	26.7	1.8	17	1,950	34
90/101	M 1	YES	2		1	1	.63	.44	.46	.23	26.4	2.9	115	13,500	6
90/533	M 1	NO	2	2			1.55	1.45	.47	.23	25.0	8.2	20	40,000	18
[illegible]	M 5	NO	2	2			1.83	1.75	.47	.29	23.2	0	40	3,400	51
12/244	H 10	NO	2			2	.11	.07	.42	.29	22.0	6.2	90	1.270	41
90/562 S	N 0	YES	3		2	1	.96	.65	.42	.20	14.1	3.3	20	19,900	5
5/640 W	M 80	YES	4	4			2.82	2.11	.44	.12	12.6	0.5	35	19,300	9
101/105	H 5	NO	4			4	.30	.23	.37	.14	12.7	2.3	100	4,100	45
90/25	M 5	YES	5		1	4	1.11	.47	.36	.13	9.4	0.6	35	55,000	35
153/10	H 20	YES	3			3	.18	.05	.33	.17	7.3	0.8	15	840	36
90/505	S 10	YES	3	2	1		2.10	1.54	.32	.12	7.0	5.0	20	11.900	36
5/709	S 5	YES	4	2		2	1.53	.81	.30	.09	2.3	1.0	33	23.300	46
173/10	N 0	YES	4			4	.15	.04	.30	.11	1.3	0	10	1,600	5
530/120	M 2	NO	2	1		1	1.74	1.05	.07	.04	0	0	70	4,600	51
405/18 W	N 0	NO	8	2	3	3	1.50	.72	.16	.03	0	0	40	27,500	13
5/710	H 2	YES	3	1	2		1.31	1.01	.18	.02	0	0.4	33	23,300	21
405/18 E	L 1	NO	8		3	5	1.05	.55	.21	.03	0	0.1	40	27,550	13
5/533 E	S 15	YES	7		3	4	.75	.49	.19	.04	0	1.3	40	23,800	15
153/17	H 50	YES	2			2	.32	.18	.22	.12	0	3.5	20	860	36
5/535 E	N 0	NO	3			3	.15	.06	.16	.02	0	0	35	56,700	9
5/535 W	N 0	NO	3			3	.09	.05	.06	.02	0	0	35	56,700	8
153/20	H 50	NO	3			3	.05	.02	.19	.11	0	2.5	20	860	40
153/16	H 10	NO	3			3	.05	.01	.19	.05	0	2.3	20	860	36

