UNCLASSIFIED

| AD NUMBER |
|---|
| **AD856906** |
| LIMITATION CHANGES |
| TO:<br>**Approved for public release; distribution is unlimited.** |
| FROM:<br>**Distribution authorized to U.S. Gov't. agencies only; Administrative/Operational Use; JUL 1969. Other requests shall be referred to Naval Cicil Engineering Laboratory, Port Hueneme, CA 93041.** |
| AUTHORITY |
| **USNCEL ltr, dtd 28 Oct 1969** |

THIS PAGE IS UNCLASSIFIED

Technical Note N-1032

# EFFECTIVENESS OF ZINC COATING ON REINFORCING STEEL IN CONCRETE EXPOSED TO A MARINE ENVIRONMENT

By

Donald F. Griffin

July 1969

Each transmittal of this document outside the agencies of the U. S. Government must have prior approval of the Naval Civil Engineering Laboratory.

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California 93041

47

# EFFECTIVENESS OF ZINC COATING ON REINFORCING STEEL IN CONCRETE EXPOSED TO A MARINE ENVIRONMENT

Technical Note N-1032

Z-R011-01-01-095

by

Donald F. Griffin

## ABSTRACT

This investigation was made to determine whether or not galvanized steel reinforcement is more suitable than non-galvanized steel reinforcement in concrete exposed to a marine environment. The criterion of comparative suitability is time-dependent cracking of reinforced concrete walls caused by expansive forces resulting from build-up of corrosion products. From the results of the investigation, the important conclusions are that galvanized steel reinforcement is, at best, no better than non-galvanized steel reinforcement, and air-entrained concrete inhibits corrosion of either galvanized or non-galvanized steel reinforcement compared to non air-entrained concrete.

Each transmittal of this document outside the agenices of the U. S. Government must have prior approval of the Naval Civil Engineering Laboratory.

## CONTENTS

## INTRODUCTION

The objective of this study is to determine whether or not galvanized steel reinforcement is more suitable than non-galvanized steel in concrete in a marine environment. The criterion of comparative suitability is time-dependent cracking of reinforced concrete caused by expansive forces resulting from build up of corrosion products.

Previous investigations have shown that concrete can accumulate considerable chloride salts when exposed to sea spray; however, the integrity of plain concrete remains relatively undisturbed up to fairly high concentrations of such salts.[1,2] In contrast to plain concrete, steel reinforced concrete is highly vulnerable to relatively low chloride concentrations, once chlorides have penetrated to the steel reinforcements.[1,2,3] Unless the steel is protected by adequate concrete cover or by extremely high quality high strength concrete, expansive forces generated by the build up of corrosion products around the steel may crack the concrete and subject the steel to accelerated deterioration.

In the absence of a tested and proven surface treatment rendering concrete impermeable to salt water in a marine environment, it appeared desirable to consider other ways of protecting concrete from effects of corrosion of reinforcing steel. Protection in the form of a zinc surface coating on the steel to prevent corrosion of the steel appeared to be worthy of consideration since the efficacy of galvanized steel in atmospheric conditions has been well established.

A study completed after this investigation was under way showed that "A consideration of all the data suggests that zinc-coated rods would have a significantly longer service life than bare (steel) rods (as concrete reinforcement)."[4] This observation was based on results of some electrochemical studies on uncoated steel as well as steel coated with selected materials. The report recommended limited field testing in an environment that would expose concrete to salt.

## EXPERIMENTAL PARAMETERS

Eleven small concrete walls were constructed and then sprayed daily with sea water in order to simulate a marine environment. Some of the walls were reinforced with steel, some were air-entrained, and some contained no steel except in the footings. The footings of the plain walls were reinforced to obviate cracking that might be attributable to differential conditions in the underlying soil. See Figure 1. The plain or unreinforced walls were included to dispel doubts as to whether or not the concrete would crack regardless of presence or absence of reinforcing steel.

### Concrete

In order to accomplish the objective within a reasonable period of time, a concrete mix design used in a previous study was selected. Reinforcing steel embedded in this concrete was known to be vulnerable to corrosion after a sufficient amount of chlorides had migrated through the concrete to the steel.[1,2,3] In addition, similar concrete made using a lower water-cement ratio and a higher cement content was known to be highly resistant to such effects.[5]

The basic mix design is shown in Table 1. Appendix A provides a petrographic description of the aggregate. The effects of air-entrainment were also investigated. To obtain the air-entrained concrete, the design in Table 1 was adjusted in accordance with the recommendations of the manufacturer of the air-entraining agent, that is, (1) reduce sand content of mix 100 to 125 pounds per cubic yard of concrete (reduced by 112.5 lbs per cu yd of concrete); (2) reduce water in mix approximately 8%; (3) add to the sand or water 1/2 to 1 fluid ounce of DAREX AEA per sack of cement (3/4 fl oz per sack used); and (4) determine air content in concrete. Air content should be between 3 - 6% by volume.

## Depth of Concrete Cover

For reasons similar to those above, it was desired to use wall sizes and especially wall thicknesses with minimum depth of cover as used in a previous investigation.[1,2,3] Therefore, a depth of cover of one inch was used. An exception is that depth of cover vertically over the top horizontal reinforcing bar is six inches. Exclusive of the footing, the wall dimensions are 3.5 inches thick, 34-1/2 inches high, and 36 inches wide, as illustrated in Figure 2.

## Reinforcing Steel

Under a cooperative arrangement with the University of California, steel reinforcing grids were furnished by Dr. Boris Bresler and Dr. I. Cornet. Reinforcing steel of the same size used previously[2] was also employed in this study. No. 5 steel bars intermediate grade conforming to ASTM Designations: A15-64 and A305-56T were used to fabricate grids as reinforcement for the walls. Bars were spaced approximately 6 inches on centers in the grids. (See Appendix B for details.)

The parameters of the steel included (a) clean sand blasted steel, (b) steel cleaned as in (a) followed by zinc coating; after the steel was bent or spot welded as required, the zinc coating wherever damaged was touched up with a zinc-enriched paint, and (c) steel treated the same as in (b) except the damaged areas of zinc were not touched up with zinc-enriched paint. Further, the steel in the grids was held in place either by tack welding all steel bars at contact points or by tieing the steel bars together with nylon fishing line after insulating the points of bar contact with plastic tape. Figures 3 and 4 show typical steel grids.

The amount of zinc on the hot-dipped steel bars was 4.5 ounces per square foot of surface area as determined by using the test method described in ASTM Designation: A90-53. This corresponds to a coating thickness of 9 mils. The latter figure was verified by actually measuring the thickness on a polished cross section using a metallograph.

## Sea Water Spray

Once each morning at about 0800 hours, the south side of each wall was sprayed with sea water. The salinity of this water from a well adjacent to the ocean at NCEL averages about $31.68^{o}/_{oo}$ (grams of salt per kilogram of sea water). The pH value of this well water is 7.40. These values may be compared with those for surface sea water a few hundred feet from the well. Salinity of the surface sea water averages $33.52^{o}/_{oo}$ and the pH averages 8.15.

The basic variables for the walls are summarized in Table 2.

## Concrete Casting

It was desired to cast the walls and specimens of concrete within the shortest feasible period of time to avoid differential effects that might be attributable either to weather or operating personnel. Therefore, it was decided to cast the walls inverted in the laboratory in contrast to casting directly in the field. Although walls 109, 110 and 111 were cast more than a month after the others, the delay could not be avoided, and fortunately weather conditions were not significantly different. In addition, the same operating personnel were available.

All aggregate had been dried, separated, and recombined for batches of 2 cu ft as shown in Table 1. A pan-type mixer was used with the following sequential operations: (1) add gravel, sand, and then cement and mix dry for 30 seconds; (2) add water at 73F with mixer running; (3) mix for 150 seconds or a total of 3 minutes including dry mixing; (4) test concrete for slump and air entrainment, and sample concrete for hydrogen - ion concentration (pH); (5) if concrete is satisfactory, place concrete in walls and specimen molds; (6) place castings in fog room. Properties of the fresh concrete are shown in Table 3.

In order not to damage the zinc coating on the reinforcing steel, external form vibrators (one on each side) were used on the wall forms in lieu of internal spud vibrators. The vibrators were activated only when concrete was actually being placed in the forms; visually, this appeared adequate.

While filling the forms with concrete, the steel grids were held securely in place with spacers as shown in Figure 5. The wooden spacers were continually withdrawn to the level of the fresh concrete; the spacers made of concrete were left in place. After a wall was half-filled with fresh concrete, the form vibrators were moved from a lower position to an upper position on the form. The concrete disks shown in Figure 5 were of the same concrete design as the corresponding wall. The disks were etched in hydrochloric acid and rinsed in fresh water prior to use.

While casting concrete cylinders, the molds rested on a metal cart; the form vibrators were attached to the cart and activated while concrete was placed in the molds.

Positive efforts on the part of all the operating personnel were made to fabricate all walls and specimens in a like manner. For the air-entrained concrete, the DAREX was added to the mix water prior to adding water to the batch.

The walls were cast in forms mounted on metal carts; after casting, the assembly was rolled into the fog room (100% RH, 73F) and left for 28 days. After 24 hours all concrete cylinders were stripped of their molds, the specimens stamped with an I.D. number and stored in the fog room.

## Placing Walls

At 28 days age, each wall and corresponding field specimens were removed from the fog room and transferred to a field site. Each wall was carefully inverted so it was right side up. By means of rope slings, the walls were lifted as shown in Figure 6 and then lowered onto a prepared sand bed. The ropes were pulled from beneath the walls with very little disturbance of the soil and then the wood forms were removed. The walls were oriented so that the horizontal bars in the steel grids were toward the face receiving sea water spray; the vertical bars were toward the opposite face. An overall view of the walls and sea water spray system is shown in Figure 7.

All surface voids of the walls were filled with fresh mortar to avoid water pockets. See Figure 8. In order to properly cure the mortar, the walls were then wrapped in polyethylene sheeting for several days. After the polyethylene sheeting was removed, the walls were subjected to sea water spray from 0800 to 0805 each morning thereafter as indicated in the note of Table 2. Enough cylinders were cast for one set to remain in the fog room, one set to be placed in the field adjacent to the walls where it received sea water spray, and one set to be placed on the opposite side of the walls where it received no sea water spray.

A thermoscreen with two recording hygrothermographs was placed adjacent to the walls for recording ambient temperatures and relative humidity.

## Properties of Hardened Concrete

Properties of hardened concrete with and without air-entrainment are shown in Tables 4 and 5, respectively. Air-entrainment had the usual effect of reducing the unit weight somewhat as well as reducing the strength of the concrete when compared to non air-entrained concrete.

In order to ascertain the effects of air-entrainment on bond strength, specimens were cast and tested in accordance with ASTM Designation: C234-62. An exception to this test is that No. 5 deformed bars were used instead of No. 6 deformed bars as specified in the test. No. 5 bars match the bars in the steel reinforcing grids. Concrete was placed in molds resting on a steel cart while the cart was vibrated using the external form vibrators.

The bond test is intended to reveal effects of variations in the properties of concrete on the strength of the bond between concrete and reinforcing steel. It is not intended for use in tests in which the principal variable is the size, shape, or type of reinforcing bar. Although the type of bar surface is a variable (zinc vs steel), the test is believed to be valid as an indicator for both variables.

Bond test results are shown as Figure 9. It is apparent that the effect of the variable in the concrete, namely entrained air, had a much more pronounced effect than did the variable in the steel, that is, presence or absence of zinc coatings. In other words, the bond strength on the zinc-coated steel was about the same as for uncoated steel for either of the concretes; however, about twice as much slippage of steel occurred in the air-entrained concrete at approximately equal ultimate loads than occurred in concrete without entrained air.

## RESULTS

Following the first application of sea water spray, all exposed surfaces of the walls were carefully inspected on a weekly basis. A hand-held magnifying glass was used to scan all surfaces for cracks.

The order of cracking is shown in Table 6. The first crack noticed was in wall No. 101 on 7 December 1967. At this time the crack was only one inch long. By 29 December 1967, the crack was 14 inches long, and by 12 July 1968, it was 27.5 inches long.

