THE EFFECT OF CATHODIC CURRENT ON BOND STRENGTH BETWEEN CONCRETE AND REINFORCING STEEL

BY

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1955

Submitted to the faculty of the Graduate School of
the Oklahoma State University of Agriculture and
Applied Sciences in partial fulfillment of the
requirements for the degree of
MASTER OF SCIENCE
August, 1957

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Thesis Approved:

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PREFACE

Cathodic protection, though beneficial in the prevention of corrosion, may produce detrimental effects in various ways. One possibility is damage, through electrolysis, to nearby reinforced concrete structures.

This paper describes a study to determine what effects such electrolysis would have when the reinforcing is cathodic. Reinforced concrete specimens were prepared and electrolyzed under various applied voltages in a dilute salt solution.

I wish to extend thanks to my major adviser, Dr. Scott P. Ewing, for his valuable guidance throughout the experimental work; to the Civil Engineering Department for helpful advice and the use of the material testing equipment; to Dr. Franklin Graybill for aid in the statistical design and evaluation of the experiment; and to the Carter Oil Company whose financial support made this work possible.

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CHAPTER I

INTRODUCTION

Cathodic protection[1] is one of the principal methods of preventing corrosion of underground and underwater pipe lines. If reinforced concrete structures are near cathodically protected pipe lines, a potential difference may be established between the reinforcing steel of the concrete and the surrounding electrolyte, resulting in electrolysis of the concrete. This difference in potential may result directly from contact with the pipe line or the direct current source, or indirectly by providing a low resistance path for current flow between the anode of the protection system and the cathodic pipe.

In the design of a cathodic protection system in which electrolysis of concrete can occur, the effect of the electrolysis on the concrete and on the bond between the concrete and the steel should be known. This bond is the anchoring effect resulting from friction, adhesion, or lug action between the reinforcing steel and the concrete.

Electrolysis of concrete with the reinforcing steel as the anode, at sufficient voltage, results in corrosion of the steel. (13, 14). The corrosion products occupy approximately 2.2 times the volume of the steel, resulting in a build-up of internal pressure. This pressure is suffi-

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[1] "Cathodic protection is the use of an impressed current to prevent or to reduce the rate of corrosion of a metal in an electrolyte by making the metal the cathode for the impressed current." (16, p 923).

cient to cause cracking of the concrete. The presence of chloride ion greatly increases the corrosion rate. (14).

When the reinforcing rod is the cathode, the effect of electrolysis on the concrete and on the bond between the concrete and the reinforcing rod has not been conclusively demonstrated. Experimental work at the National Bureau of Standards on the electrolysis of concrete indicated that the concrete was softened at the cathode. (14). The area affected was clearly defined by darkening of the concrete around the cathode. The darkened area was not as well defined after the block dried, and the concrete regained some of its initial hardness. The electrolyses were carried out at 57 to 59 volts until cumulated quantities of 24.7 to 26.2 ampere hours per square inch were reached. Tests on four treated blocks when compared with those of four identical untreated blocks indicated a loss of approximately 80% of the original bond strength. Chemical analysis of the concrete from the cathode area showed a build-up of sodium and potassium. The hydroxides of sodium and potassium were believed to attack the calcium and aluminum silicate yielding soluble silicates and thus softening the concrete.

To confirm the postulate of hydroxide attack a check was made by electrolyzing several sample blocks with the reinforcing steel anodic. The current was held at a very low value, and the electrolyte changed regularly until no sodium or potassium could be detected in the electrolyte. The current was then reversed and the blocks were electrolyzed with the reinforcing steel cathodic. Fracture of the treated blocks revealed little evidence of softening around the cathode and no detectable damage to the concrete.

Small concrete test specimens were then treated with various concentrations of sodium and potassium hydroxides. Soluble silicates were formed, evidence that the concrete was attacked. The concrete blocks were softened and in some instances the concrete was easily crumbled.

The conclusion from this experimental work was that cathodic electrolysis of concrete would weaken the bond between the concrete and the reinforcing rod. There was no evidence of any detrimental effects in the absence of strong alkalies. The results appeared to depend only on the total ampere hours rather than on the applied voltage.

A series of experiments were conducted by the British Electrical and Allied Industrial Research Association to determine the effect of cathodic electrolysis on concrete during the curing period. (11, 13). At low current densities, less than 20 μamperes per square centimeter, there was no detectable damage to the concrete or the bond. At current densities greater than 2,000 μamperes per square centimeter, however, there was a marked reduction of bond strength. The concrete was softened at the cathode, and the soft area was a lighter color and not well defined. The loss of bond strength was attributed to excessive gassing occuring at the cathode at the higher current densities. Tests conducted at current densities from 20 to 2,000 μamperes per square centimeter yielded bond strengths, almost twice as great as the untreated control blocks. Upon fracture of the blocks, white deposits were tightly adherent to the rods. Analysis revealed the deposits were calcium carbonate. Further experimental work indicated that under carefully controlled conditions, i. e., a high carbon dioxide concentration and low current density, carbon dioxide diffused to the cathode faster than carbonate ions were removed by the electrolysis. The calcium ions at the cathode united with the carbonate ions and precipated calcium carbonate. These deposits resulted in the increased bond strength noted.

All the aforementioned experimental work was performed using smooth reinforcing rods.

In 1913, Abrams (1) reported the results of a series of tests to determine the bond strength between concrete and the various types of reinforcing rods then available. As a result of this experimental work, many types of reinforcing rods became obsolete and the shortcoming of several other types were recognized. Further development along these lines lagged until the advent of World War II, at which time interest in the development of improved reinforcing bars was revived. (12). Extensive research work was carried out to select the five or six best patterns available for deformed rods or to develop new patterns superior to any of them.

Co-operation between the steel companies and the American Concrete Institute Committee 208 on Bond Stress, resulted in extensive tests by Arthur P. Clarke (7, 8, 9) which led to the evolution of ASTM Specification A-305. (2). The ACI Building Code ruled that all bars not meeting the ASTM standards were to be classified as smooth rods. The result of this action gave the approved bars dominance in all up-to-date concrete construction.

Although loss of bond strength has been found to occur in the electrolysis of concrete using smooth reinforcing rods, it does not necessarily follow that this loss would be so marked when approved ASTM bars are used. Softening of the concrete at the cathode does occur when electrolysis is carried out in solutions containing appreciable amounts of sodium and potassium ions, for example in sea water. The maximum concentration of these ions before softening of the concrete will occur has not been determined.

This work was initiated to determine the effects of cathodic electrolysis on the bond between high strength concrete and ASTM approved reinforcing bars using a dilute synthetic sea water as the electrolyte. These conditions approximate those found in Lake Maracaibo, Venezuela.

CHAPTER II

MATERIALS AND EQUIPMENT

Concrete Test Blocks

The concrete test blocks used in the experimental work were cast in cylindrical steel molds 6 inches in diameter by 12 inches long. A 6 inch diameter by 3 inch spacer with a center hole 3/4 inch diameter by 1 inch deep was used in the bottom of the mold. A 3/4 inch by 24 inch herring-bone deformed rod, meeting ASTM A-305 Specification, was centered in the mold by the center hole in the spacer and a spider clamp at the top. The resulting block was then a 6 inch diameter by 9 inch cylinder, affording the 9 inch rod imbedment specified for vertically imbedded bars in the ASTM C-234 bond test method. (6). The concrete mixer and molds are shown in Plate I.

The concrete, which was mixed in a laboratory concrete mixer, consisted of a 1:1.6:2.7 ratio by weight of Lehigh Type I Portland cement (approximate analysis in Appendix A), graded Arkansas River sand, and 3/4 inch washed limestone aggregate, with 4.8 gallons of tap water per sack of cement. The coarse and fine aggregate met ASTM C-33 Specification. (3). This mix resulted in a 5000 pounds per square inch concrete with a slump of approximately 2 inches.

PLATE I

Concrete Mixer and Casting Molds

Curing, Electrolytic Treatment, and Storage

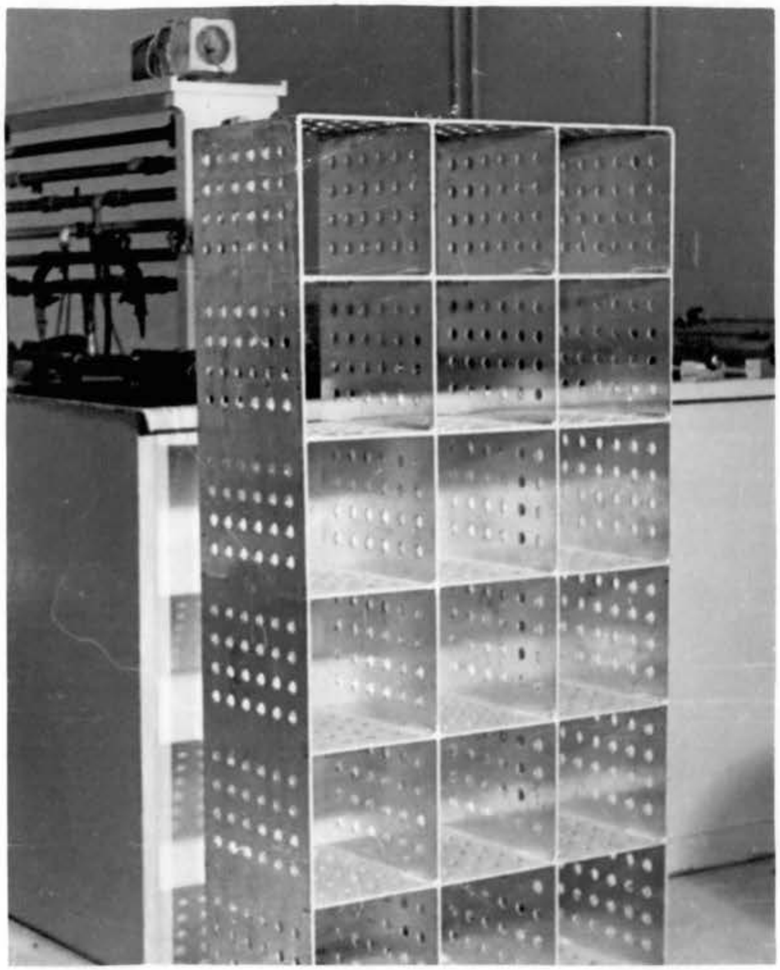
The complete experimental set up, exclusive of the electrical circuit, consisted of two steel tanks, 60 inches by 30 inches by 37 inches deep, interconnected by piping. Circulation of the electrolyte between the tanks was maintained by an Eastern D6 centrifugal pump. One tank was used for electrolytic treatment and the other for aging and storage of the control, untreated, and treated blocks. The treating tank contained an aluminum anode fabricated from 1/4 inch plate. This anode was in the form of a grid 54 inches by 27 inches by 12 inches deep containing eighteen 8 3/4 by 8 3/4 inch compartments. Aluminum was used in preference to steel because the insoluble aluminum corrosion products settled to the tank bottom and there was no staining of the concrete. The experimental apparatus is shown in Plate II.

Power for the electrolysis was supplied by four 12-volt storage batteries in series, and one 6-volt storage battery. The desired voltages for each block were then obtained by tapping the proper terminal. The batteries were kept near full charge by use of battery chargers connected at all times to the batteries. The current to each block was determined by measuring the voltage drop across a calibrated resistance with a Leeds-Northrup Potentiometer. The circuit diagram is shown in Figure I.

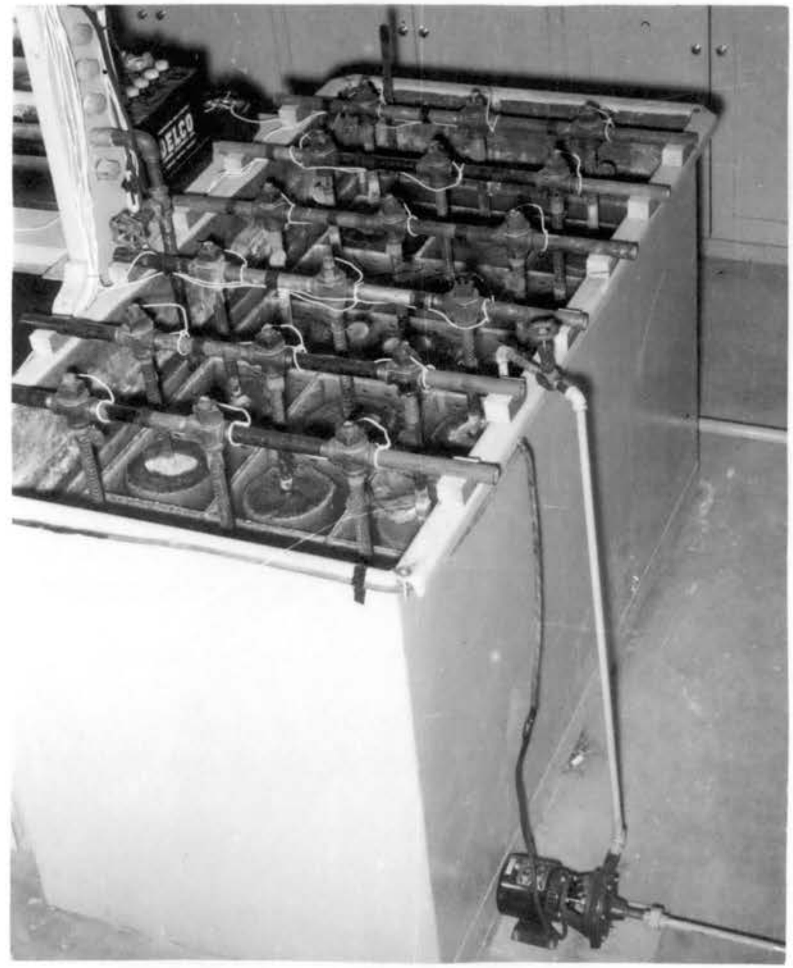
The electrolyte was synthetic sea water, given by Uhlig (16, p. 1121), diluted to a chloride concentration of 400 ppm. The pH of the electrolyte ranged from 7.2 to 9.5 while the specific resistance varied from 460 to 950 ohm centimeters. The electrolyte was maintained at a level which just covered the concrete blocks. The solution was drained and replaced with fresh electrolyte when the pH reached 9.5.

