RHO-RE-CR-8 P
-201

Long-Term Effects of Waste Solutions on Concrete and Reinforcing Steel

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Prepared for Rockwell Hanford Operations,
a Prime Contractor to the
United States Department of Energy
Under Contract DE-AC06-77RL01030

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LONG-TERM EFFECTS OF WASTE SOLUTIONS ON CONCRETE AND REINFORCING STEEL

J. I. Daniel
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of the Portland Cement Association
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April 1982

Prepared for Rockwell Hanford Operations
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Department of Energy
Under Contract DE-AC06-77RL01030

Rockwell International
Rockwell Hanford Operations
Energy Systems Group
Richland, Washington 99352

EXECUTIVE SUMMARY

This report has been prepared for the In Situ Waste Disposal Program Tank Assessment Task (WG-11) as part of an investigation to evaluate the long-term performance of waste storage tanks at the Hanford Site. This report, prepared by the Portland Cement Association, presents the results of four years of concrete degradation studies which exposed concrete and reinforcing steel, under load and at 180°F, to simulated double-shell slurry, simulated salt cake solution, and a control solution. Exposure length varied from 3 months to 36 months. In all cases, examination of the concrete and reinforcing steel at the end of the exposure indicated there was no attack, i.e., no evidence of rusting, cracking, disruption of mill scale or loss of strength.

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TABLES:

INTRODUCTION

Radioactive waste resulting from the chemical processing of reactor fuel for recovery of special nuclear materials (primarily plutonium), has been accumulating at the Hanford Site since 1944. The defense waste is currently being stored in underground waste tanks and in capsules stored in water basins.

Current U.S. Department of Energy (DOE) strategy is to emphasize development and implementation of technology for removal, solidification, and final disposition of defense waste at the Savannah River Site first, then at the Hanford Site. Final disposal of waste in tanks at Hanford is expected to consist of in-place stabilization of most tanks. Selected tank wastes may be retrieved. Disposal operations will be carried out during the next several decades. Consequently, defense waste will remain in the existing underground tanks at Hanford for at least several decades.

To ensure the safe storage of the waste, the waste storage tanks are being evaluated for continued service as part of the DOE Waste Tank Evaluation Program (AR-005-10-02-G). Technical studies and laboratory tests have been conducted to determine the effect of the stored waste's chemicals and temperature on the reinforced concrete.

Waste solutions, which can be chemically aggressive, could come in contact with the reinforced concrete waste tank wall and bottom through breaches in the steel liner. Tests have been conducted to estimate the relative durability of reinforced concrete specimens exposed to two different simulated Hanford waste solutions. Results of these tests will be used as input to a comprehensive evaluation of the integrity of the single-shell tanks for continued storage of radioactive waste. The information is also applicable to the newer double-shell tank designs.

This work was performed by the Construction Technology Laboratories, a division of the Portland Cement Association in Skokie, Illinois for Rockwell Hanford Operations (Rockwell).

Scope

Service Agreement SA-469 of the Prime Contract DE-AC06-77RL01030 between Rockwell International Corporation and the Portland Cement Association contained the following statement of work:

> "The CONTRACTOR shall, as requested by ROCKWELL, provide necessary personnel, labor, material, facilities, and equipment to conduct a research program to provide an estimate of the relative durability of reinforced concrete specimens exposed to a simulated Hanford waste solution. The program shall consist of exposing, testing, and evaluating the specimens developed and prepared under Rockwell Contract SA-256. The testing shall be conducted as a three-year and four-month program as outlined hereunder."

This final report describes the effects of two simulated Hanford waste solutions and one control solution on the relative durability of reinforced concrete specimens when subjected to elevated temperature and load.

A total of 21 reinforced concrete specimens were fabricated under Rockwell Contract SA-256 dated October 26, 1977. Twelve of these specimens were tested under Rockwell Contract SA-256. The remaining nine specimens were tested under Rockwell Contract SA-469 dated September 25, 1980.

Table 1 presents the project team, and Table 2 lists the breakdown of performance for work conducted under both contracts. As outlined in Rockwell Contract SA-469, specimens were exposed to three specific test solutions. They were simulated salt cake waste, control, and double-shell slurry. Specimen loading conditions consisted of 400 psi in compression, 10,000 psi in flexure, and 20,000 psi in flexure. Exposure periods varied from 3 to 36 months.

Objective

The objective of this project was to determine the effects of simulated waste solutions and control solutions on laboratory constructed specimens. Specimens represented wall sections of a waste storage tank. Test specimens were cast using aggregates from the same source as used for Hanford waste storage tanks. Reinforced concrete specimens, while exposed to the solutions, were placed in an oven at 180°F ± 10°F. Performance was evaluated by determining stress-strain characteristics of reinforcing steel, petrographic examination of concrete, and visual inspection of the reinforcing steel 180°F was selected to represent a top concrete temperature for most waste tanks.

FINDINGS

In general, physical testing of the reinforcing bars extracted from all of the specimens indicated no effects of the test solutions under conditions of the test exposure. Petrographic examination of the concrete showed no evidence of adverse reactions between the solutions and the concrete or the steel. Solutions penetrated to the reinforcement in the flexural specimens during exposure. However, examination of the reinforcing steel indicated no evidence of rusting, cracking, or disruption of the mill scale initially on the steel.

DESCRIPTION OF TEST SOLUTIONS

Specimens were exposed to three test solutions for different periods of time as indicated in Table 2. The test solutions were simulated salt cake waste, control, and double-shell slurry. Composition of each test solution is given in Table 3.

TABLE 1. Project Team.

Research Executed By:	Structural Experimental Section Structural Development Department Engineering Development Division
Responsible Executive:	Walter E. Kunze Group Vice President Research and Development Construction Technology Laboratories
Project Management:	Donald M. Schultz Manager Structural Experimental Section
	Dr. Henry G. Russell/ Director Structural Development Department
Principal Investigator:	James I. Daniel Structural Engineer Structural Experimental Section
Co-Investigators:	David C. Stark Principal Research Petrographer Concrete Materials Research Department
	Paul H. Kaar Former Senior Structural Engineer Structural Development Department
Lead Technicians:	William Hummerich (Testing of Reinforcement) Assistant Laboratory Foreman Structural Experimental Section
	William H. Graves (Construction and Extraction) Senior Technician Structural Experimental Section
	Bernard J. Doepp (Exposure Control) Senior Technician Structural Experimental Section

TABLE 2. Breakdown of Performance.

Specimen exposure period (month)	Solution	Specimen loading condition (load type/stress, psi x 1,000)	Prime contributors	Completion date
3	W[a]	Compressive/0.5	P. H. Kaar D. C. Stark	August 1978
3	W	Flexural/10		
3	W	Flexural/20		
6	W	Compressive/0.5	P. H. Kaar D. C. Stark	May 1979
6	W	Flexural/10		
6	W	Flexural/20		
19	W	Compressive/0.5	P. H. Kaar D. C. Stark	September 1980
19	W	Flexural/10		
19	W	Flexural/20		
19	C[b]	Compressive/0.5		
19	C	Flexural/10		
19	C	Flexural/20		
13	W	Compressive/0.5	J. I. Daniel D. C. Stark P. H. Kaar	July 1982
12	DSS[c]			
13	W	Flexural/10		
12	DSS			
13	W	Flexural/20		
12	DSS			
36	W	Compressive/0.5	D. M. Schultz	October 8, 1982
36	W	Flexural/10		
36	W	Flexural/20		
36	C	Compressive/0.5		
36	C	Flexural/10		
36	C	Flexural/20		

[a] Waste.
[b] Control.
[c] Double-shell slurry.