By comparing Tables 2 and 6, chronological cracking of walls by type of steel grid may be noted as follows:

First - Zinc coated, welded steel grid with zinc-enriched paint touch up

Second - Same as the first except without paint touch up

Third - Same as the second except grid was not welded

Fourth - Sand-blasted, welded steel grid

Fifth - Zinc coated, non-welded steel grid with paint touch up

Sixth - Sand-blasted, steel grid bars tied and insulated

All non air-entrained concrete walls with steel grids have cracked. The two walls without steel have not cracked and no wall with air-entrainment has cracked to date.

Figures 10 through 14 illustrate the cracking that has occurred on the various walls and the extent of corrosion of the embedded steel grids. In most instances there have appeared the typical brownish stains of iron rust emanating from the cracks. This has also occurred with galvanized steel reinforcement where the cracks in the concrete were mature. Some of the cracks had a width as great as 2 mm.

Figure 10 shows cracking typical of the kind occurring on the east and west end faces. The dark areas in Figure 10 are brown stains of ferrous oxide that had migrated from the reinforcing bars. Figure 11 shows the source of the rust.

Figure 12 shows two types of cracking in the two larger faces of the walls. The crack in the upper right hand corner is typical of random cracking adjacent to east or west edges. No continuous and more or less straight vertical cracks have occurred on the north or south faces. The lower horizontal crack is not uncommon. It is directly opposite the lower horizontal steel bar of Figure 13.

Concrete was removed from the steel grid of wall 101 on 11 December 1968. The steel of this wall was zinc coated and the contact welds and the bends in the horizontal bars had been touched up with zinc-enriched paint. Every horizontal bar showed white corrosion products of zinc throughout the entire length. In addition each horizontal bar had positive showings of red rust scattered over the entire length. The two vertical bars, one on either side of the grid, were affected similarly to the horizontal bars. The four inner vertical bars had white corrosion products adjacent to the weld joints for a distance of about 1.5 inches on either side of the joint. There was no evidence of red rust on these four inner bars. The portions of the horizontal bars that were bent to the vertical position were the most severely corroded. On the east end of the wall, the red rust was very heavy.

On 20 January 1969 the concrete from wall 103 was removed from its steel grid. This grid was treated identical to that of wall 101 except the horizontal and vertical bars were tied and insulated one from another and were not welded. The exposed steel of wall 103 had the same general appearance as that of wall 101. All horizontal bars were coated with white corrosion products of zinc. White corrosion products on vertical bars were less extensive and more scattered than on horizontal bars; however, all vertical bars were affected. All bars (horizontal and vertical) had scattered red rust spots; however, the lower two horizontal bars contained the most red rust. Of these two bars, the lower bar had the most red rust. Where the horizontal bars were turned down vertically, there was no more red rust than for other areas of the bars, except for the lower bar on the west end; here, the red rust was heavier but not near as heavy as for wall 101.

On 20 January 1969 concrete was removed from the steel of wall 104. All five horizontal bars had black to red oxide deposits scattered over their entire lengths, the lowest bar being most severely affected. The vertical bars were comparatively free of rust; however, each one contained spots or traces of rust. On the two westerly vertical bars, there was more pronounced rusting below the lower horizontal bar for about a two-inch length.

A comparison of steel grids for walls 101 and 103 indicated no specific evidence of welding as contributing to corrosion of the steel grids.

## DISCUSSION

Steel. Corrosion of steel embedded in concrete is fairly well understood, and the literature is replete with information about the performance of reinforced concrete in a marine environment. For corrosion of metal in concrete to occur, there must be an electrolyte and oxygen available to the metal.

In this experiment, sea water spray applied daily provided a strong electrolyte. In addition, as the sea water entered the concrete, it carried dissolved oxygen with it. The salt in the water acts to lower the pH of the concrete. According to Pourbaix,[6] "The presence of oxygen in the solution (electrolyte) will have the effect of increasing the electrode potential of the metal. At pH's below about 8, this increase will be insufficient to bring about passivation of the iron; oxygen will therefore increase the corrosion rate. At pH's above 8, oxygen will bring about passivation by forming a film on the metal ... which will, in general, be protective in case of solutions (electrolyte) not containing chloride".

Because of the above reasons, there is a rather narrow range of pH values in concrete where mild steel may remain virtually corrosion free (passivated), i.e., (11.5 to 13.2).[5] The concrete in this study had a maximum possible pH value of 12.2 at the time of casting. See Table 3. Corrosion products of mild steel occupy a greater volume than the parent metal and during formation can induce pressures great enough to spall and crack concrete. Such pressures may amount to as much as 4,700 psi.[7]

Galvanized Steel. Many conflicts of opinion about the performance of galvanized steel in concrete appear in the literature; however, there is very little experimental evidence concerning performance of zinc embedded in concrete. One bit of closely related evidence is cited in Reference 8. This reference describes water vapor transmission studies of concrete disks from Pacific Ocean Island installations. The concrete had been fabricated using sea water as the mixing water and also the hardened concrete had been exposed to sea spray for many years. The amount of chlorides expressed as a percentage of NaCl by weight of concrete ranged from 0.16 to 1.95 in the various disks.

The concrete disks were cemented in zinc plated steel cups containing fresh water. Condensation water dripping from the lower surface of the concrete carried dissolved CaOH into the cups that were partially full of water. The reaction of CaOH, water, and zinc released free hydrogen in sufficient quantities to generate enough pressure to dislodge most of the concrete specimens. By means of a mercury manometer attached to one of the galvanized cups, a repeatable experiment disclosed pressures of up to 24 inches of mercury developed.[9] The liberation of hydrogen when galvanized steel is embedded in concrete has been reported by Bird;[10] however, the potential pressure of this gas was first disclosed in Reference 8.

According to Pourbaix,[6] zinc "... is thermodynamically unstable in the presence of water ..., and tends to dissolve with the evolution of hydrogen in ... very alkaline solutions". Further, according to Pourbaix, the corrosion rate of zinc is a minimum at a pH value of 10.0; it amounts to about 18 grams per square decimeter per day. Above pH of 10.0, corrosion rates of zinc increase drastically. For example, at pH of 12, the corrosion rate for free and uninhibited continuous corrosion is about 45 grams per square decimeter per day. Thus, at the normal pH values of concrete, embedded zinc is vulnerable to a fairly high corrosion rate at the start. The application of sea water spray provides both the electrolyte and dissolved oxygen for assurance of corrosion to begin.

An important unknown factor in connection with zinc is the amount of expansive force that corrosion products can develop. Although Woods[11] suggests that "The products of reaction are not voluminous and, consequently, damaging stresses are not created," the results of the experimental walls certainly indicate that combined forces of expansive corrosion products and pressure of hydrogen gas developed is enough to crack concrete of the design employed in this experiment. Woods also points out that the usefulness of galvanized steel reinforcement in concrete in a marine environment has not been adequately demonstrated.

In laboratory studies reported by Israel Cornet and Boris Bresler, University of California,[12, 13] it was shown that concrete specimens with galvanized steel performed somewhat better than concrete specimens with black steel (unrusted bars as received). Reference 12 did, however, state: "It must be emphasized that the salt solution immersion and drying and the sustained impressed current on specimens are somewhat arbitrarily selected as severe corrosive exposures - to obtain some sort of accelerated test. No relationship between these artificial environments and real prototype exposures can be established at this time."

Air-entrained Concrete. R. F. Stratful has reported that "Air-entrained concrete seems to have a higher ambient moisture level and absorbs more water than non air-entrained concrete. Generally, steel corroded sooner in air-entrained concrete. However, the amount of corrosion as measured by length of cracks in the air-entrained concrete was found to be less in all partial immersion tests." Further, "In the partial immersion test, the air-entrained concrete absorbed less chlorides than the non air-entrained concrete; the reverse was true in the case of alternate immersion."[14]

The wall study is more nearly like the alternate immersion type of test. Results for the walls with air-entrained concrete are at some variance with Stratful's findings. None of the walls containing air-entrained concrete have cracked to date, whereas, all non air-entrained concrete walls with reinforcing steel have cracked. Differences in laboratory testing and in actual field testing may account for this.

Environment. Other than daily spray with sea water, environmental factors were not unduly severe. The maximum temperature recorded in the thermoscreen was 98°F; the low temperature on the same day was 54°F. The lowest temperature observed was 28°F; the high temperature on the same day was 56°F. The average high temperature for the period of study was 70°F; the average low was 50°F.

The relative humidity ranged from a low of 14% to a high of 94% on a single day. The average high humidity has been 90%; the average low has been 61% and the overall has been around 75%.

Corrosion Inhibitors. In experiments reported by Bird,[10] it is concluded that "Zinc, whether pure or containing impurities, will liberate hydrogen when embedded in concrete. The reaction is, however, inhibited by the presence of small amounts of chromate in some cements."

Hersch et al[15] have made the following pertinent observations.

> "It has been found that chromate, the best known inhibitor, is also the most unusual, being the only additive to inhibit all cast irons and zinc. In the presence of chlorides, the thresholds for inhibition were higher and uncertain which makes chromate dangerous because corrosion then tends to be strongly localised." "The susceptibility of zinc to various inhibitors has been examined by simple weight-loss experiments in water. Inhibitors found to have substantial potency can be arranged in order of merit as follows: chromate, picrate, 2, 4, 6-trinitrobenzoate, lauroyl sarcosinate, m-nitrocinnamate, maleic hydrazide, decoate and m-nitrobenzoate. All these inhibitors (also) work well on iron and steel ..." "Only chromate works equally well on steel and cast irons." "The presence of chloride or sulphate greatly impairs the action of all inhibitors."

From the above, it would appear that since inhibitors work well with steel, there would be no advantage to using galvanized steel in concrete since the zinc would also require the use of an inhibitor.

Bird[10] has undertaken to determine the effect of chromates on the subsequent life of a galvanized coating on reinforcing steel embedded in concrete and exposed to marine atmospheres; however, the results of his investigation are not available.

The effects of the various inhibitors above listed on concrete per se are unknown to the author. The use of any such inhibitor in concrete should include consideration of its effect on the concrete as well as its effect on the metal.

Cracking of Concrete. It was stated in the introduction that the criterion of comparative suitability of galvanized versus non galvanized steel reinforcement is time-dependent cracking of the reinforced concrete caused by expansive forces resulting from build up of corrosion products. This criterion appears to be a valid one because there is no evidence in this investigation that suggests cracking could be attributable to other causes.

In this investigation, there are no external physical forces acting on the walls. Any forces acting are internal to the walls and are induced by environmental effects. Bryant Mather mentions six specific phenomena that bring about environmentally induced cracking.[16] These phenomena include (1) expansion due to the use of unsound cement, (2) the alkali-silica reaction, (3) sulfate attack, (4) corrosion of embedded metal, (5) freezing and thawing, and (6) plastic shrinkage. These phenomena are associated with environmentally induced moisture movements in the concrete.

In addition to deliberately induced corrosion of embedded metal, there are the environmental factors of differential thermal and differential water contents to induce stresses. These latter factors are not believed to have been sufficiently influential to have induced any cracks in the walls. For example, cracking from these causes would be expected to occur during the early life of a structure before the concrete gained maturity of strength, certainly before age of one year. Also, all walls in this study would be expected to crack about the same time from such causes; this was not the case.

Previous studies have indicated to the author that cracks in walls of the type used in this investigation are attributable to corrosion of the embedded metal. Therefore, length and width of cracks were not deemed paramount. Time to first visible cracking was considered to be of utmost importance because once visible cracking had occurred, lengthening and widening of the cracks would be accelerated by more rapid corrosion of metal after once being exposed to easy entry of salt water and oxygen.

It is interesting to note that the American Concrete Institute places a limit on crack widths of concrete under tension[17]: "The design yield strength ... for tension reinforcement shall not exceed

0.015 in. (3.81 mm) for interior members and 0.010 in. (2.54 mm) for exterior members."

