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A CASE STUDY OF THREE METHODS USED IN DETECTING BRIDGE DECK DETERIORATION ASSOCIATED WITH SPALLING

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The three most widely used current methods for detecting deterioration of concrete bridge decks associated with spalling were compared with a visual inspection of the reinforcing steel and to each other in order to determine the degree of agreement among the methods. The three methods are known as the Chain Drag Method, Measurement of Corrosion Potentials, and the Hammer Method. On a bridge scheduled for deck replacement, each of the methods was used to designate the areas of deck to be removed and the results were compared with the findings of a visual inspection of the rebar. It was concluded that the three techniques were practical and effective. However, in order to ensure that a high percentage of deteriorated areas are located, two of the detection methods should be used and the areas indicated by both methods should be removed.

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INTRODUCTION

One of the major problems facing the highway maintenance engineer today is the deterioration of concrete bridge decks. Research has been performed nationally and in Virginia to determine the causes of this deterioration and to suggest methods of improving concrete deck durability.[1,2,3] Based upon results from nationwide surveys a pronounced evidence of poor performance is the spalling of concrete and the rusting of steel associated with the use of deicing chemicals. While this condition is not extensive when compared with other defects and much less prevalent in Virginia than in other states surveyed, where it does occur it requires immediate attention and very difficult repairs.

Ways of improving the durability of new concrete decks are being evaluated;[4,5] however, the maintenance engineer is faced with the problem of repair of the older decks. A major requirement in the repair of older decks is the ability to locate areas of existing or impending deterioration. Many methods of detecting concrete bridge deck deterioration have been developed to aid the engineer in locating the approximate areas needing replacement.[6] In the work reported here the three most widely used methods were evaluated in a specific instance as to their ability to show deterioration and their degree of agreement in predicting distressed areas. The three methods are associated with detecting spalling and are known as the Chain Drag Method, the Measurement of Corrosion Potential, and the Hammer Method.

BACKGROUND

In 1972 the Virginia Highway Research Council began a study to determine the effectiveness of newly adopted specifications as a means for increasing the durability of concrete decks compared to the specifications that had been previously in force and that had been adjudged to produce concrete of borderline performance. This project was designed to supplement an earlier one[4] which included visual and electrical potential surveys of each of approximately 450 decks. At that time the Council had no experience with the electrical potential techniques nor the ability to interpret their results. Thus, to gain experience it was proposed that a deck scheduled for replacement be surveyed so that interested personnel could examine the rebars and compare their condition to the electrical potential readings obtained on the deck.

It was suggested that since the condition of the rebar was to be surveyed and compared with the potential survey, the project should be extended so that comparison could be made between the other methods being used in the state to detect deterioration; namely the Hammer Method and the newly developed Chain Drag Method. Thus, three methods of detecting potential or impending deterioration were chosen to be compared with a visual inspection of the rebar and against one another.*

Bridge Studied

In midsummer of 1972, a bridge was found which was scheduled for resurfacing and which would meet the needs for the planned comparisons. This bridge is on a 4-lane divided portion of U. S. Route 360 over Swift Creek in Chesterfield County, southwest of Richmond. It is a two-lane structure carrying the northbound traffic. A plan layout of the bridge is shown in Figure 1 where the area surveyed is hatched.

The bridge is located in an area subjected to a moderate climate during the winter. Route 360 is a major commuter line into Richmond and is subject to very heavy car and truck traffic. This heavy traffic, coupled with the moderate winter conditions, means that the bridge is subject to heavy salting during winters to keep it free of ice and snow. Since salting has been found to be a major cause of bridge deck deterioration, the bridge is well suited for evaluation of the detection methods concerning deterioration caused by deicing chemicals.

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*This report will compare the results as obtained by each detection method and will not deal with a cost comparison between the methods. The relative costs to perform a given survey are comparable for all methods. However, the initial costs for the electrical potential method is higher due to the cost of the electrical equipment needed to perform the survey.

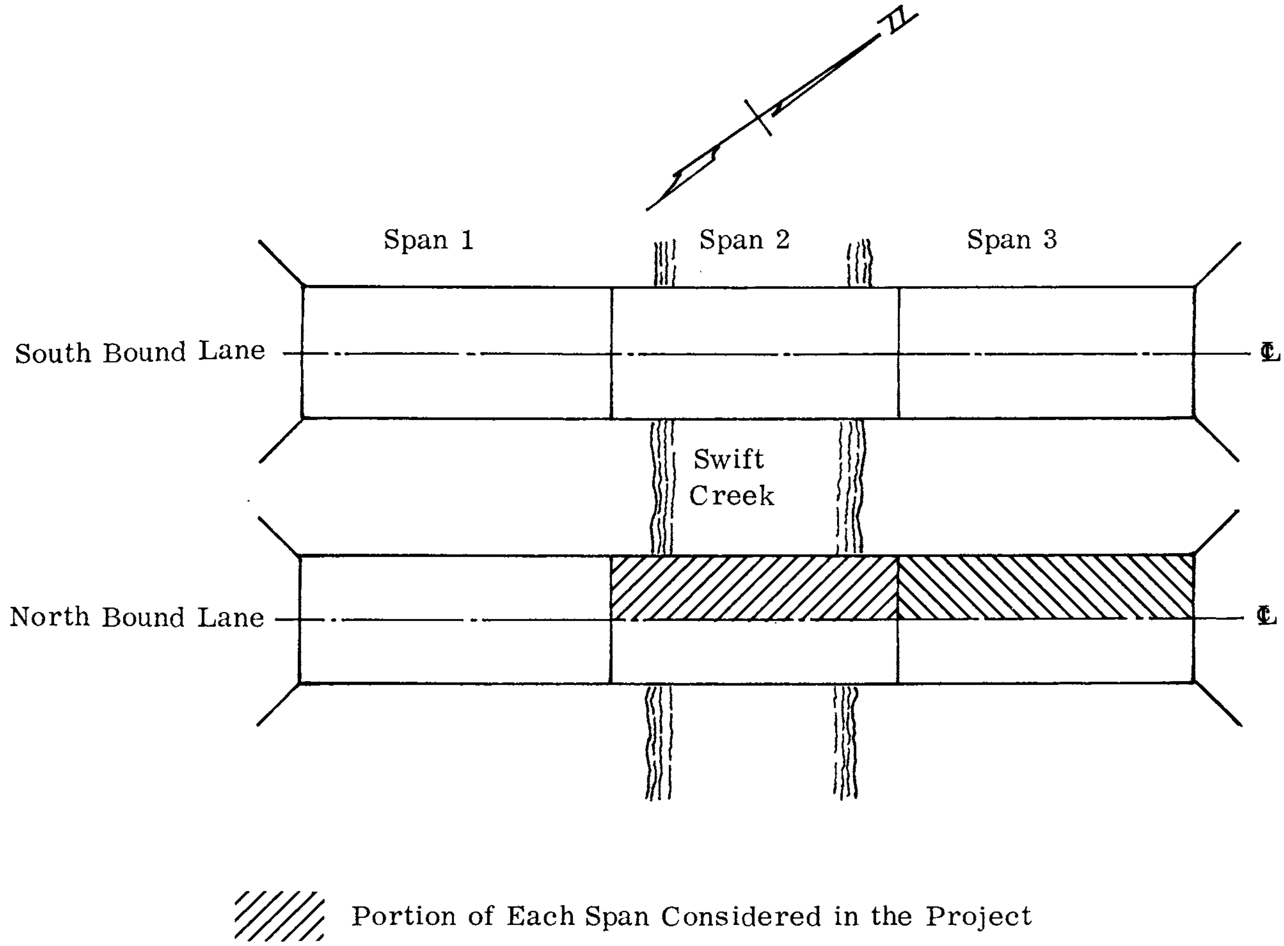

Figure 1. U.S. Rt. 360 over Swift Creek.

The bridge was constructed in 1956 and after 16 years of service the decks were in dire need of repairs. Figure 2 gives the results of a visual survey of the concrete deck using the format and definitions from both a previous and a current survey.[4,7] From this figure it is seen that a large percentage of the deck area had experienced scaling. Also there were areas of surface spalling as well as patching.

R-300 (6/70; revised 6/72)

DATA SHEET FOR RANDOM BRIDGE SURVEY INSPECTION REPORT

State VIRGINIA County CHESTERFIELD Route No. U.S. 360 Bridge No. ________

Year Built 1956 Location SWIFT CREEK NBL

Span No. 1 has been selected at the N S E (W) end of the bridge. (Circle one)

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Classification of Deck Deterioration

Span Number		1	2	3	4	5	6
Length (feet)		48'	48'	48'			
Girder Type							
SCALING	(1) % Light	40%	35%	20%			
	(2) % Medium	30%	25%	30%			
	(3) % Heavy						
	(4) % Severe						
CRACKING	(1) Transverse		M				
	(2) Longitudinal						
	(3) Diagonal	L	L				
	(4) Pattern						
	(5) "D"						
	(6) Random	M	L	L			
RUSTING	(1)						
SURFACE SPALL (number)	(1) Small		5	3			
	(2) Large			2			
JOINT SPALL	(1) Expansion						
	(2) Contraction						
	(3) Construction						
POP-OUTS (number)	(1)						
PATCHED AREAS		← PATCHED SPALLS → 5	12	8			
GROUND AREAS							

Date of Inspection 7-3-72

Figure 2. Results of a visual survey of the bridge deck.

The bridge is a 3-span structure, with each span approximately 48 feet in length with a 24-foot roadway. The construction sequence used was to repair one 14-foot lane of a span while the other spans were either being used to park or store the construction equipment or being investigated and marked for repairs. Due to equipment malfunctions and other delays, the only areas made available for study were the inside portions of spans 2 and 3 of the northbound lane as shown in Figure 1.

Mechanics of Spalling

From a synthesis of the literature(8) an empirical picture of the spalling phenomenon is possible. A brief account of the mechanics of spalling will be presented as this is the primary type of deterioration associated with the methods of detection used in this project.