104/5
5/530 W
90/545
90/40
2/7 S
527/120
155/24
2/7 N
162/22
3/118
16/5 E

HALF - CELL POTENTIAL READINGS COULD NOT BE TAKEN FOR THESE OVERLAYED BRIDGES

CHART 3 - PROJECT DATA BY HALF CELL POTENTIALS "ABOVE" (-) 0.25 VOLTS

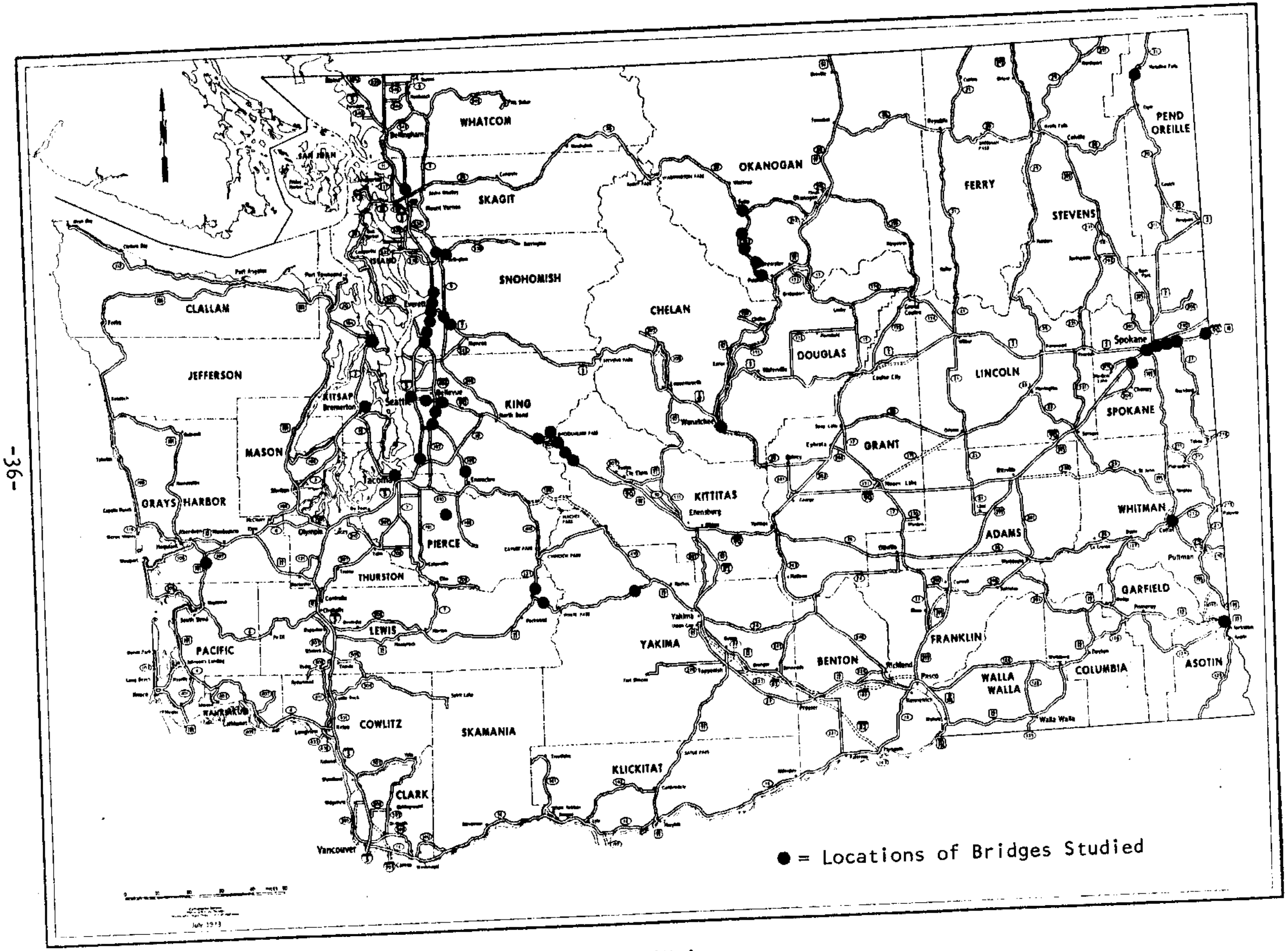
BRIDGE NUMBER	DECK APPEARANCE: PERCENT SCALING	DECK APPEARANCE: EXPOSED RE-STEEL	CHLORIDE ION ANALYSIS: SAMPLES TESTED	>1.3 LB/YD³	≤1.3; ≥0.6 LB/YD³	<0.6 LB/YD³	HIGH Cl- VALUE	AVG. Cl- VALUE	(-) HALF CELL POTENTIALS: "HIGH" VALUE	AVERAGE VALUE	% "ABOVE" 0.25	PERCENT DELAM. AREA	AVERAGE ANNUAL RAINFALL	AVERAGE DAILY TRAFFIC	AGE (YEARS)
123/2	M 5	NO	2			2	.15	.14	.34	.24	52.6	16.5	80	360	40
90/569	N 0	NO	2	1		1	1.59	1.07	.49	.32	37.5	11.8	20	40,000	18
90/106 A	H 75	YES	3	1		2	2.16	.71	1.05	.71	100.0	9.7	100	6,750	15
90/510 S	H 1	YES	3	1	1	1	1.38	.94	.73	.53	100.0	8.9	19	6,750	9
90/566	M 1	NO	2	2			1.55	1.45	.47	.23	25.0	8.2	20	40,000	18
2/250	H 1	YES	4		1		3.45	1.91	.63	.42	92.8	6.4	10	27,000	
90/99	M 1	YES	5	2	1	2	1.91	.98	.59	.39	95.8	6.3	120	13,300	6
12/284	H 10	NO	2			2	.11	.07	.42	.29	22.0	6.2	90	1,270	41
90/595	S 10	YES	3	2	1		2.10	1.54	.32	.12	7.0	5.0	20	11,900	36
153/17	H 50	YES	2			2	.32	.18	.22	.12	0	3.5	20	860	36
90/562 S	N 0	YES	3		2	1	.96	.65	.42	.20	14.1	3.3	30	19,900	5
90/101	M 1	YES	2		1	1	.63	.44	.46	.23	26.4	2.9	115	13,500	6
153/20	H 50	NO	3			3	.05	.02	.19	.11	0	2.5	20	860	40