In Holland, the maximum width of cracks for structures reinforced with round steel are limited in order to prevent inadmissible extents of corrosion. In structures with normal thickness of the concrete cover (in excess of one inch) the maximum ultimate widths of cracks may amount to 0.2 mm in the case of permanent loading and when the corrosion of the reinforcing steel alone has been taken in account.[18]

## CONCLUSIONS

On the basis of the results shown in Table 6 and the information in Table 2, the following conclusions may be noted:

1. At best, galvanized steel reinforcement is no better than non-galvanized steel reinforcement; further, it probably is not as good insofar as corrosion is concerned.

2. Painting areas of galvanized steel with zinc-enriched paint where minor damage to the zinc had resulted from weldments and bends is not effective in inhibiting corrosion of galvanized steel in concrete.

3. There is no evidence that weldments in the steel grids contribute to earlier corrosion than unwelded grids.

4. Air-entrained concrete inhibits corrosion compared to non air-entrained concrete.

5. Because the walls without steel grids did not crack, cracking of reinforced walls may be truly attributed to corrosion of the reinforcement, lacking evidence of causation from other factors such as differential volume changes in the reinforced compared to the non reinforced concrete.

## REFERENCES

1. U. S. Naval Civil Engineering Laboratory. Technical Report R-217: The effect of salt in concrete on compressive strength, water vapor transmission, and corrosion of reinforcing steel, by D. F. Griffin and R. L. Henry. Port Hueneme, Calif., November 12, 1962.

2. U. S. Naval Civil Engineering Laboratory. Technical Report R-306: The effect of salt in concrete on compressive strength, water vapor transmission, and corrosion of reinforcing steel, by D. F. Griffin and R. L. Henry. Port Hueneme, Calif., July 22, 1964.

3. U. S. Naval Civil Engineering Laboratory. Technical Report R-306 Supplement: Corrosion of mild steel in concrete, by D. F. Griffin. Port Hueneme, Calif., August 1965.

4. A. B. Tripler, Jr., E. L. White, R. H. Haynie, and W. K. Boyd of Battelle Memorial Institute. "Methods for Reducing Corrosion of Reinforcing Steel." National Cooperative Highway Research Program 23, Highway Research Board, 1966.

5. Donald F. Griffin. "Tests on Reinforced Concrete, Salt Gain Accelerates Corrosion of Steel," Materials Protection, Vol. 6, No. 7, July 1967, pp. 39-41.

6. Marcel Pourbaix. Atlas of Electrochemical Equilibria in Aqueous Solutions. Translated from the French by James A. Franklin. Pergamon Press, New York, 1966, pp. 409, 410.

7. E. B. Rosa, B. McCollum, and O. S. Peters. Electrolysis in Concrete, 1913. Technologic Papers of the Bureau of Standards (No. 18), Government Printing Office, Washington, D. C.

8. D. F. Griffin and R. L. Henry. "Integral Sodium Chloride - Effect on Strength, Water, Vapor Transmission, and Efflorescence of Concrete," Journal of ACI, Vol. 58, No. 6, December 1961, pp. 751-772.

9. U. S. Naval Civil Engineering Laboratory. Technical Report R-130: Water vapor transmission of plain concrete, by D. F. Griffin and R. L. Henry. Port Hueneme, Calif., May 16, 1961.

10. C. E. Bird. "The Influence of Minor Constituents in Portland Cement on the Behaviour of Galvanized Steel in Concrete." Corrosion Prevention & Control, July 1964, pp. 7-21.

11. ASTM, Significance of Tests and Properties of Concrete and Concrete-Making Materials. STP-169-A. 1966. Corrosion of Embedded Materials Other Than Reinforcing Steel, by Hubert Woods, pp. 230-238.

12. B. Bresler and I. Cornet. Galvanized Reinforcement in Concrete. September 1964. Mimeographed Private Communication of paper submitted for publication in the Final Report of the VII Congress of the International Association for Bridge and Structural Engineering. Summary presented at the VII Congress IABSE, Session V, Theme V-c, August 13, 1964, Rio de Janeiro, Brazil.

13. Israel Cornet and Boris Bresler. Corrosion of Steel and Galvanized Steel in Concrete. Materials Protection, April 1966, pp. 69-72.

14. California State Division of Highways. "Laboratory Tests of Reinforced Concrete Exposed to Solutions of Sodium Chloride and Sodium Sulfate," by R. F. Stratful, February 1964.

15. P. Hersch, J. B. Hare, A. Robertson, and Sheila M. Sutherland. An Experimental Survey of Rust Preventives in Water. I. Methods of Testing. II. The Screening of Organic Inhibitors. III. Some General Results. Reprinted from the Journal of Applied Chemistry, 11 July 1961, pp. 246-271.

16. American Concrete Institute, Publication SP-20. Causes, Mechanism, and Control of Cracking in Concrete. Paper No. 4 by Bryant Mather. Cracking Induced by Environmental Effects. pp. 67-72, 1968.

17. American Concrete Institute. ACI Manual of Concrete Practice. Part 2. 1968, pp. 318-67.

18. Concrete Association, The Hague, Netherlands. Report No. 10 C.U.R. 1956. Investigation on the Admissible Crack Width in Reinforced Concrete Structures. In Dutch with summary in English.

Table 1. Concrete Mix Design Information

A. Characteristics of Materials

1. Cement: Type II, Low Alkali, Portland Cement

   a. Chemical Analysis (Lab. No. 66799)

| Item | Percent | Item | Percent |
|---|---|---|---|
| SiO2 | 22.26 | $SO_3$ | 2.21 |
| $Al_2O_3$ | 4.20 | Loss on ignition | 1.35 |
| $Fe_2O_3$ | 2.66 | Insoluble residue | 0.12 |
| MgO | 2.83 | % $Na_2O$ + 0.658% $K_2O$ | 0.54 |

Potential Composition:

| | |
|---|---|
| Tricalcium silicate, $3CaO.SiO_2$ | 54% |
| Tricalcium aluminate, $3CaO.Al_2O_3$ | 7% |

   b. Physical Data

| | |
|---|---|
| Fineness, specific surface (sq. cm. per g.) | 3361 B |
| Soundness, autoclave expansion | 0.06 % |
| Compressive strength of cube at 7 days | 3375 psi |
| Time of setting (Gilmore test) water | 24.2 % |

| | |
|---|---|
| Initial Set | 3h 20m |
| Final Set | 6h 15m |

2. Aggregate: San Gabriel, a reference aggregate from the Irwindate Pit of Consolidated Rock Products Company, California

   a. Physical Data (combined coarse and fine aggregate)

| | |
|---|---|
| Bulk specific gravity, oven-dry | 2.65 |
| 24-hour absorption, percent | 1.7 |

   b. Petrographic description - See Appendix A

3. Water - Port Hueneme tap water at 73.4F. Chemical

   analyses for period prior to use (ppm)
   bicarbonate (253.8); chlorides (400); calcium (120.0)
   magnesium (33.2); sulphate (325.0); sodium (77.0);
   potassium (5.4); calcium hardness (300.0); magnesium
   hardness (136.0); ph 8.0

Table 1. Concrete Mix Design Information (cont'd)

B. Concrete Batching

1. Gradation of aggregate

Amount retained on each sieve per 2.0 cubic foot batch, lbs.

| Sieve | Without AEA | With AEA |
|---|---|---|
| 3/4 | 5.5 | 5.5 |
| 3/8 | 65.5 | 65.5 |
| No. 4 | 40.3 | 40.3 |
| No. 8 | 28.6 | 26.8 |
| No. 16 | 27.7 | 25.9 |
| No. 30 | 27.8 | 26.0 |
| No. 50 | 25.5 | 23.8 |
| No. 100 | 12.9 | 12.1 |
| Pan | 6.2 | 5.8 |
| Total, lbs. | 240.0 | 231.7 |

C. Batch of 2.0 ± cubic feet consisted of the following:

| Mix Design Factors | Non Air-Entrained | Air-Entrained |
|---|---|---|
| w/c, by wt. | 0.702 | 0.644 |
| Water (lb)[a] | 23.4 | 21.5 |
| Cement (lb) | 33.4 | 33.4 |
| Cement Factor[b] | 4.81 | 4.81 |
| Aggregate (lb) | 240.0 | 231.7 |
| Slump (in.) | 3.0 | 3.0 |
| DAREX (ml) | 0.0 | 7.88 |

a/ Does not include moisture already in aggregate or that required for absorption.

b/ Bags per cubic yard of concrete.

Table 2. Variables for Walls

| Wall No. | Concrete[a/] |  | Date Cast 1966 | Reinforcing Steel |  |  |  |
|---|---|---|---|---|---|---|---|
|  | No AEA | With AEA |  | Zn Coated | Sand Blasted | Welded | Tied Insul. |
| 101 | X |  | 11 Apr | X[b/] |  | X |  |
| 109 | X |  | 18 May | X[c/] |  | X |  |
| 102 |  | X | 13 Apr | X[b/] |  | X |  |
| 110 |  | X | 18 May | X[c/] |  | X |  |
| 103 | X |  | 12 Apr | X[b/] |  |  | X |
| 111 | X |  | 18 May | X[c/] |  |  | X |
| 104 | X |  | 11 Apr |  | X | X |  |
| 105 |  | X | 13 Apr |  | X | X |  |
| 106 | X |  | 12 Apr |  | X |  | X |
| 107 | X |  | 12 Apr |  | NO STEEL |  |  |
| 108 |  | X | 13 Apr |  | NO STEEL |  |  |

a/ AEA means air-entraining agent.

b/ Each bend and weld and bar ends were touched up with zinc-enriched paint employing a silicious vehicle.

c/ No touch up with zinc-enriched paint employing a silicious vehicle.

Note: Walls were transferred from fog room to field site 28 days after casting. For walls cast in April, sea spray was begun 16 May 66; for walls cast in May, sea water spray was begun 20 June 66.

Table 3. Properties of Fresh Concrete

| Item | Regular | | | Air-Entrained | | |
|---|---|---|---|---|---|---|
| | Min. | Av. | Max. | Min. | Av. | Max. |
| pH[a] | 12.1 | 12.1 | 12.2 | 12.1 | 12.1 | 12.2 |
| Air Content[b], % | 1.9 | 2.0 | 2.1 | 5.5 | 5.6 | 5.7 |
| Slump[c], in. | 2.7 | 3.5 | 4.5 | 4.0 | 4.5 | 5.0 |

[a] Beckman Model N-2, pH meter, reference electrode-fiber junction calomel in conjunction with general purpose glass electrode with silver-silver chloride internal element.

[b] ASTM Designation: C-231-62. Aggregate correction factor of 0.5 has been applied to the above values for air content.

[c] ASTM Designation: C143-58

## Table 4. Properties of Hardened Concrete[a/]
## (Without Air-Entraining Agent)

| Age, d | 28 | 56 | 112 | 224[b/] | 364[b/] |
|---|---|---|---|---|---|
| Unit Weight, pcf | | | | | |
| 3 in. dia by 6 in. cyl | | | | | |
| Fog cure | 144 | 149 | 149 | 152 | 145 |
| Sea side | --- | 139 | 143 | 143 | 144 |
| Land side | --- | 136 | 143 | 148 | 144 |
| 4 in. dia by 8 in. cyl | | | | | |
| Fog cure | 145 | 146 | 146 | 144 | 145 |
| Sea side | --- | 143 | 144 | 143 | 140 |
| Land side | --- | 140 | 140 | 145 | 146 |
| Compressive Strength, psi | | | | | |
| 3 in. dia by 6 in. cyl | | | | | |
| Fog cure | 2990 | 3240 | 3730 | 3650 | 3830 |
| Sea side | --- | 3920 | 4110 | 3930 | 4410 |
| Land side | --- | 3840 | 4280 | 3890 | 3930 |
| Splitting Tensile Strength | | | | | |
| 4 in. dia by 8 in. cyl | | | | | |
| Fog cure | 338 | 350 | 376 | 388 | 386 |
| Sea side | --- | 415 | 425 | 413 | 449 |
| Land side | --- | 425 | 444 | 372 | 385 |

[a/] Each value is average for 3 specimens.

[b/] Moderate to heavy rainfall for several days just prior to testing.

