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Bureau of Materials and Physical Research

FINAL REPORT

ZINC ANODES TO CONTROL BRIDGE
DECK DETERIORATION

Project IHD-20

By

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A Product Evaluation Project by
Illinois Department of Transportation
in cooperation with
U. S. Department of Transportation
Federal Highway Administration

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16. Abstract

This report described a field investigation of the use of sacrificial
zinc ribbon anodes to cathodically protect the reinforcing steel
in a bridge deck, thus controlling spalling.

After 3 years the zinc anodes were found to be capable of protecting
only a three inch (7.62 cm) wide strip each side of the anodes.

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DECK DETERIORATION
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INTRODUCTION

Purpose

The objective of this study was to evaluate an innovative system to control the corrosion of the top mat of reinforcing steel in a concrete bridge deck using cathodic protection. By controlling reinforcing steel corrosion, bridge deck deterioration in the form of spalling can be controlled. Sacrificial anodes, specifically zinc ribbons inlayed into the surface of the concrete deck, were chosen as the cathodic protection method to be used. The simplicity of construction, low initial cost, and virtually maintenance free life of the zinc anode system were the inducements for this choice.

Preliminary Evaluation

Cathodic protection with sacrificial anodes has been used for many years by the pipeline industry to control corrosion of buried pipes-both steel and reinforced concrete. Zinc anodes have been most extensively used in sea water and low resistivity soils.

Scope

Zinc ribbons were installed longitudinally in the bridge deck at both 2 (.61 m) and 4 foot (1.22 m) spacings. The project was evaluated by measuring reinforcing steel potentials with a copper in copper sulphate ($Cu/Cu\ SO_4$) half cell. Current flow between the anodes and the reinforcing steel, concrete resistivity, and chloride content were also measured. Visual observations and sounding surveys were made to determine the condition of the deck.

Conclusions

The zinc anodes were capable of applying a protective current to
the top reinforcing steel mat to a transverse distance of about 3 inches
(7.62 cm) in both directions resulting in a protected strip of 6 inches
(15.24 cm) for each anode.

Recommendations

It is recommended that the existing system be modified by placing
an open graded asphalt friction course over it. The placing of the open
graded surface should increase the average moisture content of the deck
concrete thus reducing its electrical resistivity and allowing larger
areas of protection to be obtained with the zinc anodes.

FIELD TEST PROGRAM

The bridge chosen for this study was built in 1963 and is identified
as southbound US 66 over westbound FAI-74, Section 57-20HB, Project I-74-5
(13)134, Station 635+75.15, McLean County. The bridge is located at the
south edge of Bloomington, Illinois. It is a two lane structure with
merging lane and carries an average daily traffic of 9000. The condition
of the deck was good at the time of anode installation. Very few spalls
were found and the Cu/Cu SO_4 half cell potentials were low (avg. $\sim$ 125 mV).
The average deck chloride content at the level of the top mat was 625 parts
per million (ppm).

The top rebar mat in this 7-inch-thick (17.78 cm) deck consists of
transverse steel (No. 5 rebars on 5 1/2 in. [13.97 cm] centers) over
longitudinal steel (No. 5 rebars on 14 in. [35.56 cm.] centers). The
cover over the top transverse steel was about 1 3/4 inch (4.44 cm) and was
uniform over the deck.

The layout and location of the zinc anodes are shown in Figure 1.
The experimental area consisted of about 1,700 sq. ft. (157.93 m^2) of

the total 6430 sq. ft. (597.35 m^2) of deck area. The deck panels were numbered span nos. 1-9 and will be referred to by these numbers throughout the rest of this report.

The ribbon anodes were installed on 2 foot (0.61 m) spacings in the passing lane (span 8) and on 4 foot (1.22 m) spacings in the driving lane (span 5). The zinc ribbon anodes used had a diamond shaped cross section (11/32 inch [0.87 cm] x 15/32 inch [1.19 cm]) consisting of a No. 9 gage galvanized steel wire core surrounded by 0.25 lbs. per ft. (0.37 kg/m) of Hi-Pure zinc (ASTM B-418-67, Type II). It is manufactured by the Federated Metals Division of American Smelting and Refining Company, Somerville, New Jersey, and sold in 1000 foot (304.80 m) rolls.

The placement of the anodes in the deck is shown in Figure 2. Duracal cement manufactured by U. S. Gypsum Company was chosen to make the backfill mortar to be placed around the anodes for two reasons. One is the quick setting characteristics of the mortar which allowed us to open the bridge to traffic within a couple of hours after placement. The other and primary reason for the Duracal choice is its chemical makeup. About half of the Duracal cement is gypsum or calcium sulphate, and it was felt that the sulphate environment would be more suitable for the zinc anode. There is a possibility with ordinary cements that the zinc could react with the cement to form an insoluble zinc carbonate coating on the zinc thus passivating the zinc and stopping its ability to sacrifice itself to the reinforcing steel.

Another potential problem with the zinc anodes is spalling caused by the build up of zinc corrosion products. In other words the cause of the spalling of the bridge deck would be changed from the reinforcing steel rusting to the zinc anode corroding. This problem would be much less with the zinc because its corrosion products do not expand nearly as much as steel corrosion products, and they are more soluble than the steel corrosion

products which would allow them to be more readily absorbed into the surrounding concrete. In order to compensate for this potential problem a "cushion" was placed under 5 of the 11 anodes installed. The five "cushioned" anodes are the four center anodes in span 8 and the one center anode in span 5. The "cushions" were strips of 1" (2.54 cm) x 3/8" (0.95 cm) polystyrene foam building insulation. Because it was felt that the foam would electrically insulate about half of the anode surface and thus stop it from being a part of the protection system, a "wick" was installed between the anode and the foam. The wick was made of 1" (2.54 cm) wide strips of asbestos furnace duct wrapping tape. The purpose of the "wick" was to increase the moisture content between the anode and the foam thus hopefully keeping this area in the circuit. Both the "cushion" and the "wick" were attached to the foam with string. This was done to hold the foam and asbestos tape in place while the Duracal mortar was placed. In the 4 years since this system has been installed no deterioration of the Duracal mortar has been found at any of the 5 "cushioned" or 6 "uncushioned" anodes.

The "cushions" also acted as an electrical insulator between the zinc anode and the reinforcing steel. In the "uncushioned" anodes the zinc ribbons were placed directly on top of the exposed transverse reinforcing steel. This caused the "uncushioned" anodes to be shorted wherever they touched the reinforcing steel, thus no realistic current measurements could be made between these anodes and the re-steel. No test leads were placed on the "uncushioned" anodes. The steel wires in these anodes were welded directly to the reinforcing steel. This was done by exposing an inch (2.54 cm) of the steel wire by melting the zinc off with a welding torch. The exposed wire was then welded to the re-steel using an electrical arc welder and

the exposed steel wire and weld connections were sealed in a silicone caulking (bathtub seal). The test lead wires to the five cushioned anodes and the test lead wire connections to the re-steel were also all sealed with the silicone caulking and electricians tape before the backfill mortar was placed. The test leads were placed down through the deck and strung along the beams to a terminal box accessible from the slope wall at the southeast corner of the bridge.

The anode installations were performed easily in a three day period (11/1 - 11/3/73) by a crew of 5 men. The trenches for the anodes were made by making two parallel cuts 3 1/2 inches (8.89 cm) apart and chipping out the concrete between with air hammers. The trench did not need to be this wide but it was the simplest for the maintenance crew to do with the equipment they had available. There was some difficulty experienced in making the anode lay in the trench because it is a stiff material which tends to want to retain its roll shape. After sufficient bending by hand it layed relativley flat in the bottom of the trench but it did snake from side to side.

A resistivity measuring device was installed in the Duracal mortar, as shown in Figure 3, away from the influence of the reinforcing steel. The four copper pins were placed parallel to the deck surface with the plane of the four pins perpendicular to the deck surface. This allowed the center two pins to be placed just above and just below the level of the top of the rebar mat.

The components of the Duracal mortar used were: 24 lbs. (10.89 kg) water, 200 lbs. (90.72 kg) sand, 100 lbs. (45.36 kg) Duracal cement. The addition of salt (NaCl) to the Duracal mortar was considered before the anode installation to reduce resistivity of the mortar. The idea was discarded when it was found to extend the setting time of the Duracal in

laboratory tests.

FIELD TEST RESULTS

A Simpson 313 VOM and an M. C. Miller Model RE-5 Cu/Cu SO$_4$ half cell were used to measure all of the steel potentials shown in this report.

Negative (Cathodic) Voltage Shift. According to the National Association of Corrosion Engineers a minimum negative potential shift of 300 mV is necessary to adequately protect steel. This is the voltage shift caused by the protective current. This criteria is one that has been empirically established for buried pipeline and not necessarily true for steel embedded in portland cement concrete. Some corrosion engineers believe that for steel embedded in PCC a voltage shift of 100 mV is adequate and the amount of voltage shift necessary to control bridge deck spalling may be even less than 100 mV. In other words the bridge maintenance engineer may be able to live with minor amounts of corrosion such as crevice type corrosion which does not occur in sufficient amounts to cause spalling. Just what this voltage shift needs to be to control deck spalling has not been established.

On November 1, 1973, before the anodes were installed, Cu/Cu SO$_4$ potentials were measured on a grid pattern over the entire deck. The potentials at the same locations were measured on March 5, 1974, after the system had been activated for 123 days. The potential shift was computed for each location and averaged for each group of locations which were the same distance from the anode. These average potential shifts are plotted in the upper curve in Figure 4. If it is assumed that the potentials in the bridge deck were "static" it could be said that a 100 mV potential shift was achieved at a distance as large as 15 inches (38.10 cm) from the anode. By "static" it is meant that the environment around the reinforcing

steel had not changed. However, this is not true because an additional winter of salting had occurred between 11/1/73 and 3/5/74 and the deck temperature, moisture content, etc. were not the same on 3/5/74 as they were on 11/1/73. In order to compensate for this nonstatic or changing environment, the potential shifts were adjusted as shown in the lower curve of Figure 4. There it can be seen that the 100 mV shift was achieved only to a distance of 3 inches (7.62 cm).