101/105	H 5	NO	4			4	.30	.23	.37	.14	12.7	2.3	100	4,100	45
153/16	H 10	NO	3			3	.05	.01	.19	.05	0	2.3	20	860	36
31/26	H 5	YES	3	1	1	1	1.59	.89	.56	.35	51.5	2.1	30	1,080	25
90/106 S	H 20	NO	2			2	.30	.27	.47	.27	62.7	2.0	100	6,750	19
395/542	M 75	NO	3		2	1	1.28	.78	.40	.23	26.7	1.8	17	1,950	34
2/7 E-S	M 5	NO	6	5		1	2.81	1.81	.46	.24	37.4	1.4	35	23,700	19
5/508 E	S 15	YES	7		3	4	.75	.49	.19	.04	0	1.3	40	30,800	15
90/104	H 2	YES	2		2		1.26	1.10	.47	.22	28.8	1.2	110	13,500	6
5/709	S 5	YES	4	2		2	1.53	.81	.30	.09	2.3	1.0	33	23,300	46
153/10	H 20	YES	3			3	.18	.05	.33	.17	7.3	0.8	15	840	36
90/25	M 5	YES	5		1	4	1.11	.47	.36	.13	9.4	0.6	35	55,000	35
5/640 W	M 80	YES	4				2.82	2.11	.44	.12	13.6	0.5	35	19,300	9
5/710	H 2	YES	3	1	2		1.31	1.01	.18	.02	0	0.4	33	23,300	21
12/915	H 1	YES	4	1	2	1	1.64	.87	.56	.21	32.4	0.2	13	24,600	36
405/18 E	L 1	NO	8		3	5	1.05	.55	.21	.06	0	0.1	40	27,550	12
9/132	M 5	NO	2	2			1.83	1.75	.47	.29	23.2	0	40	3,400	51
530/120	M 2	NO	2	1		1	1.74	1.05	.07	.04	0	0	70	4,600	51
405/18 W	N 0	NO	8	2	3	3	1.50	.72	.16	.03	0	0	40	27,550	13
20/636	H 20	NO	3		1	2	.72	.24	.47	.24	33.3	0	15	2,700	44
5/536 E	N 0	NO	3			3	.15	.06	.16	.02	0	0	35	56,700	9
173/10	N 0	YES	4			4	.15	.04	.30	.11	1.3	0	10	1,600	5
5/536 W	N 0	NO	3			3	.09	.05	.06	.02	0	0	35	56,700	3
12/317	H 5	NO	2			2	.08	.04	.45	.21	70.0	0	30	1,600	42
169/8	H 5	NO	3		2	1	.86	.57	.45	.22	28.6	PATCHED	50	3,100	43
104/5															