## Table 5. Properties of Hardened Concrete (With Air-Entraining Agent)[a]

| Age, d | 28 | 56 | 112 | 224[b] | 364[b] |
|---|---|---|---|---|---|
| **Unit Weight, pcf** | | | | | |
| 3 in. dia by 6 in. cyl | | | | | |
| Fog cure | 134 | 141 | 142 | 137 | 138 |
| Sea side | --- | 139 | 136 | 136 | 135 |
| Land side | --- | 137 | 133 | 135 | 135 |
| 4 in. dia by 8 in. cyl | | | | | |
| Fog cure | 138 | 137 | 138 | 137 | 137 |
| Sea side | --- | 136 | 137 | 135 | 136 |
| Land side | --- | 137 | 134 | 136 | 136 |
| **Compressive Strength, psi** | | | | | |
| 3 in. dia by 6 in. cyl | | | | | |
| Fog cure | 2510 | 2850 | 3050 | 3140 | 3280 |
| Sea side | --- | 3350 | 3620 | 3510 | 3580 |
| Land side | --- | 3150 | 3440 | 3310 | 3650 |
| **Splitting Tensile Strength** | | | | | |
| 4 in. dia by 8 in. cyl | | | | | |
| Fog cure | 257 | 274 | 300 | 340 | 320 |
| Sea side | --- | 330 | 381 | 405 | 385 |
| Land side | --- | 380 | 394 | 349 | 355 |

[a] Each value is average for 3 specimens.

[b] Moderate to heavy rainfall for several days just prior to testing.

Table 6. Chronology of Wall Cracking

| Wall No. | Date crack first visible | Time to crack, days$^{(a)}$ | Location of crack | Length of crack,$^{(b)}$ In. |
|---|---|---|---|---|
| 101 | 7 Dec 67 | 570 | E. end face | 29.5 |
| 101 | 15 Mar 68 | 669 | Sea side (U.R.) | 5.5 |
| 101 | 7 May 68 | 722 | Sea side (L.R.) | 4.5 |
| 101 | 26 Jul 68 | 802 | Land side (L.L.) | 7.5 |
| 101 | 11 Oct 68 | 879 | Land side (L.R.#1) | 3.8 |
| 101 | 25 Oct 68 | 893 | Land side (U.L.) | 6.5 |
| 101 | 11 Dec 68 | 940 | Land side (L.R.#2) | 1.0 |
| 101 | 11 Dec 68 | 940 | Sea side (L.L.) | 2.0 |
| 109 | 26 Jan 68 | 585 | Sea side (U.L.) | 19.5 |
| 109 | 26 Jul 68 | 767 | E. end face | 2.0 |
| 109 | 22 Aug 68 | 794 | Sea side (U.R.) | 2.5 |
| 109 | 31 Jan 69 | 956 | Land side (left side) | 29.5 |
| 111 | 15 Mar 68 | 634 | E. end face | 28.0 |
| 111 | 31 Jan 69 | 925 | Land side (L.L.) | 7.5 |
| 111 | 31 Jan 69 | 925 | Sea side (L.L.) | 5.2 |
| 111 | 31 Jan 69 | 925 | Sea side (L.C.) | 2.0 |
| 104 | 7 May 68 | 722 | Sea side (L.L.) | 5.5 |
| 104 | 16 Dec 68 | 945 | E. end face | 1.1 |
| 103 | 2 Aug 68 | 809 | W. end face (Upper) | 5.1 |
| 103 | 11 Oct 68 | 879 | Sea side (U.R.) | 6.1 |
| 103 | 18 Oct 68 | 886 | Land side (L.L.#1) | 13.0 |
| 103 | 9 Dec 68 | 938 | E. end face (Lower) | 3.7 |
| 103 | 16 Dec 68 | 945 | Sea side(near bottom) | 36.0 |
| 103 | 16 Dec 68 | 945 | W. end face (Lower) | 7.5 |
| 103 | 16 Dec 68 | 945 | E. end face (Upper) | 7.0 |
| 103 | 17 Jan 69 | 977 | Land side (L.R.) | 7.5 |
| 103 | 17 Jan 69 | 977 | Land side (L.R.#2) | 3.0 |
| 106 | 31 Jan 69 | 991 | Land side(near bottom) | 1.8 |

(a) Base dates: Walls 101-108, start sea spray 16 May 66
Walls 109-111, start sea spray 20 Jun 66

(b) For Wall 101 - 11 Dec 68
For other walls as of 17 Jan 69

# APPENDIX A

Petrographic description and classification of randomly selected boulders of San Gabriel rock.

Source: U. S. Naval Civil Engineering Laboratory Technical Report R-244. Water Vapor Transmission of Concrete and of Aggregates, by R. L. Henry and G. K. Kurtz. Port Hueneme, California, June 30, 1963. Appendix E.

# SAN GABRIEL ROCKS

## ROCK A. LEUCOCRATIC QUARTZO-FELDSPATHIC CATACLASTIC GNEISS

This rock shows considerable granulation with abundant large relic grains of feldspar and quartz (up to 1 cm.). Cataclastic textures have been partly obliterated by recrystallization of groundmass quartz and alkali feldspar. Feldspars and quartz exhibit pronounced undulatory extinction and sutured grain contacts. Plagioclase is badly saussuritized. Fine-grained quartz and muscovite are oriented along shear planes which give the rock a distinct foliation.

This material is moderately fresh and due to the paucity of mafic minerals it should be relatively resistant to both chemical and mechanical attack.

mode:

| | |
|---|---|
| alkali feldspar (including microcline) | 40 |
| plagioclase (oligoclase) | 15 |
| quartz | 30 |
| muscovite | 10 |
| garnet | Tr |
| clinopyroxene | 3 |
| green biotite | 2 |
| hematite | Tr |

## ROCK B. HORNBLENDE-CLINOPYROXENE QUARTZO-FELDSPATHIC GNEISS

This is a coarse-grained (2-4mm) equigranular rock with granoblastic texture, and sutured grain boundaries. Lineation results from preferred orientation of hornblende; weak foliation is due to compositional banding (quartz + feldspar layers alternate with quartz + feldspar + mafic mineral bands). Quartz and feldspars show strain shadows and some myrmekitic intergrowths, but all phases are fresh.

The abundant mafic clots of hornblende + clinopyroxene indicate that, although the rock is as yet unaltered, it is susceptible to chemical attack.

mode:

| | |
|---|---|
| alkali feldspar (including microcline) | 25 |
| plagioclase (andesine-oligoclase) | 30 |
| quartz | 25 |
| green-brown hornblende | 12 |
| clinopyroxene | 4 |
| apatite | Tr |
| magnetite | 2 |
| biotite | 2 |

## ROCK C. MONZONITE PORPHYRY

This rock is a hiatal porphyry. Large (3mm) euhedra of strongly zoned (oscillatory) plagioclase are set in a fine-grained, intensely altered mesostasis of alkali feldspar + quartz + mafic minerals. Weak (magmatic ?) flow banding results from orientation of plagioclase tablets and chlorite + biotite flakes. Primary clinopyroxene has been almost completely eliminated by alteration processes which have sericitized much of the groundmass feldspar. The phenocrysts of intermediate plagioclase are relatively fresh but are susceptible to chemical attack.

mode:

| | |
|---|---|
| phenocrysts | |
| oligoclase-andesine (strongly zoned, fragmented) . . . . . | 25 |
| saussuritized plagioclase (sericite + epidote? + calcite) . . . . . . . . . . . . . . . . . . . . . . . . . . | 2 |
| groundmass | |
| quartz . . . . . . . . . . . . . . . . . . . . . . . . . . | 10 |
| alkali feldspar (including plagioclase) . . . . . . . . . | 40 |
| biotite . . . . . . . . . . . . . . . . . . . . . . . . | 6 |
| chlorite . . . . . . . . . . . . . . . . . . . . . . . . | 14 |
| carbonate . . . . . . . . . . . . . . . . . . . . . . . | 2 |
| clinopyroxene . . . . . . . . . . . . . . . . . . . . . | Tr |
| magnetite . . . . . . . . . . . . . . . . . . . . . . . | 1 |
| hematite . . . . . . . . . . . . . . . . . . . . . . . . | Tr |
| sphene . . . . . . . . . . . . . . . . . . . . . . . . . | Tr |

## ROCK D. HORNBLENDE QUARTZ PLAGIOCLASE SCHIST

This rock has a medium-grained (~ 2mm) granular texture with foliation produced by planar orientation of chlorite + biotite, lineation of hornblende. Long axes of plagioclase + quartz grains are also aligned with this lineation. There are spotty patches of intensely sericitized plagioclase.

Equigranularity of this rock tends to increase its mechanical strength, but chemical weathering of the abundant mafic minerals would decrease its stability.

mode:

| | |
|---|---|
| plagioclase (andesine), including saussuritized plagioclase . . | 50 |
| quartz . . . . . . . . . . . . . . . . . . . . . . . . . . . | 20 |
| hornblende . . . . . . . . . . . . . . . . . . . . . . . . | 13 |
| biotite . . . . . . . . . . . . . . . . . . . . . . . . . . | 4 |
| chlorite . . . . . . . . . . . . . . . . . . . . . . . . . | 7 |
| clinopyroxene . . . . . . . . . . . . . . . . . . . . . . . | 5 |
| magnetite . . . . . . . . . . . . . . . . . . . . . . . . . | 1 |
| zoisite (?) . . . . . . . . . . . . . . . . . . . . . . . . | Tr |
| apatite . . . . . . . . . . . . . . . . . . . . . . . . . . | Tr |
| carbonate (calcite) . . . . . . . . . . . . . . . . . . . . | Tr |

### ROCK E. COARSELY PORPHYROBLASTIC HORNBLENDE QUARTZO-FELDSPATHIC GNEISS

This rock contains about 20% very large (up to 3 x 2 cm) porphyroblasts of microcline set in a medium-grained (2-3mm) groundmass. Some quartz is slightly strained and shows sutured grain boundaries. The plagioclase, alkali feldspar and quartz are intergrown in a typical granular (granoblastic) texture; rare quartz-alkali feldspar myrmekite is also evident. The original mafic mineral was probably clinopyroxene but it has been largely converted to hornblende, biotite, chlorite, sphene, and magnetite through hydration, oxidation, and recrystallization.

Partial decomposition of mafics and coarsely porphyroblastic texture probably mean this rock is relatively vulnerable to mechanical and chemical breakdown.

mode:

| | |
|---|---|
| alkali feldspar (microcline | |
| porphyroblasts | 20 |
| groundmass | 15 |
| plagioclase (calcic oligoclase) | 30 |
| quartz | 15 |
| chlorite | 3 |
| biotite | 7 |
| clinopyroxene | 2 |
| magnetite | 3 |
| sphene | 2 |
| blue-green hornblende | 3 |

### ROCK F. FINE-GRAINED PORPHYROBLASTIC BIOTITE GNEISS

This rock is a medium-grained (2-3mm) granoblastic gneiss with minor porphyroblasts (5-8mm) of perthitic alkali feldspar and plagioclase. The porphyroblasts have been somewhat milled and give the appearance of small augen in hand specimen. Quartz exhibits strain shadows. Foliation is due to preferred orientation of biotite flakes. Minor myrmekitic intergrowths of quartz and alkali feldspar are present.

This rock in general, and the feldspars in particular look very fresh.

mode:

| | |
|---|---|
| plagioclase (oligoclase) | 20 |
| alkali feldspar (microcline) | 30 |
| quartz | 35 |
| biotite | 13 |
| chlorite | Tr |
| magnetite | 1 |
| hematite | Tr |
| tourmaline | Tr |
| apatite | Tr |
| sphene | 1 |

## ROCK G. HORNBLENDE QUARTZO-FELDSPATHIC GNEISS

This rock is a foliated granoblastic equigranular gneiss. Quartz shows undulatory extinction and is more or less restricted to specific laminae. Hornblende is suboriented in the plane of foliation; mafics in general are "strung out" in this plane. Felsic and mafic minerals are all very fresh.