The twin mats of steel reinforcement in a bridge deck can cause differential settlement of the fresh concrete, that is, more settlement occurs between the bars than over them. The concrete is caused to separate as particles flow over the reinforcing bars. In addition, bleed water is trapped under the rebar and creates other areas of weakness. Due to these areas of weakness, and under the action of thermal and shrinkage stresses, cracks occur over the topmost reinforcing bar. These cracks expose the reinforcing steel to air, moisture, and salts, which can cause corrosion. The products of corrosion occupy considerably more volume than the replaced metal and the expansion produces a tensile force many times the tensile strength of concrete. When the cracks fill with water and freezing occurs, even greater pressures are exerted. These forces can cause the concrete to crack over the reinforcing steel, and under the action of subsequent traffic a spall is produced. A diagram of the genesis of a spall is shown in Figure 3.

Even if there are no cracks, water and salt can permeate the concrete. Thus different areas can have different concentrations of salts and moisture. The differences in concentration can be sufficient to set up a galvanic cell and cause a flow of current. The corrosion of the steel set up by this electrical phenomenon creates internal pressures which crack the concrete cover and allow the actions previously described to occur.

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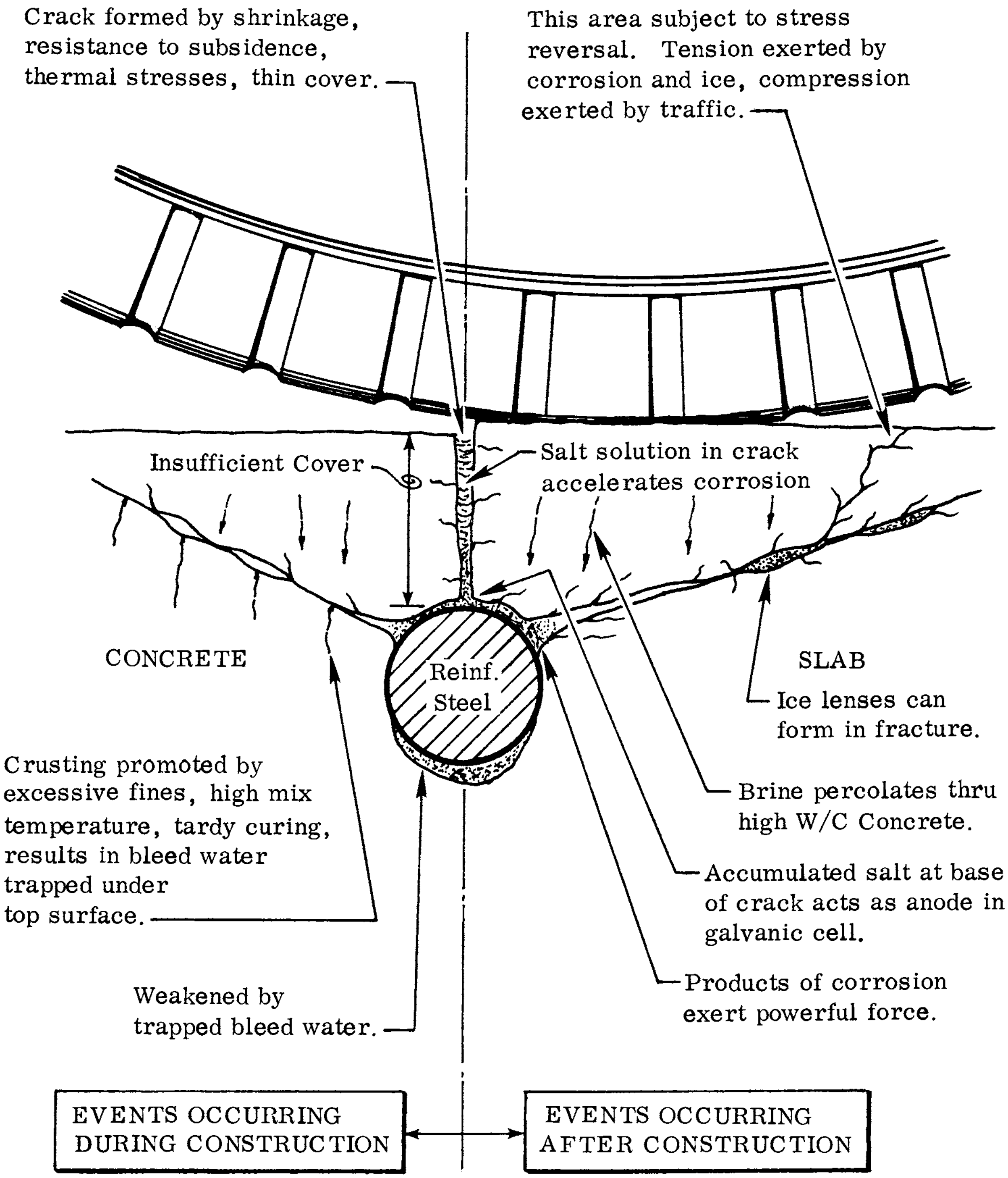

Figure 3. Genesis of a spall.
(From Reference 8.)

DETECTION METHODS

As mentioned previously, the three detection methods compared are associated with detecting existing or potential deterioration associated with spalling of concrete decks and are known as the Chain Drag Method, the Measurement of Corrosion Potential, and the Hammer Method. Detailed outlines of the methods are given below with a discussion of the results obtained by each in this study.

Measurement of Corrosion Potential

As noted previously, most of the corrosion of the reinforcing steel in bridge decks is related to an electrical phenomenon which is due to the creation of localized galvanic cells caused by differences in concentrations of salt ions and moisture in different areas of the deck. This being the case, a method was developed whereby measurements of the electrical potential of the deck could be used to locate areas of existing or potential deterioration. This method was first applied by Stratfull in 1958,[9] and interest in it has revived in recent years.

In the current study, the measurements of electrical potential were made by using the procedures and equipment described in the report from FHWA Demonstration Project No. 15.[10] The equipment was patterned after that used by the FHWA survey team, and consists of a $CuSo_4$ half-cell and a voltmeter. The equipment is shown in use in Figure 4.

In order that a contour map of the desired adequacy could be constructed, potential readings were not taken on the usual 3-5 foot grid intervals but at each intersection on a 2-foot grid system. Equipotential contours were constructed for each span and are shown in Figure 5.

Much work has been performed in trying to determine the level of voltage to be used as an indication of corrosion, the most extensive being that of Richard Stratfull with the California Department of Highways.[11] It seems that a voltage of 0.35 volt can be used to indicate areas of potential or active corrosion of the reinforcing steel. This is not to say that other areas cannot have corrosion or that all high voltage readings mean corrosion, but it seems that in most instances corrosion exists at this voltage.

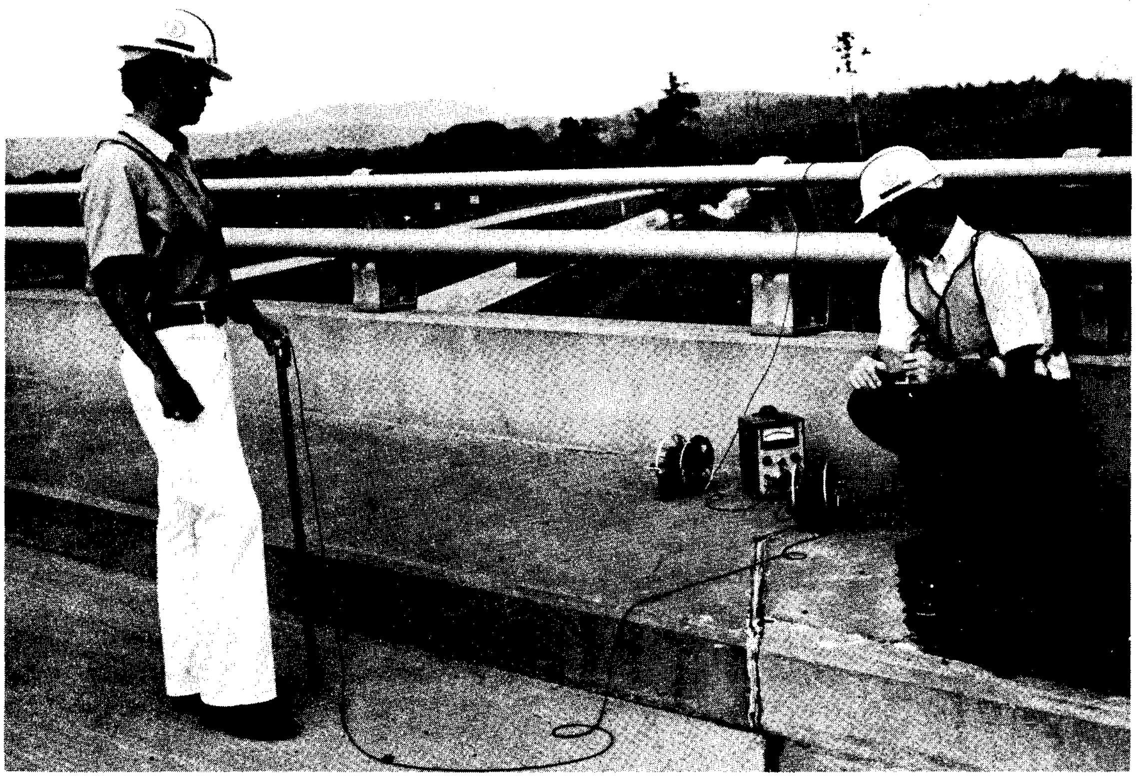

Figure 4. Measurement of potential corrosion of reinforcement.

It can be seen from the equipotential contour maps of each span shown in Figure 5 that large percentages of the areas of each span have potentials of 0.35 volt or greater. There are areas of each span that have potentials as high as 0.50 volt. To better depict the degree of high readings a frequency-voltage curve was plotted for each span as shown in Figure 6. From this figure it is possible to see the percentages of the total potential readings that fall below a given value. The value of 0.35 volt is shown by the heavy line across the figure. From the frequency-voltage curves it is seen that only 46 percent and 43 percent, respectively, of all potential readings for span 2 and span 3 fall below 0.35 volt. However, it is noted that span 2 had a higher percentage of high readings.