5/650 W
90/545
90/40
2/7 S
527/120
195/24
2/7 N
162/22
3/118
16/5 E

} DELAMINATIONS COULD NOT BE INVENTORIED FOR THESE OVERLAYED BRIDGES

CHART 4 - PROJECT DATA BY PERCENT DELAMINATED AREA

A P P E N D I X


WHATCOM
SAN JUAN
SKAGIT
OKANOGAN
FERRY
STEVENS
PEND OREILLE
ISLAND
SNOHOMISH
CHELAN
CLALLAM
JEFFERSON
DOUGLAS
LINCOLN
SPOKANE
Spokane
KITSAP
Bremerton
Seattle
KING
MASON
GRANT
KITTITAS
Ellensburg
WHITMAN
Pullman
GRAYS HARBOR
Tacoma
PIERCE
ADAMS
THURSTON
GARFIELD
Yakima
YAKIMA
LEWIS
PACIFIC
BENTON
Richland
FRANKLIN
Pasco
COLUMBIA
ASOTIN
WALLA WALLA
Walla Walla
COWLITZ
SKAMANIA
KLICKITAT
CLARK
Vancouver
● = Locations of Bridges Studied

APPENDIX A

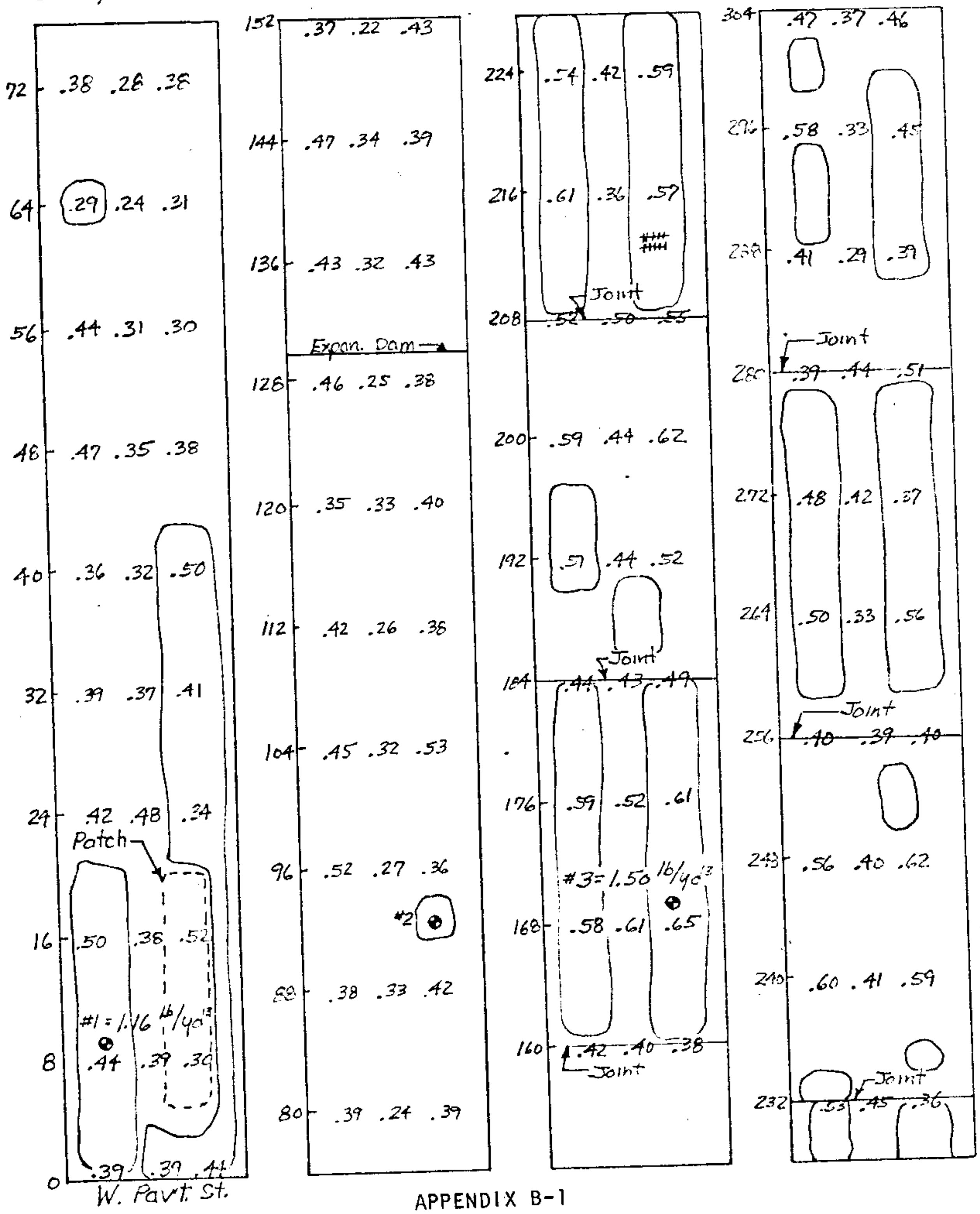
APPENDIX B - SAMPLE DATA SHEETS

Three sample data recording sheets are included here to illustrate the relationships found between locations of various half-cell potential readings and the corresponding amounts of delamination and chloride ion content. Average half-cell and percent delaminations are given for each structure, not for each separate page.

Half-cell potential values are recorded at their corresponding physical location on the outline of the deck. All values shown are negative volts. Solid outlines indicate delaminated areas, and dashed outlines indicate previously patched areas. Chloride analysis sample locations are shown by small, numbered targets, and any exposed reinforcing steel is indicated by cross-hatched lines.

It may be seen on these sample sheets that delaminated areas nearly always coincide with areas of high half-cell potential, and that some correlation exists between areas of high activity and high chloride ion content. However, it must also be noted that high chloride ion content does not necessarily indicate high half-cell potential and, similarly, high half-cell potential does not indicate that delamination has occurred.