The method used to adjust these potential shifts was developed from a study of the potential distribution curves shown in Figure 5 & 6. In Figure 5 the potential distributions of spans 5 & 8 (anodes) and spans 4, 6, 7, & 9 (no-anodes) are shown for 11/1/73. Little difference can be seen between the two curves, so the assumption was made that these deck areas are identical. They are in the same lanes which receive the same amount of salt and they were poured the same day using the same construction materials and methods. Also in Figure 5 is shown the distribution of potentials for spans 4, 6, 7, & 9 on 3/5/74. It is evident that the deck potentials on these control areas of the deck were not static. The distribution curves for spans 4, 6, 7, & 9 shifted about 80 mV between 11/1/73 and 3/5/74.

Using data presented in Figure 5 for spans 4, 6, 7, & 9, the potential shifts for spans 5 & 8 between individual (0", 6" [15.24 cm] & 12" [30.48 cm]) curves for 3/5/74 shown in Figure 6 and the 11/1/73 baseline curve were adjusted to produce the lower curve in Figure 4.

Polarization Decay. Another criterion for adequate cathodic protection accepted by corrosion engineers and the National Association of Corrosion Engineers is a minimum negative (cathodic) polarization voltage shift of 100 mV. The polarization shift is measured by interrupting the protective current — (turning system off) and measuring the potential decay. The

amount of polarization decay is to be adjusted by the immediate or instantaneous shift. For the deck in this study instantaneous shift was found to be very small or nothing and because of this it was ignored in adjusting the following data.

On March 14, 1975 potentials were measured with the system on. On April 28, 1975, after 45 days off, potential measurements were made again at the same locations measured on 3/14/75. The decay for groups (0", 6" [15.24 cm], and 12" [30.48 cm]) were averaged and plotted on Figure 7. As can be seen from this Figure the minimum decay of 100 mV was achieved only 3 inches (7.62 cm) from the anode. It is interesting to note that both the 100 mV decay and the 100 mV shift discussed in the previous section of this report occur at 3 inches (7.62 cm) from the anode. It is believed that 100 mV shift is sufficient to control corrosion if a method can be devised to adjust the data for "nonstatic" potentials. It is also believed that a shift of something less than 100 mV will adequately control deck spalling. The minimum shift which will control spalling needs to be empirically established.

Minimum - 850 mV. Another criterian accepted by NACE and the one most widely used, is the establishment of a minimum - 850 mV potential between the Cu/Cu SO_4 half cell and the steel. Figures 8, 9, & 10 depict the distribution of voltage potential from on to off for the 0-, 6-, (15.24 cm) & 12-inch (30.48 cm) distances from the anodes. From these figures the actual potentials achieved can be determined, and it can readily be seen that no where near the - 850 mV criteria was achieved. It is this author's opinion that the - 850 mV criteria is not applicable to bridge decks for economic reasons. In other words, achieving - 850 mV is not necessary on bridge decks if protection can be accomplished with substantially less. Achieving - 850 mV would require over-designing the cathodic protection system.

Progression of Spalling. Figure 11 depicts the spalling rate or sq. ft. of spalling per sq. ft. of deck for both the experimental and control areas.

A definite difference can be seen between the experimental (5 & 8) and control areas (4, 6, 7 & 9). It should be pointed out that the amount of spalling shown here is quite small (0.004 vs. 0.0095 sq. ft./sq. ft. [0.004 vs. 0.0095 m^2/m^2] on 4/20/76 which corresponds to 7 sq. ft. [0.65 m^2] and 23.5 sq. ft. [2.18 m^2] of spalling on spans 5 & 8 and 4, 6, 7 & 9 respectively) and that the time period involved is relatively short.

A disappointment was that spalling did occur on the experimental sections. The spalling that did occur were all small spalls and all occurred immediately adjacent to the Duracal mortar. In chipping out the trenches to place the anodes the steel was exposed. It is speculated that after backfilling with the Duracal mortar a concentration corrosion cell occurred between the Duracal with no chloride and the existing concrete with 625 ppm of chloride thus causing the corrosion to be accellerated in the existing concrete next to the Duracal mortar. The current distributed from the anodes apparently was not sufficient to override this concentration cell. If salt (Na Cl) had been added to the Duracal or if the rebars had not been exposed, the 7 sq. ft. (0.65 m^2) of spalling may not have occurred.

Current Flows. The flow of current between the anodes and steel was measured several times using the Simpson 313 meter and shunts but, due to inaccuracy of the meter on the low scale that had to be used, reliable data were obtained only on April 20, 1976, when a new meter was used. At that time a digital Simpson 360 was used to measure an average current flow of 6.9 mA/anode. Assuming that the sq. ft. of steel per sq. ft. of deck is 1 (one) and assuming that adequate protection is obtained with 0.05 mA/sq. ft. (0.54 mA/m^2) of steel and knowing that each anode is 63 feet (19.20 m) long a protected distance away from the anode of about 13 inches (33.02 cm) can be computed. This tends to support the theory that, if the

concentration cell had not been built in, no spalling would have occurred on the two foot (0.61 m) spacing anode area (span 8).

Resistivity. The resistivity of the Duracal was measured five times during this study and is shown in the following table:

Date	ohm – cm
3/5/74	49,200
7/24/74	19,200
12/3/74	52,500
4/28/75	24,500
4/20/76	27,900

The first four sets of readings were taken using the Simpson 313 voltmeter, calibrated resistors and lantern batteries. The last reading 4/20/76 was taken using a Vibroground Model 293 made by Associated Research Products. The variation in the data can be explained by the ambient condition at the time of testing. The highest reading on 12/3/74 was taken when the air temperature was $10^{\circ}F$ ($-12.2^{\circ}C$) and, vice versa, the lowest resistivity occurred in July. The resistivity should decrease with additional salt content and this is believed to be the reason for the drop of 49,200 to 27,900 from 3/5/74 to 4/20/76. The Chloride ion content did increase in the existing concrete from 625 ppm on 11/1/73 to 709 ppm on 1/14/76 at the level of the top mat.

SUMMARY

The use of sacrificial zinc anodes to control rebar corrosion on a bridge deck was tried with limited success. Changes could have been made in constructing the experimental system which may have made it more successful. Instead of exposing the reinforcing steel the anodes could have been placed in narrow and shallow notches sawed in the deck. This could have prevented

the spalling in the experimental system. Salt could have been added to the backfill mortar to reduce its resistivity. The resistivity of both the backfill mortar and deck concrete could have been reduced by placing a porous open graded asphalt wearing surface over them thus increasing their moisture content.