TABLE 3. Test Solutions Compositions.

Chemical	Simulated waste solution	Control solution	Double-shell slurry solution
Calcium hydroxide	None	Saturated	None
Sodium hydroxide	7N*	None	7.3N
Sodium nitrate	3N		6.0N
Sodium nitrite	3N		4.5N
Sodium aluminate	2N		4.3N
Sodium chloride	0.1N		None
Sodium carbonate	0.2N		0.7N
Sodium sulphate	0.5N		0.2N
Sodium flouride	0.1N		None
Sodium phosphate	None		0.3N

*Normality concentration (7.0 normal).

Solutions were stored separately in covered steel tanks. Bottoms of the tanks were slotted parallel to the specimen axis. The 1-1/2-in.-long by 1/8-in.-wide slots were large enough to keep the top of the specimen moist. Tanks were sealed around the bottom periphery.

DESCRIPTION OF SPECIMENS

Reinforced concrete specimens were 36-in. long, 9-in. deep, and 12-in. wide. Each specimen was reinforced with three No. 4 deformed bars. Top and side concrete cover of reinforcement was 3-in. Concrete mix proportions and materials were specified by Rockwell Hanford Operations in Service Agreement SA-256. Specimens were fabricated using ASTM Designation: C150 Type II cement containing 7% to 8% calcium aluminate (C_3A). The concrete mix design is shown in Table 4. Cement and aggregate were supplied by Rockwell and are identical to that used in the actual waste tanks. Reinforcing steel embedded in each specimen was manufactured by Bethlehem Steel Corporation.

Concrete for specimens was mixed, placed, and cured under conditions described in ASTM Designation: C192, "Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory." Specimens were cured for 28 days in a moist room at 73°F and 100% relative humidity. Subsequent to moist curing, specimens were placed in the laboratory at 73°F and 50% relative humidity until loading. Specimens were at least 44 days old when loads were applied.

TABLE 4. Concrete Mix Design.

Constituent	Quantity (lb/yd^3)
Cement	494
Sand	1,154
Gravel (3/4 in. max. size)	2,000
Water	267
Characteristics	
Water to cement ratio	0.54
Percent fine aggregate of total aggregate	36.6%
Percent air	4% to 5%

For each combination of exposure period and test solution, three specimens were loaded as indicated in Table 2. One specimen was maintained under sustained flexural loads. The uncracked compressive specimen was maintained at 500 psi compressive stress. Flexural specimens were loaded to cracking. After cracking, load was applied so that reinforcement stress was 10,000 psi in one specimen and 20,000 psi in the other. Loading apparatus and photographs of load application to compressive and flexural specimens are shown in Figures 1 through 4.

Loads required to produce the desired reinforcement stress in flexural specimens were calculated using sectional analysis based on measured material properties, equilibrium of forces, and strain compatibility. Loads were checked using a dummy specimen identical to test specimens but instrumented with strain gages on the reinforcement. After confirming that calculated loads were those necessary to obtain the desired stress, the dummy specimen was discarded. Strain gages were not used on reinforcement in test specimens.

All specimens were exposed to test solutions in an oven held at 180°F ± 10°F. Load on each specimen was adjusted several times to compensate for creep of specimens and relaxation of load apparatus. Figure 5 shows technicians adjusting loads.

Specimen Exposed to Double-Shell Slurry Solution

Specimens exposed to double-shell slurry solution were originally manufactured under Rockwell Contract SA-256. Under this contract, specimens were exposed for 13 months to the simulated salt cake solution. Upon receipt of Rockwell Contract SA-469, these specimens subsequently were exposed for 12 months to the double-shell slurry solution as indicated in Table 2.

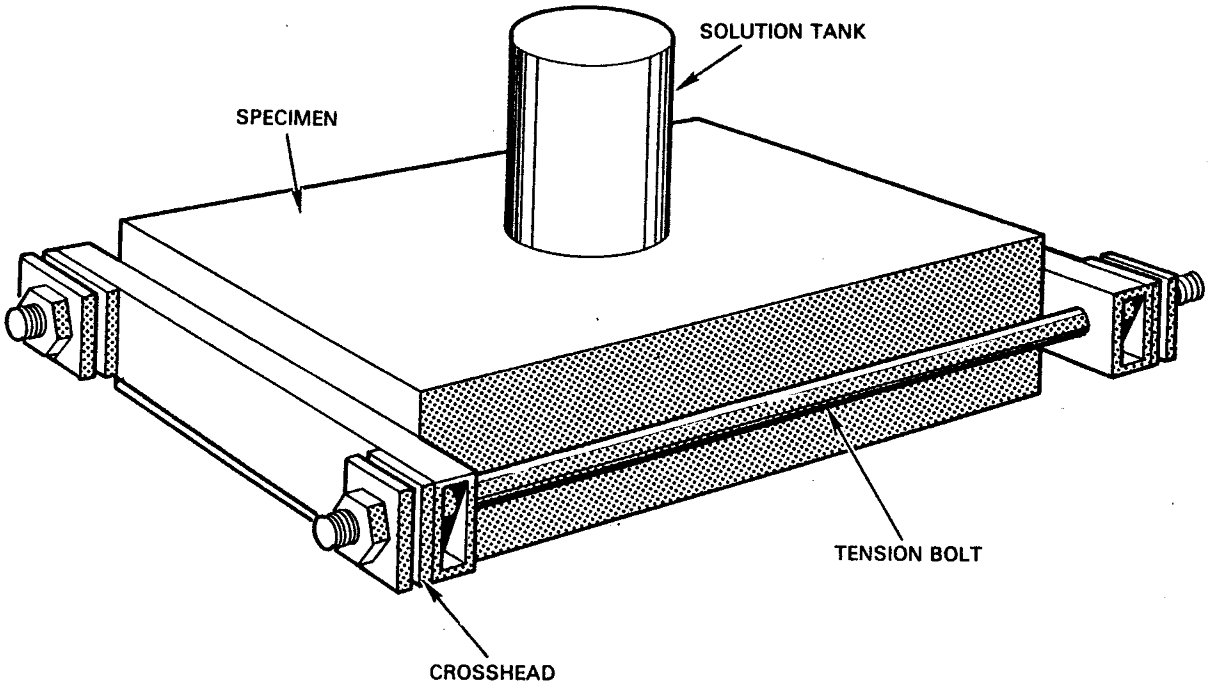


FIGURE 1. Compressive Specimen Under Load.