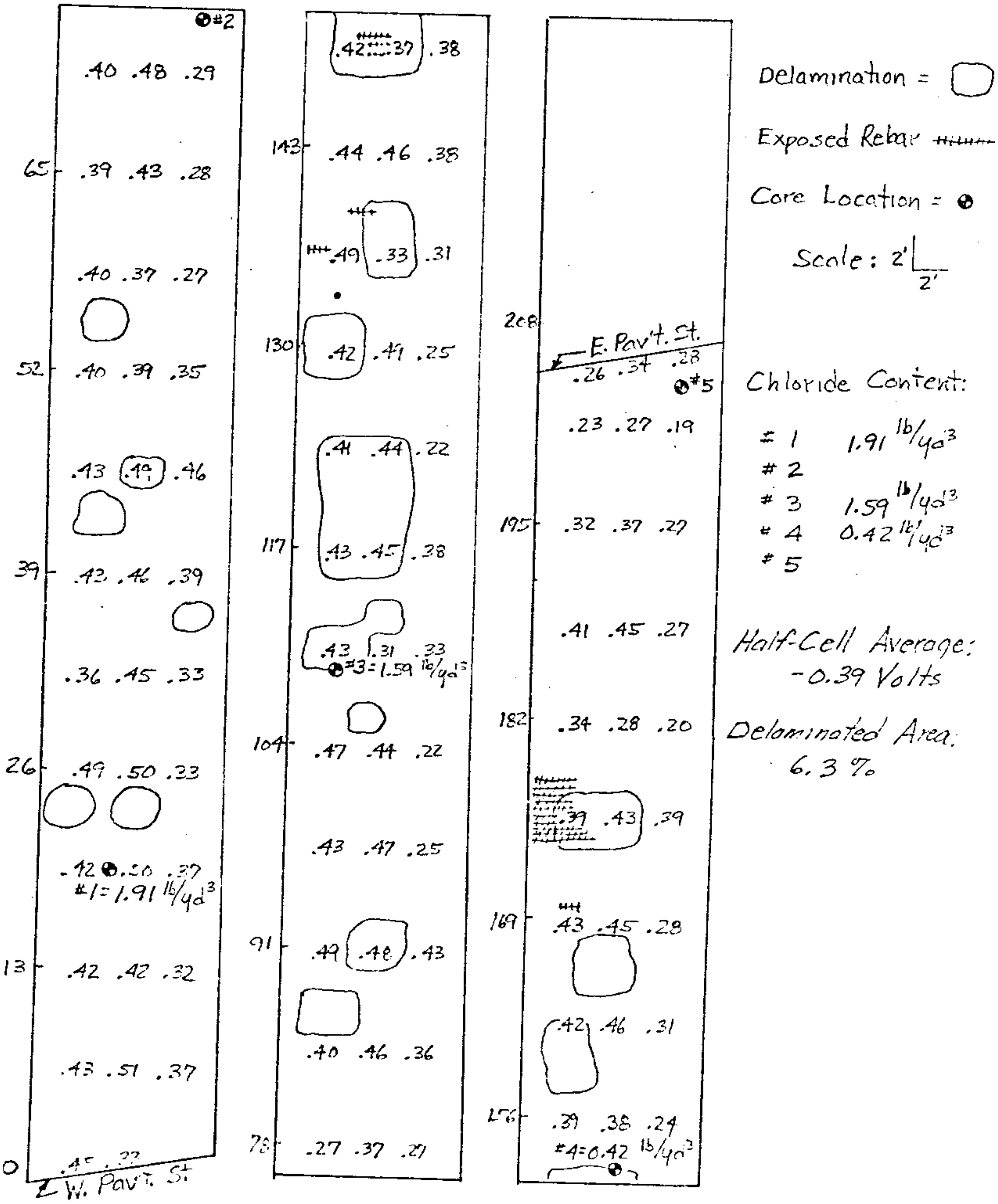
Bridge No. 2/250 Columbia River - E.B. Outside Lane



APPENDIX B-1

Sheet 1 of 2

Bridge No. 90/99 West Summit O.C. - EB Outside Lane



Chloride Content:

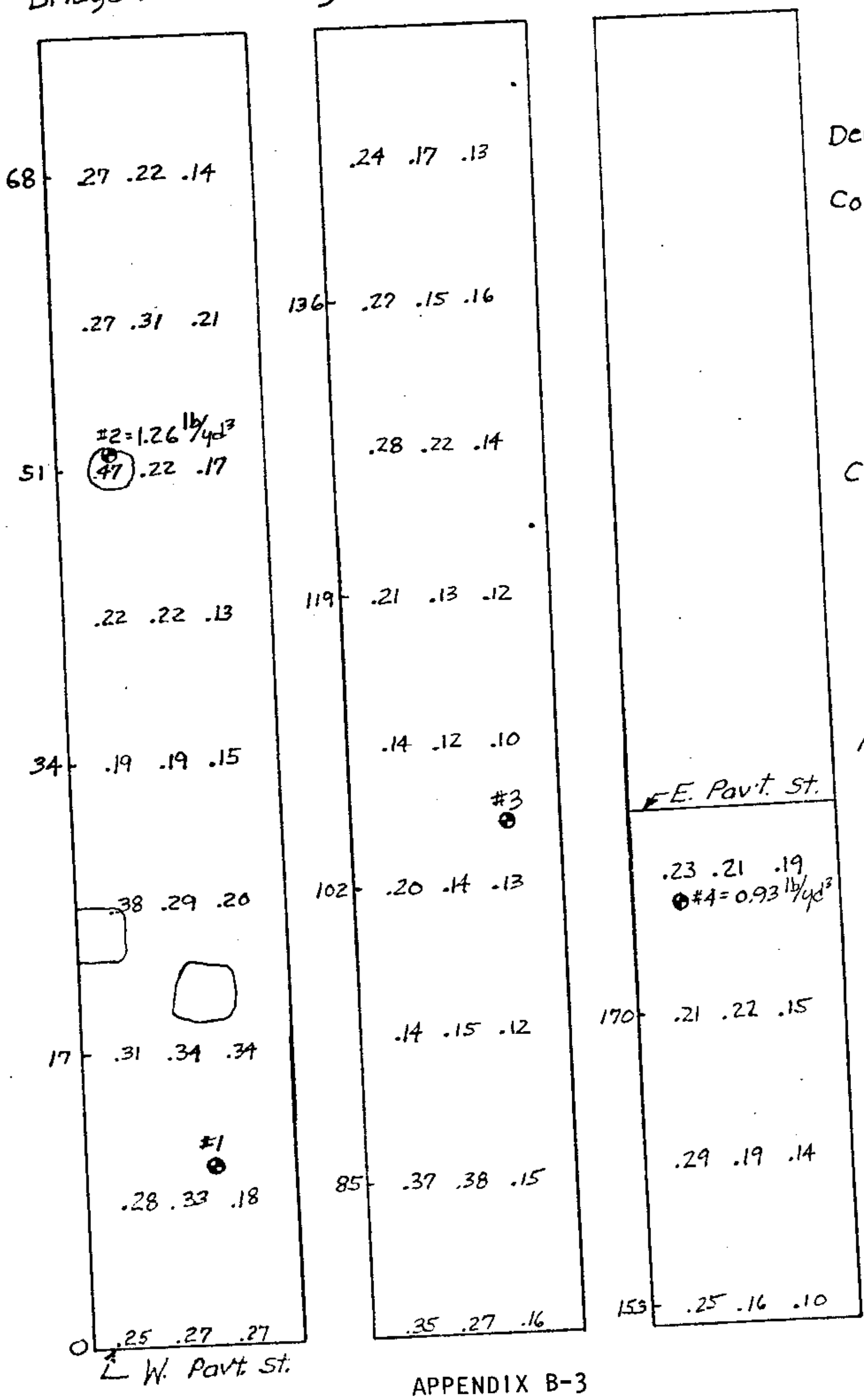
\# 1 1.91 lb/yd³
\# 2
\# 3 1.59 lb/yd³
\# 4 0.42 lb/yd³
\# 5

Half-Cell Average: -0.39 Volts

Delaminated Area: 6.3 %

APPENDIX B-2

Bridge No 90/104 Hyak Interchange O.C.-EB Outside Lane



Delamination = ▢

Core Location = ⊕

Scale = 2' 2'

Chloride Content:

1

2 1.26 lb/yd³

3

4 0.93 lb/yd³

Half-Cell Average:
-0.22 Volts

Delaminated Area:
1.2%

APPENDIX B-3

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