PLATE II

Electrolysis Equipment



1. Aluminum Anode



2. Treating Tank

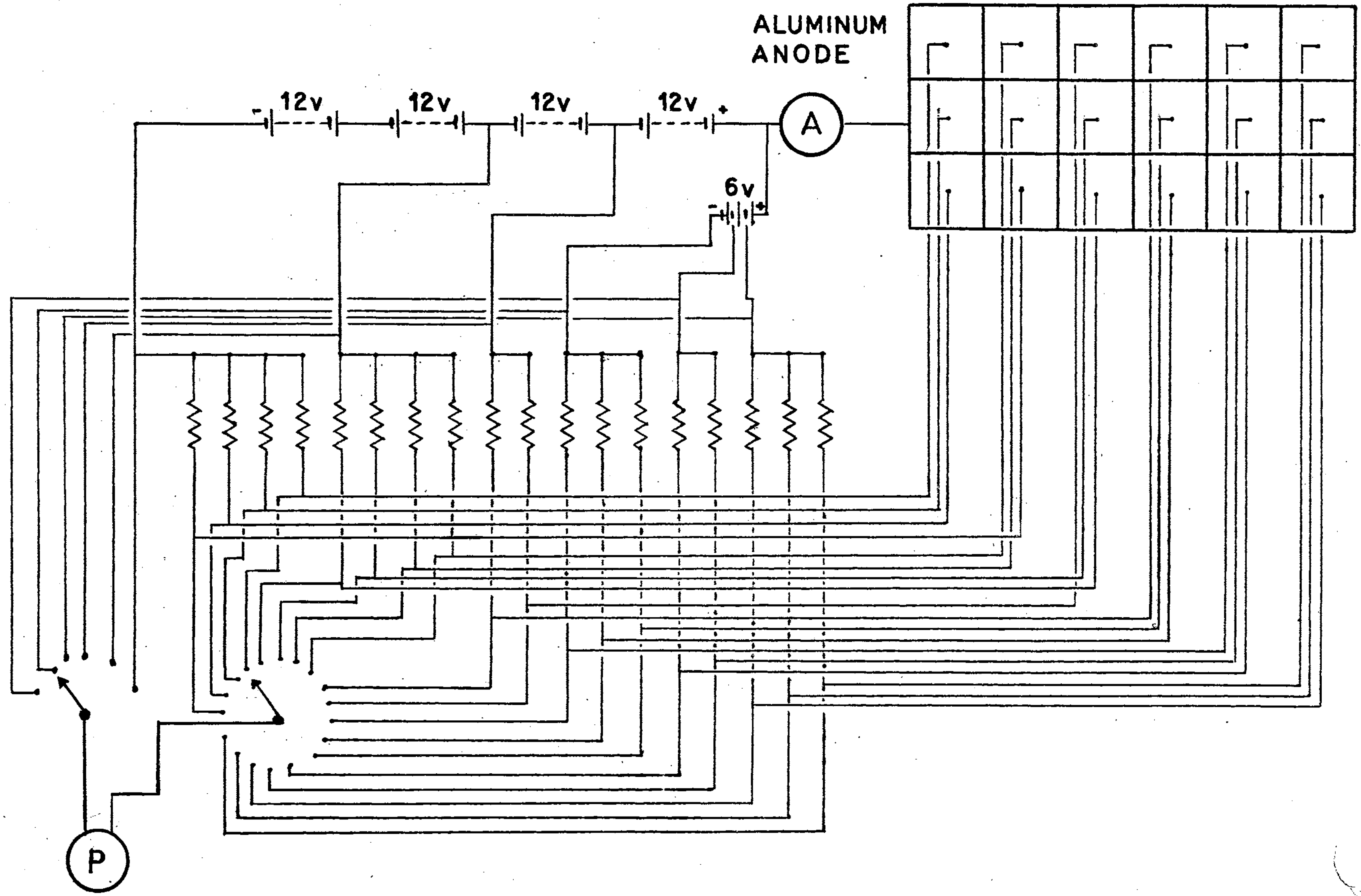


Figure 1. Circuit Diagram

Testing Equipment

The pull-out tests to determine the bond strength of the concrete were made with a hydraulic 60,000 pound universal testing machine. Compression tests were made on a 200,000 pound Olsen Compression Tester.

In the pull-out tests the bearing surface of the concrete block rested on a Cellotex cushion, which was supported by a bearing plate, consisting of two machined 7 inch diameter tapered steel plates with a 1 inch center hole. The total thickness of the two plates was 0.75 inches. The bearing plate, in turn, was supported by a 5 inch diameter by 6 inch slotted cylindrical bearing block with a 2.25 inch center hole. This block was placed directly on the testing machine. The slip[1] at the loaded end of the block was measured by dial micrometers reading to 0.001 inch clamped in a yoke attached to the lower end of the test block with set screws. The stem of the micrometers rested on a cross bar which was clamped to the reinforcing rod by means of a collet. The slip at the free end of the block was measured with a 0.001 inch dial micrometer clamped to the block with a spider clamp and set screws. The test set up and equipment are shown in Plate III.

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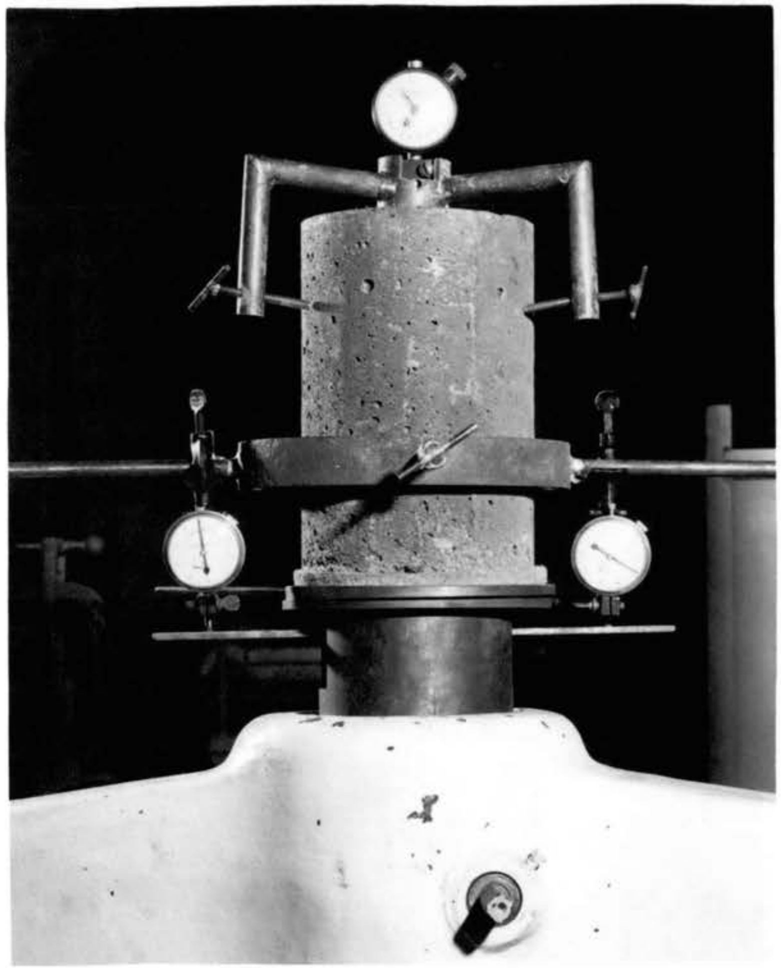
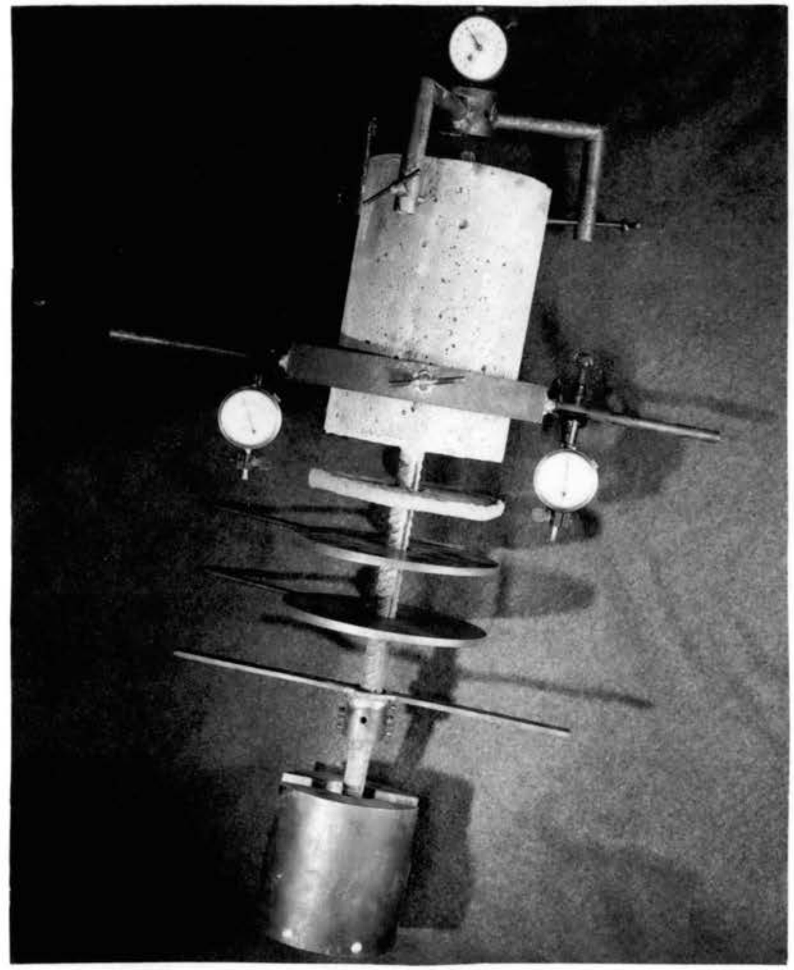
[1] Slip is the movement, as measured by the dial micrometers, of the rod relative to the concrete block.

PLATE III

Slip Measuring Equipment



1. Assembled View



2. Exploded View

CHAPTER III

EXPERIMENTAL PROCEDURE

Preparation of the Concrete Test Blocks

The concrete for the test blocks was mixed and cast following the procedures prescribed in the ASTM Tests C-192 and C-234 (5, 6) with one modification. The concrete test blocks were cast as cylinders 6 inches in diameter by 9 inches long. A more even current distribution could be expected on the cylindrical concrete blocks than would be the case for the 9 inch cubes recommended in ASTM Test C-234. Note ·x·

Six pull-out test cylinders and one compression test cylinder were cast from each batch of concrete, thus requiring 7 batches of concrete for the 42 blocks used in the experiment. Three blocks from each batch were treated; the remaining three were used as control blocks.

The blocks were removed from the molds 24 hours after casting and stored in a curing room at 75° F. and 100% humidity until they were transferred to the storage tank. The compression test cylinders remained in the curing room until they were tested.

The blocks to be electrolyzed were allowed to dry approximately 12 hours after removal from the curing room. The top and bottom surfaces of the cylinders and the reinforcing rods were painted with Tarset[1], thus insulating these surfaces so all current flow would be radial through the

[1]Manufactured by the Pittsburgh Coke and Chemical Company - ?

cylinder with no leakage directly to the rod. When the coating had set, the blocks were placed in the storage tank.

Application of Current

The concrete blocks were allowed to cure for at least 28 days before being subjected to electrolysis. The cured blocks were suspended by means of a pipe framework as shown in Plate II, so that each block was centered in a cell of the anode grid. The rods were insulated from the framework by rubber washers and polyethylene sheets placed between the reinforcing rod and framework. The blocks were then placed in the circuit by brazing the lead wire from the proper terminal of the battery through a calibrated resistor to the end of the reinforcing rod.

The current to each block was measured two or three times daily by measuring the voltage drop across a known resistance. The current was then determined and, using average values, the ampere hours were calculated. When the ampere hours summed over the treating period reached the desired value, the block was removed from the electrolysis tank and placed in the storage tank. When all blocks in one batch had been treated, pull-out tests were made on all blocks in the batch to determine the effect of the treatments.

Experimental Design

To provide a sound basis for statistical analysis of the data derived from the bond tests, and to aid in the correlation of the electrolytic treatments with bond damage both within batches and among batches, the design utilized a 3 by 3 simple lattice as shown in Figure 2. (10, p. 261). A replication of all treatments in the lattice was made and compar-

Definitions of Treatments

Ampere Hours \ Voltage	6	12	24	48
125	A	B	C	–
250	–	D	E	F
500	–	–	G	H
1000	–	–	–	I

Distribution of Treatments Among Batches

Rep. I

Batch Number			
5	A	B	C
2	D	E	F
3	I	G	H

Rep. II

Batch Number			
4	A	D	I
6	B	E	G
7	C	F	H

Figure 2. Lattice Design for Experiment Showing Treatments and Distribution Among Batches

ison among treatments was possible. Each block of the lattice contained test specimens from one batch of concrete.

The electrolytic treatments applied to the test blocks exceeded the voltages and cumulated quantity of electricity per unit area (ampere hours per square inch) which might be expected to occur in practice. These treatments were made at 6, 12, 24, and 48 volts, and for 30, 60, 125, 250, 500 and 1000 ampere hours. (1000 ampere hours is equivalent to 45.4 ampere hours per square inch based on the nominal area of the rods.) The treated blocks from batch one were not included in the lattice design so the test results from these blocks were excluded from the analysis of variance for the lattice.