From the equipotential contour maps the areas with readings below 0.35 volt were marked as areas of sound deck not to be replaced. With these areas located, it was found that 65% and 74%, respectively, of span 2 and span 3 would have to be replaced. The difference in the results presented on the contour maps as opposed to the frequency curves is that the frequency curves are affected by certain isolated points while the contour maps represent a transition between all points.

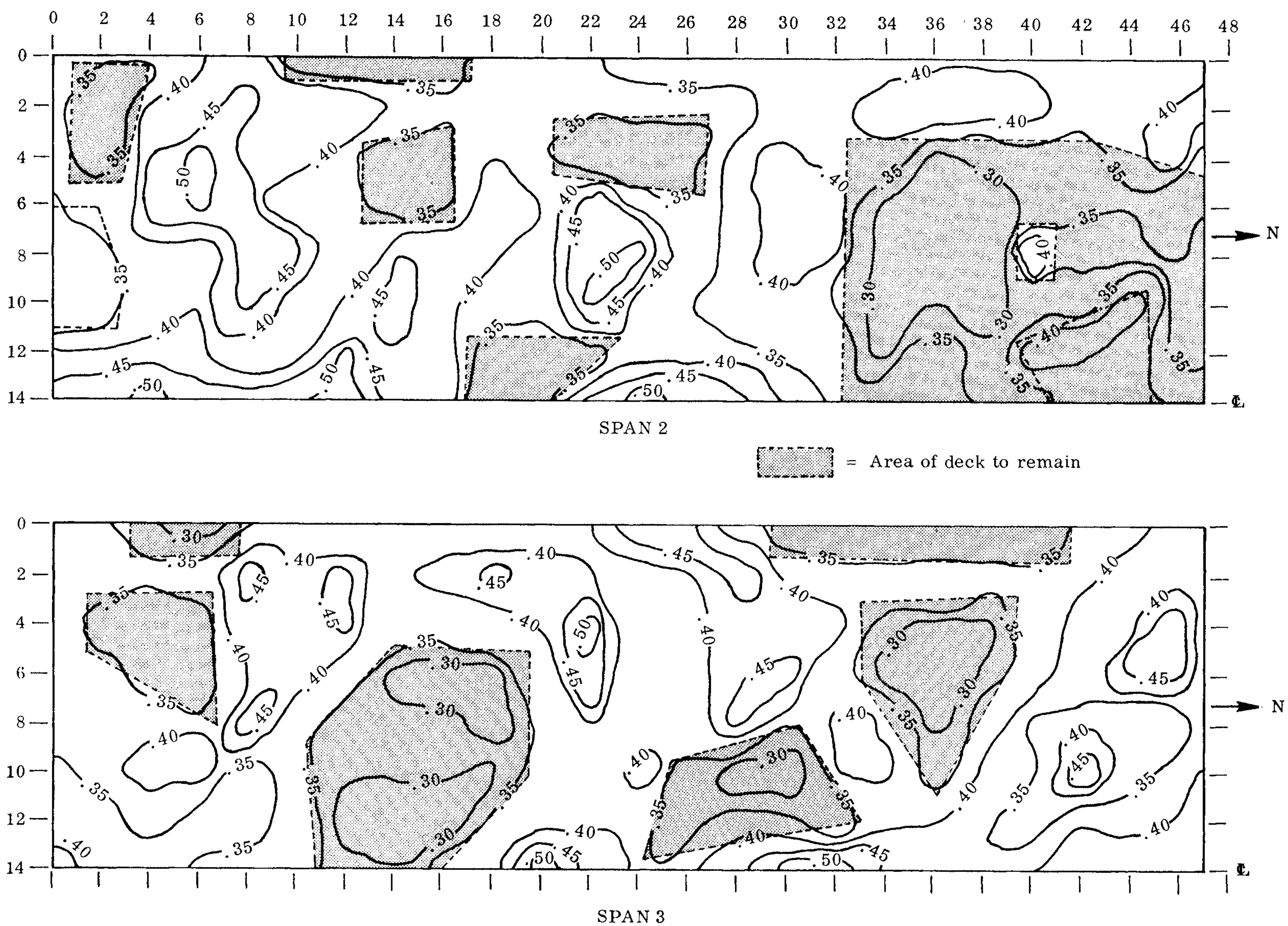

Figure 5. Equipotential contours.

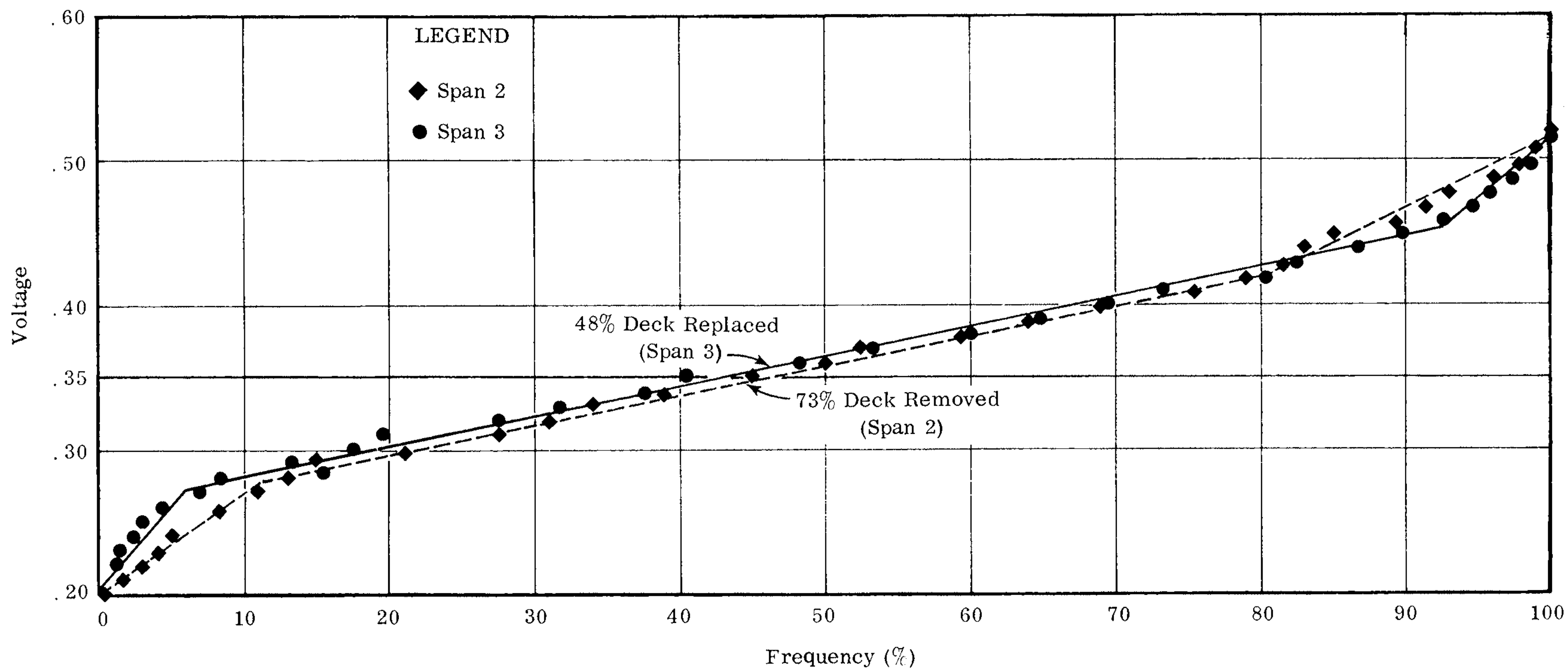

Figure 6. Frequency curves.

Chain Drag Method

The basic mechanism upon which the Chain Drag Method is based is the recognition of a "hollow sound" produced at the locations of delaminations by the detecting instrument. Figure 7 pictures the equipment used in this method. The chains, which are connected to a metal rod by ropes, are bounded and dragged across the deck area. Areas which give a distinct hollow sound are considered delaminated, and marked for replacement. The technique is very dependent upon the operator's ability to judge the distinctive hollow sound, but with some practice this becomes relatively easy.

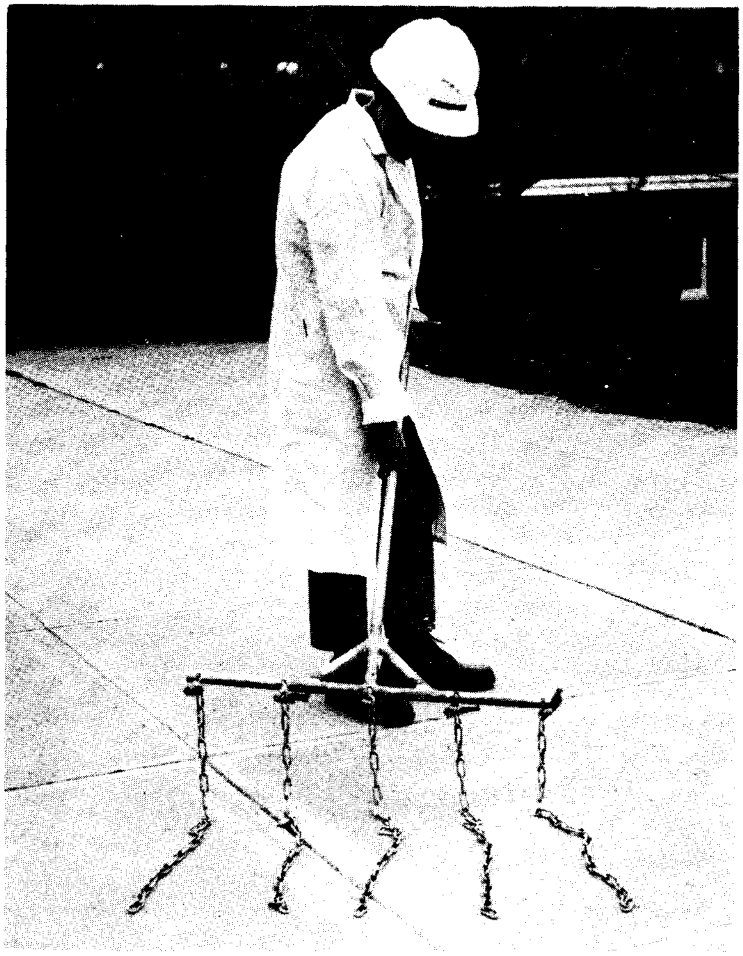

Figure 7. Chain drag apparatus.