The − 850 mV criterion for cathodic protection appears to be incorrect for bridge decks. A more realistic criterion is the 100 mV polarization decay.
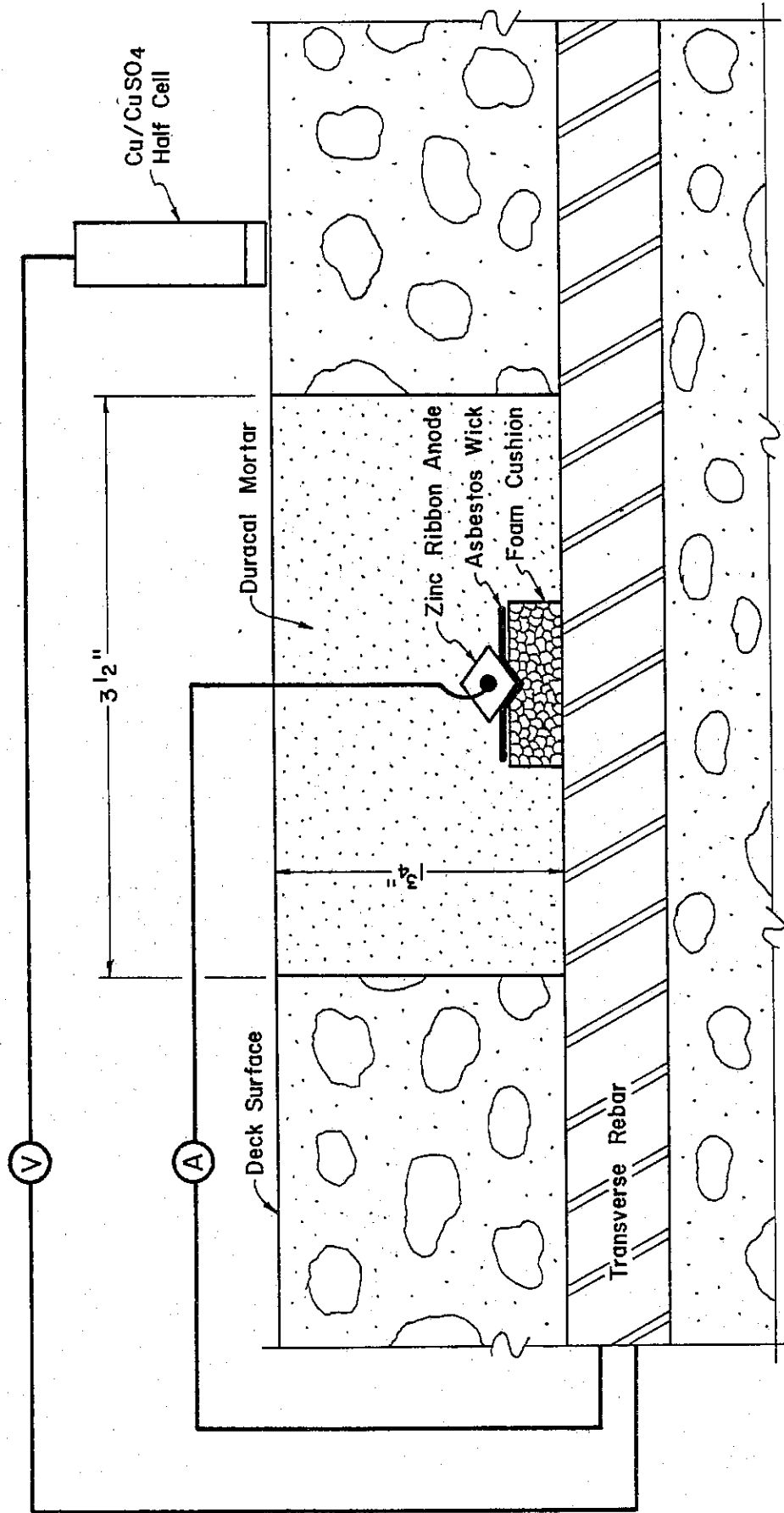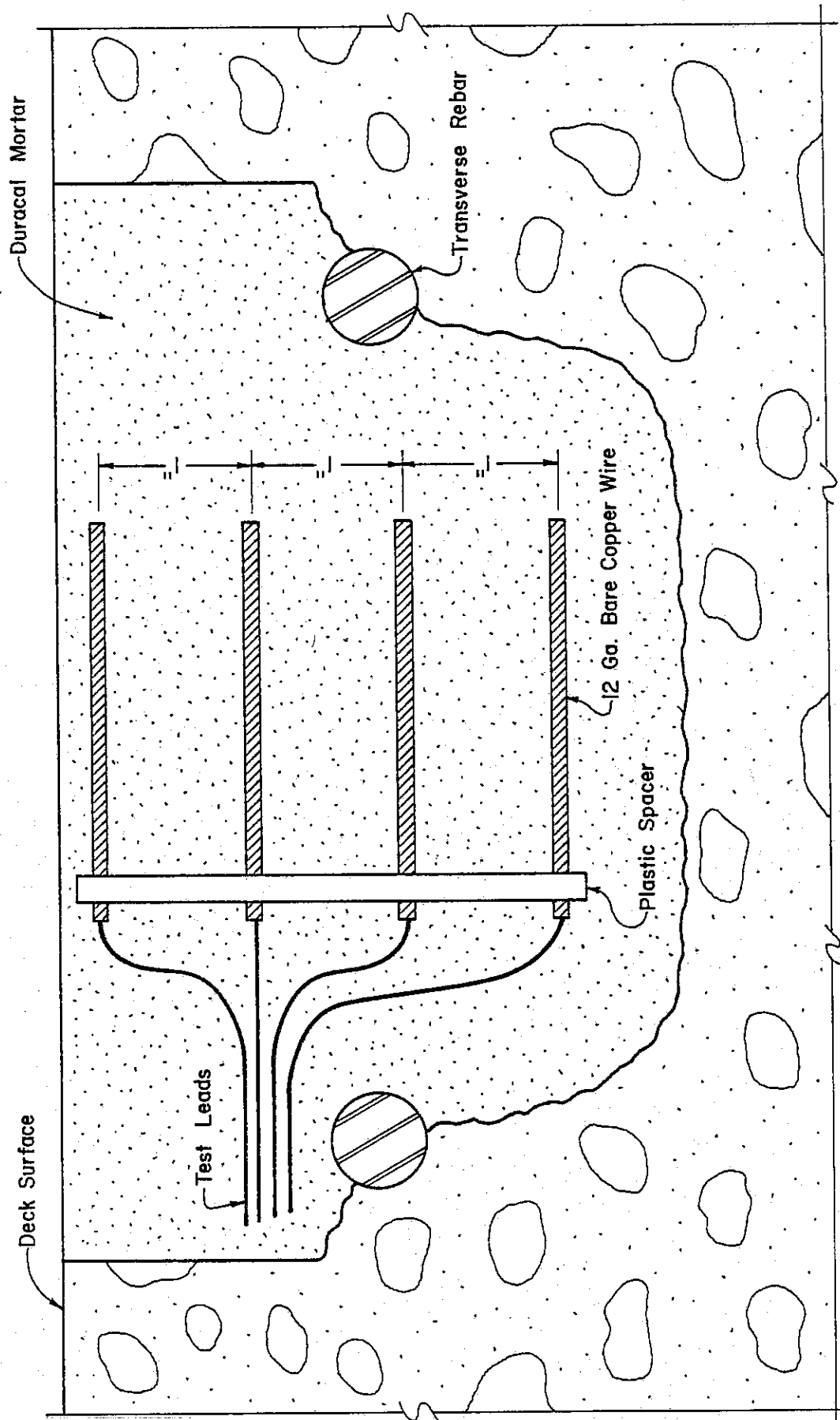
Figure 1. Layout Of Experiment

1 in. = 2.54 cm
1 ft = 0.305 m

Curb

Merging Lane

Driving Lane

Passing Lane

Expansion Joint

③ ⑥ ⑨

43'

Expansion Joint

② ⑤ ⑧

63'

Open Longitudinal Joint

Expansion Joint

① ④ ⑦

49'

Median Curb

15' 12' 15'

12

12' 15'

63'

⑤

⑧

Zinc Ribbon Anodes
@ 48" spacing

Zinc Ribbon Anodes
@ 24" spacing

Test Lead Trench

Figure 2. Anode Installation Method

1 in. = 2.54 cm

Cu/CuSO$_4$ Half Cell

Duracal Mortar

Zinc Ribbon Anode

Asbestos Wick

Foam Cushion

3 $\frac{1}{2}$"

3 $\frac{3}{4}$"

