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MISCELLANEOUS PAPER S-68-7

EVALUATION AND DESIGN OF HELICOPTER REVETMENTS

by

W. B. Fenwick

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Vicksburg, Mississippi

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13. ABSTRACT

This report describes the evaluation of twelve expedient revetments designed to be used for protection of UH-1 and CH-47 helicopters against shrapnel from the 120-mm mortar. The revetments were to require very little construction effort and time and have minimal cost. It was determined that a 4-ft-thick earth-filled wall would prevent penetration of shrapnel from the 120-mm mortar and that the UH-1 and CH-47 helicopters could most effectively be revetted by 5- and 10-ft-high walls, respectively. These statistics were used as the basis of design recommendations and dimensions for the expedient revetments that were field tested. A total of twelve revetments were studied, nine were proprietary items and three were Waterways Experiment Station designs using materials available in the theater of operations. Data are presented for all of the revetments tested and for two additional revetments which are currently in use in Vietnam.

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FOREWORD

The U. S. Army Engineer Waterways Experiment Station (WES) was requested by the Office, Chief of Engineers, in Incl 2 of a CONFIDENTIAL letter dated 3 May 1967 to develop design criteria for the construction of expedient helicopter revetments. The revetments were to require minimal cost, construction effort, and time.

The investigation was conducted by the Flexible Pavement Branch, Soils Division, WES, during the period 1 June - 13 October 1967. Engineers actively engaged in the testing, analysis, and report phases of the study were W. B. Fenwick and J. F. Sirr. The study was under the general supervision of W. J. Turnbull and A. A. Maxwell, Chief and Assistant Chief, Soils Division, and R. G. Ahlvin and A. H. Joseph. This report was prepared by Mr. Fenwick.

Director of the WES during the investigation and preparation of this report was COL John R. Oswalt, Jr., CE. Technical Director was J. B. Tiffany.

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SUMMARY

This report describes the evaluation of twelve expedient revetments designed to be used for protection of UH-1 and CH-47 helicopters against shrapnel from the 120-mm mortar. The revetments were to require very little construction effort and time and have minimal cost.

It was determined that a 4-ft-thick earth-filled wall would prevent penetration of shrapnel from the 120-mm mortar and that the UH-1 and CH-47 helicopters could most effectively be revetted by 5- and 10-ft-high walls, respectively. These statistics were used as the basis of design recommendations and dimensions for the expedient revetments that were field tested. A total of twelve revetments were studied, nine were proprietary items and three were WES designs using materials available in the theater of operations. Data are presented for all of the revetments tested and for two additional revetments which are currently in use in Vietnam.

EVALUATION AND DESIGN OF HELICOPTER REVETMENTS

PART I: INTRODUCTION

Background

1. Reports from the 1st Calvary Division in Vietnam indicate that satisfactory tactical results can only be achieved if central, semipermanent heliports are maintained in the Southeast Asia theater of operation (TO). These installations are highly vulnerable to mortar attack, but the aircraft can be adequately protected with revetments. The primary problem is the large number of troops and equipment hours required to erect revetments with presently available materials. The U. S. Army Engineer Waterways Experiment Station (WES) was assigned the job of developing an expedient means of revetting for helicopter protection and recommending design considerations as a part of Task 01 of MEANWER.

Purpose and Scope

2. The UH-1 and CH-47 helicopters were to be protected against 120-mm mortar fire. No ballistic data were available on this mortar, but it was known to be less severe than the 4.2-in. mortar. Penetration of fragments from a 4.2-in. mortar burst has been effectively prevented by a 4-ft-thick, earth-filled wall.* Thus, the revetment thickness of 4 ft was established as being adequate to protect against the 120-mm mortar. The 1st Calvary

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* Piepenburg, D. D.; Development and Evaluation of Protective Revetments, Technical Report No. AFWL-TR-66-47, Air Force Weapons Laboratory, Kirtland AFB, New Mexico, November 1966.

division engineer specified that close-in revetment heights for the UH-1 and CH-47 helicopters may not exceed 5 ft. The problem then becomes one of developing a 4-ft-thick, 5-ft-high revetment with the following characteristics:

a. Provide protection against 120-mm mortar fire.

b. Be safe enough for direct fly-in operations under conditions of darkness and pilot fatigue.

c. Require a minimum of engineer equipment and man-hours for erection.

d. Be light and compact enough so as to impose a minimum logistical burden.

e. Be versatile in erection configuration and easily dismantled for relocation.

3. This report presents revetment design configurations to afford the best possible protection for UH-1 and CH-47 helicopters against shrapnel from the 120-mm mortar. Safety considerations as listed in paragraph 2b above were beyond the scope of this investigation.

4. The report also presents the results of a field evaluation of the erection characteristics of helicopter revetting materials. The field test portion of the investigation was concerned with the comparison of the revetting materials on the basis of number of components, weight, number of personnel and time required for erection, type and time of equipment involved in erection, ease of assembly and disassembly, and evaluation of the reuse capability.

PART II: REVETMENT DESIGN

5. It is expected that most final decisions on revetment configurations will be made in the TO based on number of aircraft, available real estate, available engineer support, and other pertinent factors. The following observations are presented, however, for consideration.

UH-1 Helicopter Revetments

6. The most practical method of revetting the UH-1 appears to be with close-in, under-the-rotor-blade revetments. This is particularly desirable from the standpoint of reduced target size, as opposed to the target presented by a revetment wider than the rotor diameter. It seems highly desirable to use the individual revetment concept rather than a common wall between two helicopters. This results in a considerable reduction in the overall target size, i.e. the space between revetments is a "safe" area. Furthermore, the additional amount of revetment required is insignificant. Plate 1 shows a proposed revetment system for UH-1 helicopters. The revetments are 30 by 44 ft inside, 4 ft thick, and 5 ft high. The 30-ft inside width of the revetments was established so that a mortar burst exploding just outside the wall would only endanger the blades and rotor top of the helicopter in the adjacent revetment. This width also allows ample maneuver room for loading and unloading the helicopter.

7. The center-to-center spacing of adjacent helicopters is given by Department of the Army Technical Bulletin TB 5-330-2, "Planning and Design for Rapid Heliport Construction for the Theater of Operations." * It should be noted that this manual indicates straight alignment of the helipads. If

* Headquarters, Department of the Army, Planning and Design for Rapid Heliport Construction in the Theater of Operations, Department of the Army Technical Bulletin TB 5-330-2, January 1967.

new construction is contemplated, consideration should be given to the orientation of helipads as shown in plate 1. The circular or irregular layout has the general advantage of simpler adaption to existing real estate and the particular advantage of angled revetments, which would keep one mortar burst from entering the open end of two revetments. In the circular layout, it is assumed that 70 ft of arc is required for each revetment. Therefore, the diameter of the installation may be determined by the following equation:

$$\frac{(\text{Number of helicopters})(70\text{ ft})}{\pi} = \text{Diameter, ft}$$

CH-47 Helicopter Revetments

8. Due to the low sweep of the forward rotor on the CH-47, it is not possible to provide under-the-rotor protective revetments. Plate 1 shows a proposed CH-47 revetment layout. The revetment height of 10 ft* could be reduced if the center-to-center spacing of the helicopters was reduced, and no loss of protection would occur. The three-sided revetment shown allows 5-ft horizontal clearance between rotor tips and revetment walls. A center-line stripe and proper placement of wheel chocks would be used to maintain this 5-ft clearance. It has been suggested that revetments open on both ends would be more practical from an operational standpoint as they would eliminate the problem of backing up. Aircraft would enter one end of the revetment and depart through the other end. It is assumed that specific, individual situations will best govern the decision to use either two- or three-sided revetments.

* The stability of a 10-ft-high, 4-ft-thick earth-filled wall was investigated and found to be satisfactory.

PART III: FIELD TESTS

9. As noted in Part I of this report, the field tests were limited to an evaluation of the physical and erection characteristics of the revetting materials. No attempt was made to do ballistic evaluation. The desirability of such an evaluation should be pointed out here, since it might disclose an overdesign of the revetment wall thickness. The adjustment of revetment thickness could result in a significant reduction in the effort required to fill the revetments with soil. Ballistic tests would also determine the impact characteristics of the revetting materials and possibly eliminate some materials.