With the 2-foot grid interval still marked on spans 2 and 3 from the potential survey, chain drag readings were taken on each span. Each grid intersection at which a hollow sound was detected was marked and a plan layout constructed to show the suggested areas of deterioration. Figure 8 shows these delaminated areas for each span. This layout will be compared with the results from the visual survey, as well as from other detection methods later in this report.

Hammer Method

The Hammer Method is also a sounding technique for finding delaminated areas. The operator taps the deck with a ball peen hammer listening for a hollow sound as shown demonstrated in Figure 9. When this sound is heard, the points are marked and recorded. This technique is continued until the complete deck is covered.

This was the method used by the project personnel on the decks in this study to locate the areas for replacement. Figure 10 is a layout of spans 2 and 3 in which the areas designated for replacement by this method are shaded. These areas of the concrete deck were removed to the topmost reinforcing steel. They are important since they provided the area for the visual survey of the reinforcing steel that was used in evaluating the other methods.

Visual Survey

As stated above, the only areas for which a visual survey of the reinforcement could be made to determine its degree of corrosion were the areas exposed as determined by the Hammer Method. However, these areas were sufficiently large to provide a meaningful evaluation of the ability of the three methods of detection to show areas of corrosion. Approximately 74 percent of the area of the deck was removed on span 2 and 48 percent on span 3. Figure 11(a) shows the removal of the concrete deck on the second span. This view was taken looking north on Route 360 and also shows the condition of the repaired traffic lane.

In the visual survey, areas of corrosion as opposed to a given point of corrosion were noted. Figure 11(b) shows the typical condition of the exposed steel on span 2. This figure also shows how the concrete was removed as well as the depth to which it was removed. Note the general condition of the reinforcing steel next to the opening in the deck. This condition was considered to represent corrosion. Figures 12(a) and 12(b) are close-up views of this area showing the extent of the corrosion of the steel.

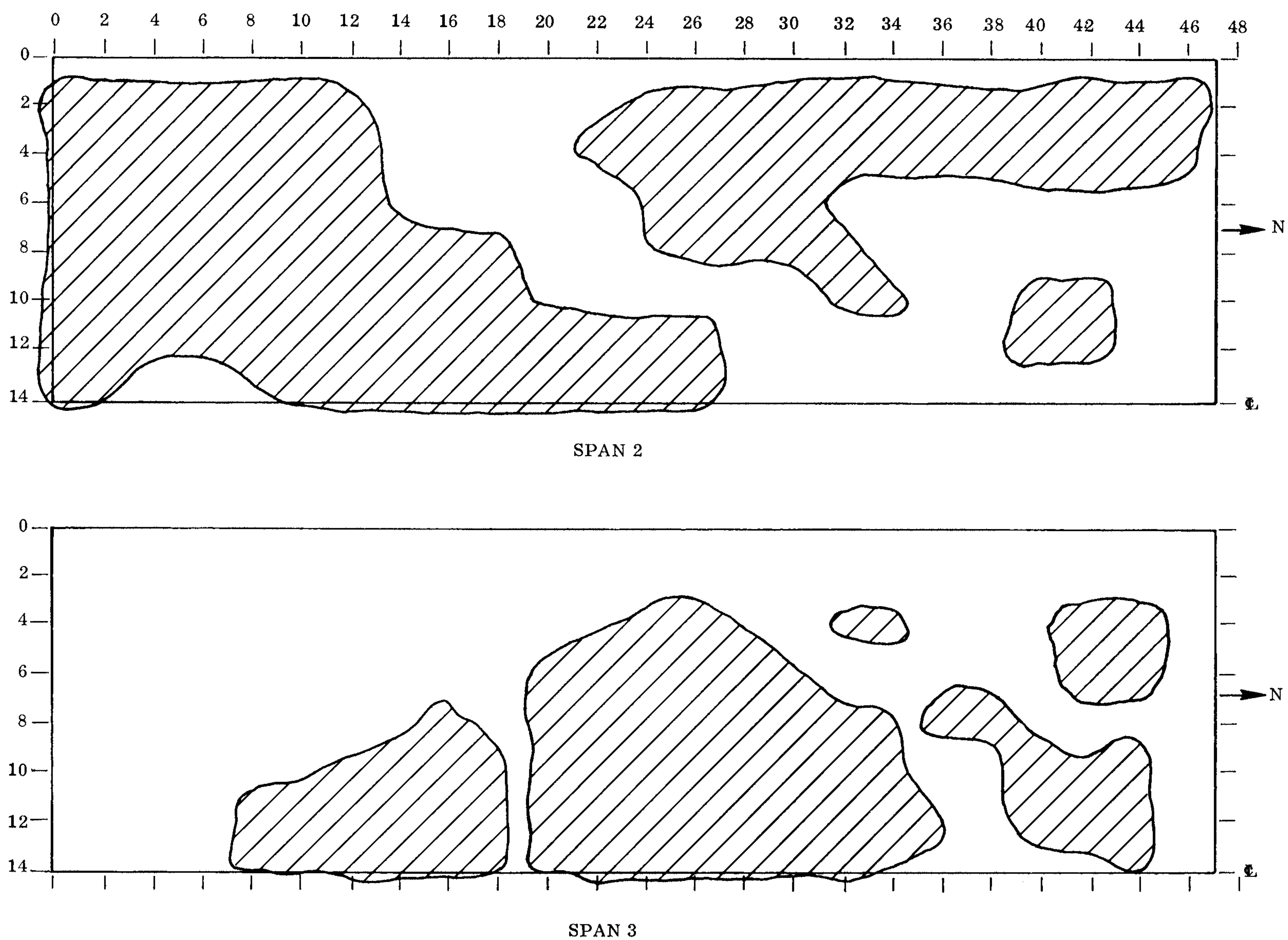

Figure 8. Delaminated areas by the chain drag method.

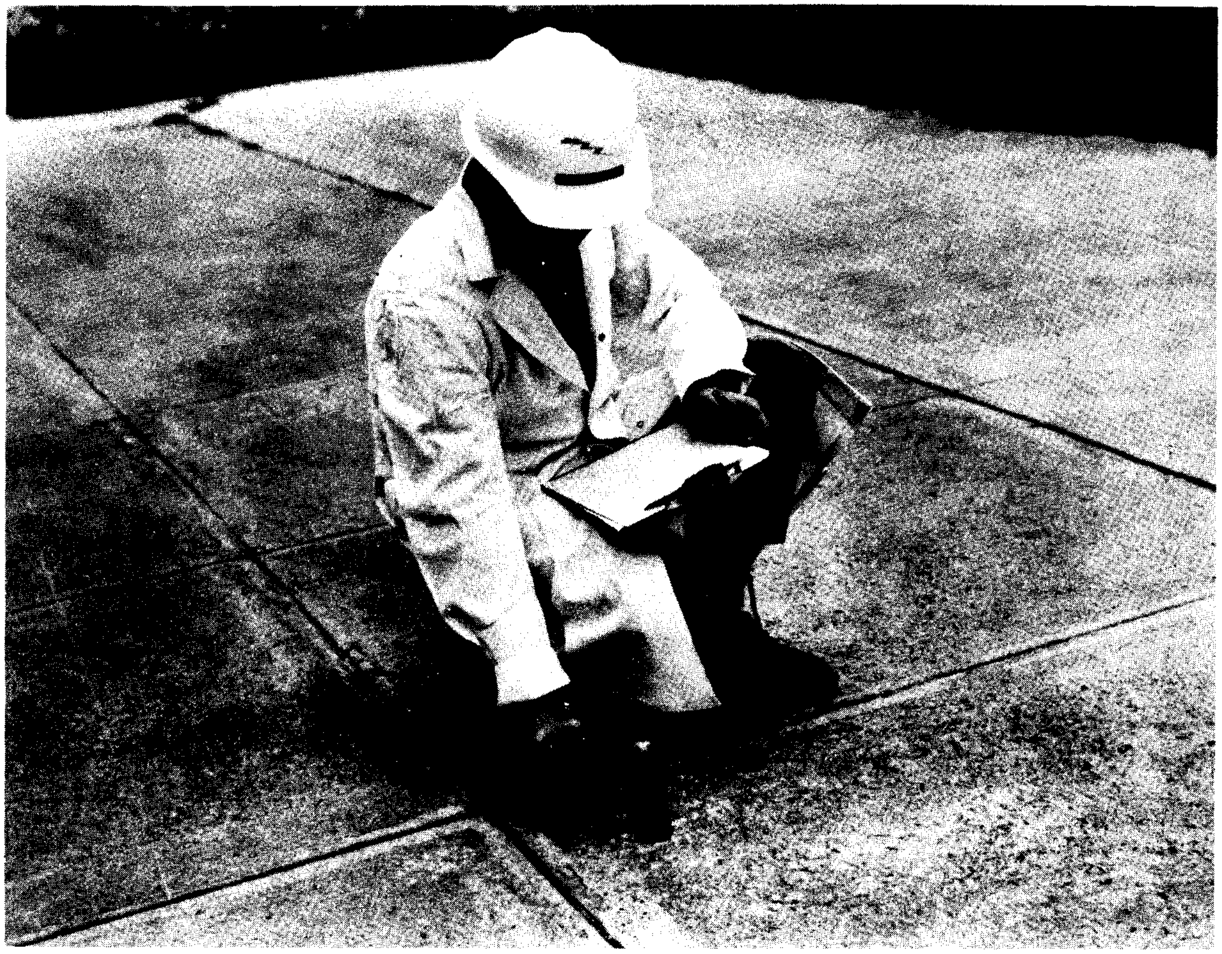

Figure 9. Demonstration of the Hammer Method.

The areas of steel considered to be corroded were determined and are given in Figure 13. These areas contained reinforcing steel that was corroded to the extent that scaling and pitting had occurred. At points, a very localized condition was observed to exist, but these were not noted as it was felt that areas of corrosion were more meaningful and would lend themselves more to a total analysis.