Testing Procedure

The ASTM Test Method C-234 with modifications was used for the pull-out tests. A spherical bearing block was unavailable; therefore, to insure that the reinforcing rod was normal to the bearing surface of the block, the tapered steel plates were so adjusted that the bearing surface of the plates was normal to the reinforcing rod. Loading was continued until the concrete split or the rod broke. Measurements were taken at the loaded end until the load exceeded the elastic limit of the steel. The important values for the analysis were the differences in slip values among the samples, not the absolute values of slip for individual blocks. Therefore, by positioning the cross piece on the reinforcing bar the same distance from the bearing surface of the concrete block each time, by the use of a jig, necessity of correcting for bar strain was eliminated. Top gauge readings were taken until the concrete split or the load reached

25,000 pounds. The top gauge was then removed to prevent its being damaged.

The compression test cylinders were capped with sulfur and tested by ASTM Test C-39. (4). Complete data for compression and pull-out tests are given in Appendix B.

CHAPTER IV

RESULTS AND DISCUSSION

From the evaluation of the test data it became apparent there were two main factors to be considered: The effect of the electrolysis on the bond between the concrete and reinforcing rod, and changes in electrical resistance of the concrete. These factors are considered in the following discussion.

Effect on the Bond

The results obtained from the pull-out tests were evaluated for loads required to produce slips of 0.005 and 0.010 inches and for slips resulting from loads of 16,000 and 18,000 pounds. When loading exceeded 18,000 pounds the steel was at or near its yield point. Once the yield point was reached the slip could not be determined independently of the strain of the rod. The ASTM C-234 bond test method recommends that in evaluating the results of pull-out tests comparison be made for slips not exceeding 0.010 inches. The data for these values are given in Table I.

Analysis of variance was made on the data for the control blocks to determine if there were significant differences among the batches of concrete. (15, p. 260). The results shown in Table II indicated no significant differences existed among batches. Therefore, no correction for batches was necessary.

TABLE I

COMPOSITE OF BOND TEST DATA

Batch	Block Number	Treatment V	Treatment A. H.	Load, Pounds, for Slip of 0.005"	Load, Pounds, for Slip of 0.010"	Slip, Inches, From Load of 16,000#	Slip, Inches, From Load of 18,000#	Ultimate Load, Pounds	Age of Blocks, Days: Current Applied	Age of Blocks, Days: Current Removed	Age of Blocks, Days: Bond Tested
5	1	24	143+	12700	20150	0.0067	0.0072	27725*	44	54	106
	2	12	125	14850	18525	0.0061	0.0089	24275*	35	54	106
	3	6	125	14725	19650	0.0058	0.0072	27400*	35	71	106
	4	--	--	13725	19775	0.0061	0.0073	25575*	--	--	106
	5	--	--	12400	19475	0.0071	0.0086	26550*	--	--	106
	6	--	--	17225	19575	0.0045	0.0055	27925*	--	--	106
2	7	48	250	10875	17900	0.0074	0.0102	25050**	47	58	91
	8	24	250	13575	18725	0.0065	0.0090	26520**	49	66	96
	9	12	250	12850	20200	0.0065	0.0075	26125**	47	87	96
	10	--	--	13450	19475	0.0064	0.0073	26150**	--	--	91
	11	--	--	14525	19475	0.0059	0.0077	25800*	--	--	96
	12	--	--	14850	18700	0.0059	0.0081	26150*	--	--	96
3	13	48	500	11225	18025	0.0080	0.0100	26150**	56	74	103
	14	24	500	11150	18400	0.0081	0.0096	25800*	45	86	103
	15	48	1000	12775	18550	0.0071	0.0089	26150**	57	79	103
	16	--	--	13725	17375	0.0072	0.0114	25300**	--	--	103
	17	--	--	14050	19925	0.0061	0.0074	26150**	--	--	103
	18	--	--	12475	17100	0.0085	0.0125	25850**	--	--	103
4	19	24	125	13150	18175	0.0071	0.0096	24925**	51	64	94
	20	48	250	13450	19650	0.0065	0.0079	23650*	31	46	94
	21	48	500	9600	17350	0.0087	0.0105	25650*	36	55	94
	22	--	--	14750	18975	0.0059	0.0079	23100*	--	--	94
	23	--	--	16200	19000	0.0049	0.0072	25150**	--	--	94
	24	--	--	13950	18550	0.0070	0.0086	22175*	--	--	--

TABLE I (Continued)

Batch	Block Number	Treatment V	Treatment A. H.	Load, Pounds, for Slip of 0.005"	Load, Pounds, for Slip of 0.010"	Slip, Inches, From Load of 16,000#	Slip, Inches, From Load of 18,000#	Ultimate Load, Pounds	Age of Blocks, Days: Current Applied	Age of Blocks, Days: Current Removed	Age of Blocks, Days: Bond Tested
6	25	12	125	13300	18225	0.0068	0.0091	24250*	30	57	81
	26	24	250	10225	17475	0.0089	0.0104	24000**	45	61	81
	27	24	500	8875	15000	0.0109	0.0130	25400*	30	68	81
	28	--	--	13200	18125	0.0071	0.0095	24425*	--	--	81
	29	--	--	10175	16575	0.0095	0.0126	24325*	--	--	81
	30	--	--	13700	19700	0.0063	0.0078	24200*	--	--	81
7	31	6	125	12075	17550	0.0081	0.0109	24800*	30	83	101
	32	12	250	10850	17175	0.0086	0.0113	23600*	29	73	101
	33	48	1000	9925	15975	0.0100	0.0129	27520**	29	58	101
	34	--	--	13900	19000	0.0062	0.0081	26600*	--	--	101
	35	--	--	12175	17575	0.0078	0.0108	26100*	--	--	101
	36	--	--	12275	19325	0.0070	0.0089	26175*	--	--	101
1	37	48	125	12150	18450	0.0074	0.0093	23000*	51	64	88
	38	48	60	12850	17250	0.0079	0.0121	23700*	51	54	88
	39	48	30	10750	15225	0.0118	0.0162	21000*	51	52	88
	40	--	--	13900°	18338°	0.0063°	0.0084°	27800*	--	--	88
	41	--	--	14975	18425	0.0055	0.0074	26700*	--	--	88
	42	--	--	12800	18250	0.0070	0.0094	26150**	--	--	88

*Concrete broke
**Rod broke
° Data are uncertain therefore averages of 41 and 42 were used in analysis.
+ Value result of experimental error, difference was small so no correction was made.

TABLE II

ANALYSIS OF VARIANCE INTER-INTRA BATCHES (CONTROL)

Evaluated at a Slip of 0.005 Inches

Source of Variation	Degrees of Freedom	Sum of Squares x 10^6	Mean Square x 10^6	F	Probability Level
Individuals	14	29.003	2.072	1.266	35%
Batches	6	15.737	2.623		
Total	20				

Evaluated at a Slip of 0.010 Inches

Source of Variation	Degrees of Freedom	Sum of Squares x 10^6	Mean Square x 10^6	F	Probability Level
Individuals	14	12.059	.861	1.098	44%
Batches	6	5.669	.945		
Total	20				

Evaluated at a Load of 16,000 Pounds

Source of Variation	Degrees of Freedom	Sum of Squares x 10^6	Mean Square x 10^6	F	Probability Level
Individuals	14	16.67	1.19	1.26	34%
Batches	6	8.98	1.50		
Total	20				

Evaluated at a Load of 18,000 Pounds

Source of Variation	Degrees of Freedom	Sum of Squares x 10^6	Mean Square x 10^6	F	Probability Level
Individuals	14	38.26	2.73	1.67	21%
Batches	6	27.33	4.56		
Total	20				

TABLE III

ANALYSIS OF VARIANCE OF LATTICE (TREATED BLOCKS)

Evaluated at a Slip of 0.005 Inches

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Probability Level
Total	17	51,853,924			
Blocks	5	21,500,382			
Treatment	8	26,288,124	3,286,016	3.23	10%
Error	4	4,065,418	1,016,352		

Evaluated at a Slip of 0.010 Inches

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Probability Level
Total	17	30,540,000			
Blocks	5	16,527,500			
Treatment	8	9,124,625	1,140,581	.9334	—
Error	4	4,887,848	1,221,962		

Evaluated at a Load of 16,000 Pounds

Source of Variation	Degrees of Freedom	Sum of Squares x 10^8	Mean Square x 10^8	F	Probability Level
Total	17				
Total	17	3,227			
Blocks	5	1,777			
Treatment	8	1,330	166.25	5.54	7%
Error	4	120	30.00		

TABLE III (continued)

Evaluated at a Load of 18,000 Pounds

Source of Variation	Degrees of Freedom	Sum of Squares x 10^8	Mean Square x 10^8	F	Probability Level
Total	17	4,932			
Blocks	5	2,950			
Treatment	8	1,377	172.1	1.136	48%
Error	4	605	151.5		

The effect of different treatments was analyzed using the simple lattice design given by Cochran and Cox. (10). From the ratio of variances shown by Table III only the data for 0.005 inch slip and 16,000 pounds loading gave any significant correlation between bond strength and electrolytic treatment.

The curves shown in Figures 3, 4 and 5, confirm the above analysis. At a slip of 0.005 inches the curves are separated slightly and the curves for the treated blocks are, in general, displaced slightly to the right of those for the control blocks. At a slip of 0.010 inches and load of 18,000 pounds, however, the curves approach one another and in some cases intersect. This can be seen in Figure 5 at 0.0085 inches slip. As the curves tend to the horizontal no consistent differences resulting from treatment are noticeable.

Comparison of the mean values for the treated blocks with the average for the control blocks shows a slight trend toward a weakened bond as the ampere hours increased. (See Table IV). This trend is much more pronounced at a slip of 0.005 inches.