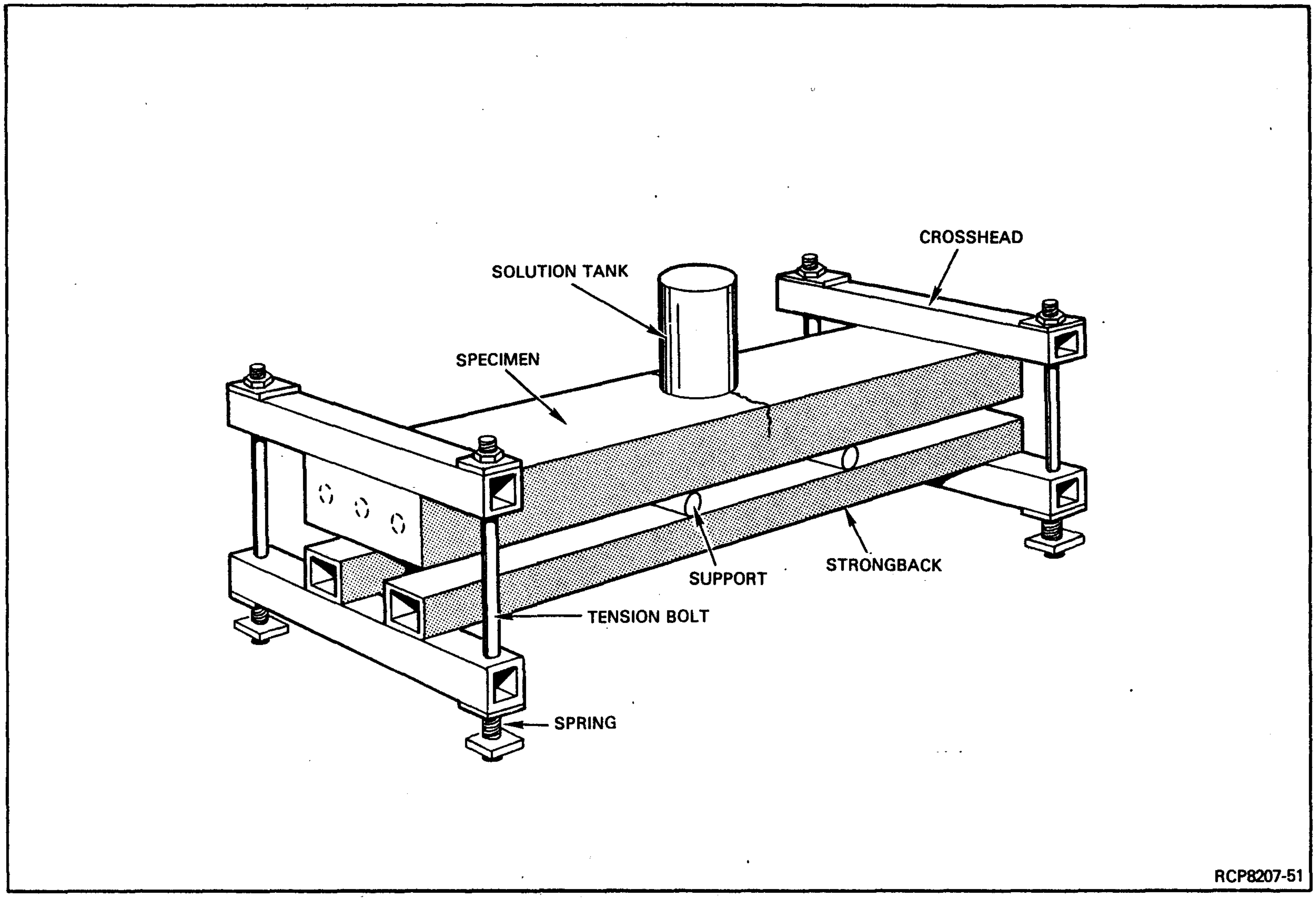


FIGURE 2. Flexural Specimen Under Load.

FIGURE 3. Load Application to Flexural Specimen.

FIGURE 4. Load Application to Compressive Specimen.

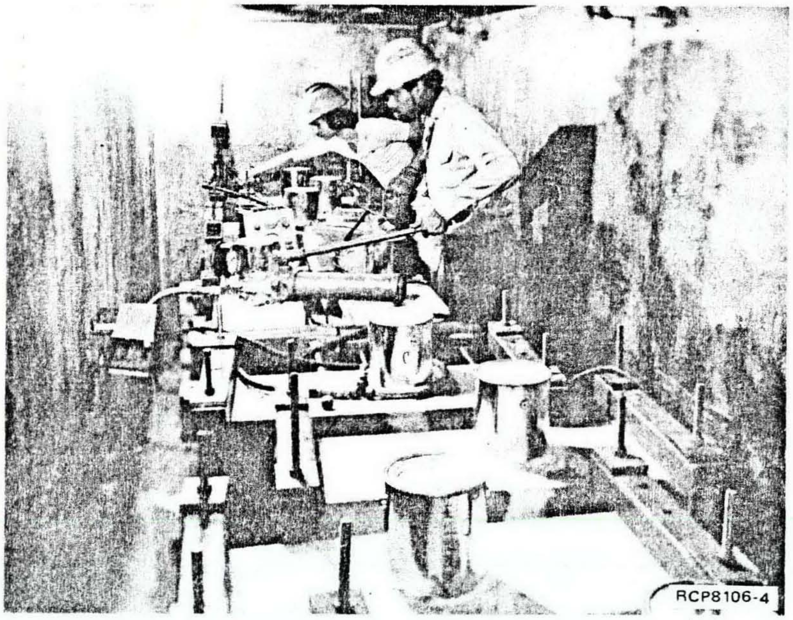


FIGURE 5. Load Adjustments Being Conducted During Exposure Test.

TEST RESULTS

Tensile Tests of Reinforcing Bars

At end of the exposure period, specimens were removed from the oven and the reinforcement was extracted. All three reinforcing bars from each specimen were tested. Tensile test results for all reinforcing bars are tabulated in Tables 5 through 11. Values of yield stress correspond with the yield plateau.

Load versus strain relationships of the reinforcement before and after exposure are shown in Figures 6 through 12. Some curves showed a rounding behavior prior to reaching the yield plateau. However, no significant differences were observed in the yield plateaus of reinforcement tested before and after exposure.