Description of Revetments and Test Procedures

10. A total of twelve revetment materials were studied; nine were proprietary items and three were WES designs using materials available in the TO. In most cases, a 4-ft-thick, 5-ft-high wall was erected including a right-angle turn. Both of these dimensions varied occasionally due to the amount and size of material available at the time of testing and to the design configuration. All walls were filled with uniform concrete sand. Filling was accomplished with a front-end loader and was not considered as a variable between the revetment types. The erection and disassembly procedures are discussed in the following paragraphs.

Air Logistics Corporation

11. Type I. The MO-SHEL (a product tradename) came in 5 by 10 ft flat sheets and was crated as shown in photograph 1. Each fiber glass

reinforced-plastic sheet was rolled into a 34-in.-diam cylinder and bolted together (photographs 2 and 3). The cylinders were then clipped together and stood on end as shown in photographs 4 and 5. A heavy rubber liner bag is shown in photograph 6. This bag was furnished to be used in areas where water or slurry is the only available fill material. It was used in only one cylinder and filled with sand. A view of the completed wall is shown in photograph 7. Photograph 8 shows a truck crane emptying the MO-SHEL cylinders. The front-end loader was unable to lift these cylinders. After emptying, the cylinders were unbolted and restacked in flat sheets.

12. Type II. A second revetment concept of the Air Logistics Corporation utilized the same fiber glass sheets described above plus 18-gage steel connecting panels and pins packaged as shown in photograph 9. One wall section was erected using flat sheets of STRATOGLAS. The result was practically identical to the MO-SHEL with economy being the sole advantage. The steel cross panels had tabs that fitted holes in the fiber glass and were pinned as shown in photograph 10. Photographs 11 and 12 show the filling operation and completed revetment, respectively. The disassembly was accomplished by relieving the pressure on the pin with the front-end loader, pulling the pin by hand, and backing the front-end loader away to let the wall open.

American Electric, Inc.

13. This revetment (AEI) consisted of individual 18-gage steel boxes, 4-ft sq and 2-1/2 ft high, with a piano-type hinge at the four corners. The boxes were folded flat for shipping (photograph 14). Photograph 15 shows a single box opened for use (note the internal stiffeners). Two of these

boxes were stacked to form each 5-ft-high module. Photographs 16 and 17 show the erection procedures and photograph 18 shows the completed revetment. A special spreader bar with sheet metal clamps was used with the front-end loader to disassemble the revetment (photograph 19).

ARMCO Steel Corporation

14. Type I. The packaged revetment (ARMCO I) is shown in photograph 20. It consisted of 16-, 18-, and 20-gage steel sheets with loops on the cross panels for pinning. The sheets were 5 ft high and 4, 5, or 6 ft wide. A special pin (photograph 21) was used to facilitate disassembly. It was so designed that when raised about 3 in., all loops were disengaged at once. Photographs 22 and 23 show the assembly procedure and corner configuration, respectively. The completed wall included all gages and sheet sizes and is shown in photograph 24. As can be seen in photograph 25, the 20-gage metal was light enough to permit deformation at the bottom of the sheets indicating that the 16- or 18-gage sheets should be used in any future revetments.

15. Type II. The sheets and posts (ARMCO II) are shown in photographs 26 and 27, respectively. The 16-, 18-, and 20-gage sheets were 5 ft high and in 4- and 6-ft lengths with extruded aluminum posts for connecting. A crimp along the panel edges held them in the slotted posts. The assembly of the revetment is shown in photograph 28, the filling in photograph 29, and the completed wall in photograph 30. The completed wall included sheets of all gage sizes. The same type of deformation occurred in the 20-gage panels (photograph 31) as was noted in the 20-gage type I ARMCO revetment. The crimp failed (photograph 32) on several 20-gage panels during the disassembly operations which are shown in photographs 33 and 34. A final design

would probably use a double-folded metal edge in lieu of the crimp, which should eliminate this problem.

Kaiser Aluminum Company

16. The packaged Kaiser Aluminum revetment is shown in photograph 35. Photographs 36-39 show various phases of the assembly operation. The completed revetment, shown in photograph 40, was 6 ft high. Minor damage occurred during the disassembly operations (photographs 41 and 42) but could probably have been avoided with the proper lifting arrangements.

Kaiser Steel Corporation

17. Type I. The packaged Kaiser I revetment and special tools and parts are shown in photographs 43 and 44, respectively. The individual panels were 2-1/2 ft wide and 3 ft high. Upper and lower sections were clipped together, which resulted in a 5-ft-wide and 6-ft-high revetment. The assembly and filling operations are shown in photographs 45 and 46, respectively. Photograph 47 shows the completed wall and the disassembly is shown in photograph 48.

18. Type II. The modified Kaiser concept provided single panels 4 ft wide and 5 ft high, shown in photograph 49 as received. Photographs 50-52 show the assembly operation, completed revetment, and disassembly operation, respectively.

Republic Steel Corporation

19. This revetment, shown in shipping package, photograph 53, and 3- by 12-ft side panels with 3- by 4-ft cross panels. The accessories are shown in photograph 54. All cross-panel ends were flared (photograph 55) prior to erection to permit the interlock at a three-way junction. The flare

was intentionally omitted by the manufacturer to permit nesting during shipment. Polyethelene lining was used at the revetment ends to prevent sand leakage in the corners (photograph 56). Special clips were used to turn the right angle (photograph 57). The completed revetment is shown in photograph 58. Disassembly was accomplished by holding the panels with the front-end loader (photograph 59), pulling the pins, and backing the loader away to let the panel fall (photograph 60).

WES expedient designs

20. Plywood. A 4-ft-wide and 5-ft-high revetment was built of 1/2-in. AC plywood and 2x4 pine lumber shown in photograph 61. The 2x4's were nailed into 4- by 5-ft frames (photograph 62). The frames were then raised and the plywood nailed to them, as shown in photograph 63. Photograph 64 shows the right angle turn, and photograph 65 shows the disassembly procedure.

21. M8A1. This revetment utilized M8A1 landing mat and 1/2-in. reinforcing bars that are readily available in the TO. The assembly operation, shown in photographs 66-76, took a minimal amount of time and compared favorably with the other expedient revetments. Disassembly, shown in photograph 77, resulted in bending of most of the reinforcing bars; however, the M8A1 was not damaged.

22. Ground mat. This revetment was constructed from Republic Steel ground mat. The frame work that supported the ground mat was fabricated from 1/2-in. reinforcing bars. The walls were secured using pins. The assembly operation is shown in photographs 78-82. The assembly time compared closely with other expedient revetments. The disassembly, shown in photograph 83,

resulted in severe damage to all of the material. It should be noted that this revetment became unstable during disassembly.

Discussion of Test Results

23. Table 1 summarizes the test results. It presents weight, approximate cost, assembly time, and disassembly time information for all twelve materials. For comparative purposes, data were compiled for sand bag and M8A1 (Standard) revetting techniques being used at the present time. The information included in table 1 for these techniques was taken from correspondence from the First Air Calvary Division; Army Engineers Research and Development Laboratory Report, "Evaluation of Steel Panels for Revetment Walls," and AFWL Report "Development and Test of Aircraft Protective Revetments."

24. Probably the single most important consideration is the number of man-hours required for erection. It can be seen from table 1 that the American Electric and ARMCO I revetments went up the fastest. Requiring about half again as much time were the Air Logistics II and Kaiser Steel II materials. The other erection times varied to up to eight times as great as the two fastest times. The WES expedient designs using M8A1, ground mat, and plywood; Air Logistics II; and American Electric revetments were disassembled fastest, followed closely by both ARMCO types and the Kaiser Steel II. The plywood revetment was disassembled without the aid of any equipment while the others required at least a front-end loader, and some required a truck crane. The ground mat revetment was unstable and severely damaged during disassembly. In addition, about 70 percent of the Republic

Steel revetment sustained damage during disassembly. Subsequent development of proper disassembly techniques, however, will eliminate this problem. The remaining revetments were disassembled with little or no damage.

25. It can be seen from table 1 that of the materials tested the Air Logistics II, Kaiser Aluminum, and plywood revetments were the lightest (22-26 lb per linear ft). It should be noted that the Kaiser Aluminum was 6 ft high, and the reduction to 5 ft would result in a significant weight reduction. Examination of the cost figures, which are approximate, indicates that plywood is by far the cheapest at $1.75 cents per linear ft, followed by Kaiser Steel II at $6.00. With the exception of the very expensive Air Logistics I, the remaining materials are in the $10 to $12 per linear ft range.