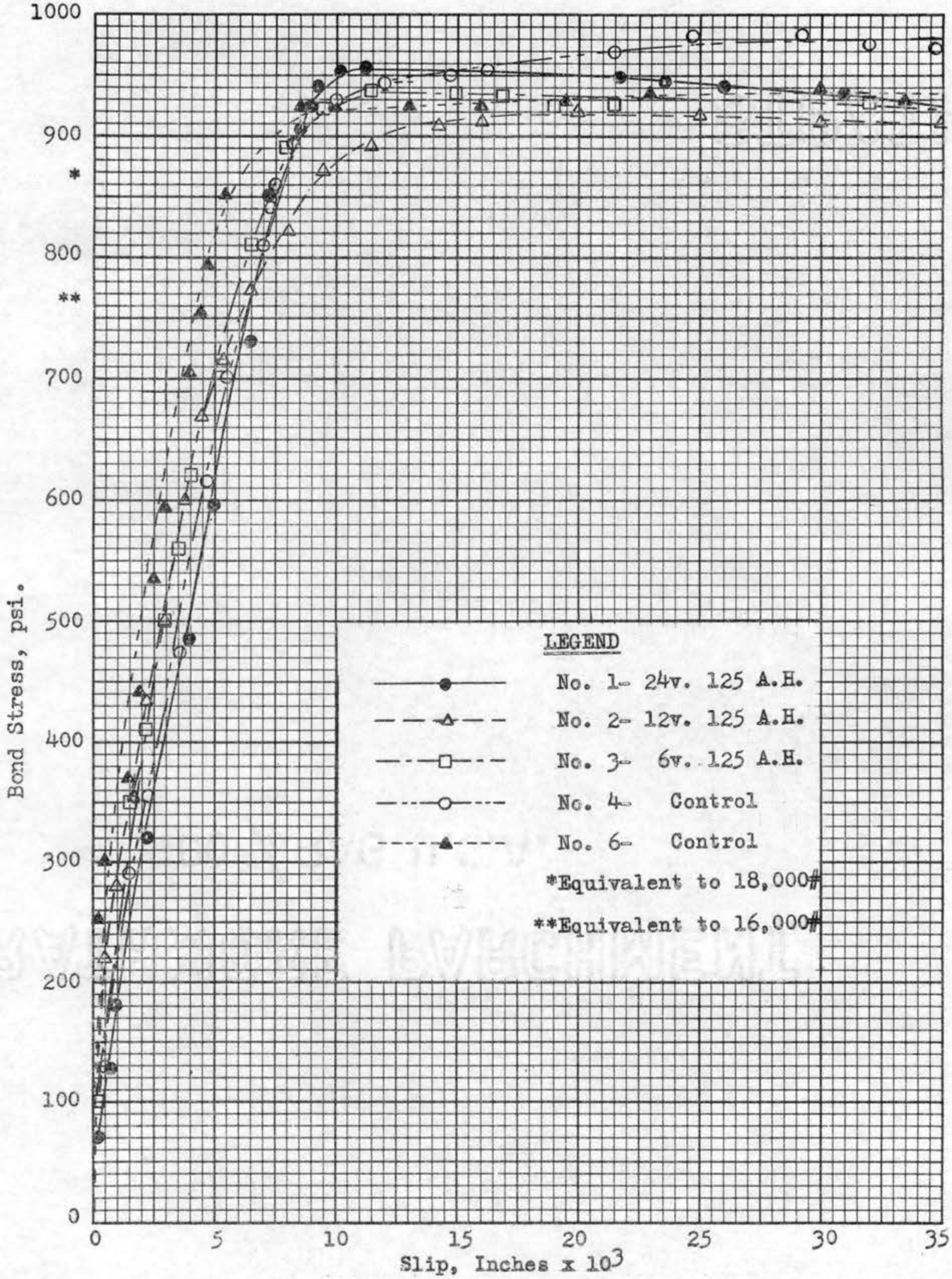


Figure 3. Pond Stress-Slip Curves

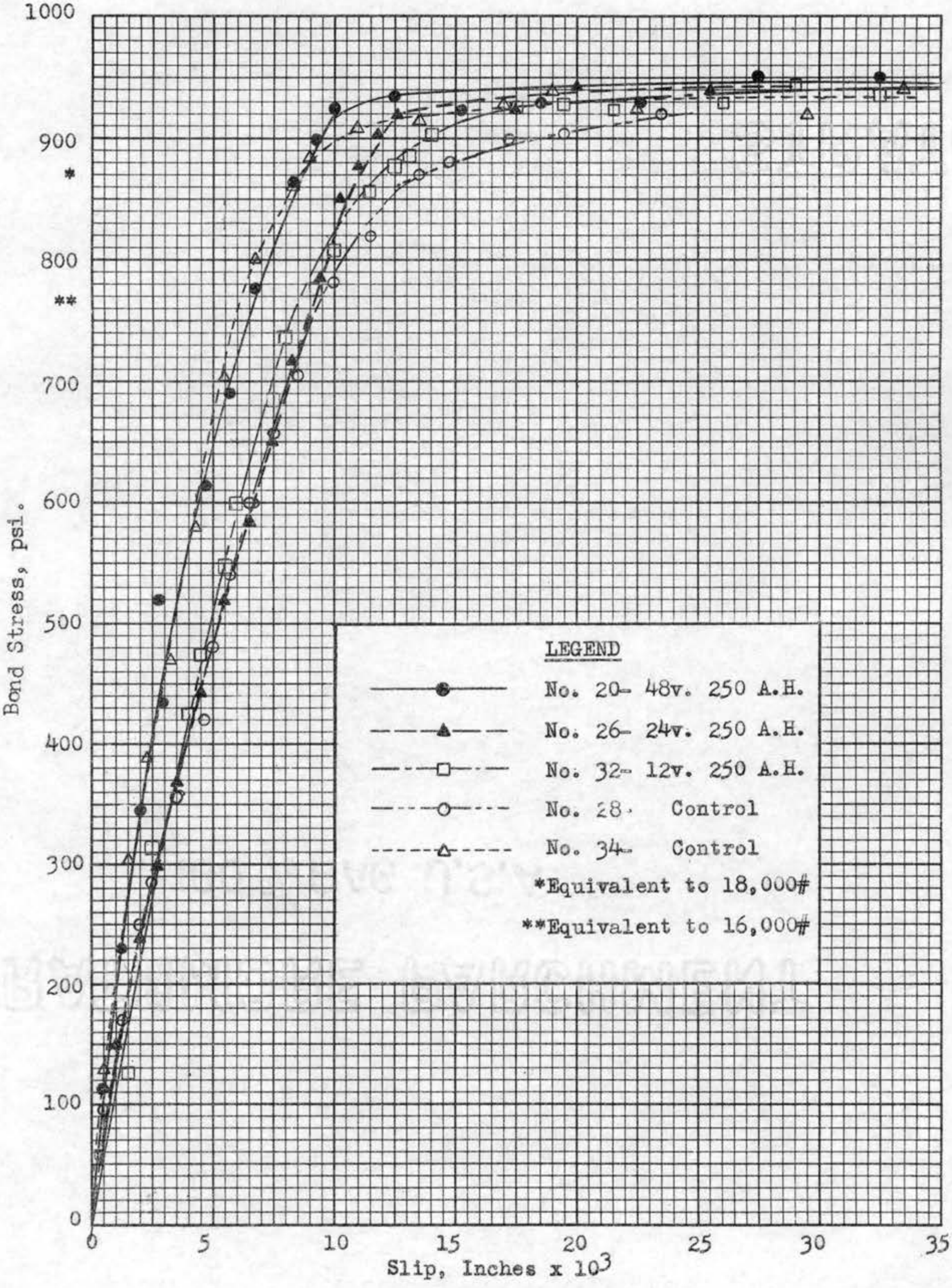


Figure 4. Bond Stress-Slip Curves

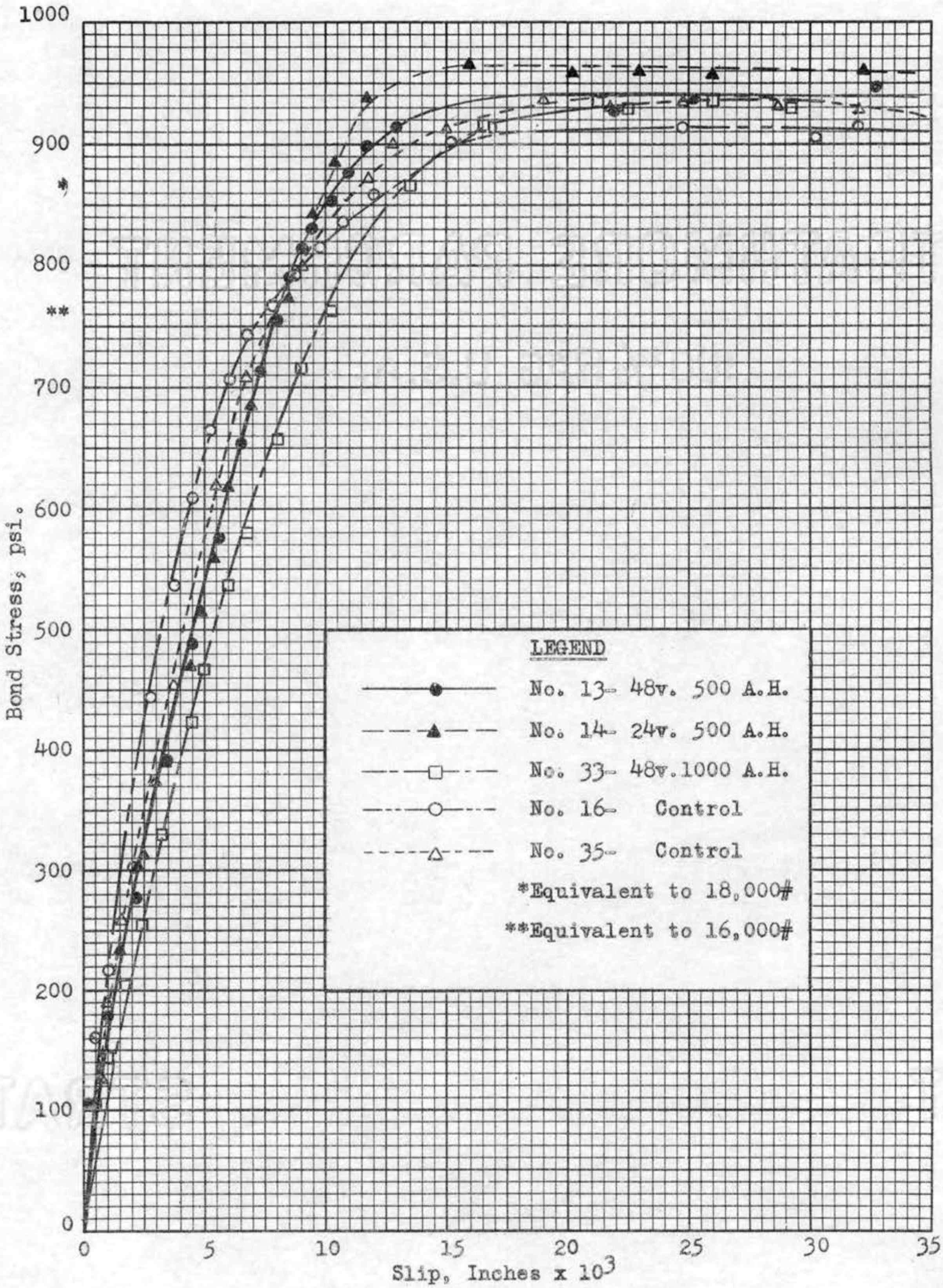


Figure 5. Bond Stress-Slip Curves

TABLE IV

MEAN VALUES FOR TEST BLOCKS

Loads Resulting in a Slip of 0.005 Inches (Pounds)

Voltage / Ampere Hours	6	12	24	48
125	13,400	13,700	12,925	
250		11,850	11,900	12,150
500			10,025	10,425
1000				11,350

Mean Load Value of Control Blocks 13,700

Loads Resulting in a Slip of 0.010 Inches (Pounds)

Voltage / Ampere Hours	6	12	24	48
125	18,600	18,375	19,175	
250		18,675	18,100	18,775
500			16,700	17,675
1000				17,275

Mean Load Value of Control Blocks 18,775

Slip Resulting From a Load of 16,000 Pounds (Inches)

Voltage / Ampere Hours	6	12	24	48
125	.0070	.0065	.0069	
250		.0076	.0077	.0070
500			.0095	.0084
1000				.0086

Mean Slip Value of Control Blocks 0.0066

TABLE IV (continued)

Slip Resulting From a Load of 18,000 Pounds (Inches)

Voltage	6	12	24	48
Ampere Hours				
125	.0091	.0090	.0084	
250		.0094	.0097	.0091
500			.0113	.0103
1000				.0109

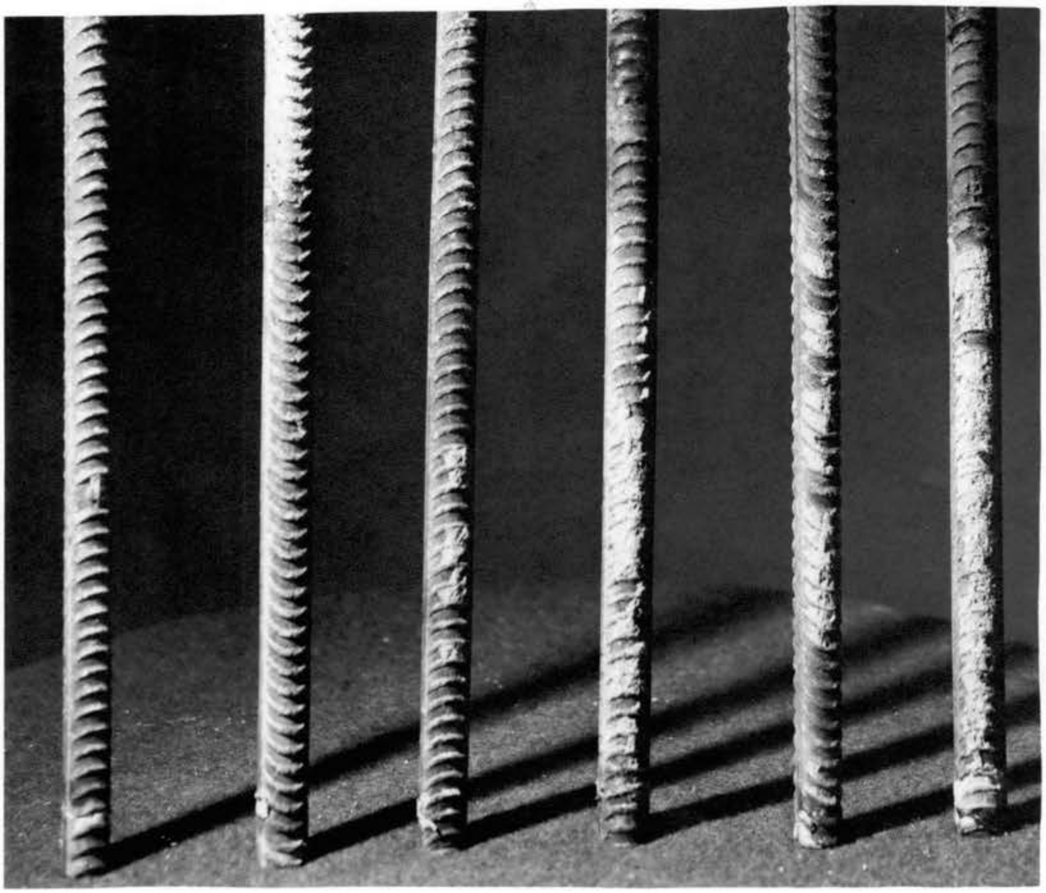
Mean Slip Value of Control Blocks 0.0087

Rupture of the blocks (either as a result of breaking during test or splitting open after testing when the rod broke) revealed differences in bond failure between treated and control blocks. The reinforcing rods from the treated blocks had large areas covered with adherent concrete; however, those from the control blocks were almost free of any concrete. (See Plate IV). The failure of the bond in the treated concrete appeared to be failure of the concrete, that for the control, actual bond failure at the surface of the rods. In those cases of rod failure, some treated blocks showed no indication of bond failure at any point, since the pattern in the concrete from the deformations was clearly defined. The control blocks gave evidence of initial bond failure at the loaded end in all cases; the deformation pattern had been destroyed by the action of the rod drag. Even on rod failure evidence of slip extended two to four inches into the cylinder.

The area surrounding the rod in the treated blocks appeared to be softened and in some cases there was darkening of the concrete in this area. These results, although not nearly so marked, confirmed observa-

PLATE IV

Comparison of Bars from Treated and Untreated Blocks



Three Bars on Left from Untreated Blocks
Three Bars on Right from Treated Blocks

tions reported by the National Bureau of Standards for the cathodic electrolysis of concrete at higher concentrations of sodium and potassium ions. (14). The softening apparently increased the plasticity of the concrete surrounding the rod, permitting the distribution of the load over a greater area. Initial loading, therefore, gave a higher value for the slip of the treated blocks than for the control. Since initial bond failure occurred at lower loads for control blocks than for treated blocks the length of rod contributing to the total slip measurement was greater for the former. Once the initial failure occurred, the measured slip of the control blocks increased faster than that for the treated blocks. This results in the intersection of curves previously noted. The preceeding discussion is evidenced in Plates IV, V, VI, and VII.