TABLE 5. Reinforcement Tensile Tests After Three Months Exposure to Simulated Salt Cake Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0 49.0 52.0 Av. 50.0	81.5 82.0 83.0 Av. 82.2	19.1 20.6 17.4 Av. 19.0
Compression 500 psi	48.5 48.0 49.5 Av. 48.7	81.0 81.0 81.5 Av. 81.2	20.6 20.3 19.0 Av. 20.0
Flexure 10,000 psi	48.5 50.0 48.5 Av. 49.0	82.0 82.0 82.0 Av. 82.0	17.7 18.5 18.6 Av. 18.3
Flexure 20,000 psi	46.5 48.0 48.0 Av. 47.5	80.0 81.5 81.5 Av. 81.0	15.9 18.6 18.0 Av. 17.5

TABLE 6. Reinforcement Tensile Tests After Six Months Exposure to Simulated Salt Cake Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0	81.5	19.1
	49.0	82.0	20.6
	52.0	83.0	17.4
	Av. 50.0	Av. 82.2	Av. 19.0
Compression 500 psi	49.0	82.0	19.2
	50.0	82.5	17.8
	49.5	83.0	22.3
	Av. 49.5	Av. 82.5	Av. 19.8
Flexure 10,000 psi	49.0	81.0	21.2
	51.0	82.5	19.3
	50.5	81.5	18.1
	Av. 50.2	Av. 81.7	Av. 19.5
Flexure 20,000 psi	49.5	81.0	17.6
	47.0	79.5	16.6
	47.5	80.5	18.2
	Av. 48.0	Av. 80.3	Av. 17.5

TABLE 7. Reinforcement Tensile Tests After 19 Months Exposure to Simulated Salt Cake Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0	81.5	19.1
	49.0	82.0	20.6
	52.0	83.0	17.4
	Av. 50.0	Av. 82.2	Av. 19.0
Compression 500 psi	51.0	81.0	19.4
	51.0	81.5	13.7*
	50.5	80.0	19.9
	Av. 50.8	Av. 80.8	Av. 17.7
Flexure 10,000 psi	51.5	80.5	19.4
	51.0	81.5	20.4
	51.0	80.5	18.2
	Av. 51.2	Av. 80.8	Av. 19.3
Flexure 20,000 psi	50.5	80.5	19.6
	50.0	81.0	20.2
	51.0	80.0	19.6
	Av. 50.5	Av. 80.5	Av. 19.8

*Bar fractured outside gage points.

TABLE 8. Reinforcement Tensile Tests After 19 Months Exposure to Control Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0	81.5	19.1
	49.0	82.0	20.6
	52.0	83.0	17.4
	Av. 50.0	Av. 82.2	Av. 19.0
Compression 500 psi	49.5	79.0	18.7
	50.5	81.5	17.2
	49.5	79.0	18.9
	Av. 49.8	Av. 79.8	Av. 18.3
Flexure 10,000 psi	50.5	80.2	16.2*
	51.0	80.0	19.9
	51.5	80.5	15.6*
	Av. 51.0	Av. 80.2	Av. 17.2
Flexure 20,000 psi	50.0	80.5	20.0
	50.0	79.0	17.2
	50.2	79.5	16.2*
	Av. 50.1	Av. 79.7	Av. 17.8

*Bar fractured outside gage points.

TABLE 9. Reinforcement Tensile Tests After 13 Months Exposure to Simulated Salt Cake Solution and 12 Months Exposure to Double-Shell Slurry Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0	81.5	19.1
	49.0	82.0	20.6
	52.0	83.0	17.4
	Av. 50.0	Av. 82.2	Av. 19.0
Compression 500 psi	49.5	80.0	16.6
	49.0	81.5	14.8
	51.0	82.0	19.5
	Av. 49.8	Av. 81.5	Av. 17.0
Flexure 10,000 psi	50.5	81.8	18.5
	50.0	81.8	18.9
	49.0	81.0	21.0
	Av. 49.8	Av. 81.5	Av. 19.5
Flexure 20,000 psi	50.0	81.0	17.5
	49.0	81.0	*
	50.0	81.5	17.5
	Av. 49.7	Av. 81.2	Av. 17.5

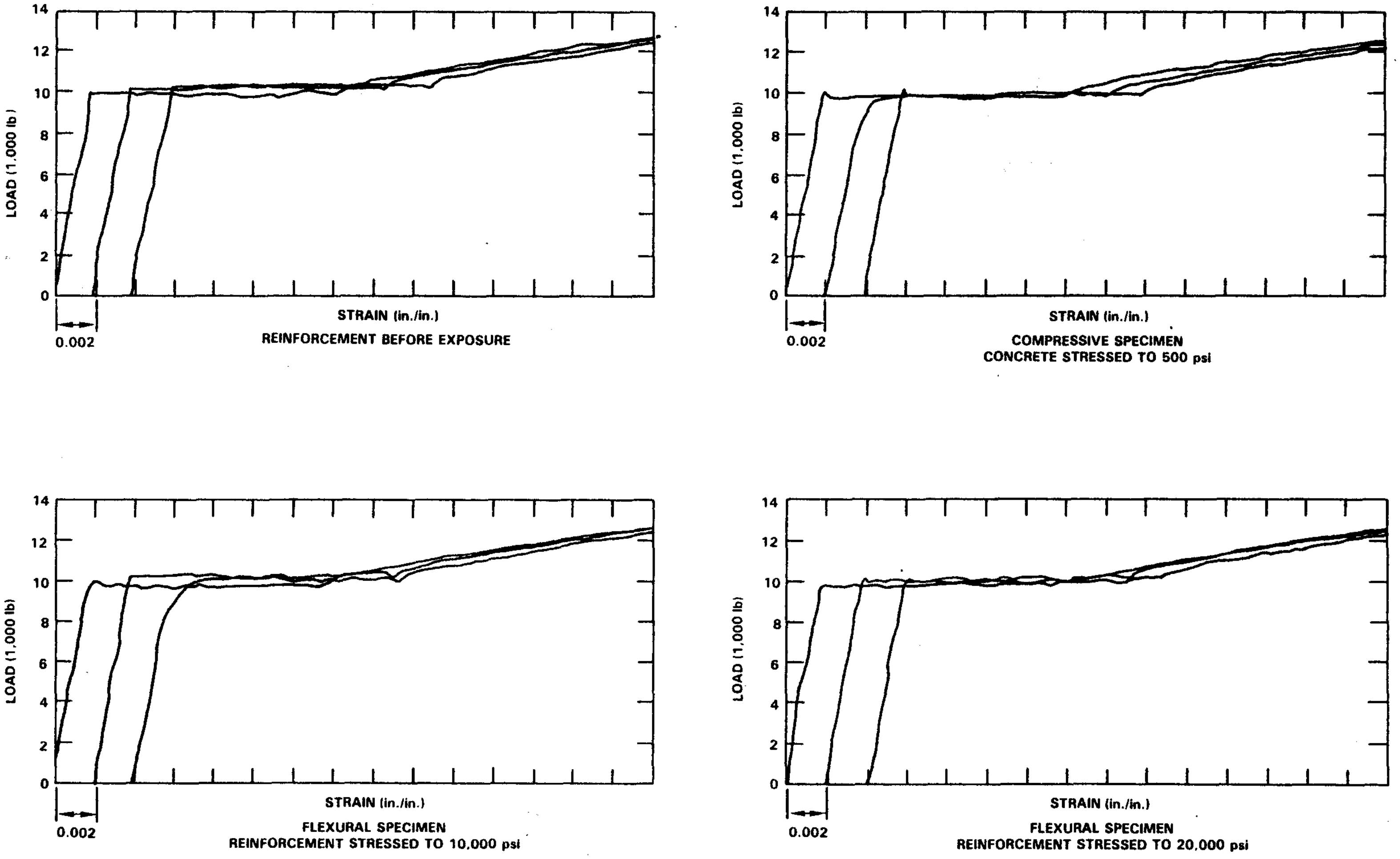
*Bar fractured outside gage points.