Table 1

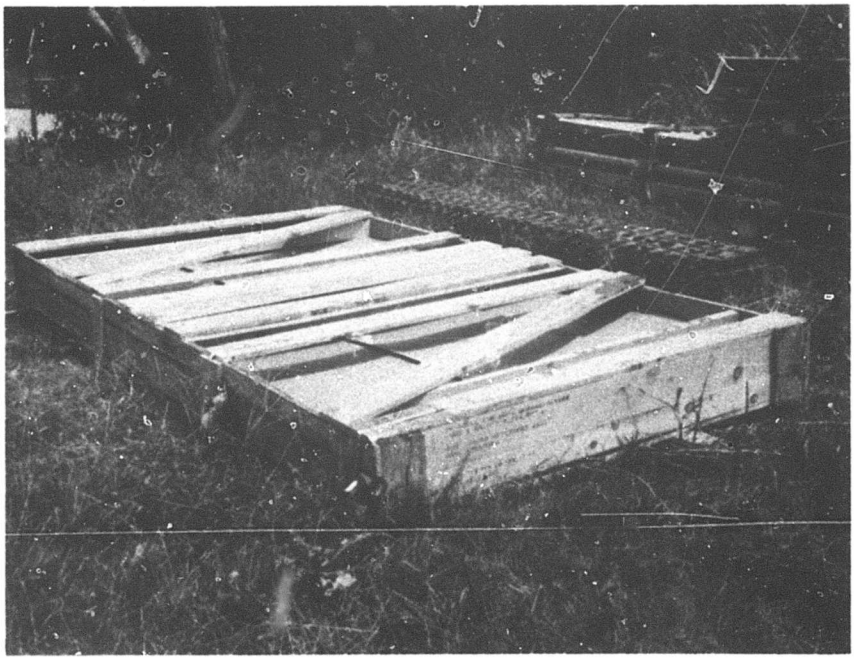
Helicopter Revetment Material Characteristics

Material		Wt/Lin Ft of 5-ft-High Wall, lb	Cost/Lin Ft of 4-ft-thick Wall	Assembly Time man-hr/lin ft of 4-ft-thick Wall	Disassembly Time man-hr/lin ft of 4-ft-thick Wall*	Equipment Time for Disassembly equip-hr/lin ft of 4-ft-thick Wall
		Field Tests of Proprietary Items				
Air Logistics Corp:	I. Fiber glass reinforced-plastic (MO-SHEL)	35.0	$98.25	0.486	Phase I 0.272 Phase II 0.236	0.071 truck crane
	II. Fiber glass reinforced-plastic & 18-gage steel	22.4	$22.50 MO-SHEL $12.50 STRATOGLAS	0.073	0.094	0.23 front-end loader
American Electric Inc:	18-gage steel	62.0	$9.00 to $10.000	0.052	0.096	0.019 front-end loader
ARMCO Steel Corp:	I. 16-, 18-, & 20-gage steel	40.3, 33.1, 30.3	Less than $10.00	0.053	0.113	0.014 front-end loader
	II. 16-, 18-, & 20-gage steel	37.5, 32.4, 27.3	Less than $10.00	0.092	0.125	0.024 front-end loader
Kaiser Aluminum & Chemical Corp:	16-gage aluminum**	21.9**	Less than $12.00	0.460**	Phase I 0.177 Phase II 0.C8	0.012 truck crane
Kaiser Steel Corp:	I. 18-gage steel#	72.4#	$13.50	0.308#	0.308	0.037 front-end loader
	II. 18-gage steel	31.7	$ 6.00	0.076	0.142	0.006 front-end loader
Republic Steel Corp:	18-gage steel**	44.2**	Less than $12.60	0.286**	0.338**	0.069 front-end loader

Table 1 (concluded)

Material	Wt/Lin Ft of 5-ft-High Wall, lb	Cost/Lin Ft of 4-ft-thick Wall	Assembly Time man-hr/lin ft of 4-ft-thick Wall	Disassembly Time man-hr/lin ft of 4-ft-thick Wall	Equipment Time for Disassembly equip-hr/lin ft of 4-ft-thick Wall
Field Tests of WES Expedient Designs					
1/2-in. plywood & pine 2x4 in. posts	26.6	$1.75	0.154	0.084	None
M8A1 landing mat	74	$10.00	0.187	0.097	0.005 front-end loader
Ground mat	50	$6.40	0.130	0.082	0.013 front-end loader
Items in Current Use					
M8A1 (Standard)	--	$10.00	1.16	--	--
Sand bags	0.85	$15.00	3.3 to 5.3	--	--

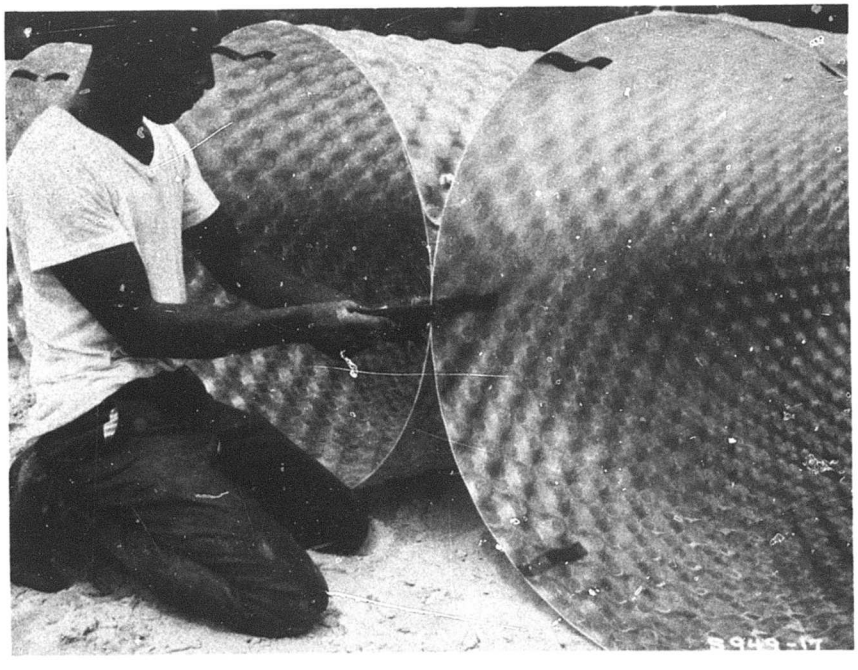
* Where noted: Phase I included emptying cylinders.
Phase II included bolt removal.
** 6-ft-high wall.
# 6-ft-high, 5-ft-wide revetment.



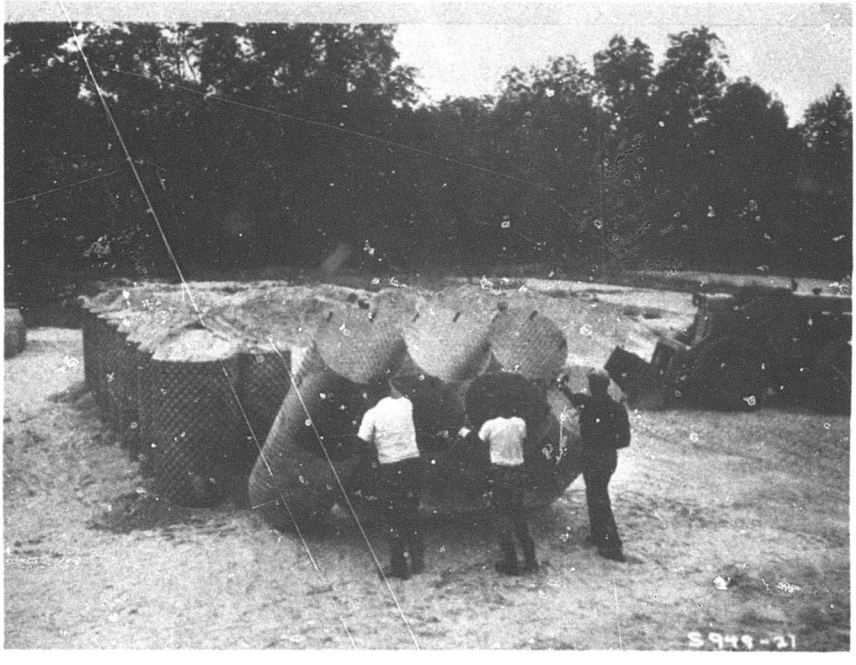
Photograph 1. Air Logistics Corporation MO-SHEL in shipping crate