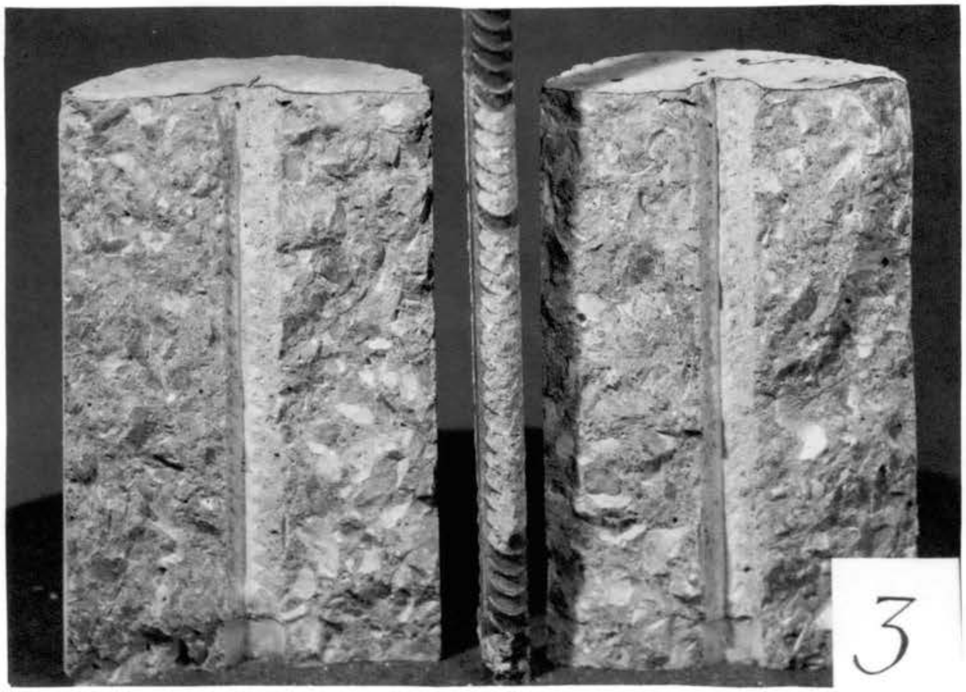
As previously stated, there appears to be some correlation between ampere hours and bond damage. However, the data was not sufficient to provide a clearly significant correlation between bond damage and treatment.

Changes in Electrical Resistance

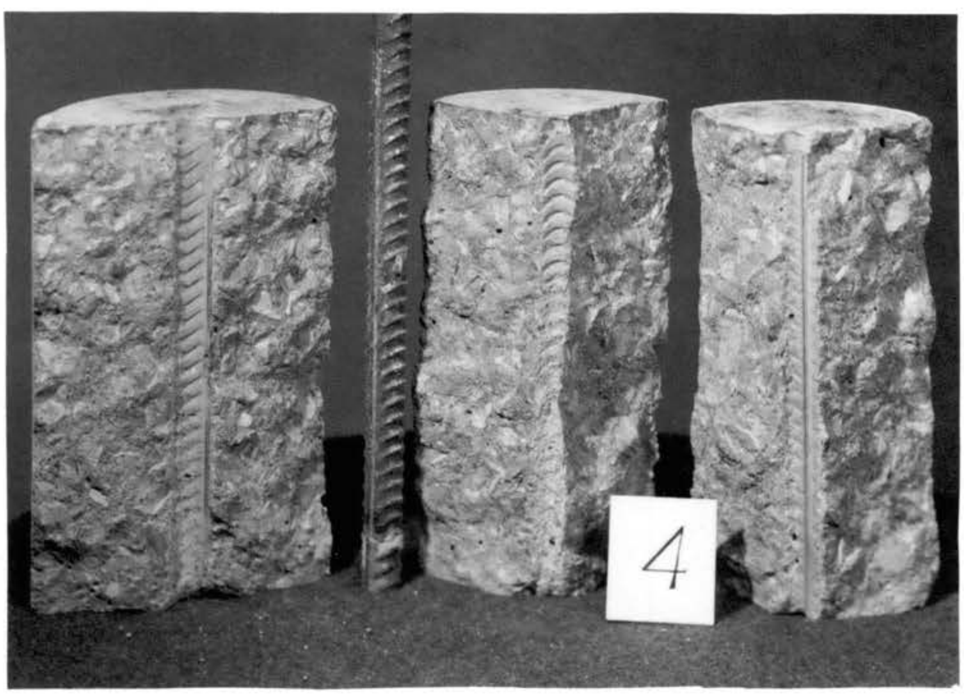
Electrolyses of concrete in tap water performed at the National Bureau of Standards (14) resulted in increased resistances from initial values of less than 100 ohms to an average resistance greater than 7,000 ohms. This increase was manifest in anodic treatment for 4 to 5 ampere hours per square inch. Similar treatment with the reinforcing bar as the cathode caused an increase in resistance, but from only 2 to 5 times the initial value. When an aqueous three precent sodium chloride electrolyte

PLATE V

Treated and Untreated Blocks



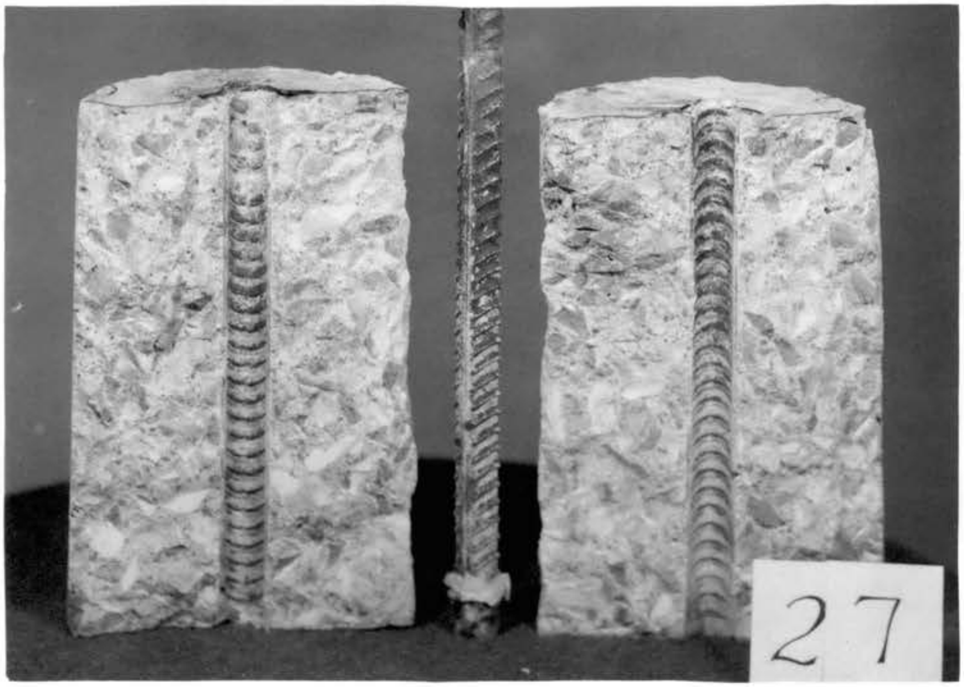
1. Treated Block, 6 Volts-125 Ampere Hours



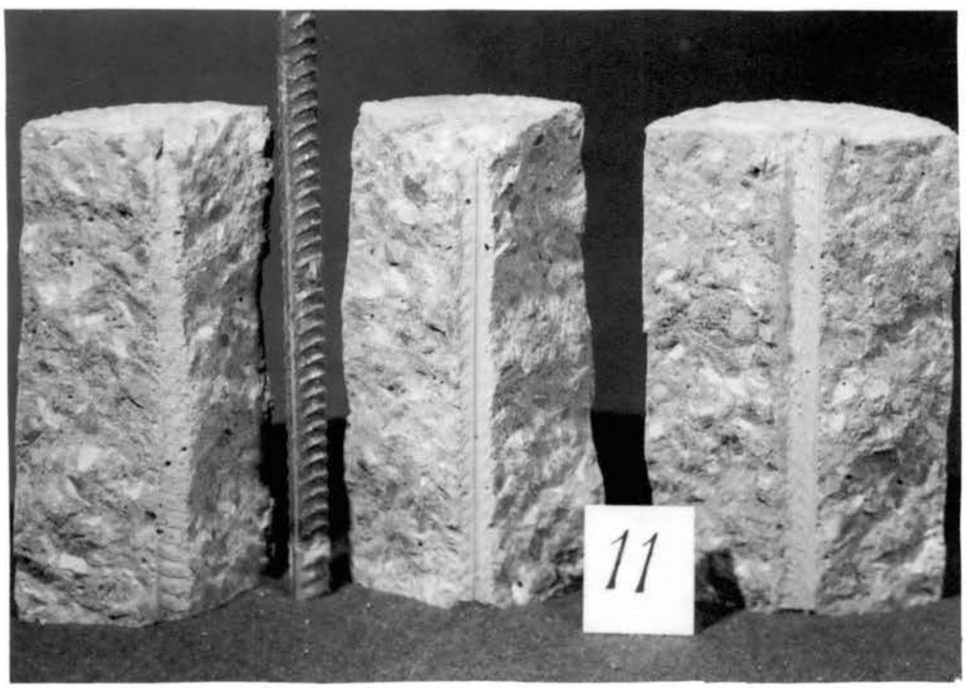
2. Control Block

PLATE VI

Treated and Untreated Blocks



1. Treated Blocks, 24 Volts-500 Ampere Hours

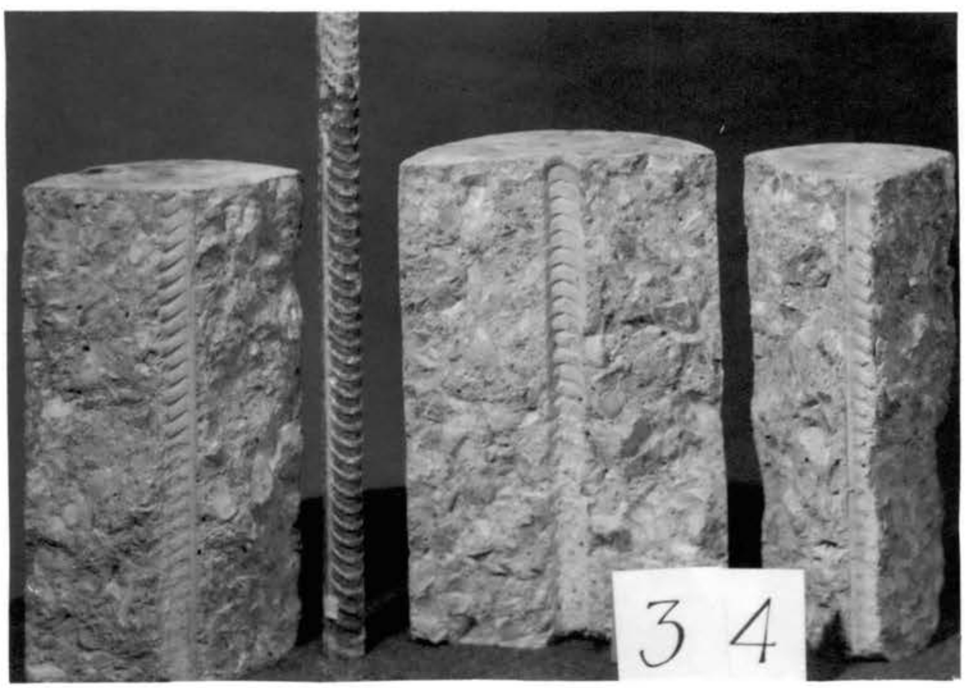


2. Control Blocks

PLATE VII

Treated and Untreated Blocks

1. Treated Block, 48 Volts-1000 Ampere Hours



2. Control Block

was used, anodic treatment reduced the resistance of the concrete, and cathodic treatment increased the resistance only 25 to 50%.

The increased resistance for the anodic treatments with no salt present was attributed to the transfer of calcium ions to the surface of the test block where calcium carbonate was precipitated by carbon dioxide in the electrolyte. Cathodic polarization by hydrogen evolution in cathodic treatment caused the increased resistance. The reduction in resistance when the sodium chloride solution was used was attributed to the action of the acidic chlorine ion in preventing the formation of calcium carbonate. The results reported by the National Bureau of Standards were corroborated by the research work of Mole. (13).

The experimental work reported here gave little indication of such a resistance rise. In only one case was there an appreciable increase in the resistance of a test block. The resistance of the block subjected to 48 volts and 125 ampere hours increased from 80 to 117 ohms. All remaining test samples either had no significant change or a decrease in resistance up to 60% of the initial value; all treatments exceeding 250 ampere hours decreased in resistance as shown in Table V. Electrolysis in a dilute salt solution effects the movement of soluble cations toward the negatively charged cathode. This migration of ions to the cathode increases the conductivity of the electrolyte in the pores of the concrete. The decreased resistance resulting from the increased ion concentration in the concrete is offset, to a certain extent, by polarization of the cathode by the evolution of hydrogen. A third factor in the resistance of the block is the effectiveness of the insulating mastic which covered the top and bottom surfaces of the test cylinders. Defects in the coating, especially on the bar, would present a lower resistance path for the current.

However, these defects were nullified by the gas film arising from the evolution of hydrogen and the diffusion of the hydrogen through any such pinholes. It was assumed that the final resistance was the result of a balance between the increased resistance from gas polarization and the decrease from the increased ion concentration in the concrete.