Deck Surface

Transverse Rebar

Figure 3. Resistivity Test Device

1 in. = 2.54 cm
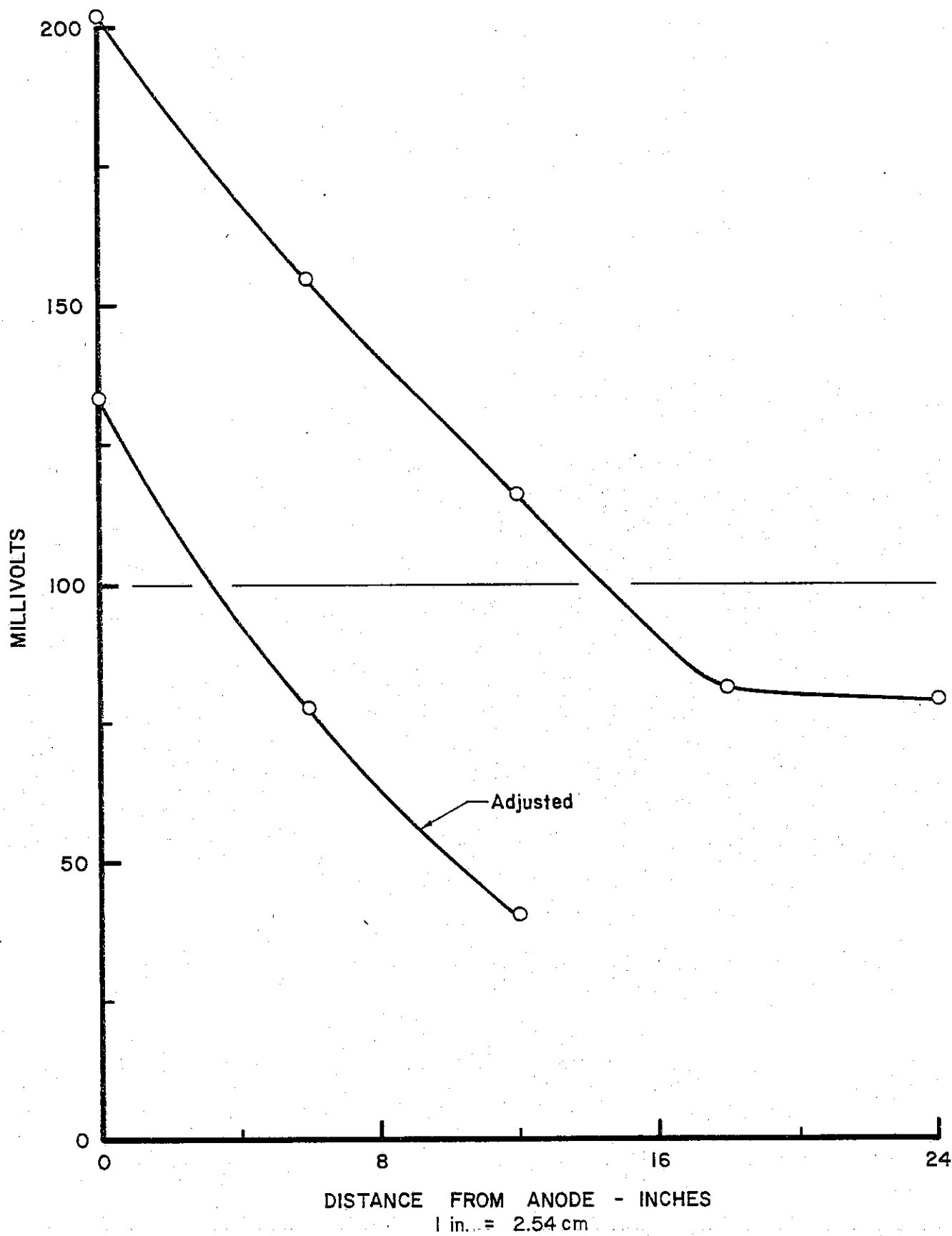
Figure 4. Average Potential Shift 11-1-73 To 3-5-74