Photograph 2. Rolling MO-SHEL into a cylinder

Photograph 3. Bolting MO-SHEL cylinder

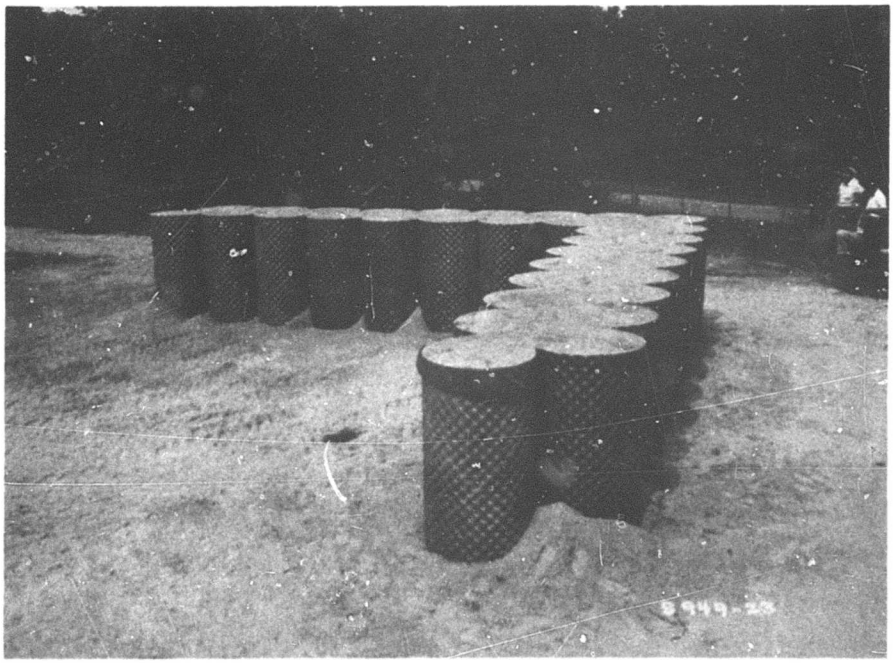


Photograph 4. Clipping MO-SHEL cylinders together



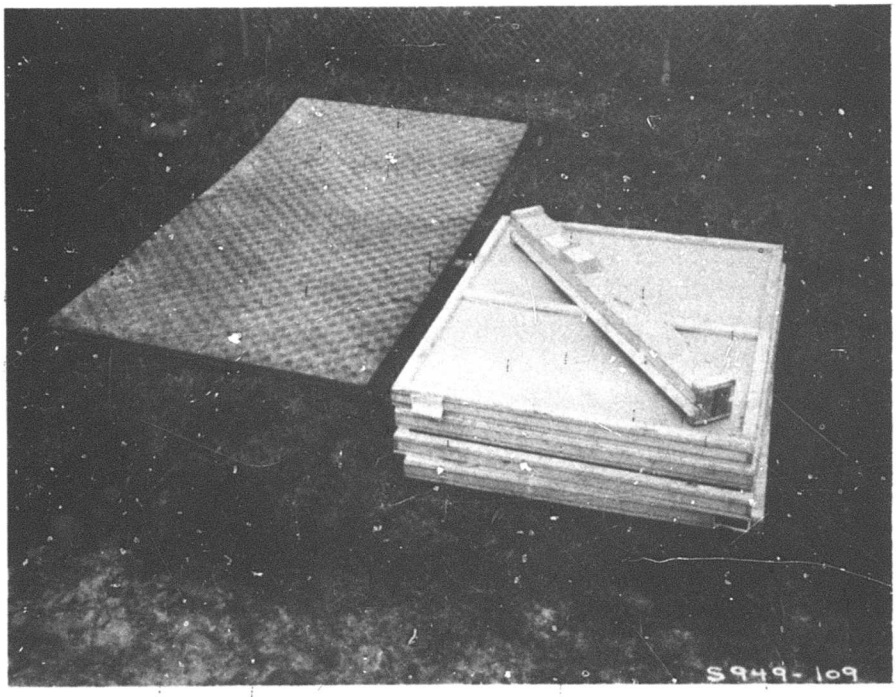
Photograph 5. Forming MO-SHEL cylinder wall

Photograph 6. Liner bag placed in one MO-SHELL cylinder

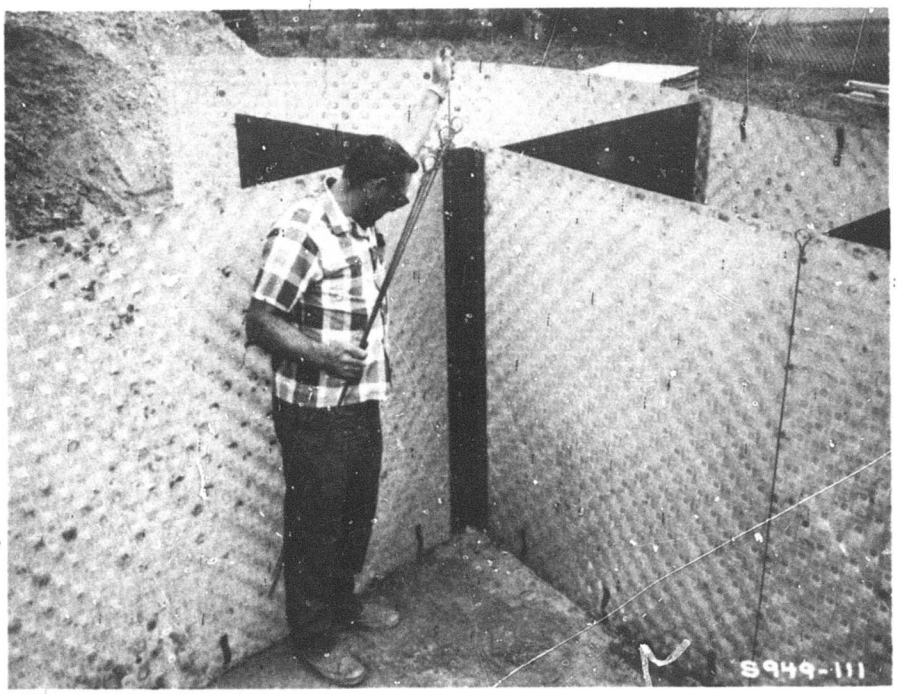


Photograph 7. Completed MO-SHEL wall

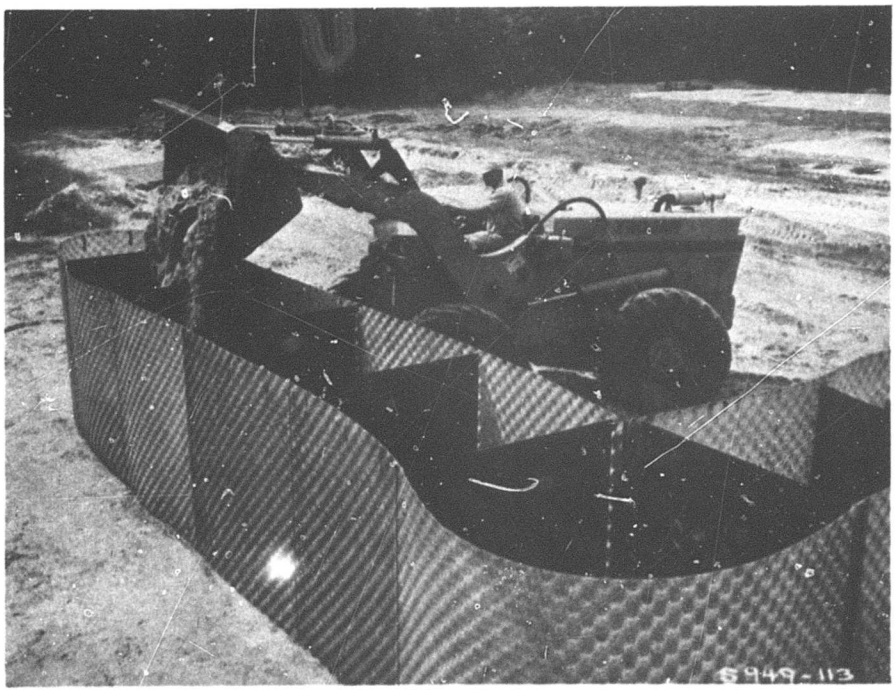
Photograph 8. Truck-mounted crane emptying MO-SHEL cylinders