It is conceded that the only areas available for the visual survey were those determined to be deteriorated by the Hammer Method and that other areas of corrosion might exist. However, one of the objectives of this study was to build up confidence in the use of these methods of surveying bridge decks, and it was felt that the total areas of the deck removed was sufficient for this purpose.

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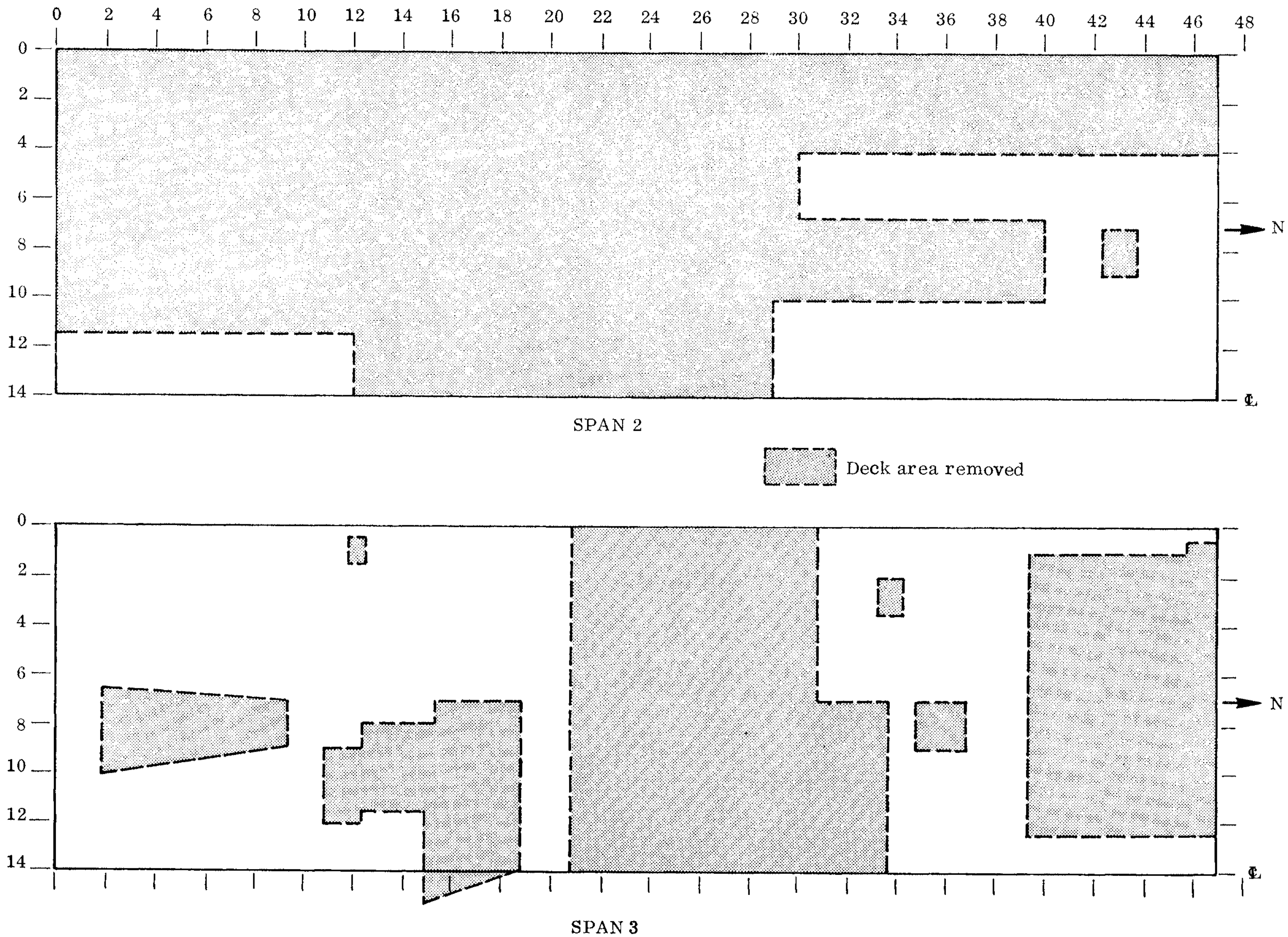
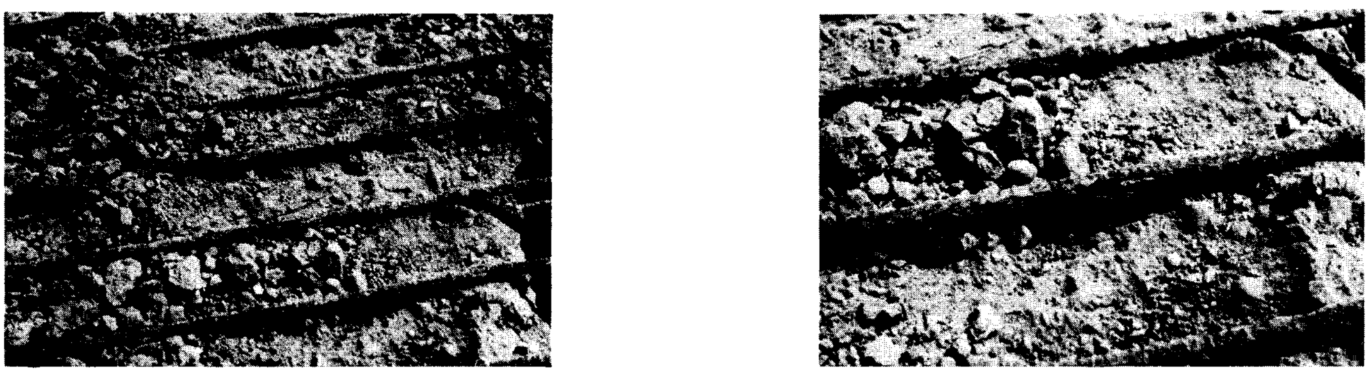


Figure 10. Delaminated areas located by the hammer technique and area of deck replaced.

a b

Figure 11. Exposed steel on second span (view looking north from first span).



a b

Figure 12. Close-up view of exposed steel showing corrosion (second span).

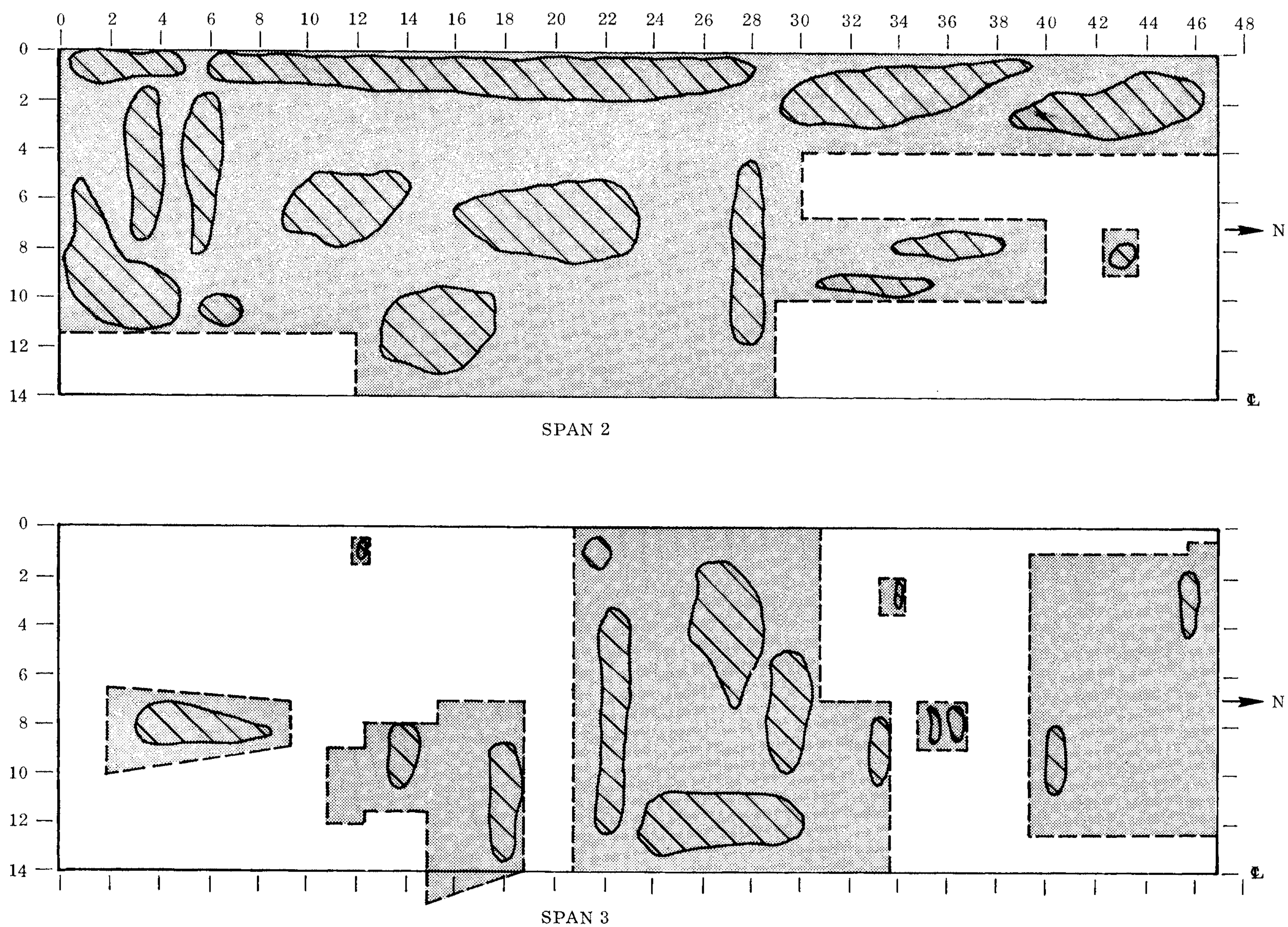


Figure 13. Visual survey of areas of heavy corrosion.

DEGREE OF AGREEMENT

Table 1 presents the results obtained from the three methods of detection and the comparison of these results with those obtained from the visual survey. These figures were obtained by using overlays of the results of the different methods and a polar planimeter. The overlays and a brief discussion of the comparisons are presented in the Appendix.