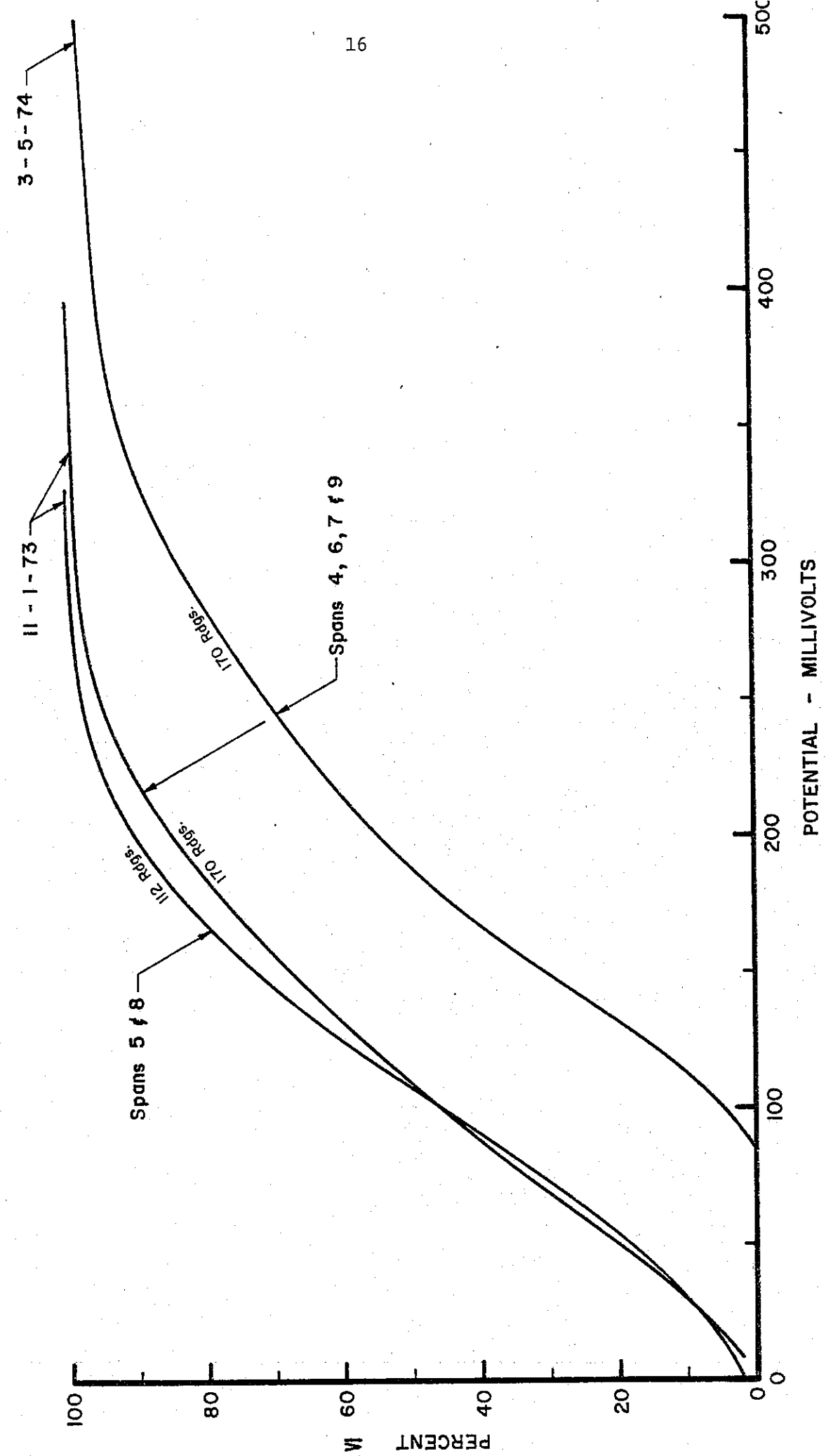
Figure 5. Distribution Of Steel Potentials
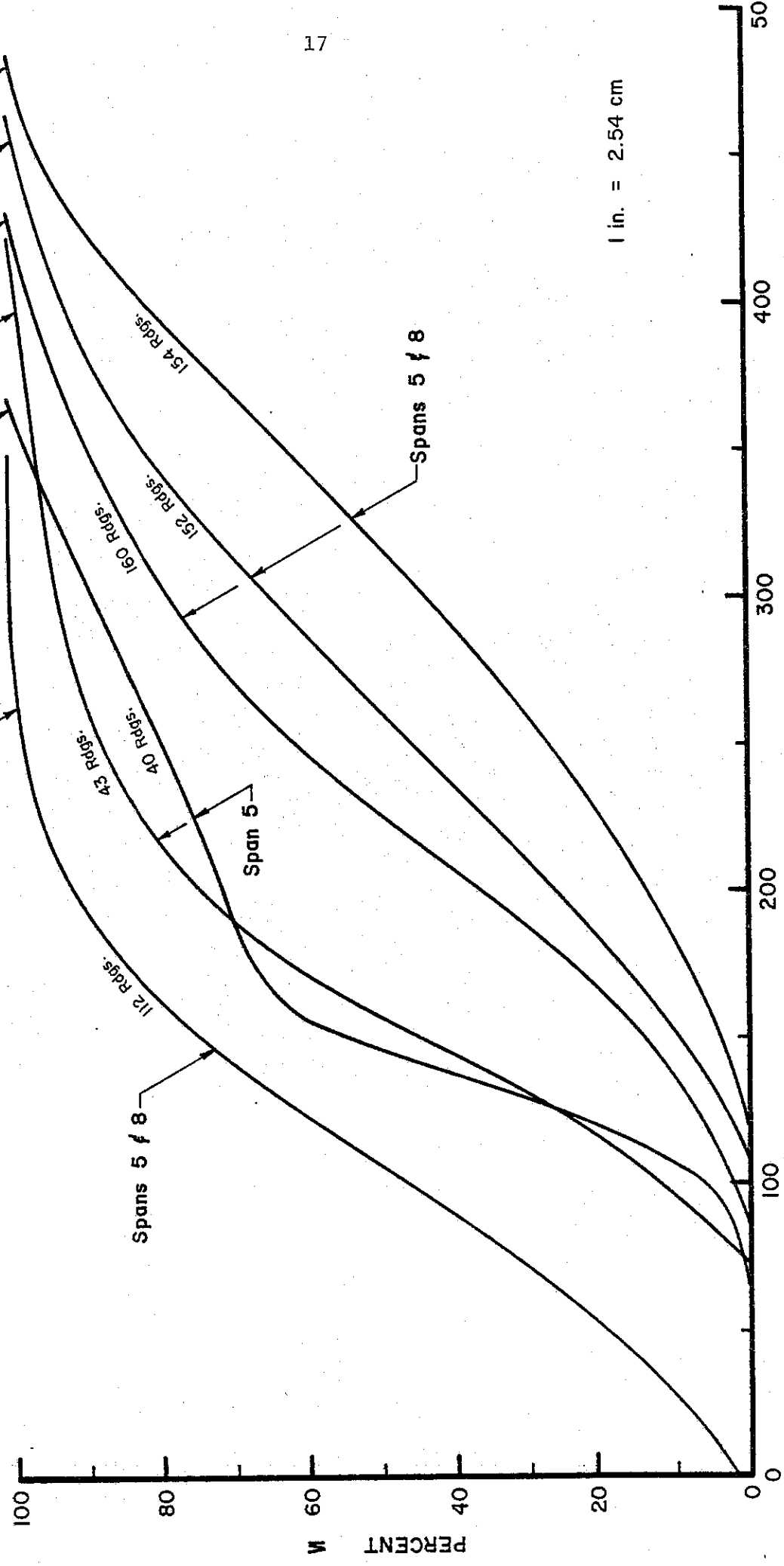
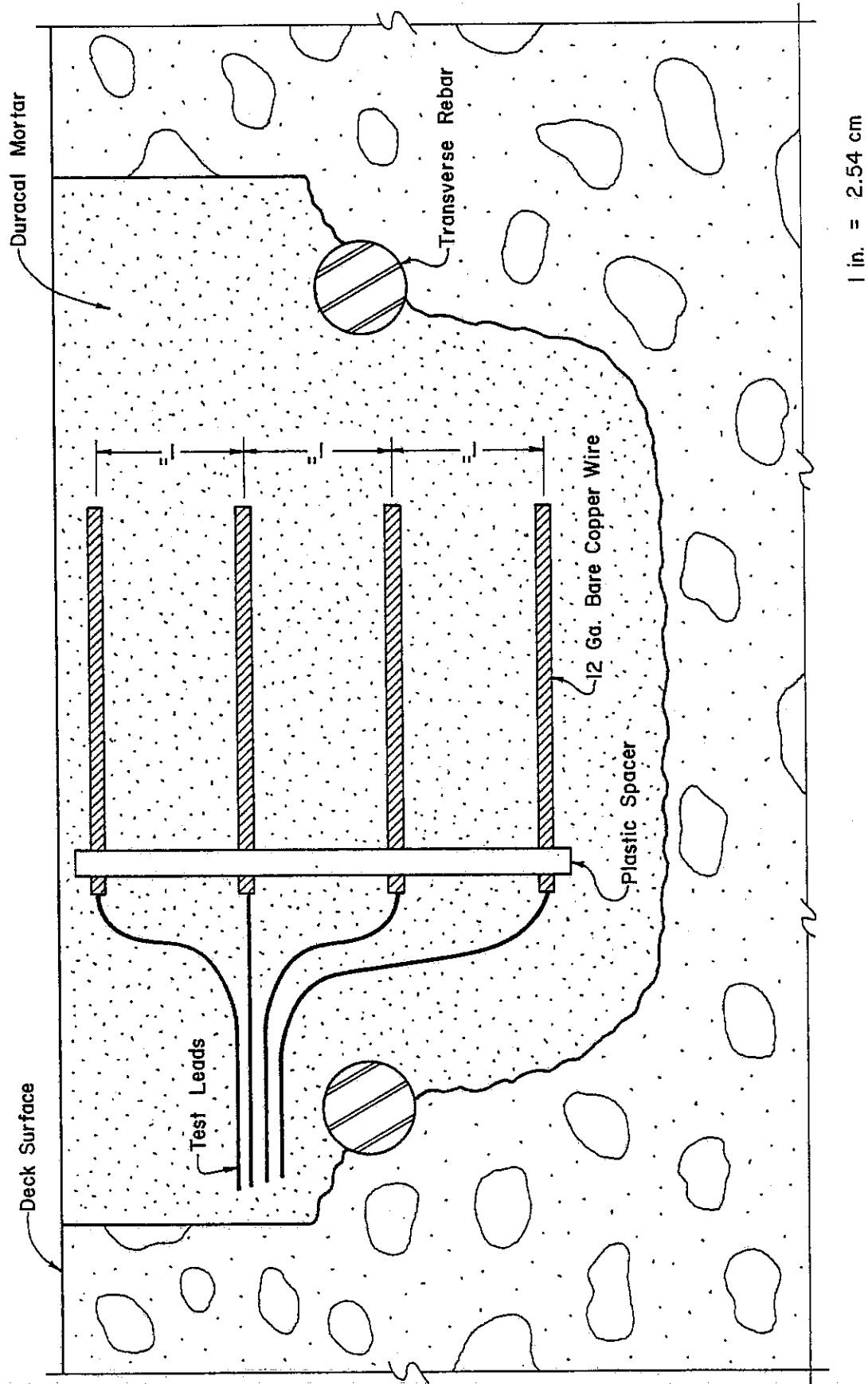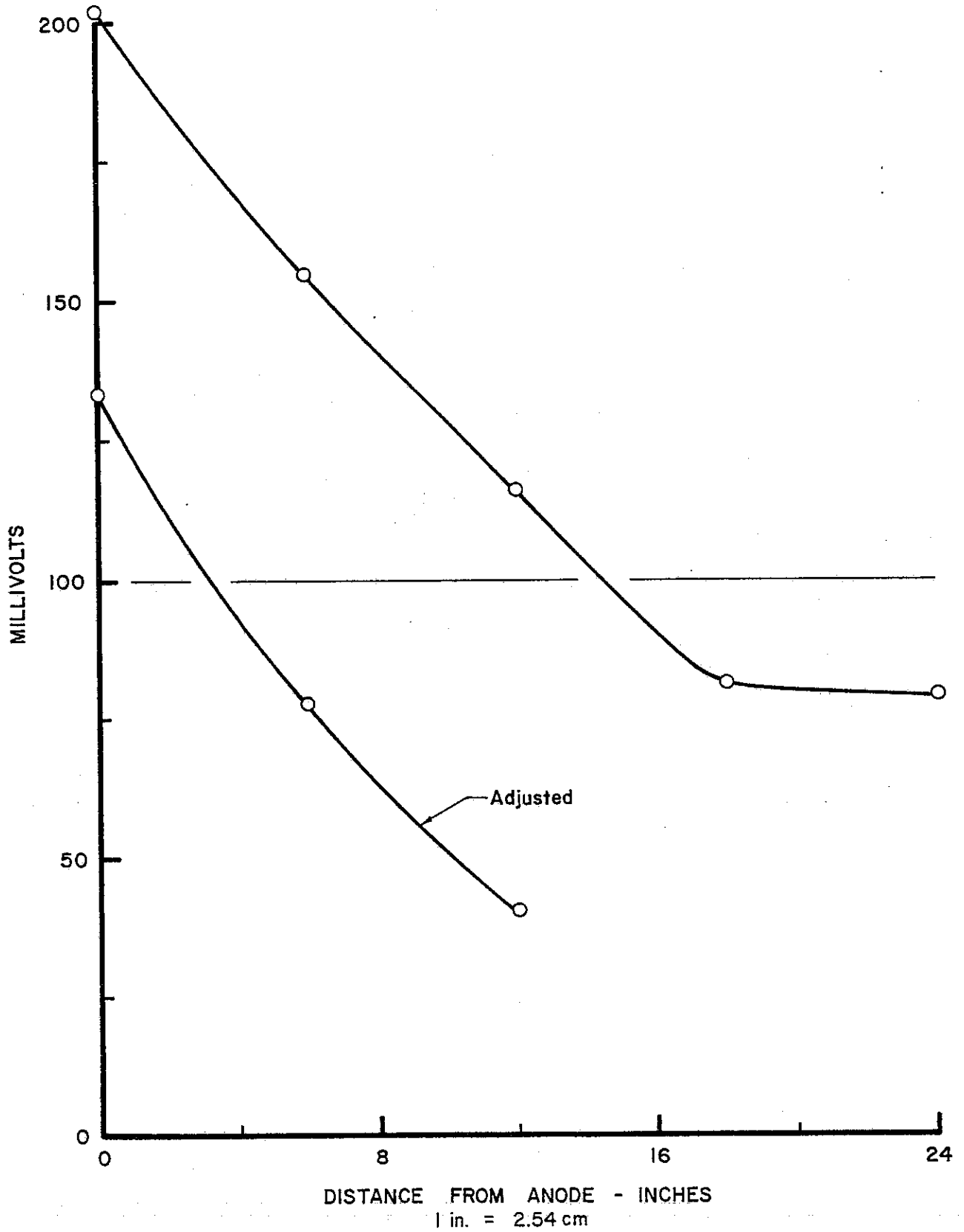