Photograph 9. Air Logistics Type II side sheets and crated cross panels



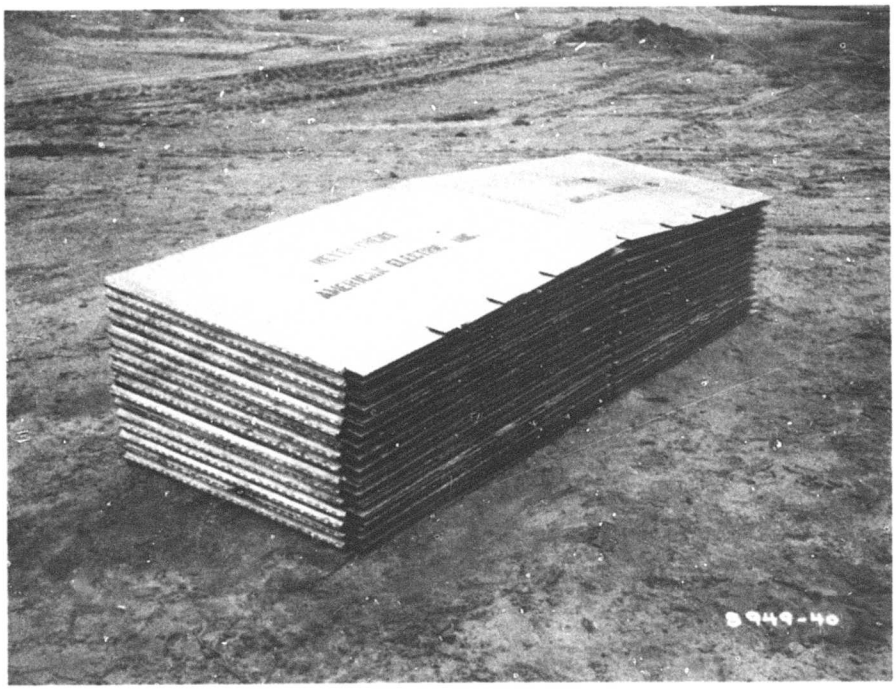
Photograph 10. Inserting pins in Air Logistics II revetment



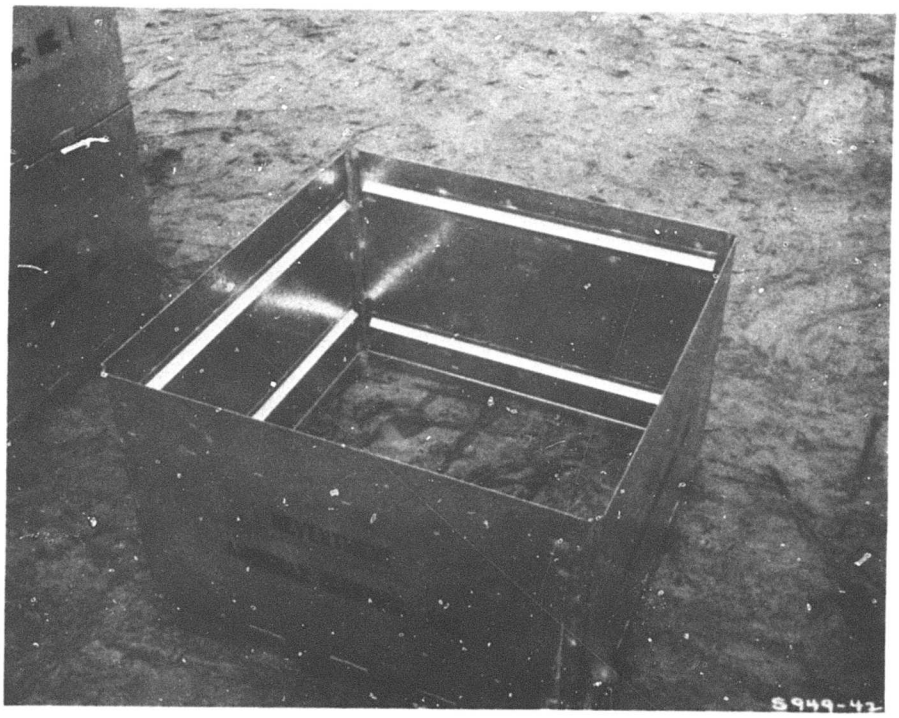
Photograph 11. Filling Air Logistics II revetment

Photograph 12. Completed Air Logistics II revetment

Photograph 13. Disassembly of Air Logistics II revetment



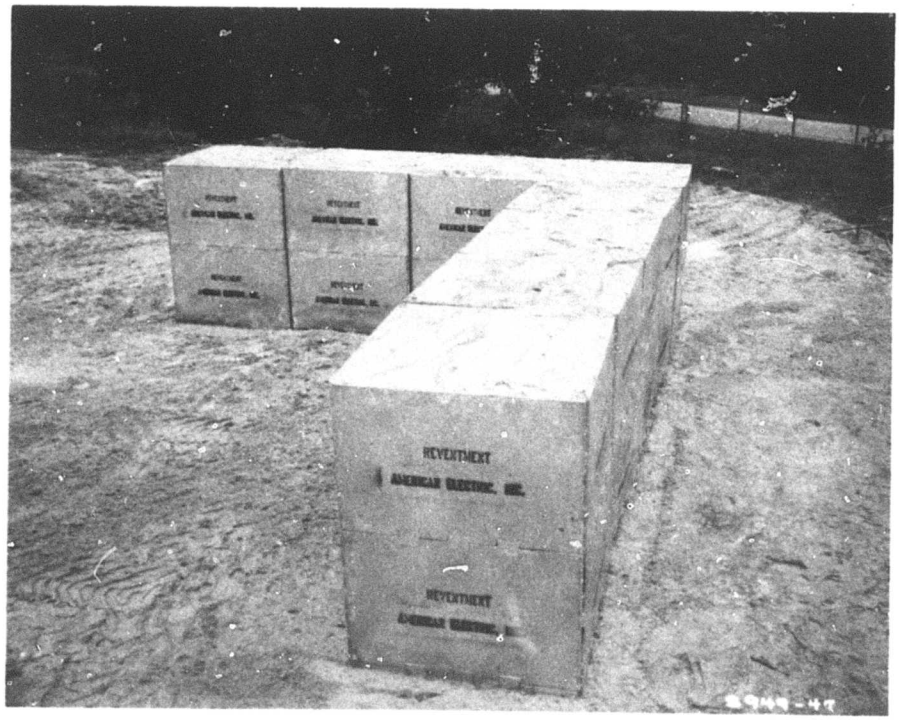
Photograph 14. American Electric Inc. revetment folded for shipping



Photograph 15. A single AEI revetment box
(Note internal stiffeners)

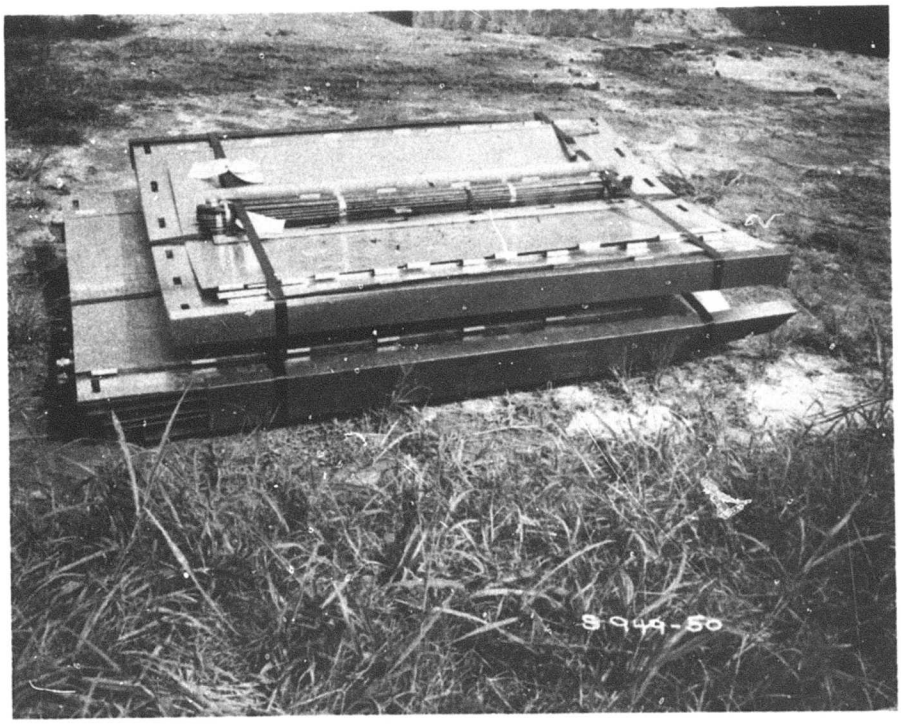
Photograph 16. Erection of AEI revetment module