TABLE 10. Reinforcement Tensile Tests After 36 Months Exposure to Simulated Salt Cake Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0 49.0 52.0 Av. 50.0	81.5 82.0 83.0 Av. 82.2	19.1 20.6 17.4 Av. 19.0
Compression 500 psi	50.0 49.5 51.0 Av. 50.2	81.0 81.0 81.5 Av. 81.2	19.0 18.3 19.6 Av. 19.0
Flexure 10,000 psi	50.0 50.0 50.0 Av. 50.0	81.0 80.0 81.0 Av. 80.7	17.8 21.0 18.3 Av. 19.0
Flexure 20,000 psi	50.5 49.0 49.0 Av. 49.5	81.0 80.5 80.5 Av. 80.7	18.4 18.1 20.6 Av. 19.0

TABLE 11. Reinforcement Tensile Tests After 36 Months Exposure to Control Solution.

Specimen	Yield stress (psi x 1,000)	Ultimate stress (psi x 1,000)	Percent elongation in 8 in.
Reinforcement as received	49.0 49.0 52.0 Av. 50.0	81.5 82.0 83.0 Av. 82.2	19.1 20.6 17.4 Av. 19.0
Compression 500 psi	50.5 48.0 51.0 Av. 49.8	81.0 80.5 81.0 Av. 80.8	17.9 21.9 18.3 Av. 19.4
Flexure 10,000 psi	51.0 52.0 51.0 Av. 51.3	81.5 82.0 81.0 Av. 81.5	19.9 18.8 18.9 Av. 19.2
Flexure 20,000 psi	51.0 50.0 50.0 Av. 50.3	81.5 81.0 81.5 Av. 81.3	18.4 20.3 18.0 Av. 18.9



REINFORCEMENT BEFORE EXPOSURE

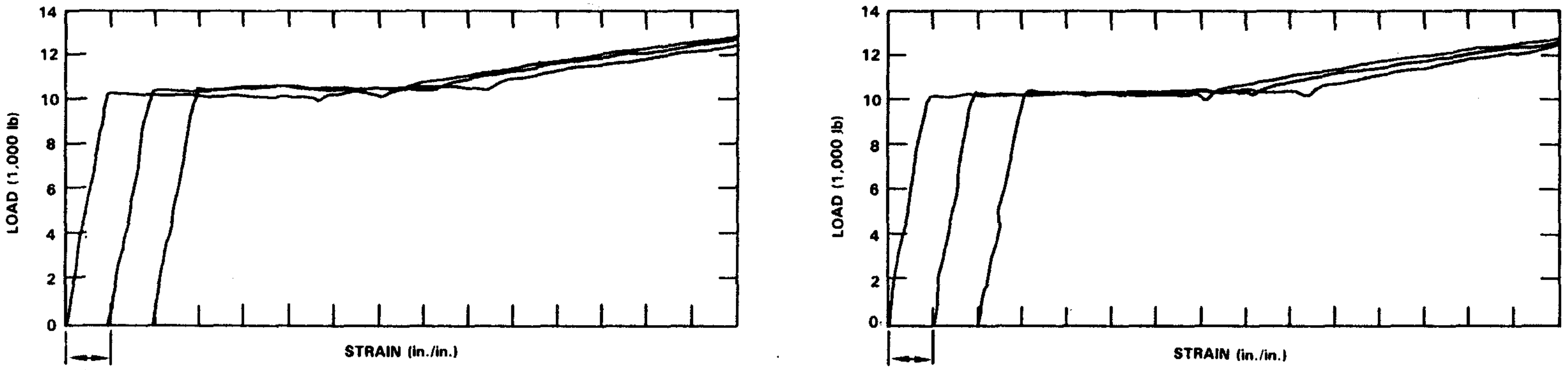
COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

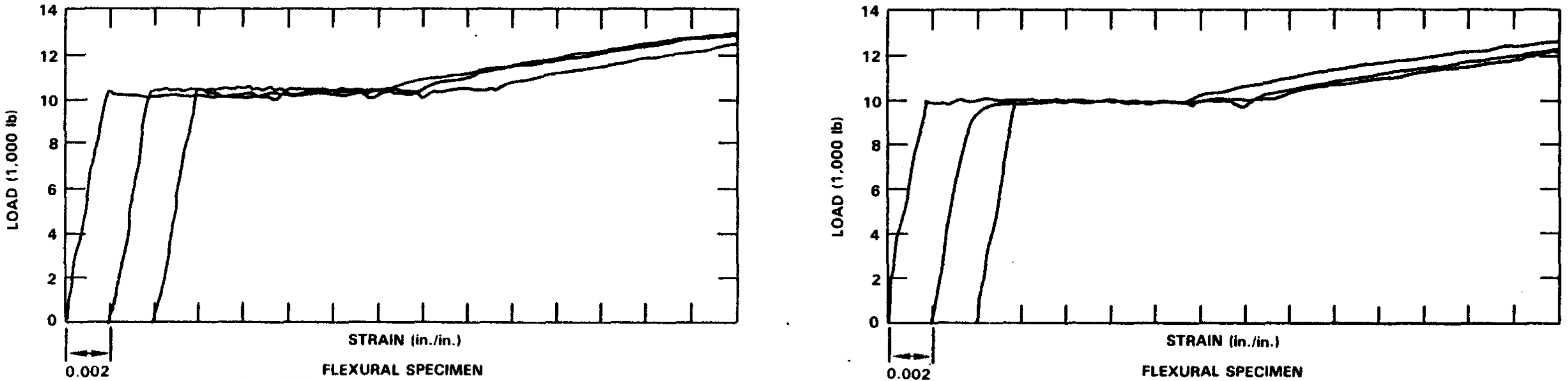
RCP8212-7

FIGURE 6. Load Versus Strain Relationships of Reinforcement Before and After Exposure for Three Months to Simulated Salt Cake Solution.