Abundant hornblende clots probably will cause this rock to alter along shear planes during oxidation.

mode:

| | |
|---|---|
| alkali feldspar (microcline) | Tr |
| quartz | 25 |
| plagioclase (calcic oligoclase) | 50 |
| blue-green hornblende | 20 |
| magnetite | 1 |
| sphene | 2 |
| clinopyroxene | 1 |
| chlorite | 1 |
| apatite | Tr |

## ROCK H. EQUIGRANULAR BIOTITE GRANITE GNEISS

This rock is a medium-grained (~ 3mm) equigranular gneiss with granoblastic texture. Sutured contacts are common, quartz shows strongly undulatory extinction, and feldspars exhibit weak twinning. Plagioclase is faintly zoned. Rare wormy intergrowths between quartz and microcline were observed. Feldspars are moderately sericitized and biotite is partly replaced by chlorite.

mode:

| | |
|---|---|
| alkali feldspar (microcline) | 35 |
| quartz | 20 |
| plagioclase (albite-oligoclase) | 30 |
| brown biotite | 12 |
| muscovite | 1 |
| chlorite | 1 |
| magnetite | 1 |

# APPENDIX B

Description of Galvanized Steel as furnished by Dr. Boris Bresler and Dr. I. Cornet of University of California.

## DESCRIPTION OF GALVANIZED STEEL

Approximately 900 lbs of No. 5 steel bars were furnished from a single heat (electric furnace heat 322 M). A chemical analysis of the steel showed:

| | | | |
|---|---|---|---|
| Manganese | 0.43% | Silicon | 0.06% |
| Carbon | 0.33% | Molybdenum | 0.04% |
| Copper | 0.26% | Tin | 0.032% |
| Chromium | 0.13% | Sulphur | 0.024% |
| Nickel | 0.10% | Phosphorous | 0.005% |

About 450 lbs of bars from this steel were galvanized. Prior to commercial hot dip galvanizing, the bars were prepared as follows:

a. Immersed in caustic (4 oz per gal) at a temperature of 170F, and then rinsed in water for one minute.

b. Immersed in pickling bath of 7.64% sulphuric acid (66° Baume) used with 3 lbs Ultrawet and 0.5 gal of No. 359 activol inhibitor at a temperature of 140F for one minute.

c. Rinsed in water for one minute at a temperature of 75F.

d. Immersed in flux of non-foaming zinc ammonium chloride at a temperature of 130F, Baume 24° for 3 minutes followed by drying 5 minutes in a blower tunnel at 110F.

e. Immersed horizontally into galvanizing kettle for 1.5 minutes at 860F, then onto shaker table for 17 seconds to remove excess zinc, followed by water quenching for 20 seconds at 120F. All bars were brought up through the kettle flux clean and fast.

A spelter sample taken approximately 16 in. from the surface of the bath showed the following composition:

| | | | |
|---|---|---|---|
| Lead | 1.21% | Tin | 0.014% |
| Copper | 0.05% | Aluminum | < 0.001% |
| Cadmium | 0.04% | Zinc by difference | 98.65 % |
| Iron | 0.036% | | |

The weight of zinc coating was calculated from the surface area of an equivalent 5/8 in. plain round rod and found to be 3.65 oz per sq ft (NCEL obtained 4.5 oz per sq ft on the one sample tested). Physical tests showed the following properties:

| Bar | Yield Point, psi | Tensile Strength, psi | Elong.% |
|---|---|---|---|
| Not galvanized | 47,150 | 73,660 | 23 |
| Galvanized | 47,750 | 75,880 | 20 |

Note: 8 in. gage length used to determine elongation

Weight of bar: 1.06 lbs per foot

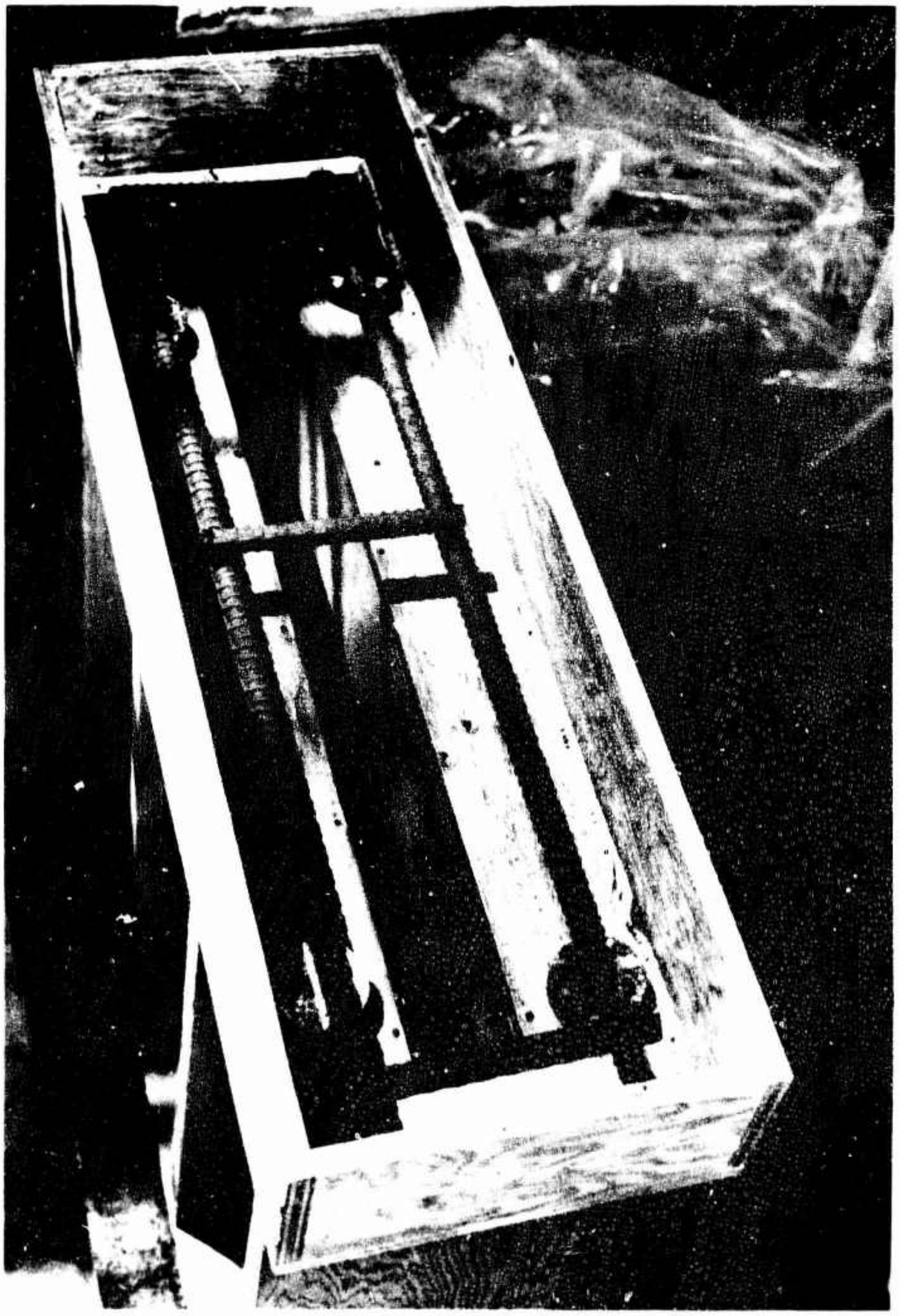
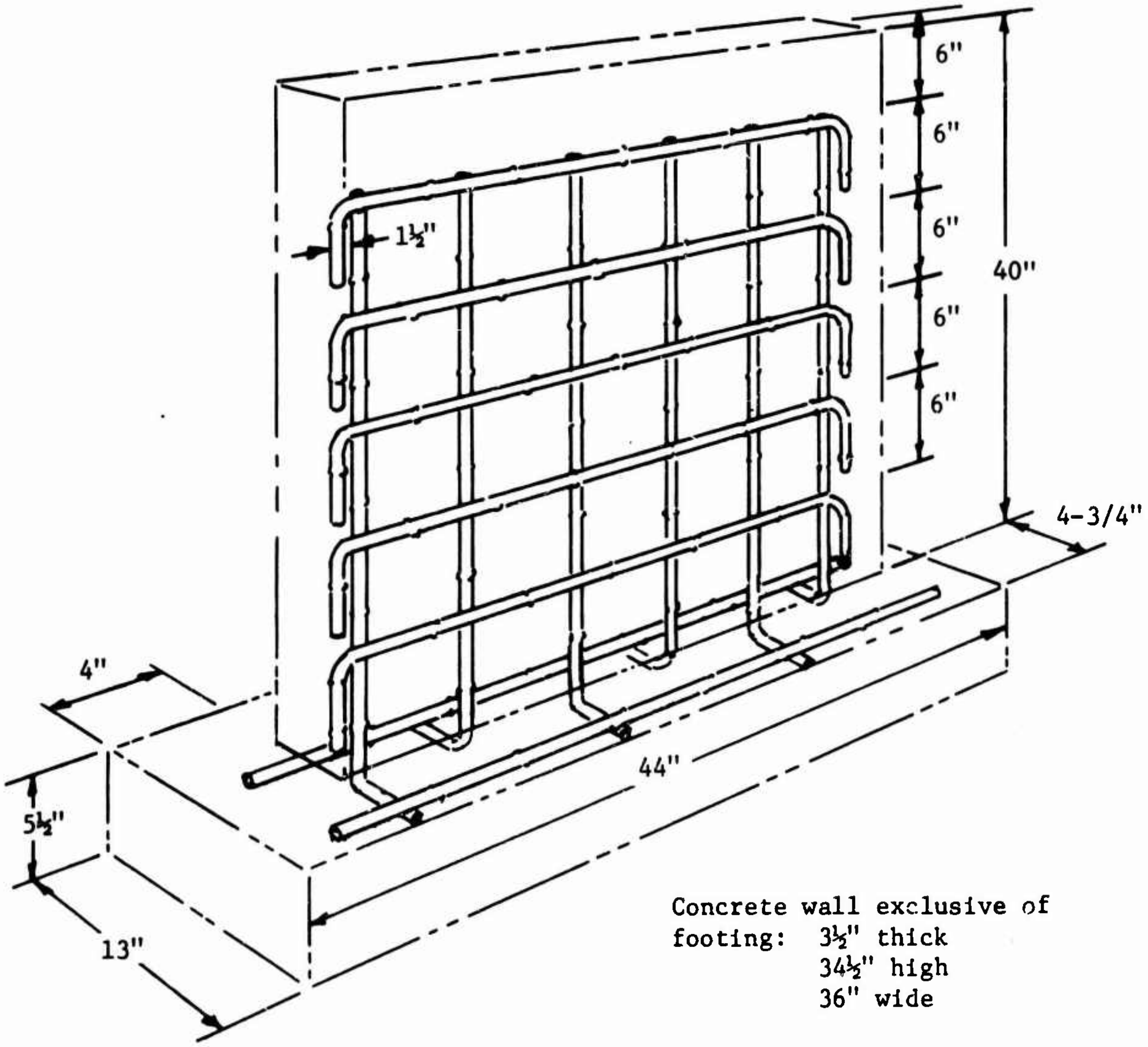


Figure 1. Reinforcement for footings of plain concrete walls.

**#5 deformed steel bars - 6" O.C. Within wall portion all depth of cover is 1" except as noted at top.**



Concrete wall exclusive of footing:
3½" thick
34½" high
36" wide

Figure 2. Reinforcing steel in concrete wall.