Photograph 17. Erection of AEI revetment



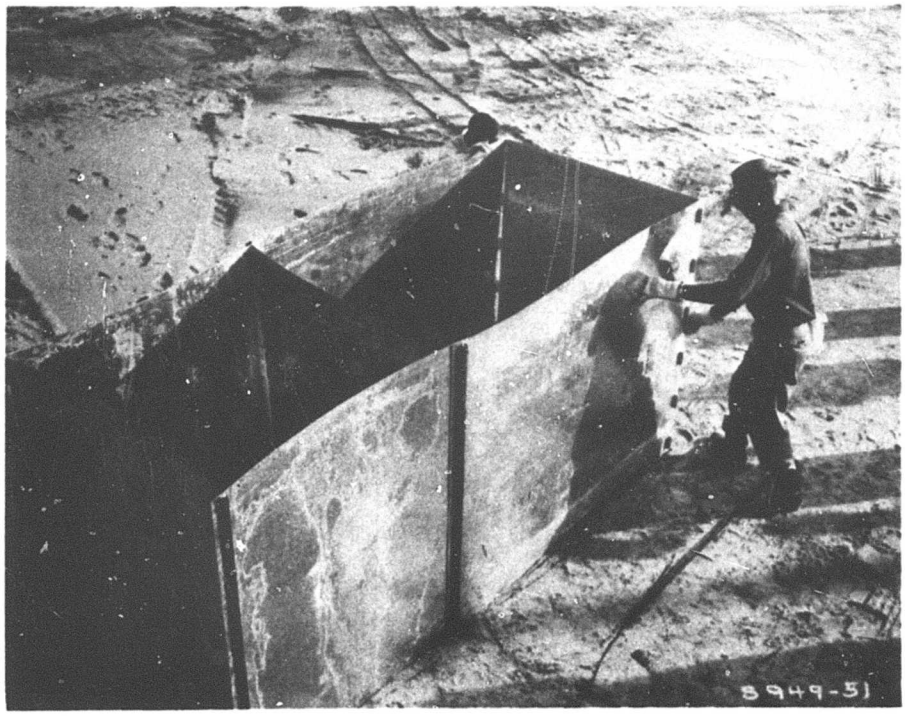
Photograph 18. Completed AEI revetment

Photograph 19. Spreader bar being used to disassemble AEI revetment

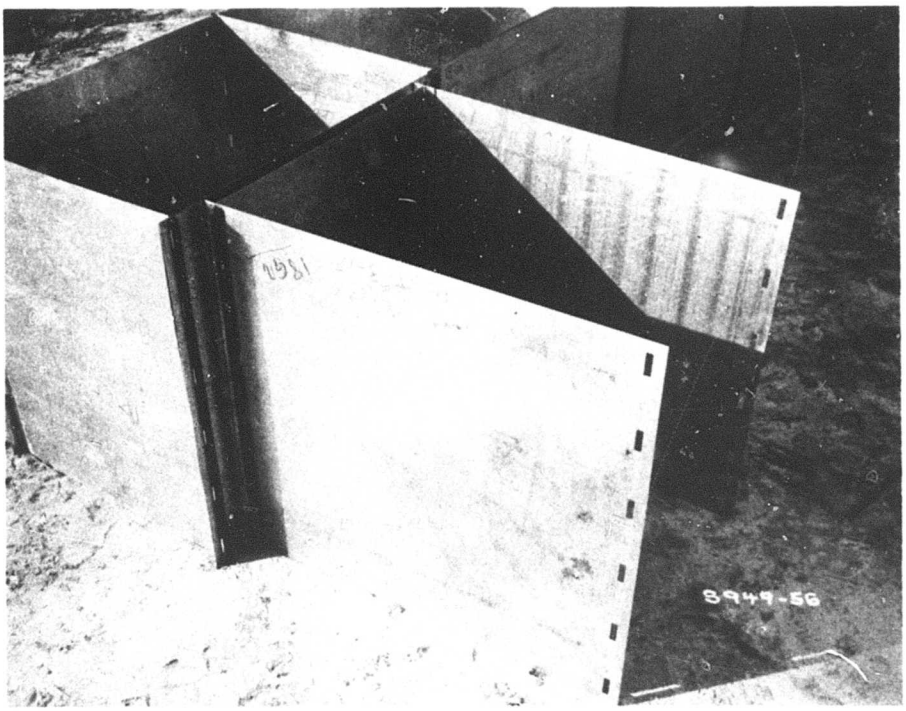


Photograph 20. Armco Steel Corporation Type I revetment as received

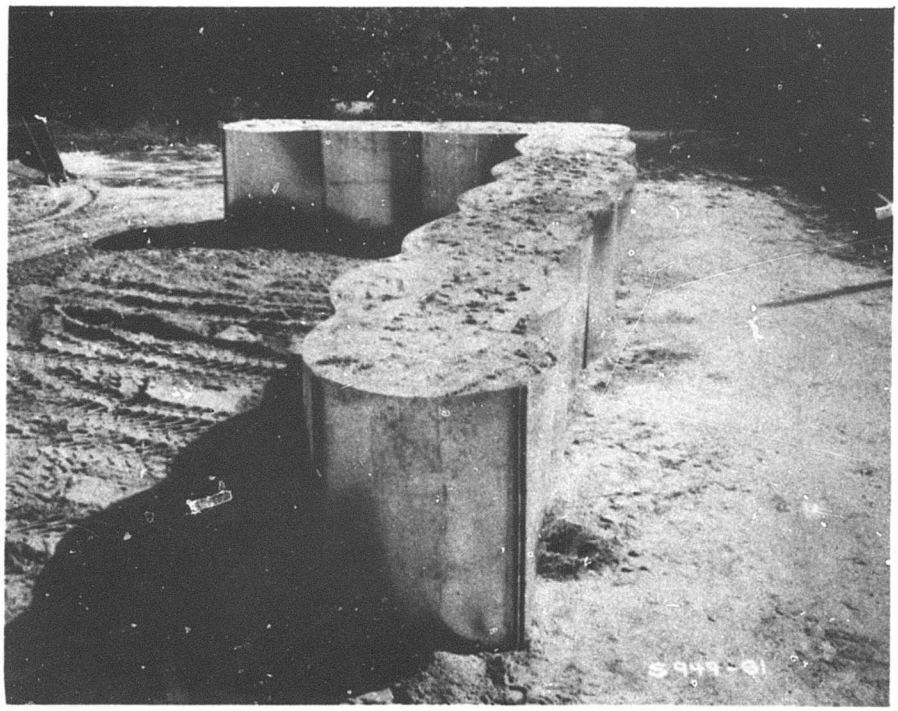
Photograph 21. Sheets of ARMCO I connected by pins