TABLE V

APPARENT ELECTRICAL RESISTANCE OF THE CONCRETE BLOCKS

Block Number	Voltage	Ampere Hours	Initial Resistance ohms	Final Resistance ohms	Difference ohms
39	48	30	67.6	64.9	- 2.7
38	48	60	54.5	64.9	+ 10.4
3	6	125	93.7	61.2	-32.5
31	6	125	74.1	30.2	-43.9
2	12	125	41.4	44.4	+ 3.0
25	12	125	61.5	48.0	-13.5
1	24	125	40.7	42.9	+ 2.2
19	24	125	38.7	41.4	+ 2.7
37	48	125	80.0	117.0	-37.0
9	12	250	75.0	34.2	-40.8
32	12	250	60.0	36.4	-23.6
8	24	250	53.3	40.0	-13.0
26	24	250	41.4	38.1	- 3.3
7	48	250	48.5	41.1	- 7.4
20	48	250	67.6	28.9	-38.7
14	24	500	68.6	27.3	-41.3
27	24	500	64.9	29.6	-35.3
13	48	500	41.7	33.3	- 8.4
21	48	500	42.5	27.9	-14.6
15	48	1000	61.5	33.1	-28.4
33	48	1000	60.8	24.6	-36.2

The effect of electrolysis on the resistance of concrete is obviously important. A large increase in resistance will reduce the current to negligible proportions and reduce further electrolytic damage. On the other hand, a decrease in resistance would increase the current and the damage. In electrolysis of concrete under conditions similar to those in this experimental work, change in resistance does not appear to be an important contributing factor to either increasing or decreasing possible damage.

CHAPTER V

SUMMARY AND CONCLUSIONS

The experimental work reported in this paper was an attempt to determine the effect of cathodic electrolysis on the bond between concrete and reinforcing steel. Electrolyses of 21 test blocks were carried out in synthetic sea water diluted to a chlorine concentration of 400 ppm. The procedure was so designed as to permit statistical evaluation of all test data, and to provide a basis for the correlation of bond damage, if any, with ampere hours and/or applied voltage. The concrete samples were tested using the ASTM C-234 Comparative bond test method with modifications.

Analysis of variance of the pull-out test data for the control blocks indicated there were no significant differences in bond strength arising from differences in the six batches of concrete used in casting the cylinders.

The variance of the treated blocks when analyzed at a slip of 0.005 inches or 16,000 pounds, by the method for simple lattices indicated differences in bond strength resulting from treatment; analysis at 0.010 inches or 18,000 pounds revealed no differences arising from treatment.

Examination of the average values for treated and untreated blocks reveals a slight trend toward a weakened bond with increasing ampere hours. This trend is more pronounced at a slip of 0.005 inches.

Visual examination of the rods and area around the rod after rupture of the blocks (either as a result of breaking during test or splitting open after tests in which the rod broke) revealed differences in the manner in which the bond failed. The failure in the control blocks was failure of the concrete surrounding the rod; that for the control, bond failure at the surface of the steel. The concrete surrounding the rod was softened by the electrolysis and in some cases the softened area was defined by a darkening of the concrete.

The electrical resistance of the concrete determined from current voltage relationships tended toward reduced values. This decrease was a balance between two major factors--gas polarization at the cathode and increased ion concentration in the concrete.

As a consequence of observations and analysis these conclusions were derived.

The bond damage shown by analysis of the test data is a result of deterioration of the concrete and not a result of reducing the adhesion of the concrete to the steel.

The damage from the applied treatments was not extensive, however, its significance would have to be determined by the initial design factors of individual structures.

Since there was no increase in resistance from the electrolysis, no protection from electrolytic damage by reduction in current could be expected.

Recommendations for Future Work

As an outgrowth of this work, the following recommendations for future work are made:

The use of various concentrations of salt both in the electrolyte and in concrete blocks to provide data for a correlation of salt concentration to bond damage.

Fracture of blocks at different loads during testing to study differences in bond failure produced by electrolytic treatment.

Chemical analysis of the concrete at various points in the concrete for inspection of chemical changes effected by treatment.

Continue treatment of blocks at 2, 4, 6, 12, and 24 volts and 125, 250, 500, and 1000 ampere hours to obtain data for lower voltages and longer exposure time.

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APPENDIX A

TABLE VI

COMPOSITION OF ELECTROLYTE

Salt	Concentration ppm
$NaCl$	560
$MgCl_2$	51.7
$MgSO_4$	63.5
$CaCl_2$	24.2
KCl	15.3
$NaHCO_3$	4.3
$NaBr$	1.7

TABLE VII

TYPICAL ANALYSIS OF LEHIGH TYPE I

PORTLAND CEMENT USED IN EXPERIMENT

CHEMICAL, Percent	
Silica (SiO_2)	20.9
Alumina (Al_2O_3)	5.7
Ferric Oxide (Fe_2O_3)	3.2
Magnesia (MgO)	3.2
Sulfuric Anhydride (SO_3)	
When $3CaO.Al_2O_3$ is over 8.0%	1.8
Ignition Loss	1.0
CaO	63.5
Potential Compounds	
Tricalcium Silicate ($3CaP.SiO_2$)	52.
Tricalcium Aluminate ($3CaO \cdot Al_2O_3$)	10.
PHYSICAL	
Fineness, Specific Surface, (Wagner)	1730
(Blaine)	3000
Soundness, Autoclave Expansion	0.2
Time of Set (Gillmore)	
Initial (Hr. : Min.)	3:30
Final (Hr. : Min.)	6:00
Tensile Strength, psi.	
3-day	330
7-day	430
Compressive Strength, psi.	
3-day	1700
7-day	3000

APPENDIX B

TABLE VIII

COMPRESSION TEST DATA

Batch Number	Ultimate Load Pounds	Crushing Strength psi
1	149250	5130
2	135800	4750
3	145900	5140
4	148500	5250
5	158790	5610
6	150000	5300
7	143190	5060

TABLE IX

STRESS-BOND SLIP DATA

Block No. 1

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	1525
0.75	0.00	2725
1.10	0.00	3800
2.25	0.00	6775
4.00	0.00	10325
5.00	0.00	12700
6.50	0.00	15500
7.25	0.00	18050
8.50	0.00	19250*
9.00	0.00	19575
9.25	0.05	19975
10.25	0.05	20225
11.25	0.05	20325
21.75	0.05	20150
23.50	0.05	20000
26.00	0.05	19950
26.75	0.05	19850
27.00	0.05	19850
28.00	0.05	19925
31.00	0.05	19850
36.00	0.05	20125
42.25	0.05	20050
53.50	0.05	21400
62.50	0.05	22100
71.00	0.10	22700
	0.10	23350
	0.20	24175
	0.25	24525
Breaking Strength		27400
Ultimate Strength		27725

Block No. 2

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	4625
1.00	0.00	5950
1.75	0.00	7500
2.25	0.00	9225
3.00	0.00	10700
3.75	0.00	12725
4.50	0.00	14150
5.25	0.00	15200
6.50	0.00	16450
8.00	0.00	17425
9.50	0.05	18375
11.50	0.05	19000*
14.25	0.10	19300
16.00	0.10	19475
20.00	0.10	19650
21.50	0.10	19500
25.00	0.10	19575
30.00	0.20	19500
35.00	0.20	19550
39.00	0.20	19600
40.50	0.20	19675
44.25	0.20	19850
52.00	0.20	20950
58.50	0.20	21100
66.00	0.25	22050
80.00	0.40	22800
	0.70	24000
	0.80	24150
	1.00	24400
	1.20	24000
	1.30	23875
	1.50	24000
	1.70	24300
	1.90	24350
	2.10	24350
	2.30	24350
	2.40	24250
	3.00	24275
Breaking Strength		24275
Ultimate Strength		24275

Block No. 3

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25		3225
1.50		7400
2.25		8700
3.00		10675
3.50		11950
4.00		13125
5.25		15125
6.50		17200
8.00		18900
8.75		19450*
9.50		19575
11.50		19875
15.00		19800
17.00		19775
19.00		19675
21.50		19700
22.75		19775
26.00		19800
29.00		19800
31.00		19650
32.00		19700
35.50		19800
36.00		19800
41.00		19600
45.50		20075
50.00		20400
56.50		21400
65.00		21975
75.00		22550
83.00		23050
Breaking Strength		27150
Ultimate Strength		27400

*Yield Point

TABLE IX (continued)

Block No. 4

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.60	0.00	2800
1.60	0.00	6100
2.25	0.00	7500
3.50	0.00	10050
3.75	0.00	11225
4.75	0.00	13150
5.50	0.00	14900
6.00	0.00	15800
6.75	0.00	17175*
7.25	0.00	17875
7.50	0.00	18250
8.25	0.00	19000
9.25	0.00	19575
10.00	0.00	19775
12.00	0.00	20075
14.75	0.00	20200
17.50	0.00	20325
21.50	0.00	20600
24.75	0.00	20825
29.25	0.00	20850
34.75	0.00	20650
41.25	0.00	20675
52.50	0.00	20800
60.00	0.00	21900
68.50	0.05	22200
74.00	0.20	23100
	0.50	24000
	0.70	24375
	0.80	24675
	0.90	24850
	1.00	25000
	1.20	25200
	1.40	24350
	1.50	25400
	1.70	25500
Breaking Strength		25200
Ultimate Strength		25575

Block No. 5

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	1350
0.50	0.00	1600
0.75	0.00	1975
1.00	0.00	2950
1.50	0.00	4200
2.00	0.00	5275
2.25	0.00	6725
2.75	0.00	7600
3.50	0.00	9200
4.50	0.00	11150
5.00	0.00	12400
5.50	0.00	13675
6.50	0.00	14650
7.00	0.00	15700
7.50	0.00	16750
8.50	0.00	17825
9.25	0.00	18900
11.50	0.05	20600
12.50	0.05	21500
14.00	0.10	22100
15.75	0.10	22575
17.50	0.20	23125
20.00	0.20	23650
22.50	0.20	24150
25.00	0.25	24525
27.75	0.30	24900
	0.30	25250
		25550*
Breaking Strength		26550
Ultimate Strength		26550

Block No. 6

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	6450
1.50	0.00	7800
1.75	0.00	8700
2.00	0.00	9450
2.50	0.00	11350
3.00	0.00	12600
3.75	0.00	14100
4.00	0.00	14925
4.50	0.00	16000
4.75	0.00	16850
5.50	0.00	18000
6.50	0.00	18475
8.50	0.00	19575
10.00	0.00	19575
13.00	0.00	19600
16.00	0.00	19650
19.50	0.00	19700
23.00	0.00	19800
30.00	0.00	19925
33.50	0.00	19775
36.00	0.00	19900
40.50	0.00	20225
47.00	0.00	20850
54.00	0.00	21500
58.50	0.00	22000
63.00	0.00	22325
68.00	0.05	22625*
72.50	0.05	22950
	0.10	23400
	0.15	25000
Breaking Strength		27925
Ultimate Strength		27925

*Yield Point

TABLE IX (continued)

Block No. 7

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
1.10	0.00	3100
2.10	0.00	5200
3.80	0.00	8800
7.20	0.00	12250
9.50	0.00	15850
12.30	0.00	17650
14.70	0.00	19000
16.00	0.00	19400
16.50	0.00	19400
19.50	0.00	19600
22.00	0.00	19700
24.70	0.00	19800
29.00	0.00	19950
34.00	0.00	19900
39.50	0.00	19650
44.10	0.00	20250
47.20	0.00	20500
47.50	0.00	20400
57.00	0.00	21100
	0.05	24650
Rod Broke at		25725

Block No. 8

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	2100
0.75	0.00	3450
1.10	0.00	5275
1.75	0.00	6475
2.25	0.00	7750
3.25	0.00	9700
4.40	0.00	12250
5.25	0.00	14125
6.00	0.00	15400
7.50	0.00	12125
9.25	0.00	18150*
10.00	0.00	18725
14.00	0.00	19550
20.50	0.00	19950
26.50	0.00	19875
38.00	0.00	19650
40.00	0.00	20000
44.50	0.00	20075
48.50	0.00	20175
54.75	0.00	21150
60.25	0.00	21650
69.50	0.00	22225
	0.10	25050
	0.20	25700
	0.30	25775
	0.40	25925
	0.50	26100
	0.60	26325
	0.70	27550
	0.80	26600
	0.90	26750
	1.00	26900
	1.10	26975
	1.20	27000
Breaking Strength		27000
Ultimate Strength		27000

Block No. 9

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	2600
1.10	0.00	4000
2.00	0.00	6000
2.25	0.00	7050
2.90	0.00	8400
4.25	0.00	11400
6.05	0.00	14850
7.05	0.00	17600
8.90	0.00	19100*
10.00	0.00	20200
12.50	0.00	20500
16.20	0.00	24200
19.00	0.00	20200
22.30	0.00	20300
25.25	0.00	20450
28.00	0.00	20500
33.00	0.00	20000
38.00	0.00	20150
45.50	0.00	22800
48.00	0.00	23200
53.00	0.00	23850
Rod Broke at		27900

*Yield Point

TABLE IX (continued)

Block No. 10

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.65	0.00	3000
1.75	0.00	6150
2.25	0.00	7200
2.75	0.00	8450
3.30	0.00	9650
3.50	0.00	10300
4.00	0.00	11500
4.55	0.00	12350
4.75	0.00	12850
5.00	0.00	13450
5.25	0.00	13925
5.50	0.00	14450
5.75	0.00	15000
6.35	0.00	16000
7.35	0.00	18100
7.95	0.00	19025
8.50	0.00	19300
9.25	0.00	19500*
11.40	0.00	19450
12.60	0.00	19600
17.00	0.00	19500
20.00	0.00	19300
22.50	0.00	19300
28.75	0.00	19700
32.75	0.00	19725
36.50	0.00	19300
41.00	0.00	19750
46.50	0.00	19925
52.50	0.00	20075
61.00	0.00	21375
72.00	0.00	22125
76.75	0.30	22450
	0.10	23450
	0.15	24100
	0.20	24400
	0.25	24700
	0.30	25050
Rod Broke at		25050

Block No. 11

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.10	0.00	4500
0.17	0.00	6100
0.20	0.00	7000
0.27	0.00	9100
0.35	0.00	10650
0.41	0.00	12500
0.44	0.00	13400
0.52	0.00	15000
0.62	0.00	16450
0.70	0.00	17500
0.84	0.00	18500
0.10	0.02	19550
0.13	0.06	20300
0.16	0.06	20400*
0.19	0.08	20700
22.10	0.09	20750
26.00	0.10	20850
33.50	0.10	20550
37.50	0.10	20550
45.00	0.10	20850
50.00	0.10	20550
57.00	0.10	20750
61.00	0.12	22000
66.25	0.13	22450
71.70	0.16	22650
78.50	0.19	23100
	0.20	23450
	0.30	24900
Breaking Strength		26520
Ultimate Strength		26520