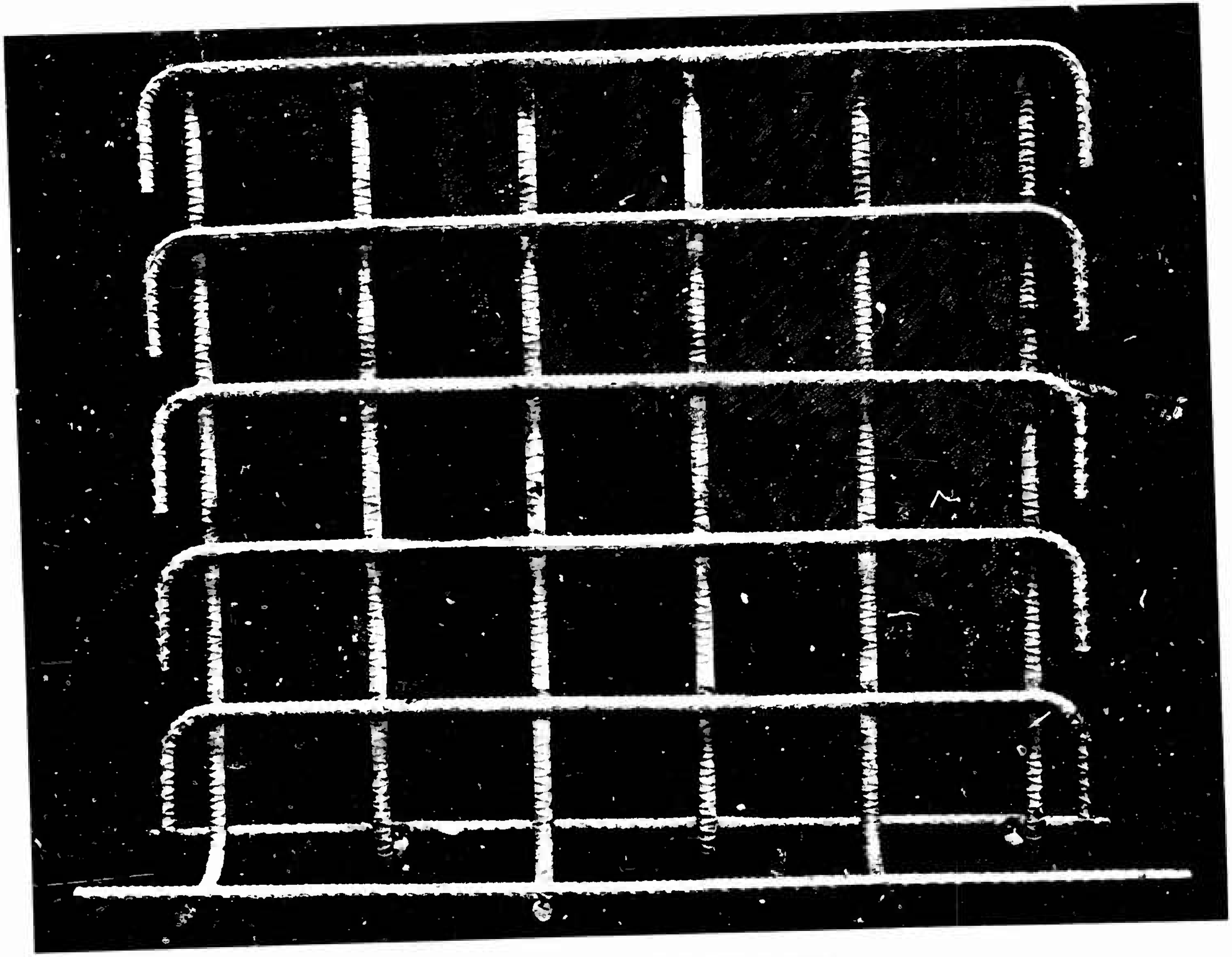


Figure 3. Typical welded steel grid.

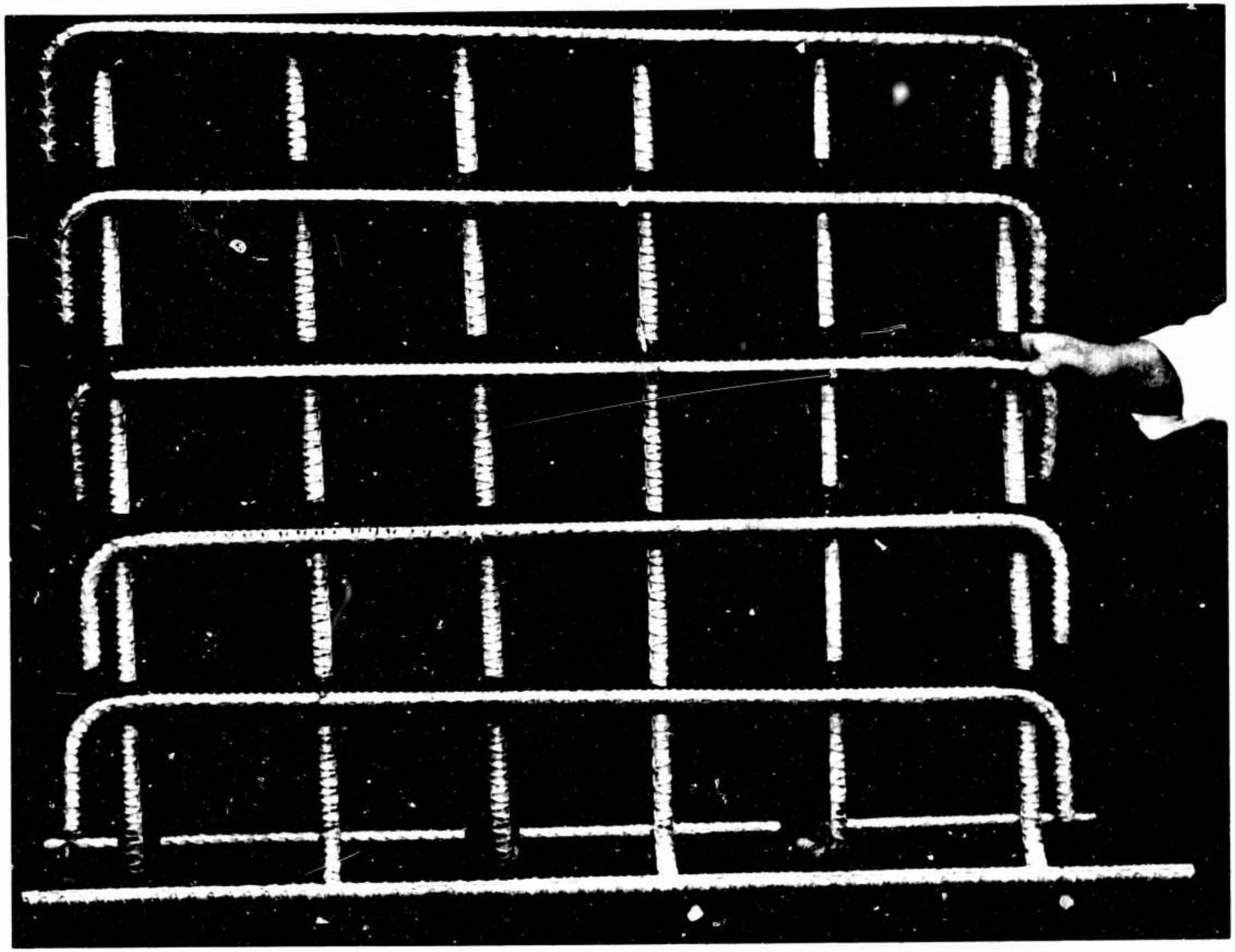


Figure 4. Typical tied and insulated steel grid.

Figure 5. Wooden spacers in place for holding steel grid. Concrete disks are permanent vertical spacers.

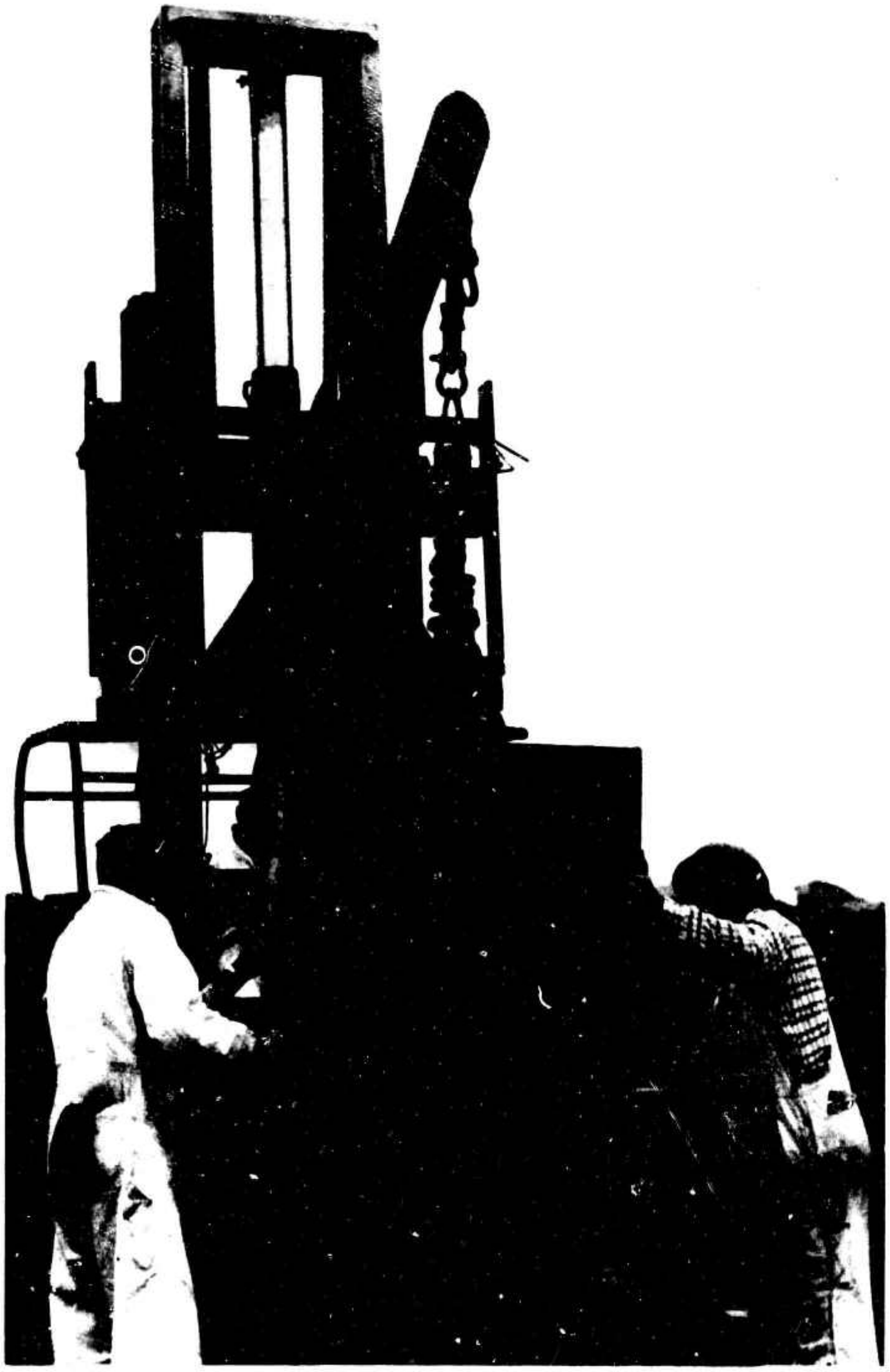


Figure 6. Lifting wall for placement at field site.