Items 1, 2, and 3 in Table 1 give the percentage of the deck area of each span designated as deteriorated by each of the three methods of detection. From this information, it is seen that there is fair agreement among them.

The remainder of the items in Table 1 pertain to the results of the visual survey. It should be restated that the complete deck of neither span was exposed and the visual survey was conducted only on the areas exposed — the areas determined by the Hammer Method to be delaminated. These items also show that the percentages of corrosion in the areas designated by the methods are approximately equal. However, by examining the overlays of the results as presented in the Appendix, it is seen that the areas do not match. In fact, the percentages of the total corrosion as found in the visual survey and by all the methods of detection amount to only 53% and 43%, respectively, for span 2 and span 3.

It could be concluded from the information presented in Table 1 that any one method does not locate all areas of deterioration. Also, it is noted that the areas of agreement between any two methods or all the methods do not locate a high percentage of the corrosion found in the visual survey. Considering these two points, it is suggested that a more desirable solution would be to replace all areas designated as being deteriorated by any two methods as opposed to using only one method. The methods chosen would depend on the time and experience of the personnel available as all methods seemed to give fairly consistent results. It could be advantageous to use the electrical potential method, if available, along with one of the other methods, since this method locates areas of existing as well as impending deterioration.

Table 1

RESULTS OBTAINED FROM METHODS OF DETECTION

1. Percent deck area deterioration by Chain Drag Method:

Span 2	54%
Span 3	34%

2. Percent deck area deterioration by Hammer Method:

Span 2	74%
Span 3	48%

3. Percent deck area deterioration by Electrical Potential Method:

Span 2	65%
Span 3	74%

4. Percent area of corrosion to deck replaced as defined by the Hammer Method:

Span 2	33%
Span 3	23%

5. Percent of total areas of corrosion in area defined by the Chain Drag Method:

Span 2	62%
Span 3	73%

6. Percent of total area of corrosion in area defined by the Electrical Potential Method:

Span 2	71%
Span 3	80%

7. Percent area of corrosion to area of agreement by all methods:

Span 2	53%
Span 3	45%

CONCLUSIONS AND RECOMMENDATIONS

An attempt has been made to show the degree of agreement between the indications from the three most widely used methods for detecting bridge deck deterioration associated with spalling. This was done by using the three methods to survey two spans of a bridge that was scheduled for deck replacement, drawing scale layouts of deteriorated areas as indicated by the methods, and superimposing these layouts so that areas of agreement could be found. A visual survey was conducted on the reinforcing steel exposed during the replacement operation as a basis for evaluating the effectiveness of the detection methods. The following general conclusions can be drawn from this project:

1. The three techniques were found to be practical and effective.

2. It was concluded from comparing the potential survey results with the results of the visual survey that high potential readings in a large percent of the areas relate to corrosion of the reinforcing steel. However, it was noted that in some instances that this was not true.

3. In order to ensure that a high percentage of the deteriorated areas of a deck are located, two of the detection methods should be used and the areas indicated by both methods should be removed.

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APPENDIX

In order to see more clearly how the results of the three detection methods compared, and how they compared with the visual survey, a series of overlays were prepared. In an attempt to put the results in a mathematical form, a polar planimeter was utilized to obtain exact areas as defined by the overlays. Once the overlapped areas were found, the results then could be presented as a percentage of one method of detection as compared to another method of detection. From these percentages and the visual descriptions on the overlays conclusion might be drawn as to the validity of using these methods to define areas of corrosion and impending deterioration.

The first overlay to be considered is that of the chain drag superimposed over the potential contours. This overlay is given in Figure A-1. The areas of delamination as found by the chain drag method cover approximately 54% of span 2 and 39% of span 3. An examination of the overlay of span 2 reveals that the chain drag method detected delaminations in all areas with potential readings of 0.35 volt except one large area in the center of the span. This area will be referred to again when considering the visual survey. The agreement on span 3, however, is not as good. Here there is a greater percentage of the .40 to .45 volt contours which were not indicated to be delaminated by the chain drag method. In span 3, it is noted that two areas which exhibited 0.35 volt potentials still indicated areas of delamination as determined by the chain drag method, showing that the deck could be deteriorated in areas of low potentials.

The comparison of the potential reading versus the area determined as delaminated by the Hammer Method is shown in Figure A-2. (The Hammer Method was used to designate the deck area to be replaced.) This method showed that approximately 74% of span 2 and 48% of span 3 was deteriorated and would need to be replaced. There seems to be a good agreement between areas of high potential readings and areas of delamination as designated by the Hammer Method. There are a few areas of span 2 which show high potentials but no delaminations by the hammer survey. But the data from span 3 (which had a smaller percentage of the total deck removed than span 2) seem to correlate very well with the high potential readings.

Figure A-3 shows the visual survey as well as the hammer survey superimposed on the potential contour plan. Since the areas designated by the hammer survey were the areas removed, all corrosion found in the visual survey fell inside these areas. It should be stated that this does not mean that corrosion could not exist elsewhere in each span. But as stated before, it is felt that the areas removed from each deck were so large that some conclusions could be made concerning the merits of each method.

In Figure A-3, it is clear from the number of corrosive areas and their locations that some type of correlation does exist between high potential readings and corrosion of the reinforcing steel. Of the area of the deck where the steel was exposed, the coincidence of corrosion and high potential readings is very extensive. It is noted that high potential contours also exist in areas not exposed by the hammer survey and it is recalled that this was also the case with the chain drag method. So as not to be over reactive in stating that all corrosion means high potential readings it is seen that corrosion can exist in areas of low potential. However, a great majority of the corrosive areas do have high potentials.

Most of the above information has been concerned with the comparison of the potential contours with the other methods used to survey the deck. In an effort to see how well the chain drag and hammer method correlated, Figure A-4 was prepared. From this figure it is seen that there is a fairly close correlation between these two methods.

This layout gives the total percentages of areas as indicated by the chain drag method corresponding to the areas of the deck removed to be 69% for span 2 and 77% for span 3. It is of interest to note that in span 3 some of the isolated areas corresponded quite well.

Figure A-5 is the same as Figure A-4, except it has the results of the visual survey superimposed on it. From this layout, the ability of the chain drag method to locate areas of corrosion can be seen. The areas of corrosion amounted to approximately 25% of the total area indicated by the chain drag method on both spans. However, 62% of the total corrosion of span 2 and 73% of the total corrosion of span 3 were indicated by the chain drag method. Comparing this with the hammer method, the total area of corrosion represented only 33% of span 2 and 23% of span 3. From these data it is seen that the chain drag method is very effective in locating concentrated areas of corrosion. By examining Figure A-5, the close correlation between corrosion and the chain drag method is readily seen.

In order to show the total correlations between all the methods discussed Figure A-6 was prepared. This figure shows the results of the hammer survey, chain drag survey, potential survey, and visual survey all superimposed on one layout plan. Each of these methods has been discussed separately, but it was felt that by superimposing them in this manner a more conclusive estimate could be made as to how the methods interact in showing deterioration of the decks. From this layout, it is obvious that the three methods of detection do have a fairly high degree of agreement.

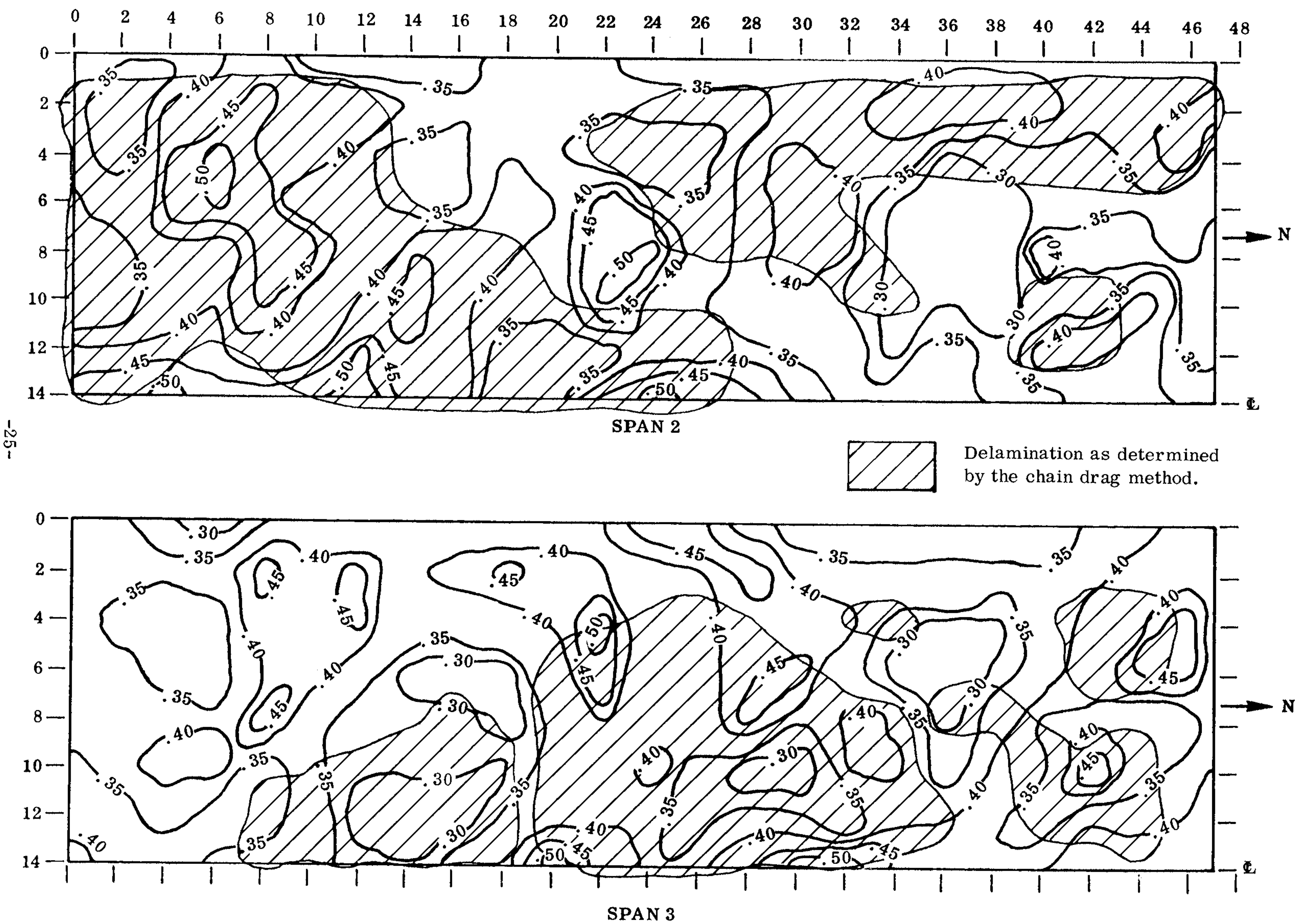

Figure A-1. Potential survey vs. chain drag survey.