REINFORCEMENT BEFORE EXPOSURE

COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

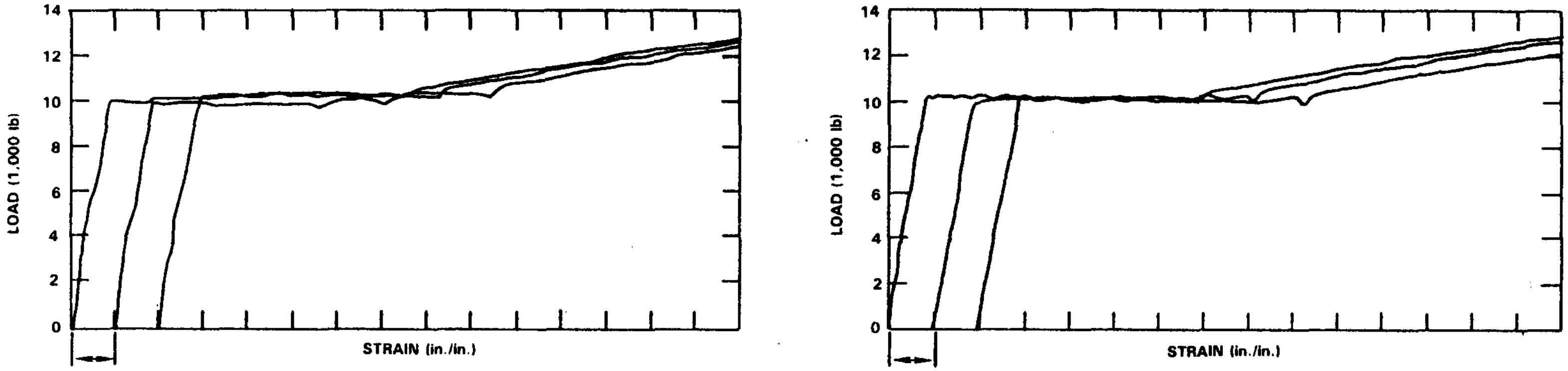


FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

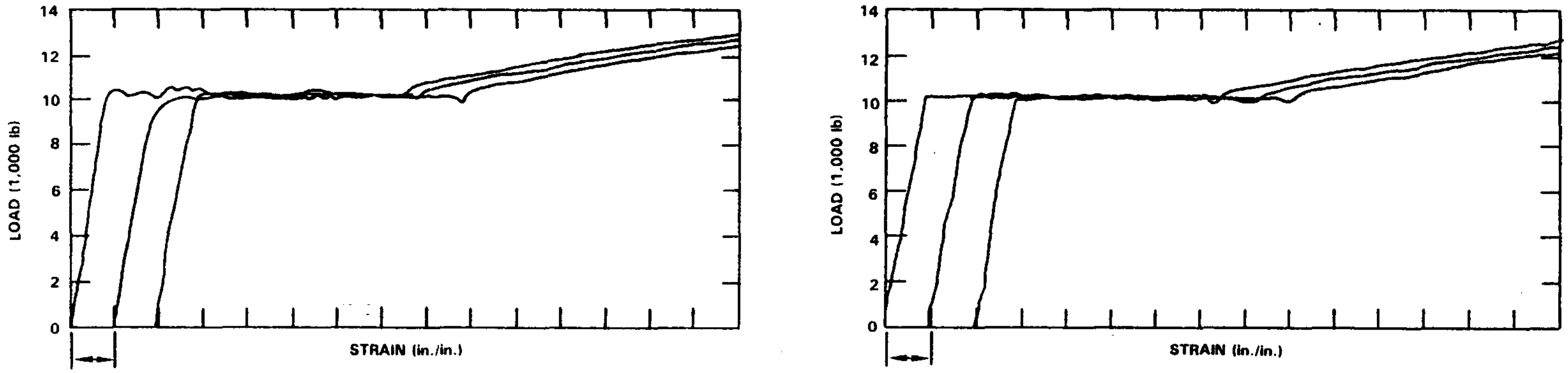
RCP8212-8

FIGURE 7. Load Versus Strain Relationships of Reinforcement Before and After Exposure for Six Months to Simulated Salt Cake Solution.



REINFORCEMENT BEFORE EXPOSURE

COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

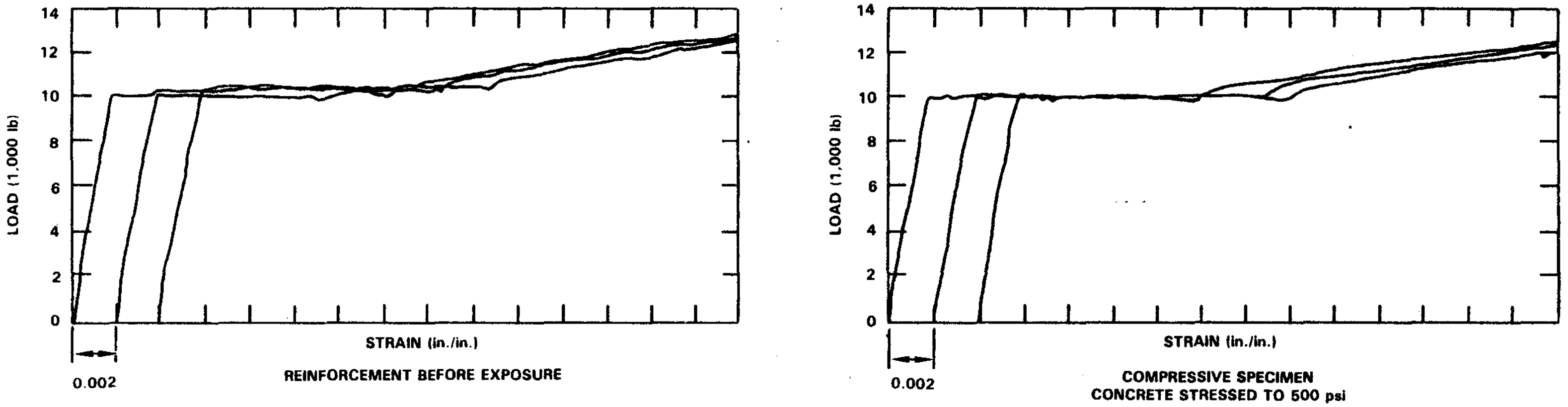


FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

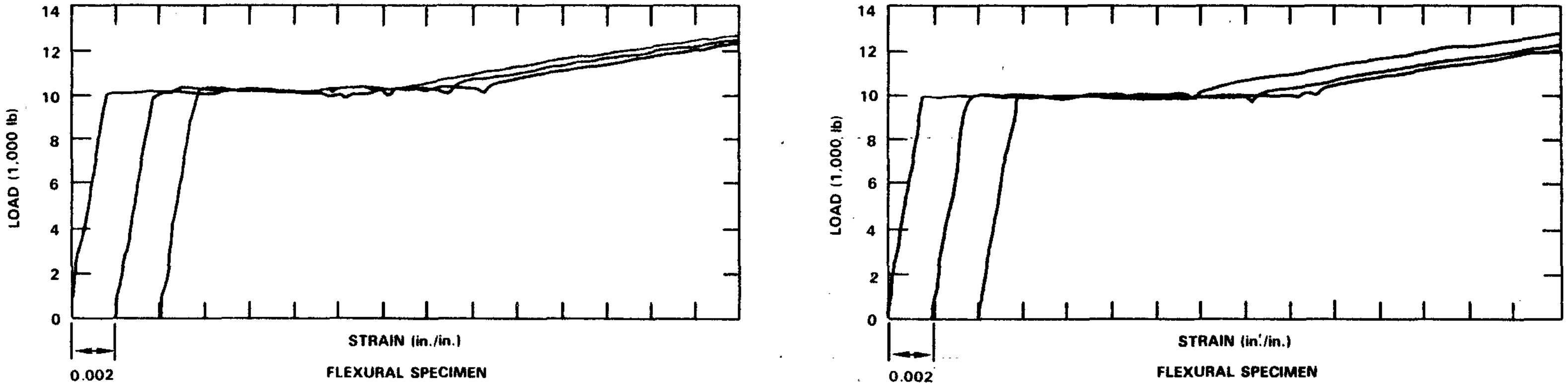
RCP8212-9

FIGURE 8. Load Versus Strain Relationships of Reinforcement Before and After Exposure for 19 Months to Simulated Salt Cake Solution.