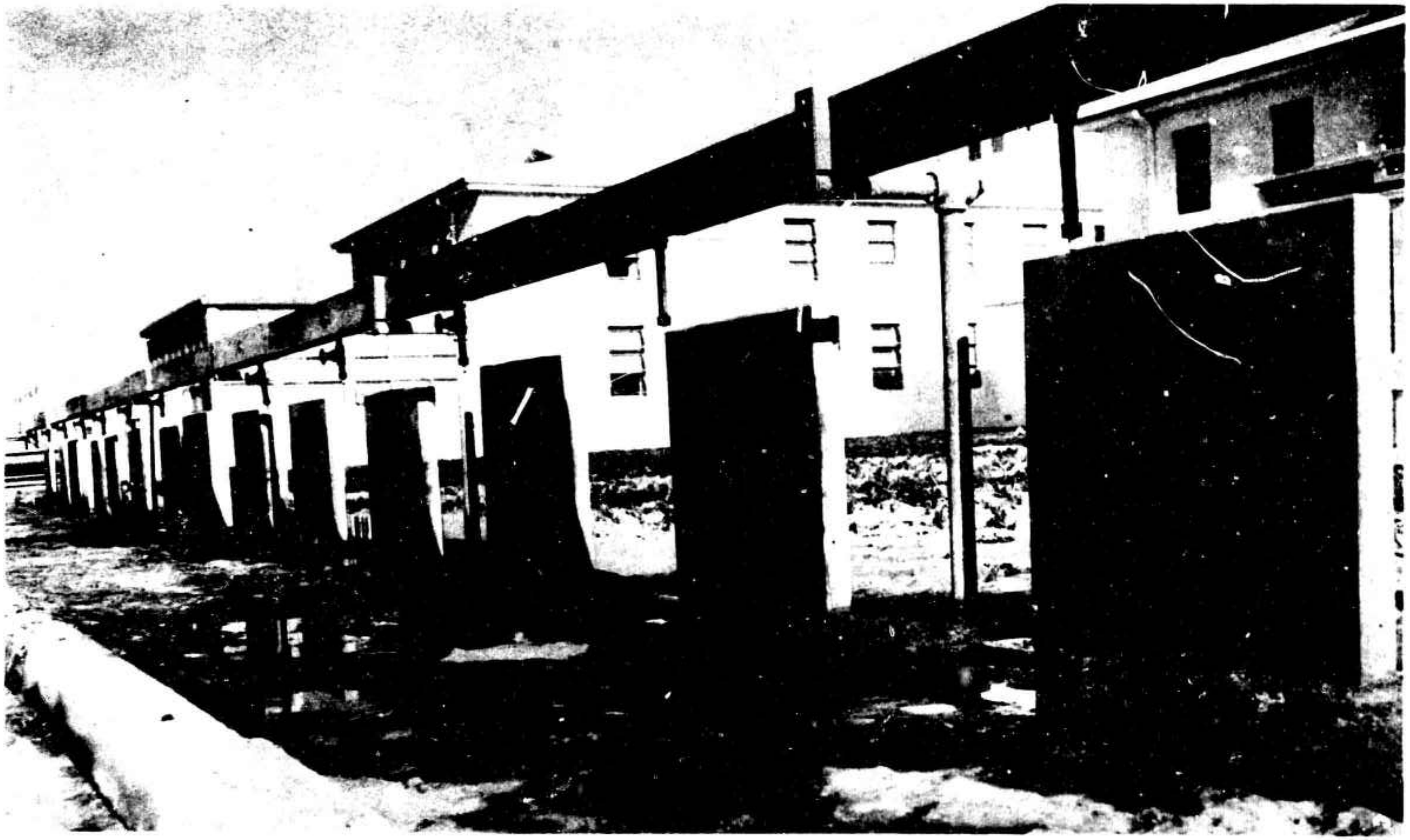
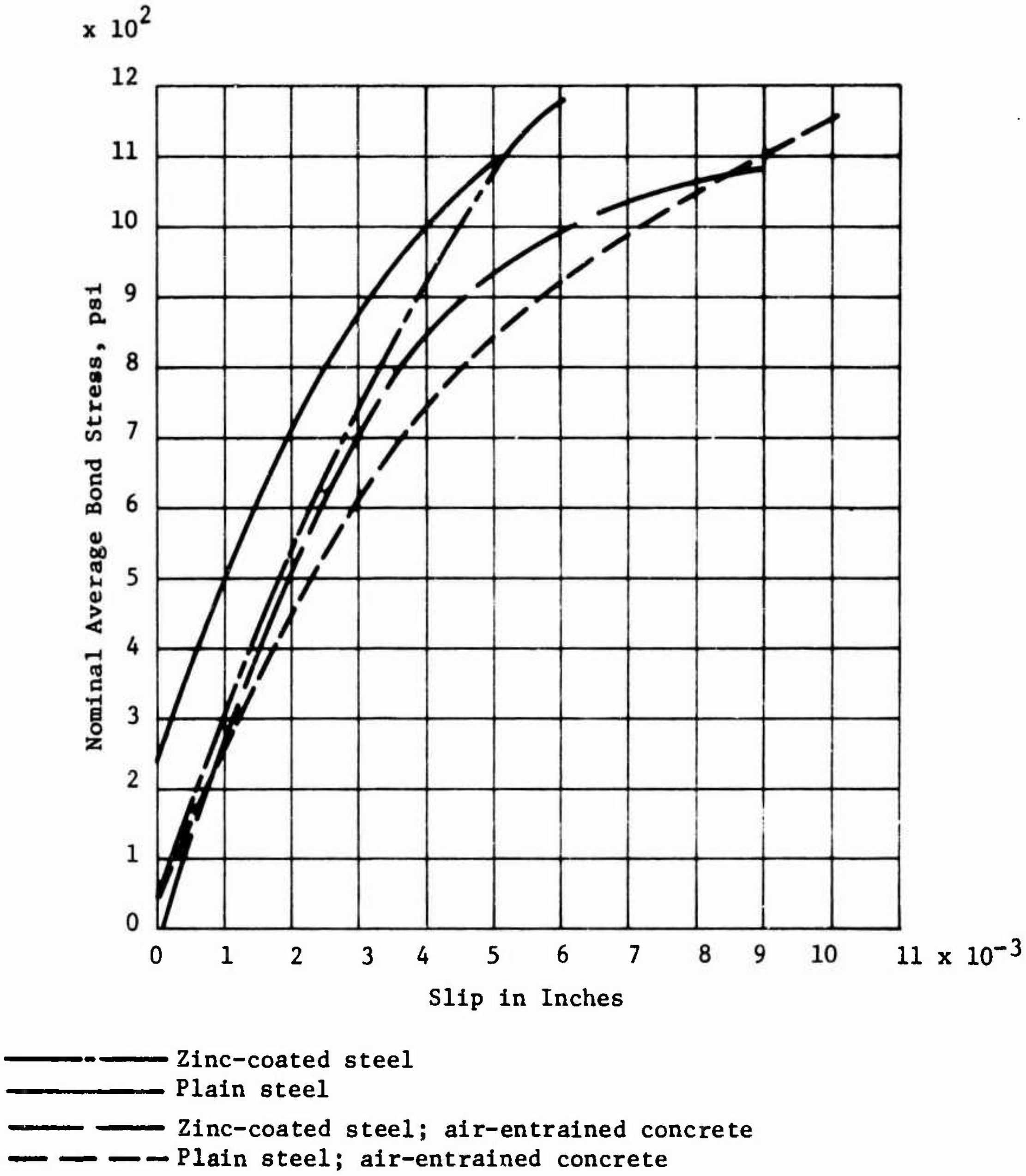


Figure 7. Overall view of walls and sea water spray system.

Figure 8. Typical wall in place at field site.



Note: Each curve represents average results for three specimens.

Figure 9. Bond strength versus slip for vertically embedded No. 5 deformed steel bars. (ASTM Designation C234-62).

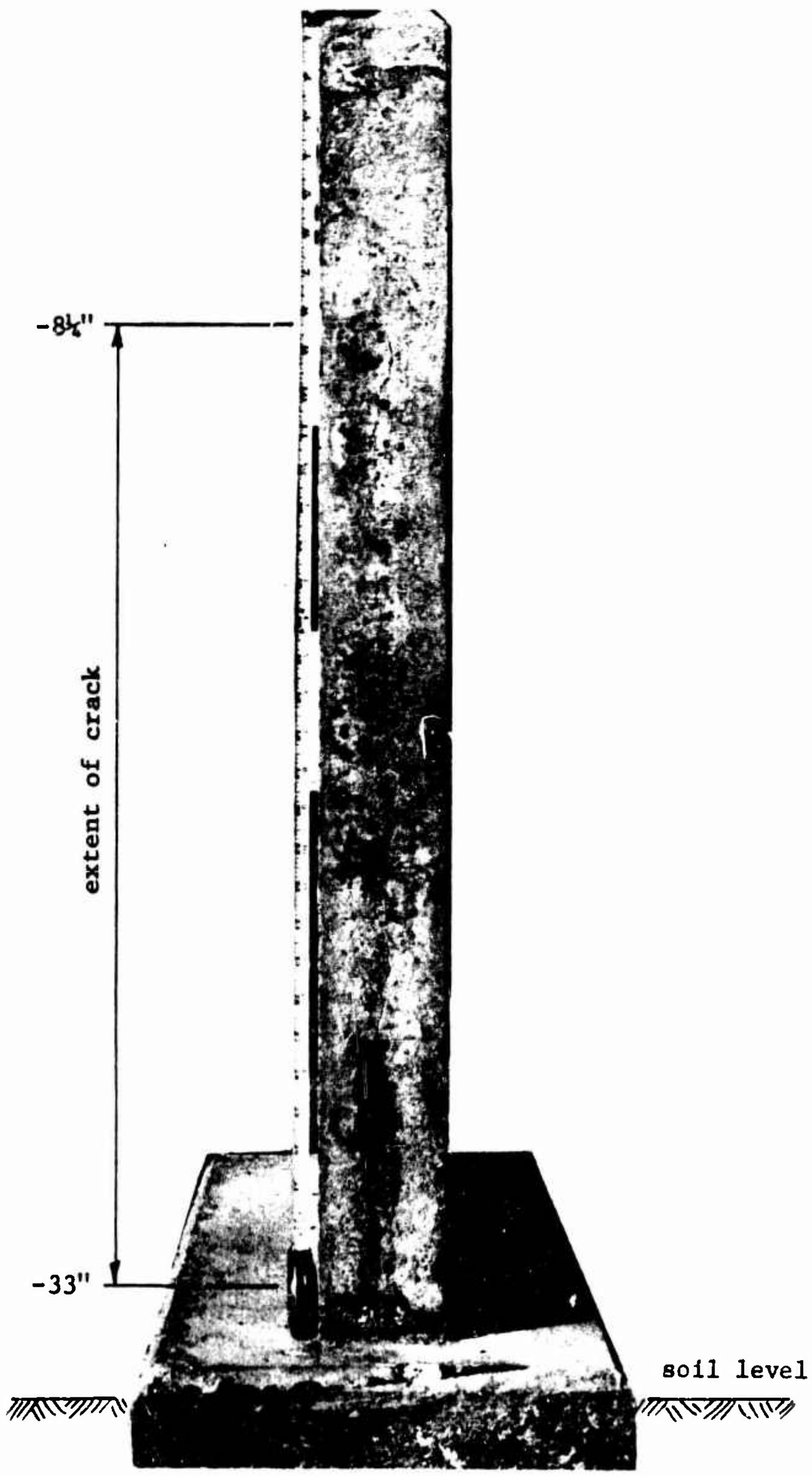


Figure 10. Crack on east end of Wall 101.
Note ferrous oxide stains.

Figure 11. Ferrous oxide on zinc-coated steel bars - east end of Wall 101.