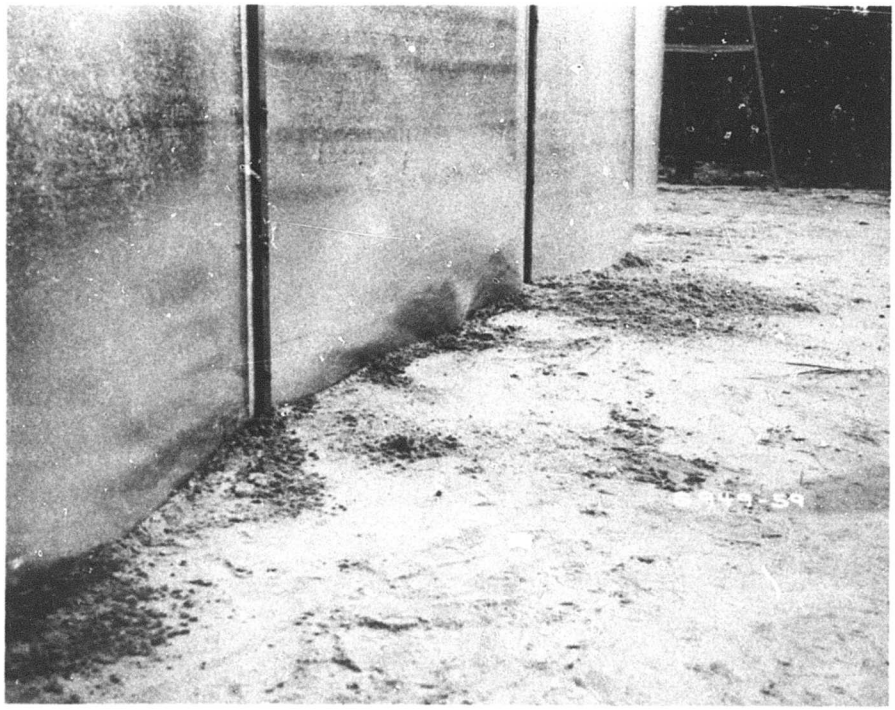
Photograph 22. Assembly of ARMCO I revetment



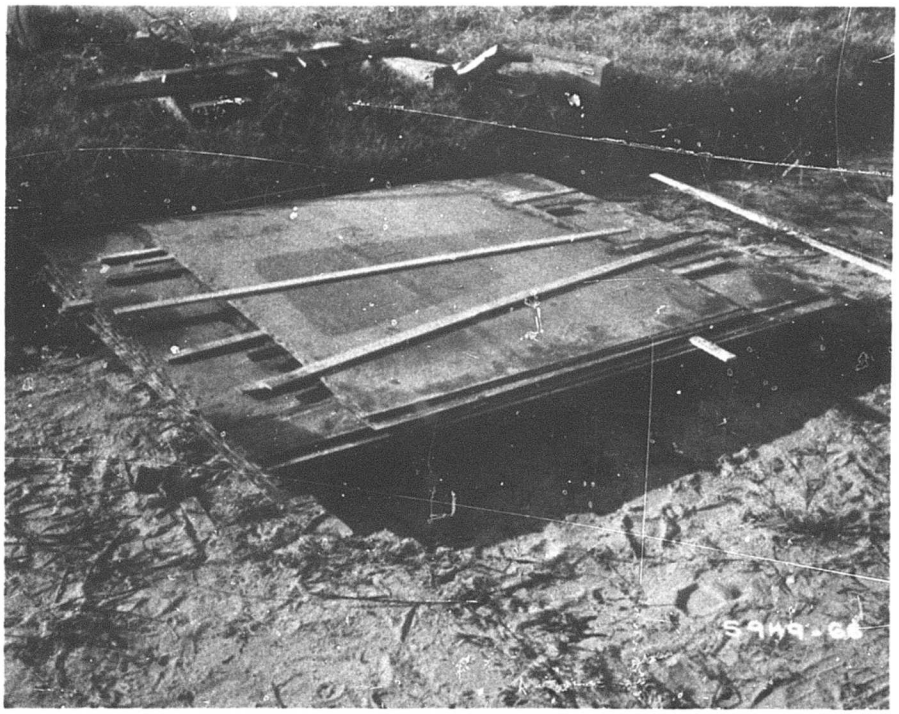
Photograph 23. Corner assembly of ARMCO I revetment



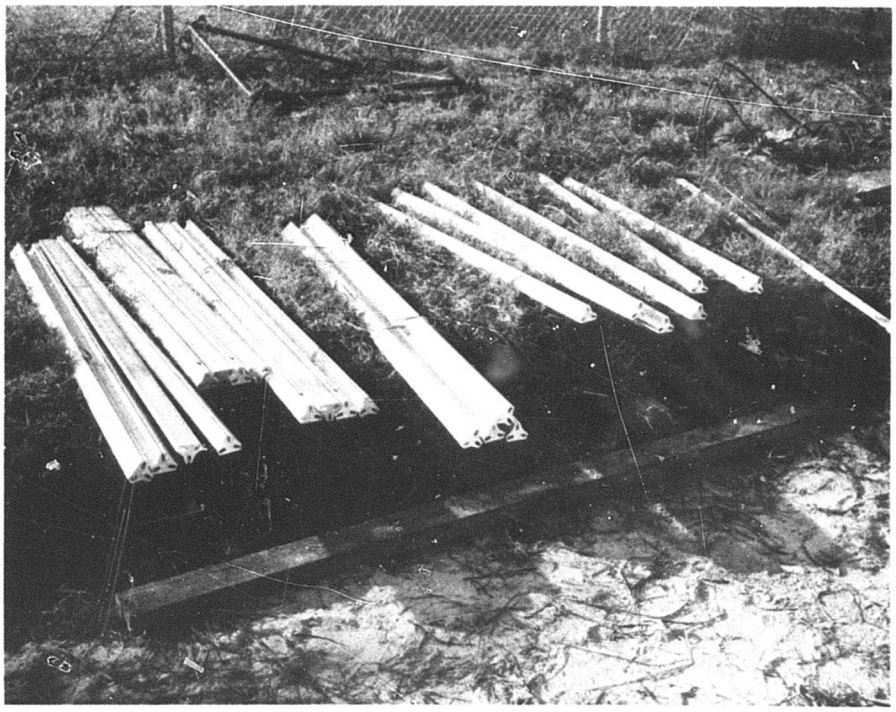
Photograph 24. Completed ARMCO I wall



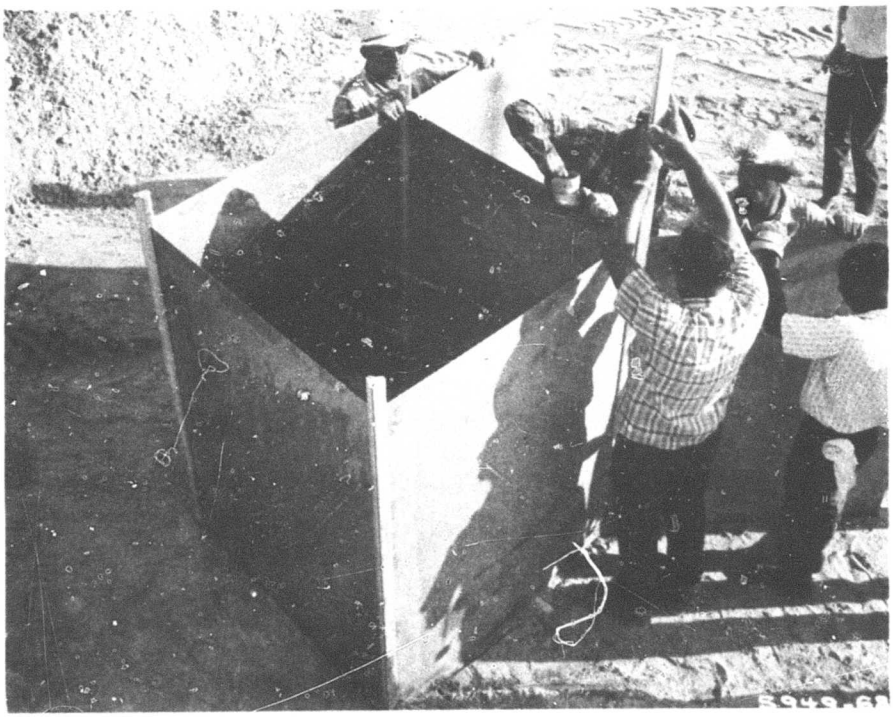
Photograph 25. Deformation of 20-gage ARMCO I sheets due to sand fill in revetment