Block No. 12

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	3200
1.00	0.00	4700
1.85	0.00	7600
2.85	0.00	10100
3.50	0.00	12000
4.25	0.00	13650
5.25	0.00	15250
6.50	0.00	16800
7.50	0.00	17650
8.50	0.00	18250
11.50	0.00	19150*
16.50	0.00	19650
18.25	0.00	19550
22.85	0.00	19850
40.00	0.00	19900
48.50	0.00	20450
32.50	0.00	20900
62.00	0.10	21600
67.50	0.10	22050
74.00	0.50	22500
81.00	0.80	23000
90.50	0.11	23500
97.50	0.13	23500
	0.18	24450
	0.20	25550
	0.25	25700
	0.30	25800
	0.40	25925
	0.50	26050
	0.60	26100
	0.70	26125
	0.80	26125
	0.90	26125
	1.00	26125
	1.20	26125
Breaking Strength		26125
Ultimate Strength		26125

*Yield Point

TABLE IX (continued)

Block No. 13

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	2200
0.60	0.00	2825
1.10	0.00	3800
1.50	0.00	4625
2.25	0.00	5875
3.50	0.00	8300
4.50	0.00	10350
5.60	0.00	12250
6.50	0.00	13900
7.40	0.00	15125
8.00	0.00	16075
8.50	0.00	16800
9.00	0.00	17325
9.40	0.00	17625
9.75	0.00	17900
10.25	0.00	18175
11.00	0.00	18650
13.00	0.00	19400
22.00	0.00	19700*
25.25	0.00	19925
28.75	0.00	20100
27.50	0.00	20125
35.50	0.00	20075
42.50	0.00	20125
49.00	0.00	20300
52.50	0.00	20700
63.50	0.00	21650
70.75	0.00	22075
76.25	0.00	22475
86.50	0.00	23150
97.50	0.00	23850
Rod Broke at		26150

Block No. 14

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	2000
0.75	0.00	2700
1.50	0.00	4975
2.25	0.00	6475
3.40	0.00	8300
4.40	0.10	9975
4.90	0.15	10950
5.40	0.20	11900
6.05	0.25	13100
7.00	0.25	14550
8.50	0.30	16450
9.50	0.35	17950
10.45	0.35	18800*
11.75	0.35	19900
16.00	0.35	20550
20.25	0.38	20350
23.00	0.40	20400
26.00	0.40	20300
32.75	0.40	20450
35.50	0.40	20400
43.00	0.40	20350
48.00	0.40	20550
52.75	0.40	20950
54.00	0.55	20700
	0.90	20900
	0.90	21050
	0.95	22900
	0.95	25500
Breaking Strength		25800
Ultimate Strength		25800

Block No. 15

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	2400
0.75	0.00	3675
1.25	0.00	5175
2.00	0.00	6875
3.25	0.00	9400
5.50	0.00	13725
7.00	0.00	15900
7.75	0.00	16800
8.50	0.00	17425
9.25	0.00	18200
10.25	0.00	18650
11.25	0.00	19300
13.00	0.00	19800*
18.50	0.00	20100
22.25	0.00	20300
25.75	0.00	20375
29.00	0.00	20325
34.50	0.00	20400
38.75	0.00	20400
43.75	0.00	20300
49.25	0.00	20100
52.25	0.00	20500
53.25	0.00	20450
55.00	0.00	21200
59.50	0.00	21425
65.00	0.00	21875
75.00	0.00	22525
80.00	0.00	22850
83.75	0.00	23075
Rod Broke at		26150

*Yield Point

TABLE IX (continued)

Block No. 16

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.40	0.00	3150
0.75	0.00	3950
1.25	0.00	5450
2.00	0.00	6400
2.75	0.00	9425
3.75	0.00	11375
4.50	0.00	12900
5.25	0.00	14125
6.00	0.00	15000
6.75	0.00	15750
7.75	0.00	16300
8.75	0.00	16800
9.75	0.00	17275
10.75	0.00	17725
12.00	0.00	18275
13.50	0.00	18775
15.25	0.00	19125*
16.75	0.00	19375
24.75	0.00	19375
30.25	0.00	19200
32.00	0.00	19425
35.50	0.00	19175
38.75	0.00	19275
40.50	0.00	19300
48.75	0.00	20250
60.25	0.00	21150
70.00	0.00	21900
80.00	0.50	22650
	0.50	23350
	1.00	23575
	1.50	23800
	2.00	24350
	3.00	24950
Rod Broke at		25300

Block No. 17

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	3100
1.45	0.00	5700
2.00	0.00	7300
2.70	0.00	8800
3.25	0.00	10200
3.90	0.00	11625
4.50	0.00	12975
5.10	0.00	14275
5.75	0.00	15350
6.40	0.00	16450
7.00	0.00	17525
8.25	0.00	19100
8.75	0.00	19900
9.25	0.00	20025
9.75	0.00	20000
10.50	0.00	19750
12.50	0.00	19900
13.25	0.00	20100
14.75	0.00	19925
19.25	0.00	19800
28.25	0.00	19900
35.00	0.00	19900
42.00	0.00	20000
48.00	0.00	20475
53.00	0.00	20850
59.50	0.00	21500
68.25	0.00	22200
74.00	0.00	22600
79.00	0.00	22500
		24000
Rod Broke at		26150

Block No. 18

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.75	0.00	3100
1.00	0.00	3900
1.50	0.00	5400
2.10	0.00	6825
2.75	0.00	8250
3.50	0.00	9700
4.25	0.00	11100
5.25	0.00	12925
7.25	0.00	14850
9.00	0.00	16400
9.75	0.00	16900
10.50	0.00	17275
11.25	0.00	17550
12.00	0.00	17725
12.75	0.00	18125
13.75	0.00	18500
14.50	0.00	18625
15.25	0.00	18775
16.25	0.00	18825
17.75	0.00	18975
21.00	0.00	19225*
23.75	0.00	19225
31.50	0.00	19600
34.75	0.00	19500
38.50	0.00	20125
47.50	0.00	20050
52.50	0.00	20250
60.75	0.00	20900
66.50	0.00	21375
71.50	0.00	21750
		23675
Rod Broke at		25850

*Yield Point

TABLE IX (continued)

Block No. 19

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.05	0.00	3350
1.00	0.00	4100
1.25	0.00	5300
1.75	0.00	6250
2.00	0.00	7600
2.75	0.00	8900
3.50	0.00	10800
5.00	0.00	13150
5.75	0.00	14550
6.50	0.00	15425
7.00	0.00	15800
7.25	0.00	16900
9.00	0.00	17500
9.50	0.00	17975
10.50	0.00	18375
12.00	0.00	19100
16.75	0.00	19525
23.25	0.00	19850
31.50	0.00	19950
39.00	0.00	19950*
41.50	0.00	20200
48.00	0.00	20300
53.50	0.00	19900
57.00	0.00	21025
65.50	0.00	21650
79.25	0.00	22575
	0.05	23300
	0.10	23425
	0.20	23825
	0.30	24200
	0.40	24050
	0.50	24275
	0.60	24450
	0.70	24550
	0.90	24775
	1.10	24900
	1.30	24800
	1.50	24700
Rod Broke at		24925

Block No. 20

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	1975
0.75	0.00	3500
1.25	0.00	4875
2.00	0.00	7300
2.90	0.00	9275
3.75	0.00	10850
4.75	0.00	13050
5.75	0.00	14700
6.75	0.00	16500
8.25	0.00	18400
9.25	0.00	19100
10.00	0.00	19650
12.50	0.00	19850*
15.25	0.00	19625
18.50	0.00	19800
22.75	0.00	19800
27.50	0.00	20150
32.50	0.00	20200
38.75	0.00	20025
42.75	0.00	19975
48.00	0.00	20150
55.00	0.00	20200
63.00	0.00	21350
67.75	0.00	21670
72.00	0.00	20025
83.75	0.00	22700
	0.10	24750
	0.20	24750
	0.30	24750
	0.40	24150
	0.50	24100
	0.60	24025
	0.70	23950
	0.80	23900
	0.90	23850
	1.00	23800
Breaking Strength		23650

Block No. 21

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.75	0.00	2300
1.55	0.00	3525
2.10	0.00	4575
2.90	0.00	5625
3.50	0.00	6850
4.40	0.00	8300
5.10	0.00	9825
5.75	0.10	10875
6.50	0.20	12300
8.00	0.20	14900
8.75	0.25	16175
10.25	0.30	17600
10.50	0.30	18000
11.50	0.50	19400*
12.00	0.50	19425
13.50	0.50	19750
20.50	0.50	19100
24.00	0.50	19500
28.00	0.50	19400
34.50	0.55	19300
	0.70	20400
	0.80	22550
	0.90	23150
	1.00	23850
Breaking Strength		24950
Ultimate Strength		25650

*Yield Point

TABLE IX (continued)

Block No. 22

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.75	0.00	3300
1.50	0.00	5900
1.75	0.00	7050
2.50	0.01	8875
3.25	0.01	11500
4.00	0.02	13125
4.75	0.02	14400
5.75	0.05	15825
7.00	0.06	17050
8.00	0.09	18050
9.50	0.10	18725
11.20	0.11	19600
14.20	0.15	20200*
18.25	0.19	20550
22.50	0.21	20750
26.00	0.25	20850
34.00	0.28	20800
37.50	0.29	20950
44.00	0.32	20950
54.50	0.33	21500
59.50	0.35	21250
68.00	0.38	22250
78.50	0.38	22800
	0.65	23250*
	0.70	23550
	0.80	23750
	1.00	24000
	1.10	24100
	1.20	24100
	1.30	24100
	1.40	23850
	1.70	23700
	1.90	23600
	2.20	23550
	2.80	23450
	3.50	23250
	4.00	23150
	4.70	23100
Breaking Strength		23100
Ultimate Strength		23100

Block No. 23

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.75	0.00	4800
1.25	0.00	7100
1.75	0.00	8400
2.00	0.00	9150
2.75	0.00	10950
3.25	0.00	11825
3.50	0.00	12500
3.75	0.00	13550
4.00	0.00	14500
4.75	0.00	15475
5.00	0.00	16200
6.50	0.00	16800
7.00	0.00	17875
8.00	0.00	18475
11.50	0.00	19400*
13.00	0.00	19400
14.25	0.00	19700
18.00	0.00	19875
21.50	0.00	19875
24.00	0.00	19700
35.50	0.00	20025
41.50	0.00	20175
48.00	0.00	20875
57.00	0.00	21700
64.00	0.00	22000
71.00	0.00	22300
	0.01	24850
	0.02	25150
	0.04	25425
Rod Broke at		25150

Block No. 24

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.75	0.00	4225
1.25	0.00	5800
2.50	0.00	8250
3.00	0.00	10225
3.75	0.00	12125
5.20	0.00	14300
6.75	0.00	15200
7.00	0.00	16200
7.50	0.00	17075
8.75	0.00	18100
9.50	0.00	18200*
11.00	0.00	19250
12.00	0.00	19400
16.00	0.10	19475
19.00	0.10	19500
22.50	0.20	19450
22.50	0.20	19525
30.00	0.20	19550
38.00	0.20	19600
42.00	0.20	19625
	0.30	19450
	0.50	21000
	0.60	21275
	0.70	21375
	0.80	21575
	0.90	21750
	1.00	21850
	1.10	21950
	1.20	22000
	1.30	21075
	1.40	21100
	3.50	22100
	4.00	22175
Breaking Strength		22175
Ultimate Strength		22175

TABLE IX (continued)

Block No. 25

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	1900
0.75	0.00	3425
1.10	0.00	4525
1.75	0.00	6000
2.00	0.00	6925
2.75	0.00	8675
3.50	0.00	10600
4.50	0.00	12425
5.25	0.00	13725
5.75	0.00	14675
6.25	0.00	15500
7.25	0.00	16425
8.25	0.00	17400
8.90	0.00	17950
9.35	0.00	18050
9.50	0.00	18250
10.50	0.00	18200
11.25	0.00	18500
12.00	0.00	19200
13.50	0.10	19575
15.25	0.10	19725
20.50	0.20	20100
28.00	0.20	20250
33.50	0.20	20150
37.50	0.20	20300
42.00	0.20	20050
48.50	0.20	20200
52.75	0.20	20850
63.00	0.20	21700
68.00	0.20	21900
76.00	0.20	22325
Breaking Strength		23850
Ultimate Strength		24250

Block No. 26

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.35	0.00	2050
1.00	0.00	3200
1.25	0.00	3875
2.00	0.00	5100
2.75	0.00	6450
3.60	0.00	7900
4.50	0.00	9450
5.50	0.00	11000
6.40	0.00	12475
7.40	0.00	13800
8.35	0.00	15200
9.35	0.00	16625
10.25	0.00	17800
11.00	0.00	18625
11.95	0.00	19150
12.65	0.00	19525
17.50	0.00	19675
20.00	0.00	20050
25.50	0.00	19975
28.00	0.00	19750
31.25	0.00	19800
37.50	0.00	19675
40.75	0.00	19750
48.75	0.00	19950
55.25	0.00	19700
60.00	0.00	19750
72.00	0.00	20200
Rod Broke at		24000