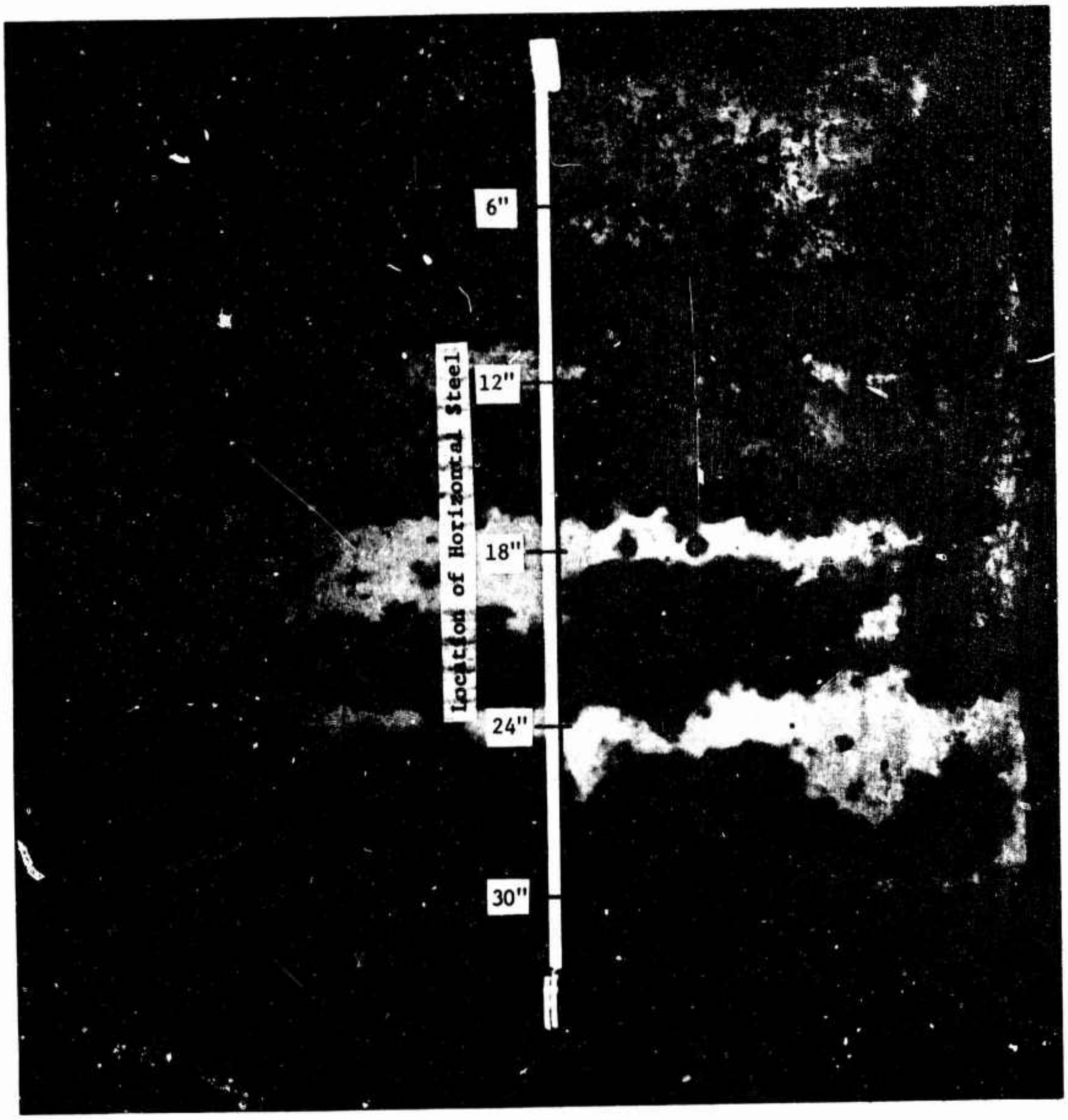


Figure 12. Cracks on south face of Wall 103. Horizontal crack is directly opposite a steel bar.

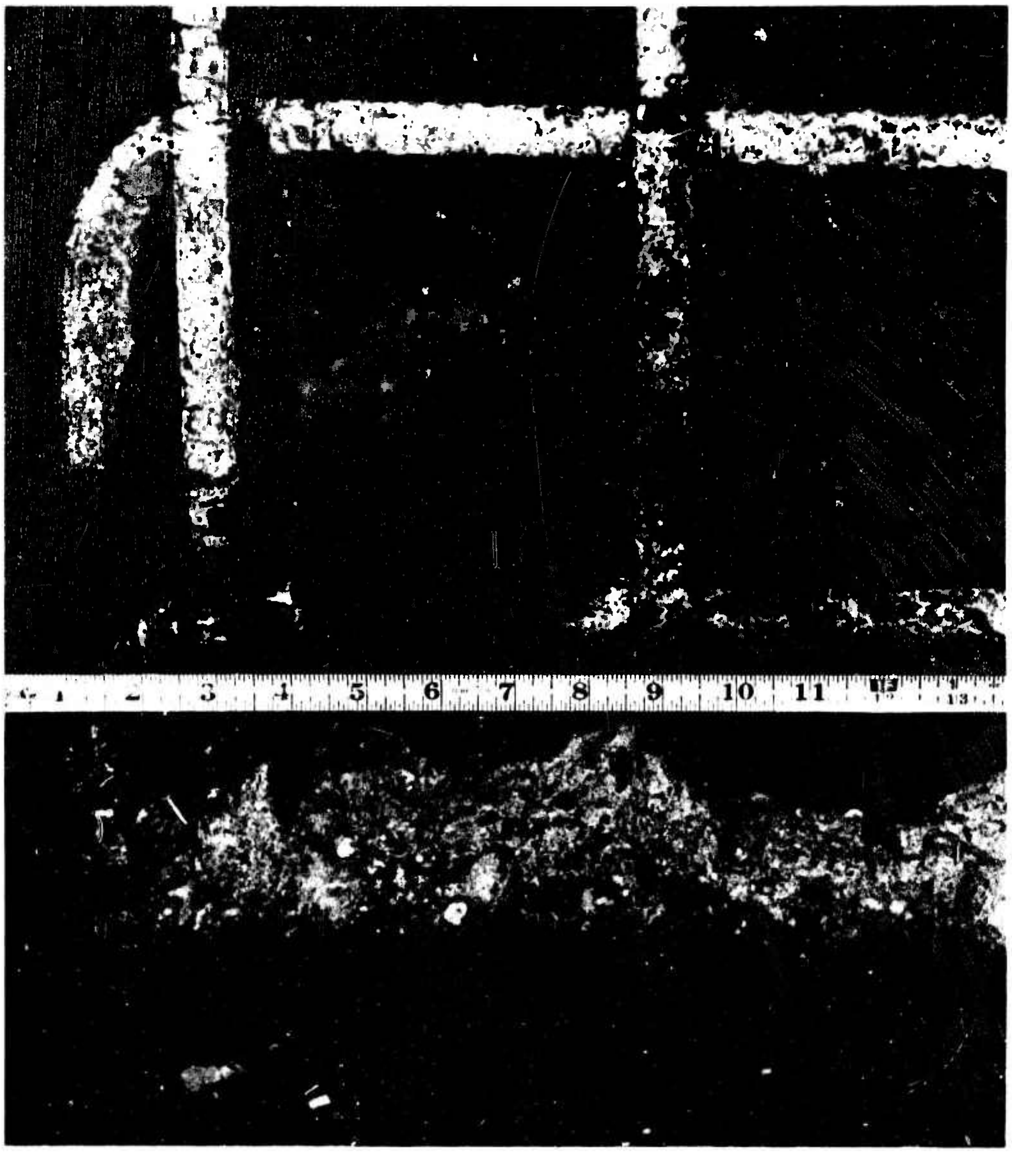


Figure 13. Steel exposed for Wall 103. Dark areas are ferrous oxide. Lower bar is opposite horizontal crack in Figure 12.

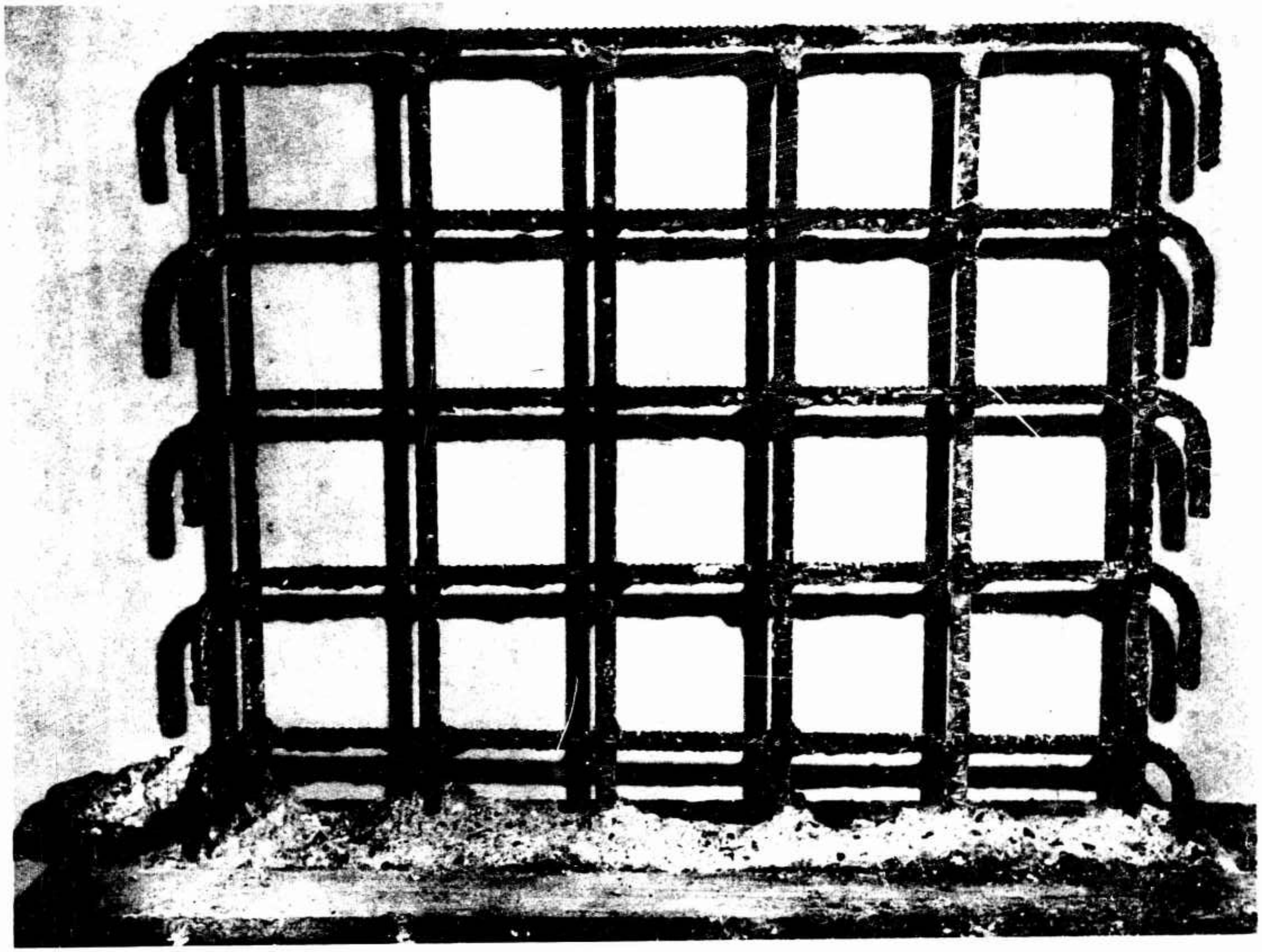


Figure 14. Exposed steel of Wall 104.

## DOCUMENT CONTROL DATA - R&D

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY *(Corporate author)*<br>Naval Civil Engineering Laboratory<br>Port Hueneme, California 93041 | 2a. REPORT SECURITY CLASSIFICATION<br>Unclassified<br>2b. GROUP |

3. REPORT TITLE

Effectiveness of Zinc Coating on Reinforcing Steel in Concrete Exposed to a Marine Environment

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

Donald F. Griffin

| | | |
|---|---|---|
| 6. REPORT DATE<br>July 1969 | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS<br>18 |
| 8a. CONTRACT OR GRANT NO.<br>b. PROJECT NO. Z-R011-01-01-095<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>TN-1032<br>9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* | |

10. AVAILABILITY/LIMITATION NOTICES

Each transmittal of this document outside the agencies of the U. S. Government must have prior approval of the Naval Civil Engineering Laboratory.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>Director of Navy Laboratories<br>Room 2002, Main Navy Building<br>Washington, D. C. 20360 |

13. ABSTRACT

This investigation was made to determine whether or not galvanized steel reinforcement is more suitable than non-galvanized steel reinforcement in concrete exposed to a marine environment. The criterion of comparative suitability is time-dependent cracking of reinforced concrete walls caused by expansive forces resulting from build-up of corrosion products. From the results of the investigation, the important conclusions are that galvanized steel reinforcement is, at best, no better than non-galvanized steel reinforcement, and air-entrained concrete inhibits corrosion of either galvanized or non-galvanized steel reinforcement compared to non air-entrained concrete.

Unclassified

Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| zinc coatings | | | | | | |
| protective coatings | | | | | | |
| reinforcing steels | | | | | | |
| reinforced concrete | | | | | | |
| concrete construction | | | | | | |
| marine atmospheres | | | | | | |
| galvanized materials | | | | | | |
| air entrained concretes | | | | | | |

## INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
________________________________________ ."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
________________________________________ ."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
________________________________________ ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.