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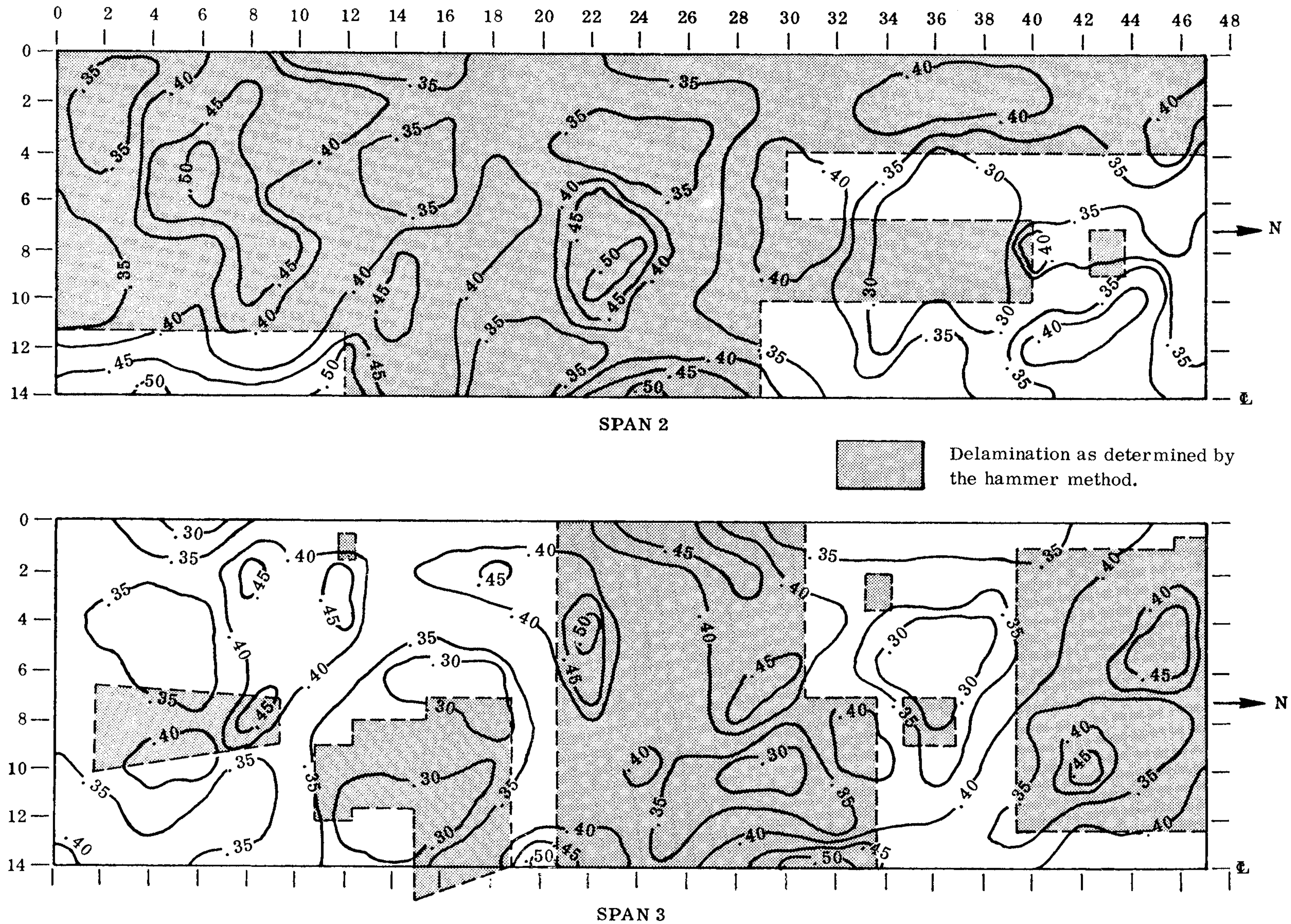

Figure A-2. Potential survey vs. hammer survey.

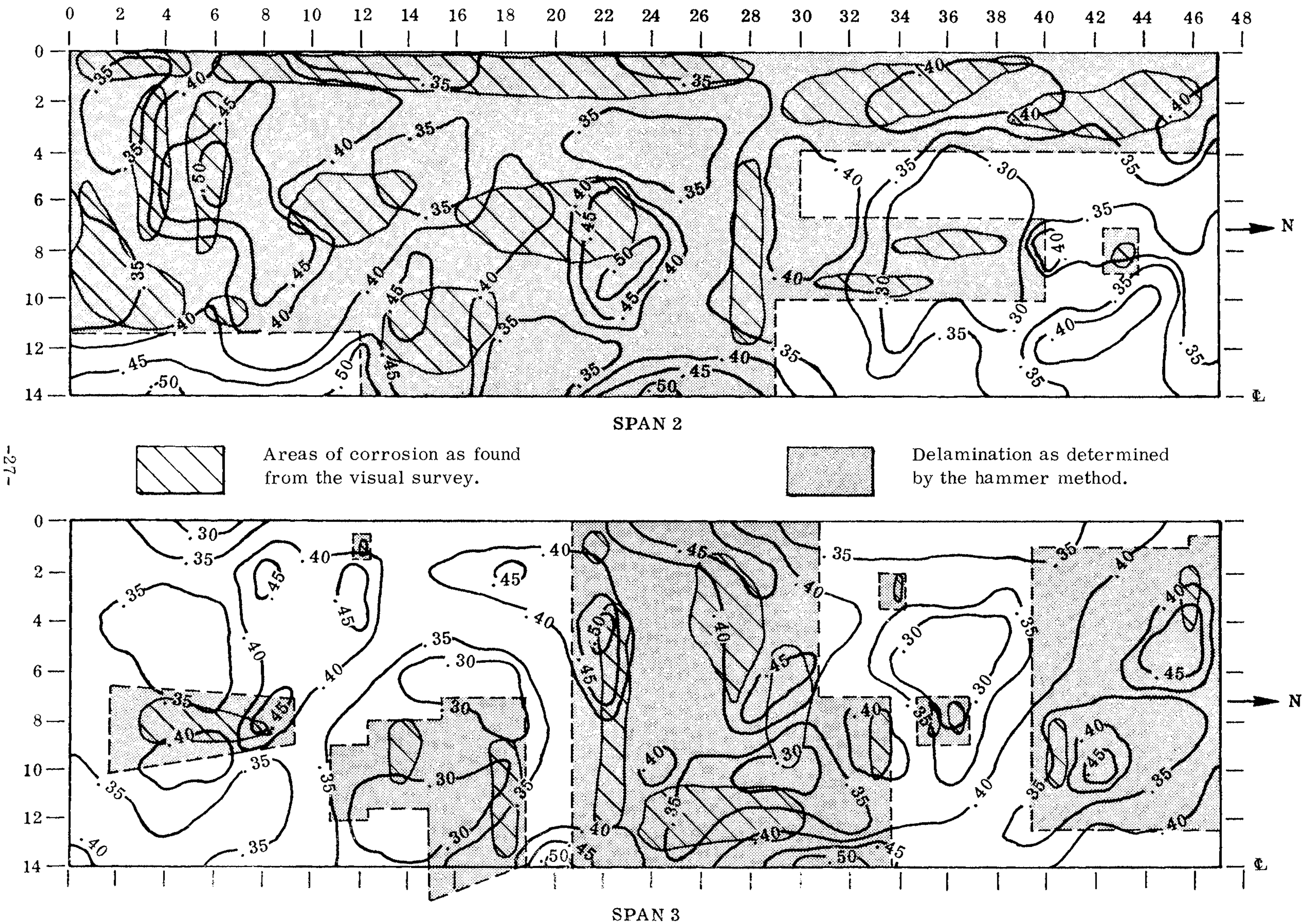

Figure A-3. Comparison of potential, visual, and hammer surveys.