Block No. 27

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
1.70	0.00	4275
2.50	0.00	5550
3.25	0.00	6700
4.00	0.00	7725
4.90	0.00	8700
5.50	0.00	9725
6.25	0.00	10725
7.00	0.00	11600
7.75	0.00	12400
9.10	0.00	13925
10.60	0.00	15700
12.25	0.00	17200
13.75	0.00	18725
15.00	0.00	19875
15.90	0.00	20400*
19.60	0.00	20500
22.25	0.00	20550
26.00	0.00	20550
31.25	0.00	20750
36.50	0.00	20750
42.50	0.00	20700
47.50	0.00	20750
53.75	0.00	20750
60.25	0.00	20650
67.25	0.00	21700
76.50	0.00	22225
Breaking Strength		25400
Ultimate Strength		25400

*Yield Point

TABLE IX (continued)

Block No. 28

Slip Inches x 10^3 Loaded End	Free End	Stress Pounds
0.75	0.00	2500
1.50	0.00	4825
2.00	0.00	7125
2.50	0.00	8200
3.00	0.00	9475
3.75	0.00	10750
4.40	0.00	12000
5.00	0.00	13200
5.75	0.00	14000
6.75	0.00	15525
7.50	0.00	16450
8.25	0.00	17300
8.50	0.00	17600
9.00	0.00	17900
12.50	0.00	18675*
13.50	0.00	18675
14.25	0.00	18875
16.50	0.00	19325
21.00	0.00	19450
28.00	0.00	19500
35.00	0.00	19525
43.25	0.00	19800
51.00	0.10	20800
59.00	0.20	21350
67.00	0.25	21900
73.00	0.30	22350
	0.40	23050
	0.50	23300
	0.60	24000
	0.70	24225
	0.80	24300
	1.00	24250
	1.10	24250
	1.30	24250
	1.50	24200
	1.80	24000
Breaking Strength		24000
Ultimate Strength		24425

*Yield Point

Block No. 29

Slip Inches x 10^3 Loaded End	Free End	Stress Pounds
0.50	0.00	2100
1.25	0.00	3600
2.00	0.00	5350
2.50	0.00	5950
2.90	0.00	6100
3.50	0.00	7700
4.65	0.00	8900
5.75	0.00	11500
6.50	0.00	12750
7.50	0.00	13925
8.50	0.00	14950
10.00	0.00	16575
13.50	0.00	18425
14.75	0.00	18700
17.25	0.00	19075
19.50	0.10	19225
23.50	0.10	19500
26.25	0.10	19625*
38.50	0.10	19700
51.50	0.10	19950
62.00	0.15	21025
73.00	0.25	21925
79.50	0.30	22350
	0.50	23300
	0.60	23675
	0.75	24100
	1.00	23950
	1.20	23900
	1.30	24000
	1.50	24125
	1.75	24200
	2.00	24200
	2.50	24225
	3.00	24350
	3.20	24375
	3.50	24300
	3.70	24300
	3.90	24350
Breaking Strength		22725
Ultimate Strength		24325

Block No. 30

Slip Inches x 10^3 Loaded End	Free End	Stress Pounds
0.50	0.00	2350
0.10	0.00	3325
2.10	0.00	7050
2.75	0.00	8625
3.50	0.00	10500
4.25	0.00	12200
5.75	0.00	15200
7.75	0.00	18000
8.50	0.00	18250
9.50	0.00	19650*
12.20	0.00	19950
18.00	0.00	20100
29.50	0.00	20050
38.50	0.00	20100
46.50	0.00	20100
48.25	0.00	19950
50.50	0.00	20850
57.25	0.00	21050
68.50	0.00	21750
78.50	0.00	22975
	0.10	23850
Breaking Strength		24200
Ultimate Strength		24200

TABLE IX (continued)

Block No. 31

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.75	0.00	3600
1.50	0.00	5500
2.25	0.00	6875
3.00	0.00	8625
3.75	0.00	10800
4.25	0.00	11150
5.00	0.00	12075
6.00	0.00	13775
7.00	0.00	15050
8.25	0.00	16150
9.00	0.00	16825
9.90	0.00	17500
11.75	0.00	18425
13.25	0.00	18850
16.00	0.10	19200
18.50	0.10	19350
22.75	0.10	19525
25.50	0.10	19650
32.00	0.10	19750
40.50	0.20	19725*
44.50	0.20	20325
55.00	0.25	21625
62.50	0.30	22175
67.50	0.30	22500
81.00	0.40	23350
92.00	0.40	23850
Breaking Strength		24800
Ultimate Strength		24800

*Yield Point

Block No. 32

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
1.00	0.00	2625
2.50	0.00	6600
4.00	0.00	9025
4.50	0.00	10100
5.50	0.00	11625
6.00	0.00	12700
7.25	0.00	14550
8.00	0.00	15600
9.25	0.10	16400
10.00	0.10	17175
11.50	0.20	18150
12.50	0.20	18625
14.00	0.25	19125
17.50	0.25	19400*
19.50	0.25	19500
21.50	0.25	19625
26.00	0.30	19775
32.50	0.30	19850
37.00	0.30	20150
44.00	0.30	20000
50.00	0.30	20400
58.50	0.30	20925
Breaking Strength		22850
Ultimate Strength		23600

Block No. 33

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	2200
1.00	0.00	3050
2.40	0.00	5350
3.25	0.60	7000
4.50	0.70	8950
5.00	0.75	9925
6.00	0.75	11400
6.75	0.75	12300
8.00	0.75	13950
9.00	0.75	15200
10.25	0.75	16175
13.50	0.75	18400
16.50	0.75	19400
21.25	0.75	19800
26.00	0.75	19820
29.25	0.75	19750
40.50	0.75	19800
49.25	0.75	19850
	1.00	21300
	1.25	22000
	1.60	22600
	1.75	22725
	2.10	23050
	2.25	23600
	2.50	23900
	2.70	24125
	2.80	24250
	3.00	24450
	3.20	24725
	3.25	24775
	3.30	24850
	3.50	25025
Rod Broke at		27520

TABLE IX (continued)

Block No. 34

Slip, Inches x 10^3: Loaded End	Slip, Inches x 10^3: Free End	Stress Pounds
0.50	0.00	2775
1.00	0.00	4900
1.65	0.00	6250
2.25	0.00	8250
3.25	0.00	10050
4.25	0.00	12325
5.50	0.00	14950
6.75	0.00	16950
8.25	0.00	18200*
9.00	0.00	18800
11.00	0.00	19225
13.50	0.00	19500
17.00	0.00	19750
22.50	0.00	19700
29.50	0.00	19525
33.50	0.00	19900
43.00	0.00	19850
51.50	0.00	20600
66.00	0.10	21800
78.00	0.10	22700
	0.20	23400
	0.35	24150
	0.30	24500
Breaking Strength		26600
Ultimate Strength		26600

*Yield Point

Block No. 35

Slip, Inches x 10^3: Loaded End	Slip, Inches x 10^3: Free End	Stress Pounds
1.00	0.00	4050
1.65	0.00	5450
2.50	0.00	6675
3.00	0.00	7950
3.75	0.00	9700
5.50	0.00	13175
6.75	0.00	15100
9.00	0.00	17000
11.75	0.00	18550
13.75	0.10	19125
15.00	0.10	19400
16.75	0.10	19675
19.00	0.10	19925
21.75	0.10	19800
24.75	0.10	19875
28.50	0.10	19800
32.00	0.10	19725
39.00	0.10	19900
47.50	0.10	20100
51.00	0.10	19825
61.50	0.10	21450
75.15	0.10	22500
	0.30	23250
	0.40	24300
	0.45	25000
Breaking Strength		25800
Ultimate Strength		26100

Block No. 36

Slip, Inches x 10^3: Loaded End	Slip, Inches x 10^3: Free End	Stress Pounds
0.25	0.00	1250
0.65	0.00	2350
1.75	0.00	5350
2.35	0.00	6750
3.00	0.00	8250
5.00	0.00	12275
6.25	0.00	14625
7.25	0.00	16400
8.50	0.00	17675
9.50	0.00	18550*
10.75	0.00	19625
13.00	0.00	19900
16.50	0.00	20025
21.50	0.00	19825
24.00	0.00	19775
28.00	0.00	19900
41.50	0.00	20050
48.75	0.00	20150
54.50	0.00	20875
62.50	0.00	21450
72.50	0.10	22050
78.50	0.10	22475
	0.20	23850
	0.25	24350
	0.30	24775
	0.40	25150
	0.45	25350
Breaking Strength		26175
Ultimate Strength		26500

TABLE IX (continued)

Block No. 37

Slip, Inches x 10^3: Loaded End	Slip, Inches x 10^3: Free End	Stress Pounds
0.50	0.00	3500
1.00	0.00	4400
1.50	0.00	5250
2.00	0.00	6250
2.50	0.00	7350
3.00	0.00	8400
3.60	0.00	9600
3.90	0.00	10150
4.25	0.00	10800
5.25	0.00	12700
5.55	0.00	13700
6.25	0.00	14200
7.10	0.00	15600
8.50	0.00	17300
9.50	0.00	18200
10.75	0.00	18800
12.00	0.00	19300
13.10	0.00	19700
14.75	0.00	19850
17.25	0.00	20150
20.75	0.00	20150
25.75	0.00	20250
30.75	0.00	20350
34.25	0.00	20300
43.75	0.00	20150
48.25	0.00	20400
53.50	0.00	21000
	0.05	22700
	0.10	21900
	0.15	22800
	0.20	22900
	0.25	22900
	0.30	22900
	0.50	23000
Breaking Strength		23000
Ultimate Strength		23000

Block No. 38

Slip, Inches x 10^3: Loaded End	Slip, Inches x 10^3: Free End	Stress Pounds
0.50	0.00	2800
1.00	0.00	3700
1.50	0.00	5700
2.25	0.00	7750
2.50	0.00	9350
4.00	0.00	11300
5.00	0.00	12850
6.15	0.00	13850
6.50	0.00	14750
7.25	0.00	15400
8.00	0.00	16100
8.75	0.00	16700
10.00	0.00	17250
13.50	0.00	19250
22.50	0.00	19300
25.00	0.00	19300
31.00	0.20	19350
33.75	0.20	19400
40.00	0.20	19600
45.00	0.20	19700
55.00	0.50	20650
61.00	0.50	21100
	1.00	21600
	1.50	22250
	2.00	22550
	2.50	22650
	3.00	22650
	5.00	22650
	7.00	22650
	8.00	22300
Breaking Strength		22700
Ultimate Strength		22700

Block No. 39

Slip, Inches x 10^3: Loaded End	Slip, Inches x 10^3: Free End	Stress Pounds
0.50	0.00	2000
1.00	0.00	3600
1.85	0.00	5600
2.75	0.00	7350
3.80	0.00	9100
5.00	0.00	10750
5.90	0.00	12000
7.75	0.00	13100
8.50	0.00	14100
9.60	0.00	15050
11.40	0.00	15800
13.00	0.00	16550
14.60	0.00	17250
18.00	0.00	18700
21.60	0.00	19200*
28.00	0.00	19300
33.75	0.00	19400
37.00	0.00	19425
45.75	0.00	19650
	0.05	21650
	0.10	21750
	0.15	21900
	0.30	22250
	0.50	22400
	0.70	22500
	0.90	22450
	1.10	22400
	1.30	22375
	1.50	22350
	2.00	22200
	2.20	22150
	2.70	22000
	3.50	21800
	4.00	22650
	4.50	22500
	5.00	21350
	5.50	21200
	6.00	21000
Breaking Strength		21000
Ultimate Strength		21000

*Yield Point

TABLE IX (continued)

Block No. 40

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
1.00	0.00	2000
2.25	0.00	2700
3.00	0.00	3000
3.40	0.00	3300
4.25	0.00	3700
5.10	0.00	4300
5.85	0.00	5500
6.90	0.00	5950
7.25	0.00	7350
7.75	0.00	8050
10.10	0.00	14100
10.50	0.00	15500
11.25	0.00	17300
12.75	0.00	18500
14.50	0.00	19800
18.35	0.00	20250
20.40	0.00	20550
21.50	0.00	20600
23.25	0.00	20650
25.00	0.00	20550
29.25	0.00	21000
34.00	0.00	20900
39.25	0.00	20900
44.25	0.00	20900
49.25	0.00	22050
54.40	0.00	22900
	0.50	26700
	1.00	27750
	1.50	27800
Breaking Strength		27800
Ultimate Strength		27800

Block No. 41

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.25	0.00	4000
1.40	0.00	6300
2.40	0.00	8800
2.90	0.00	9900
3.40	0.00	11000
3.90	0.00	12150
4.40	0.00	13500
4.90	0.00	14750
5.40	0.00	15850
7.40	0.00	18200
8.75	0.00	19000
10.75	0.00	19150
15.40	0.00	19350
22.50	0.00	19800
28.50	0.00	19400
29.25	0.00	19450
32.25	0.00	19200
41.75	0.00	19500
48.50	0.00	20400
53.50	0.00	20800
60.00	0.00	21500
66.50	0.00	21950
71.00	0.00	22250
75.25	0.00	22550
	0.20	25000
	0.50	25800
	1.00	26500
	1.50	26650
	2.00	26650
	5.00	26700
Breaking Strength		26700
Ultimate Strength		26700

Block No. 42

Slip Inches x 10^3 Loaded End	Slip Inches x 10^3 Free End	Stress Pounds
0.50	0.00	2150
1.05	0.00	3600
2.10	0.00	6200
2.65	0.00	7550
3.25	0.00	8900
3.75	0.00	10175
4.55	0.00	11950
6.15	0.00	15000
7.55	0.00	16700
9.00	0.00	17850
10.50	0.00	18450
12.25	0.00	18725
13.40	0.00	18900
14.75	0.00	18975
18.25	0.00	19075
21.40	0.00	19250
28.50	0.00	19350*
32.75	0.00	19400
36.00	0.00	19350
42.50	0.00	19650
51.00	0.00	20900
	0.30	24000
	0.50	24250
	1.00	24750
	2.00	25900
Rod Broke at		26150

*Yield Point

VITA

Burton Maurice Casad

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Master of Science

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