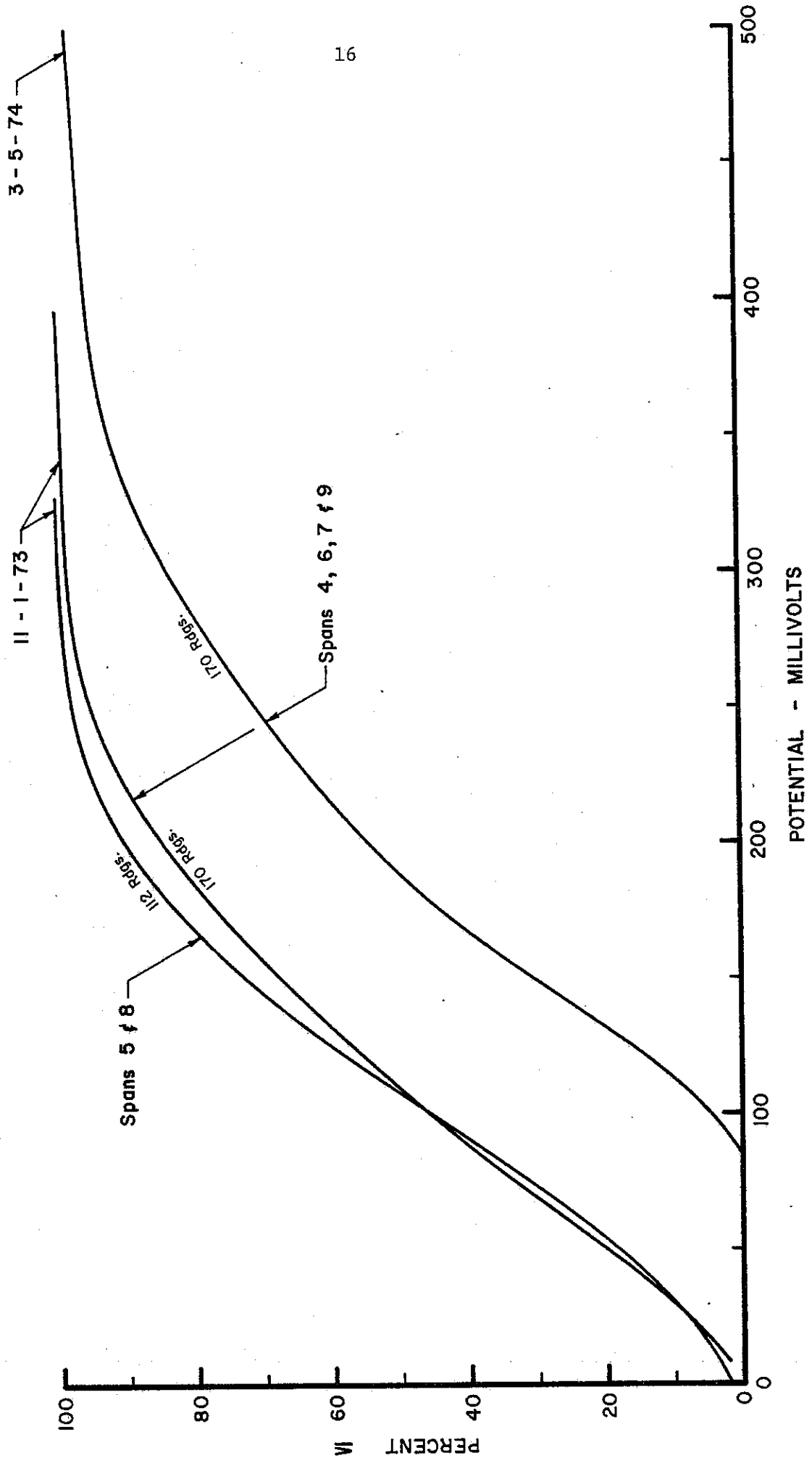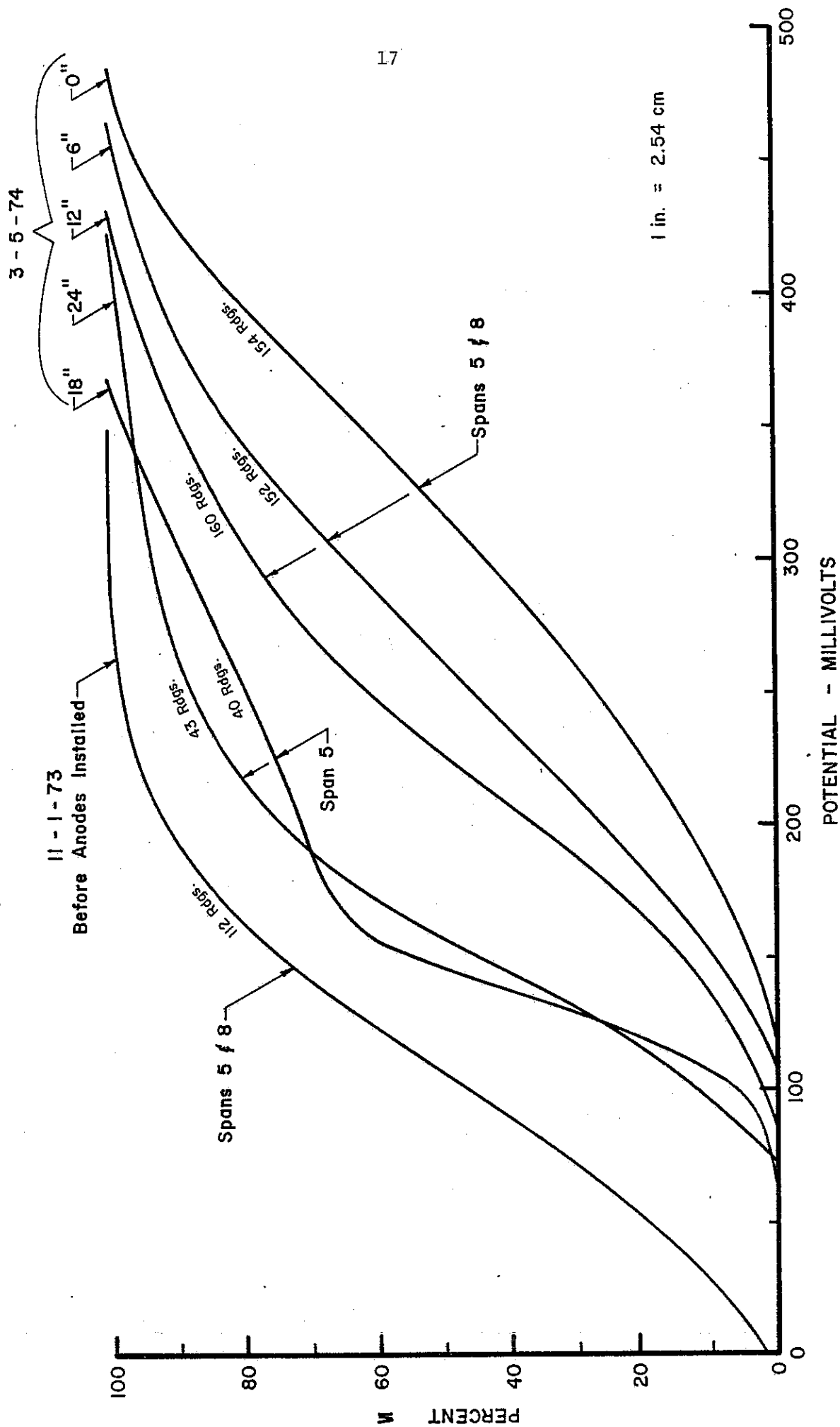Figure 6. Distribution Of Steel Potentials
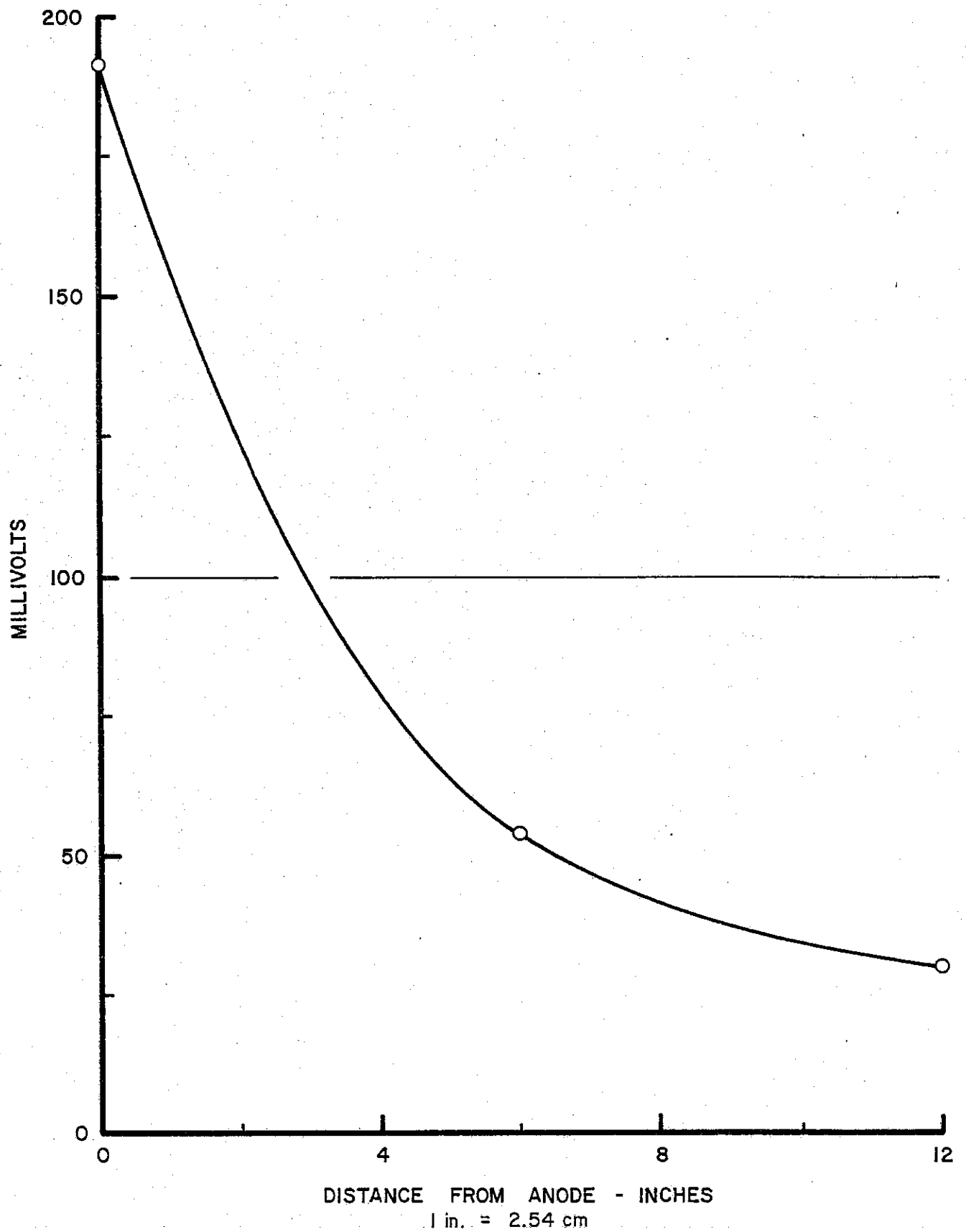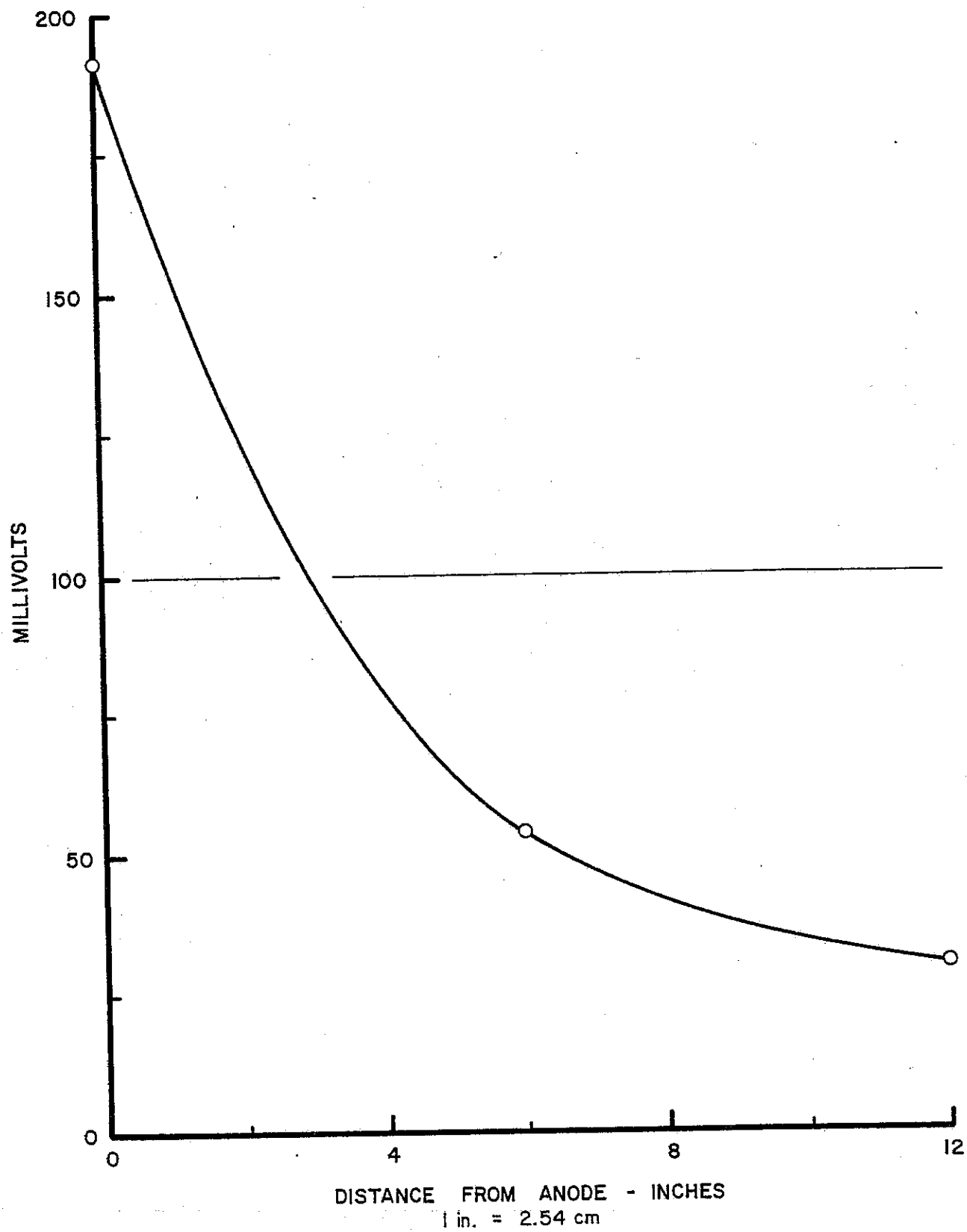