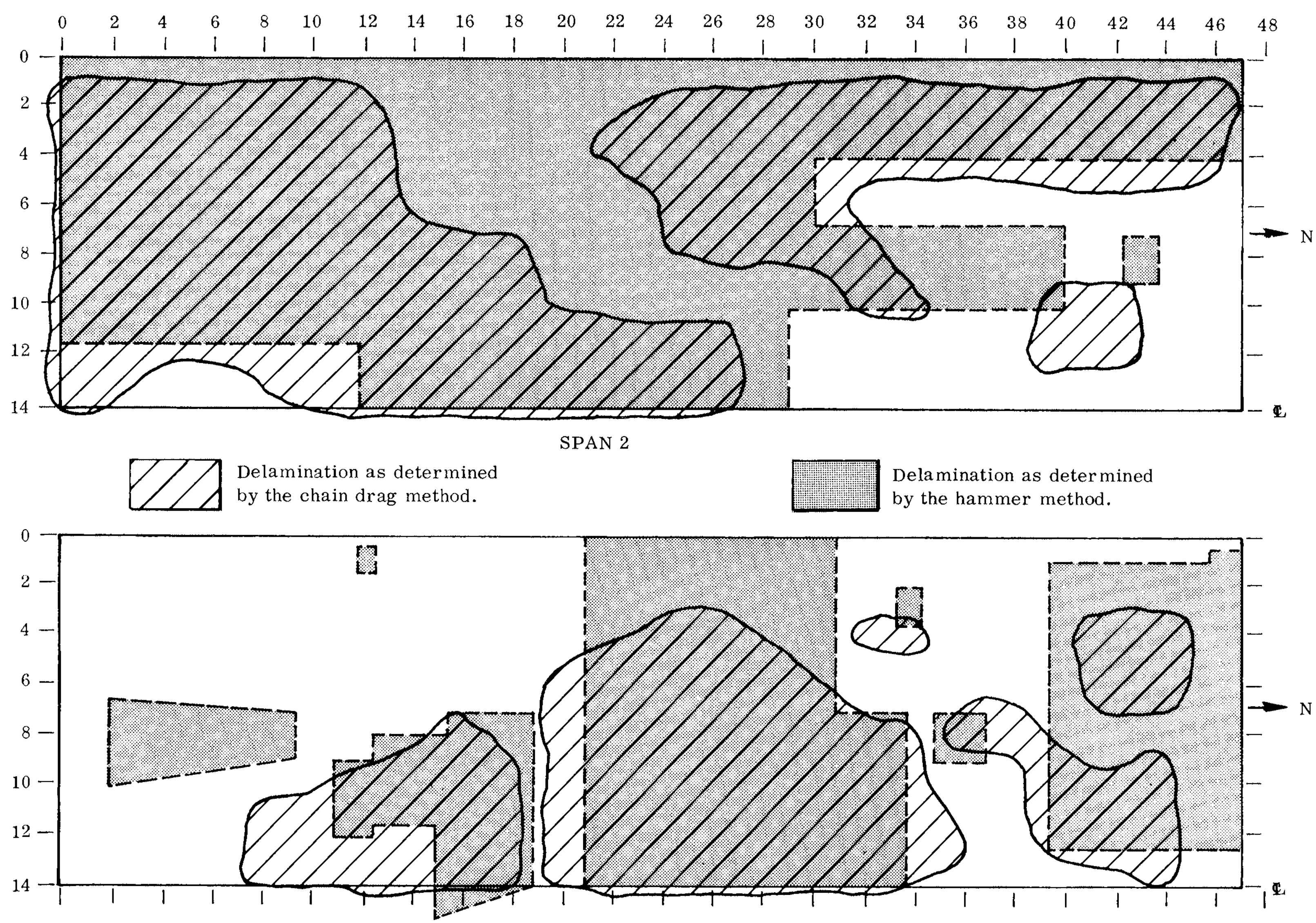

Figure A-4. Hammer survey vs. chain drag survey.

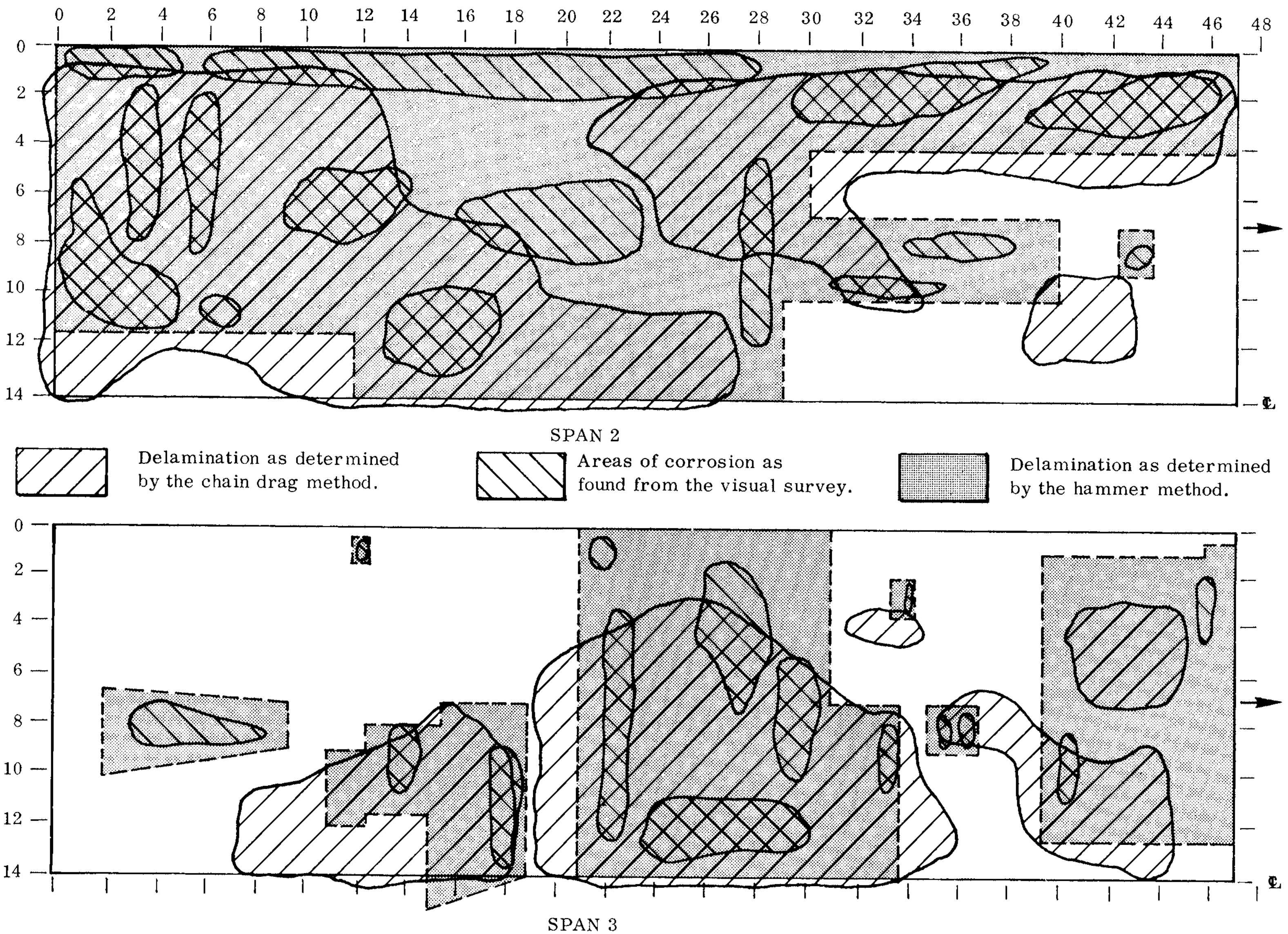

Figure A-5. Comparison of corrosion, chain drag, and visual surveys.

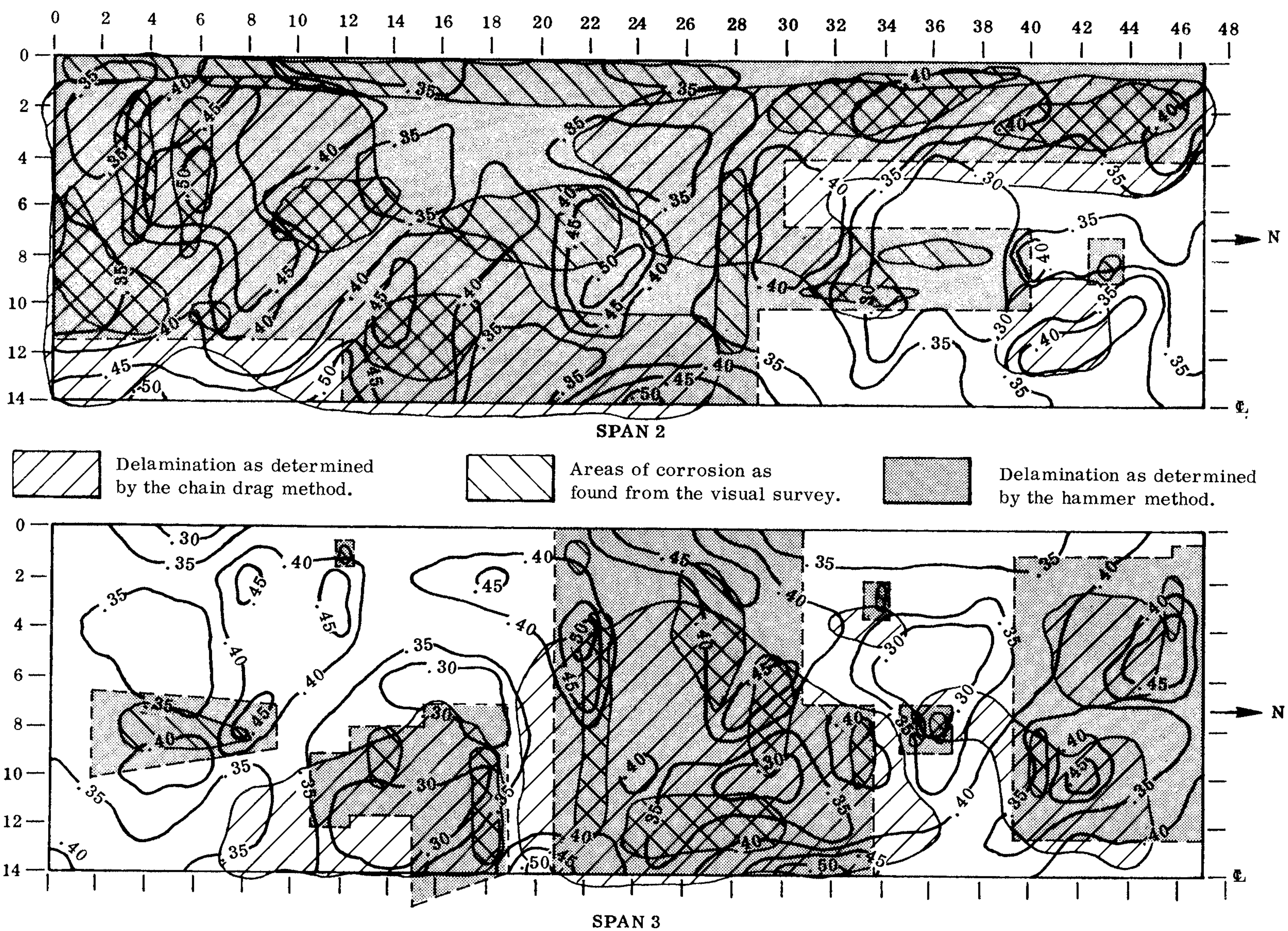

Figure A-6. Comparison of potential, hammer, chain drag, and visual surveys.