REINFORCEMENT BEFORE EXPOSURE

COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

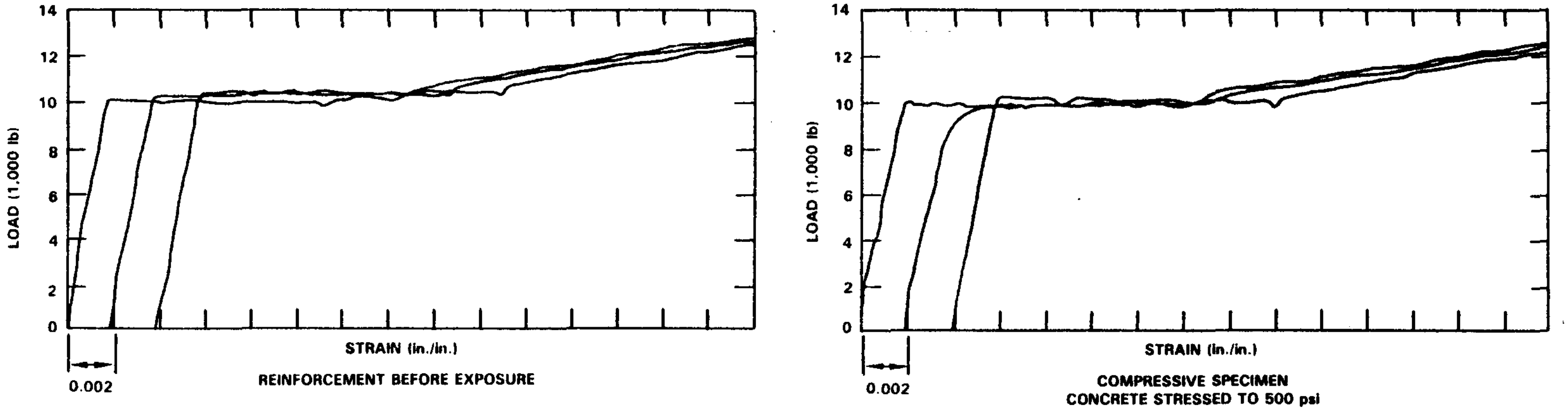


FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

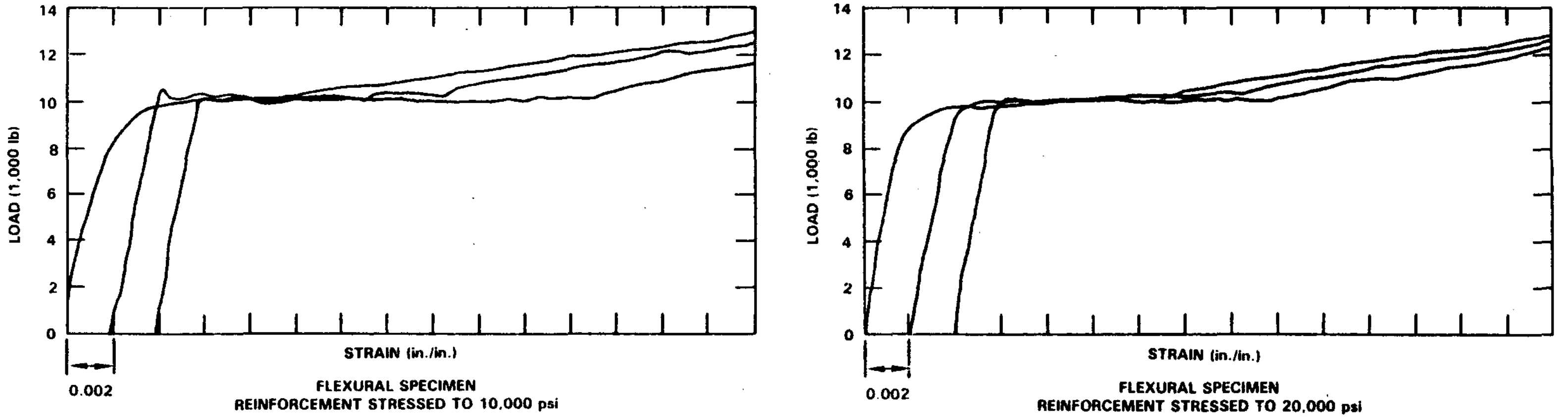
RCP8212-10

FIGURE 9. Load Versus Strain Relationships of Reinforcement Before and After Exposure for 19 Months to Control Solution.