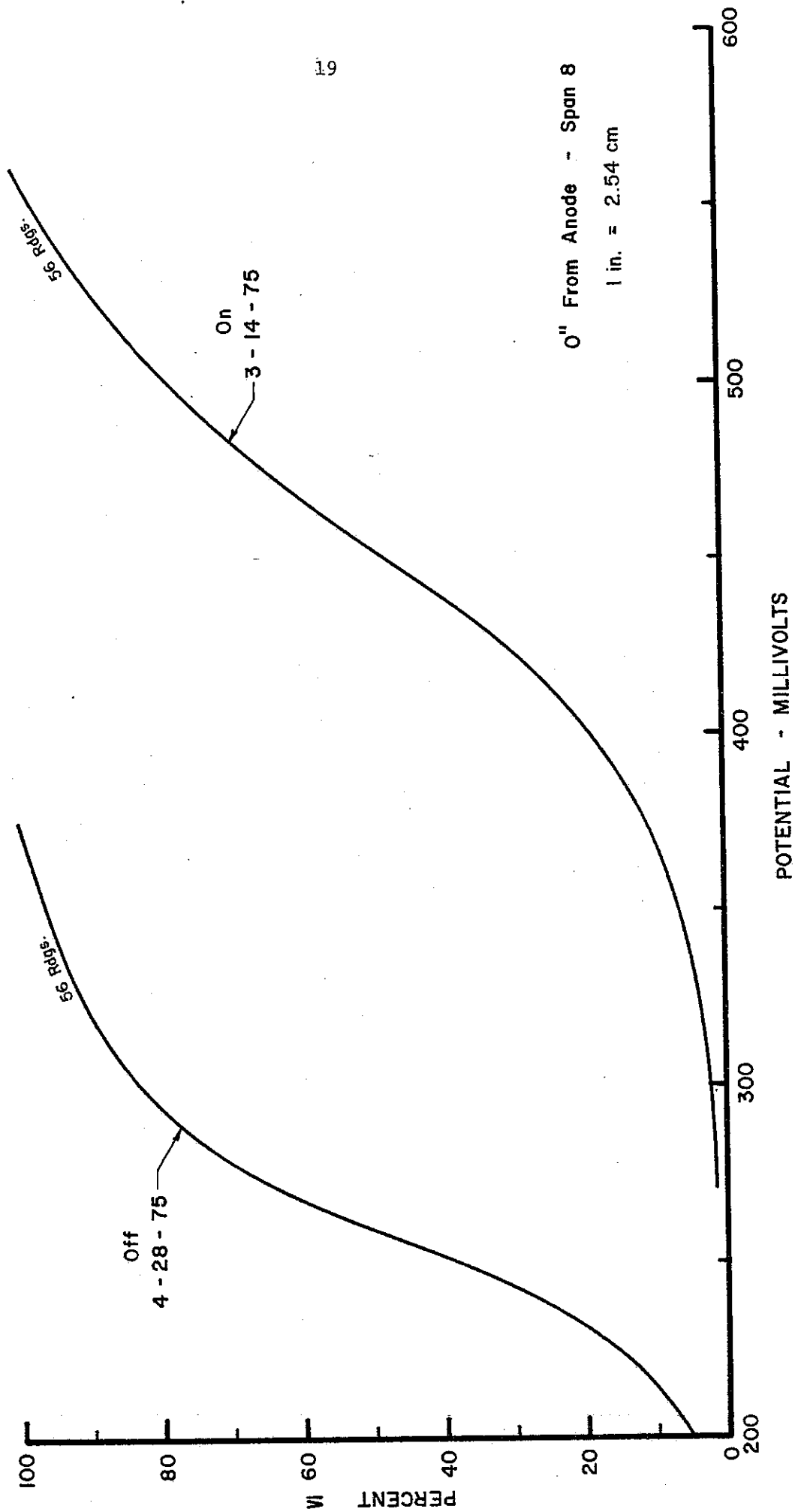Figure 7. Average Polarization Decay 3-14-75 To 4-28-75
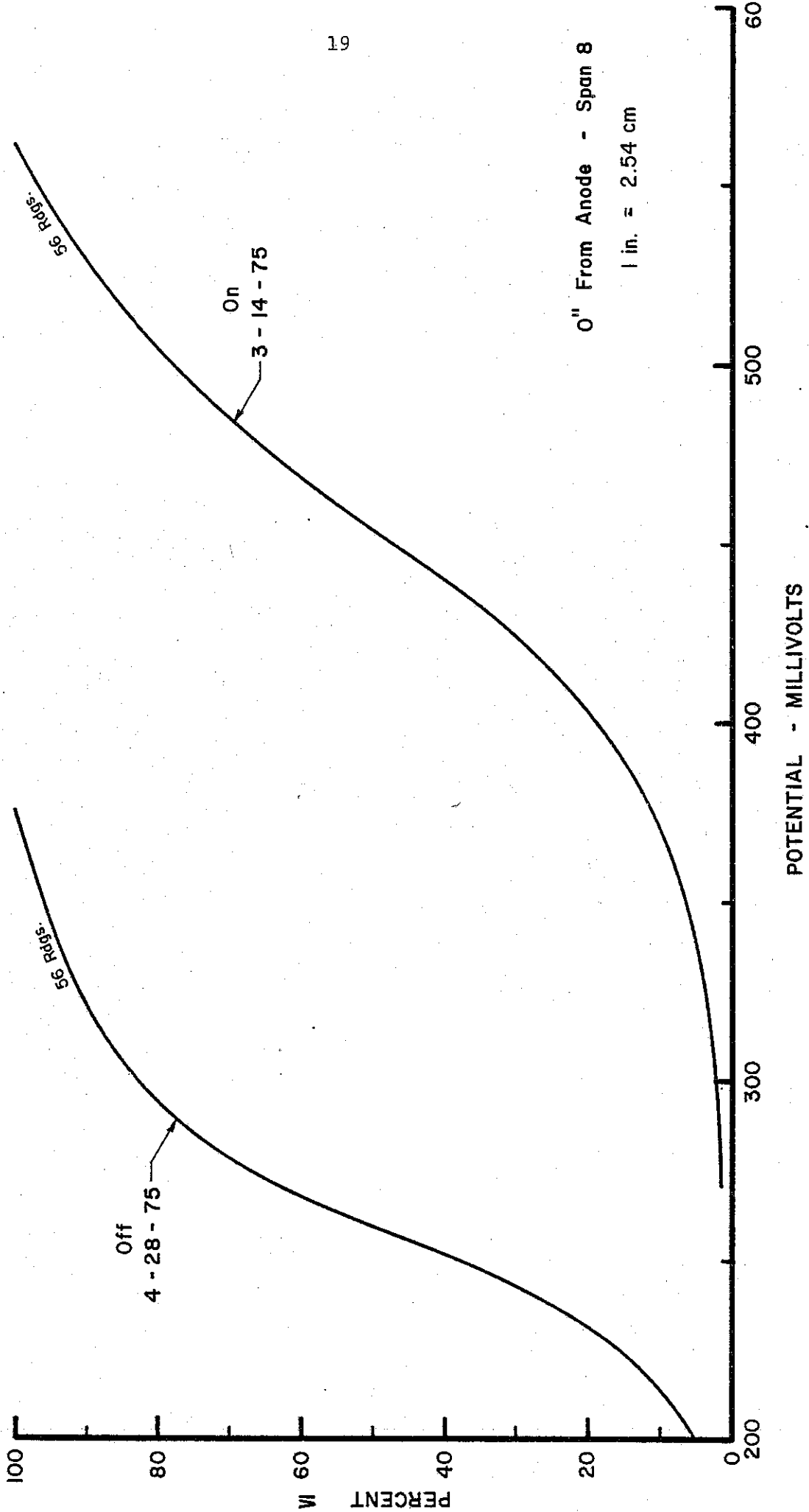
Figure 8. Distribution Of Steel Potentials

Figure 9. Distribution Of Steel Potentials

Figure IO. Distribution Of Steel Potentials

I sq. ft. = 0.0929 sq.m

SPALLING RATE – SQ. FT./ SQ. FT. $\times 10^3$

Spans 4, 6, 7 ƒ 9

Spans 5 ƒ 8

II-I-73   3-5-74   7-24-74   3-14-75   4-20-76

DATE

Figure II.   Progression Of Spalling

Merging Lane

Expansion Joint

③

Driving Lane

⑥

Passing Lane

⑨

43'

Curb

②

⑤

⑧

63'

Expansion Joint

①

Open Longitudinal Joint

④

⑦

Median Curb

49'

15' 12' 15'

¢

N

12

12' 15'

¢

63'

⑤

⑧

Zinc Ribbon Anodes @ 48" spacing

Zinc Ribbon Anodes @ 24" spacing

Test Lead Trench

1 in. = 2.54 cm
1 ft = 0.305 m

Figure I. Layout Of Experiment

13

Figure 2. Anode Installation Method

Cu/CuSO₄ Half Cell

Duracal Mortar

Zinc Ribbon Anode

Asbestos Wick

Foam Cushion

Deck Surface

Transverse Rebar

$3\frac{1}{2}''$

$1\frac{3}{4}''$

I in. = 2.54 cm

Figure 3. Resistivity Test Device

1 in. = 2.54 cm

Deck Surface

Duracal Mortar

Transverse Rebar

Test Leads

12 Ga. Bare Copper Wire

Plastic Spacer

Figure 4. Average Potential Shift 11-1-73 To 3-5-74

Figure 5. Distribution Of Steel Potentials

Figure 6. Distribution Of Steel Potentials

Figure 7. Average Polarization Decay 3-14-75 To 4-28-75
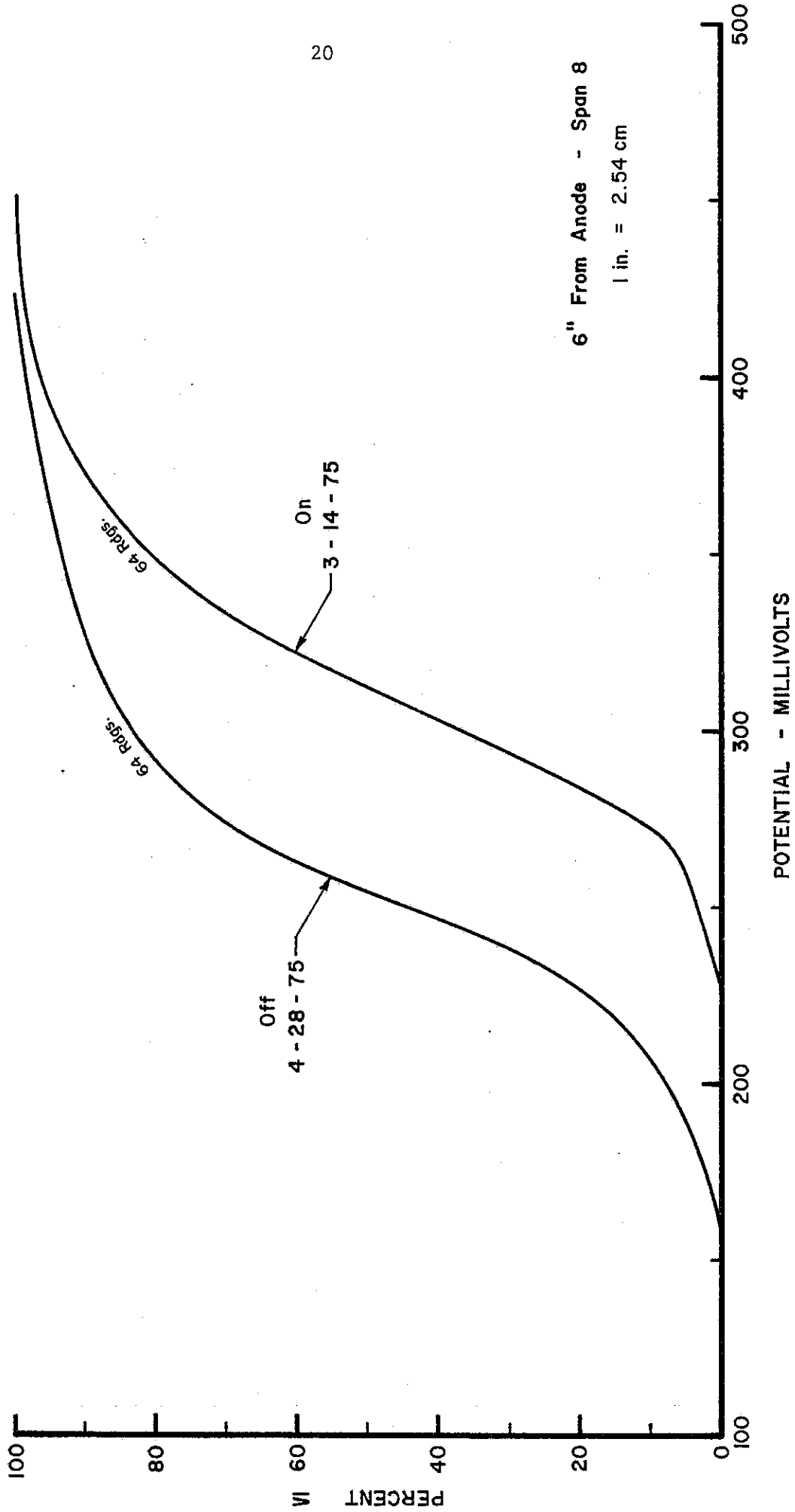
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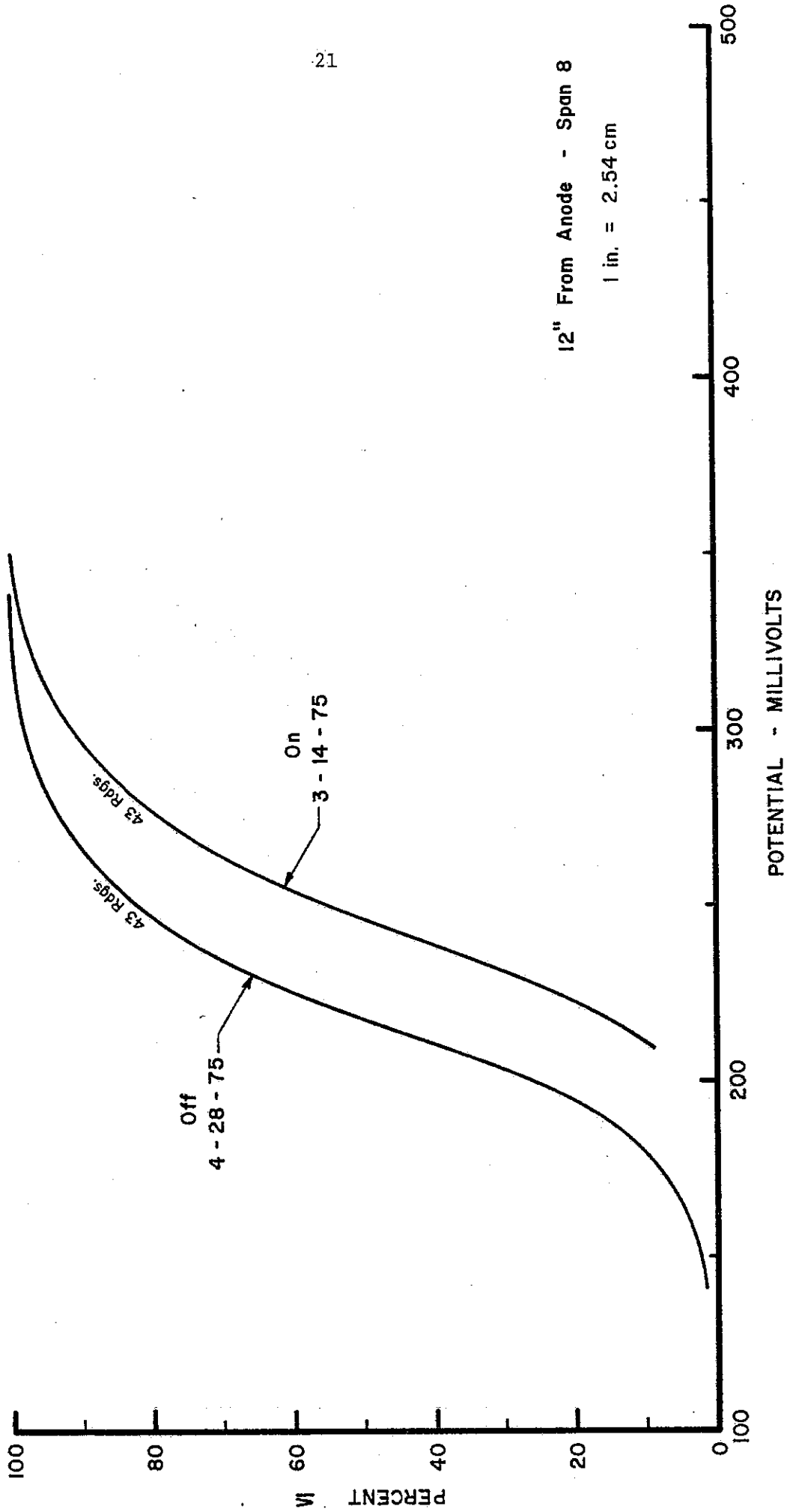
19

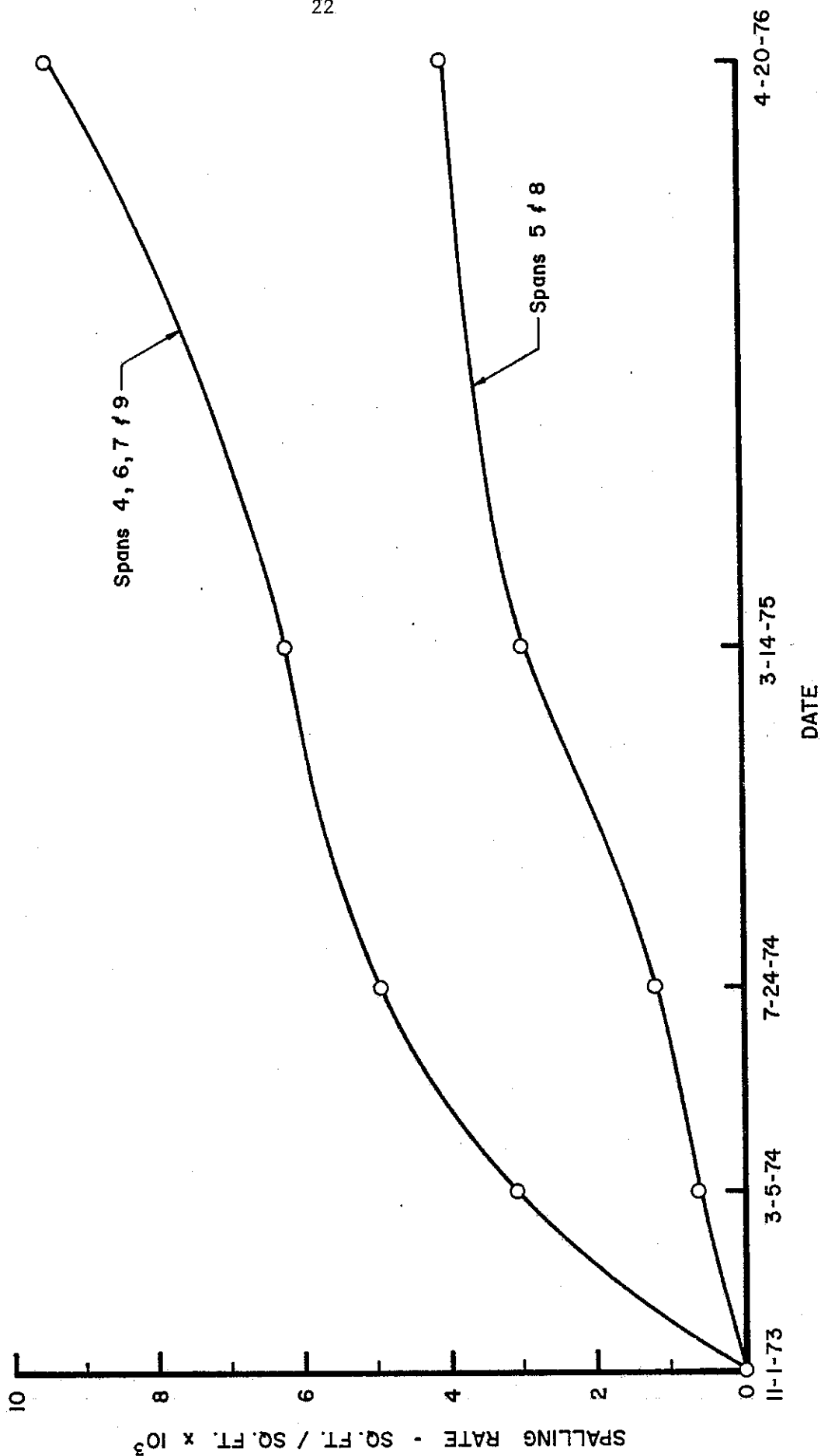Figure 9. Distribution Of Steel Potentials

Figure 10. Distribution Of Steel Potentials

Figure II. Progression Of Spalling