REINFORCEMENT BEFORE EXPOSURE

COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

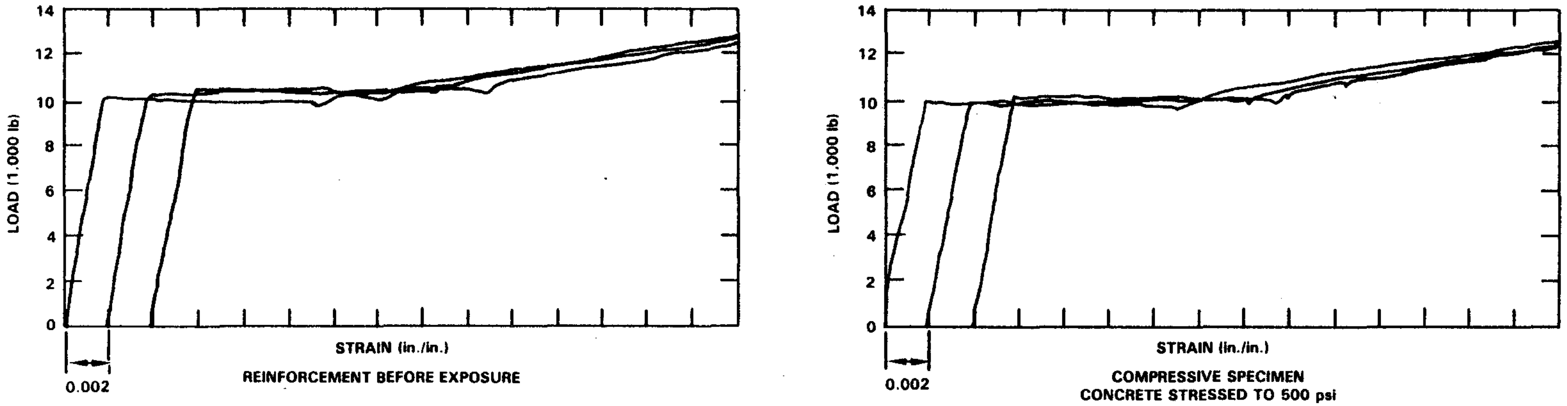


FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

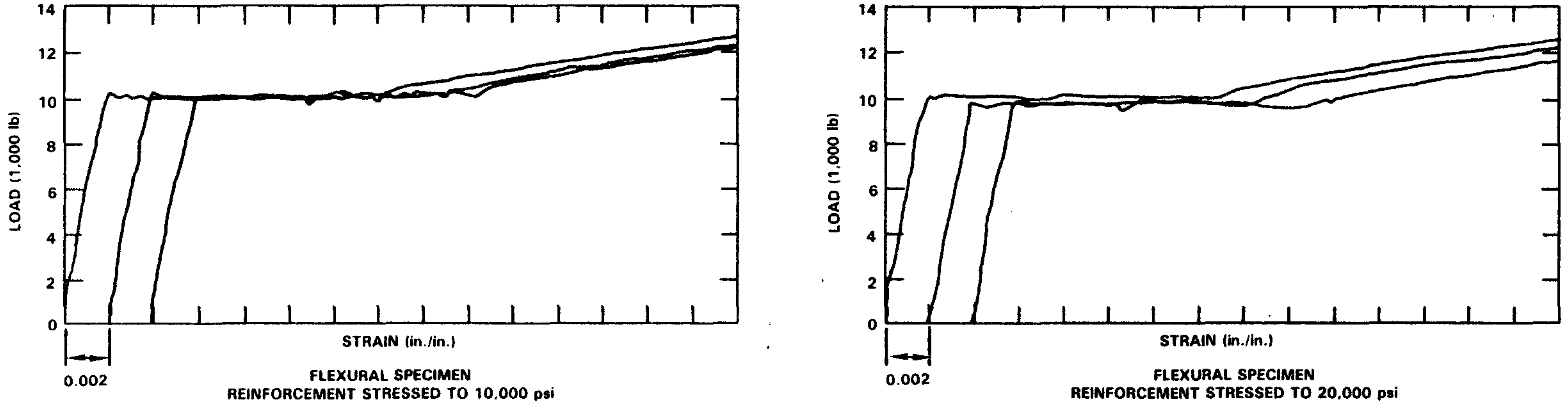
RCP8212-11

FIGURE 10. Load Versus Strain Relationships of Reinforcement Before and After Exposure for 13 Months to Simulated Salt Cake Solution and 12 Months to Double-Shell Slurry Solution.



REINFORCEMENT BEFORE EXPOSURE

COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

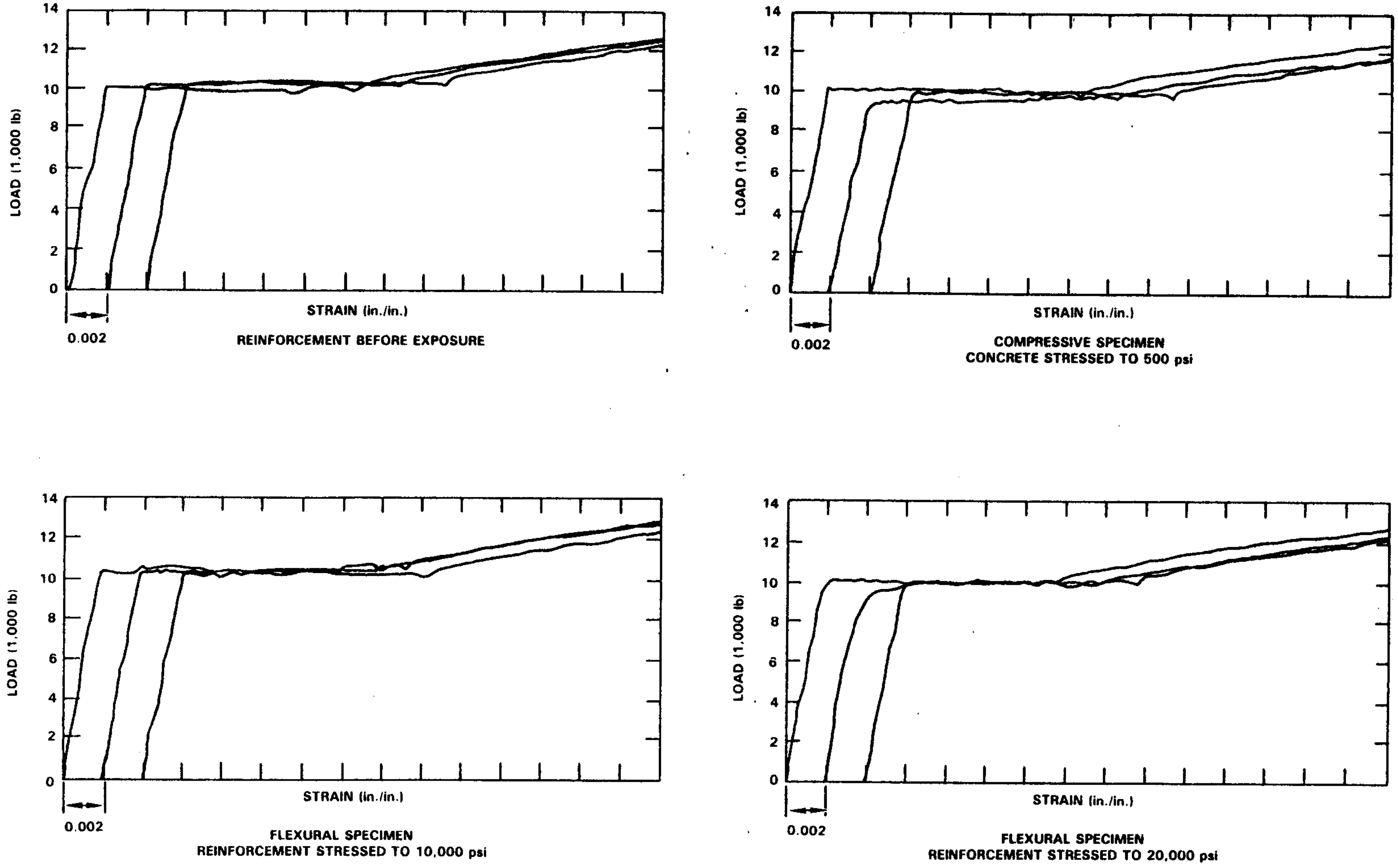


FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

RCP8212-12

FIGURE 11. Load Versus Strain Relationships of Reinforcement Before and After Exposure for 36 Months to Simulated Salt Cake Solution.



REINFORCEMENT BEFORE EXPOSURE

COMPRESSIVE SPECIMEN
CONCRETE STRESSED TO 500 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 10,000 psi

FLEXURAL SPECIMEN
REINFORCEMENT STRESSED TO 20,000 psi

RCP8212-13

FIGURE 12. Load Versus Strain Relationships of Reinforcement Before and After Exposure for 36 Months to Control Solution.

Petrographic Examinations

Petrographic examinations of concrete and visual inspection of reinforcing bars extracted from all specimens revealed no evidence of steel corrosion, as indicated by the presence of corrosion reaction products. Electrical potentials measured on the steel while embedded in the concrete also indicated no active corrosion. Inspection of flexural crack surfaces revealed that the test solutions penetrated to the steel. Thus, it is concluded that the steel did not incur electrochemical corrosion in the presence of any one of the three test solutions under conditions of the test exposure.

CONCLUDING REMARKS

This final report describes specimens simulating a wall section of a Hanford reinforced concrete waste storage tank exposed for several time periods to simulated waste solutions. Similar specimens were subjected to a control solution of saturated calcium hydroxide. For the time periods of exposure to the test solutions, there was no significant change in concrete or reinforcement properties examined.

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