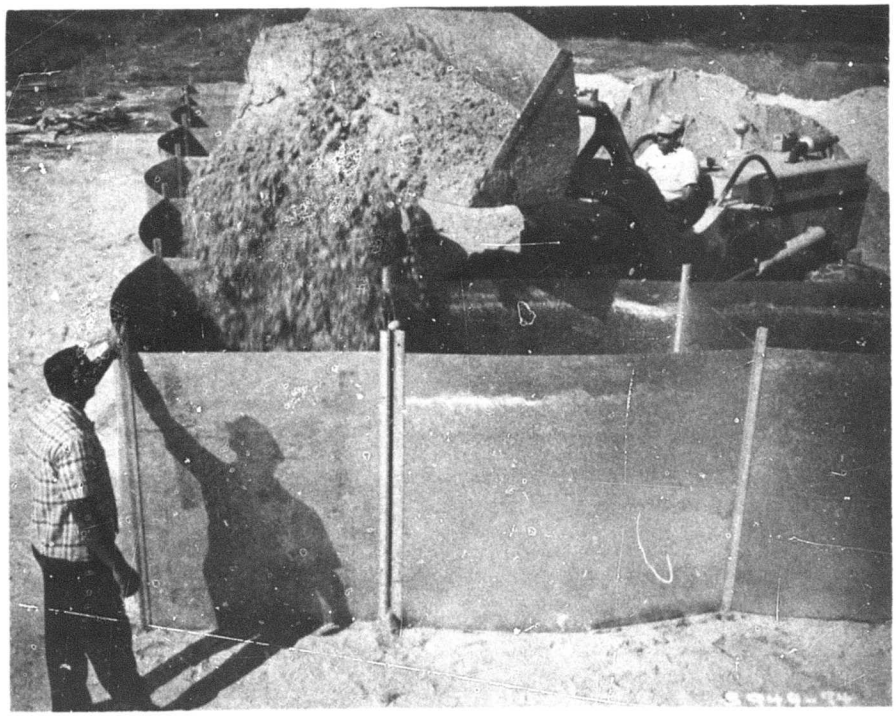
Photograph 26. Armco Steel Corporation Type II sheets as received



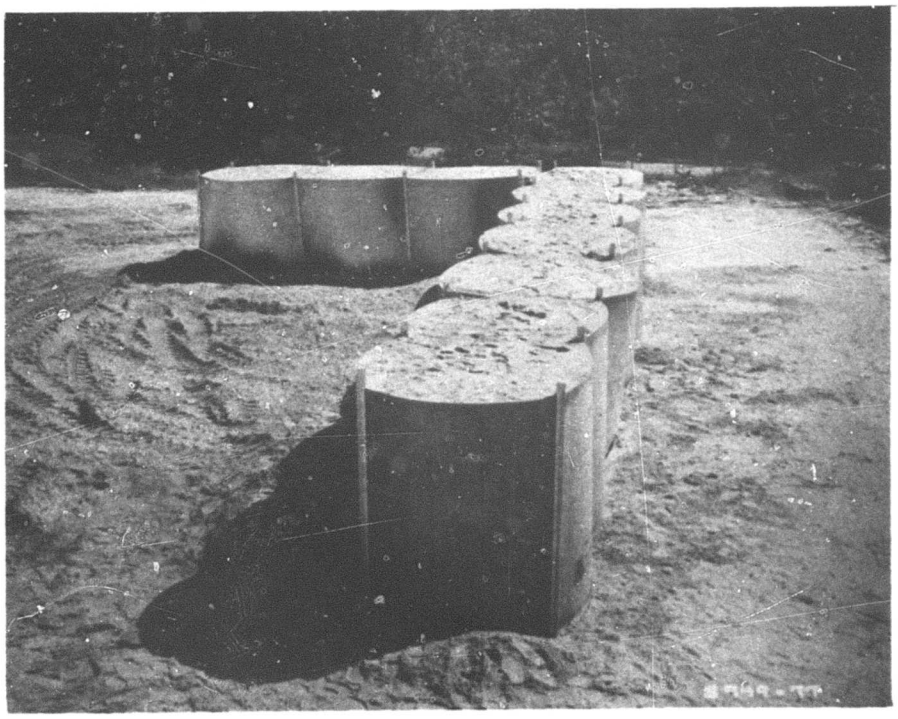
Photograph 27. Extruded aluminum posts for ARMCO II revetment



Photograph 28. Assembly operation of ARMCO II revetment

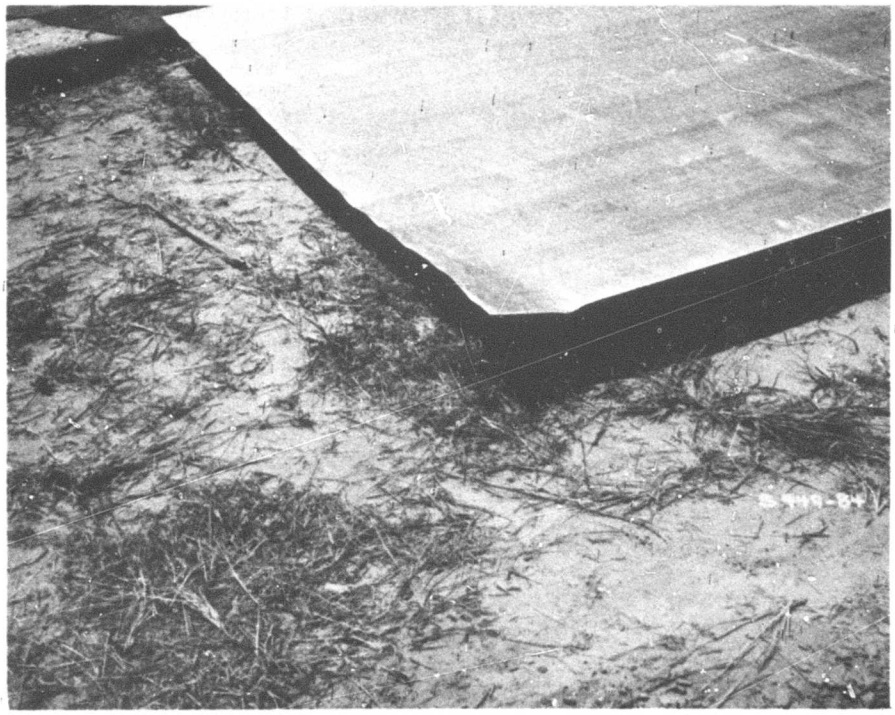


Photograph 29. Filling ARMCO II wall



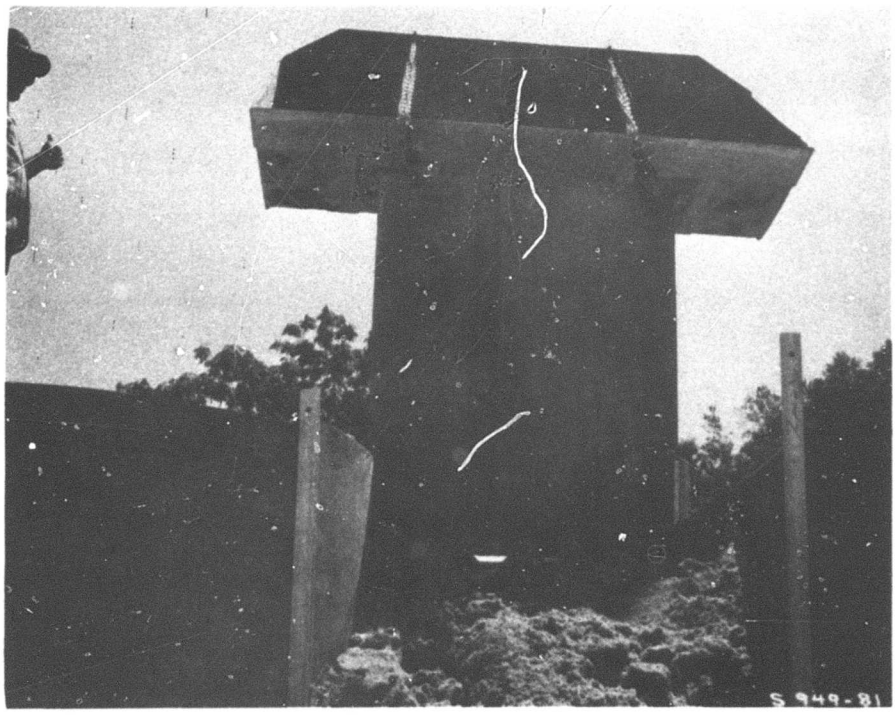
Photograph 30. View of completed ARMCO II wall

Photograph 31. Buckling of 20-gage ARMCO II paneling at bottom of revetment



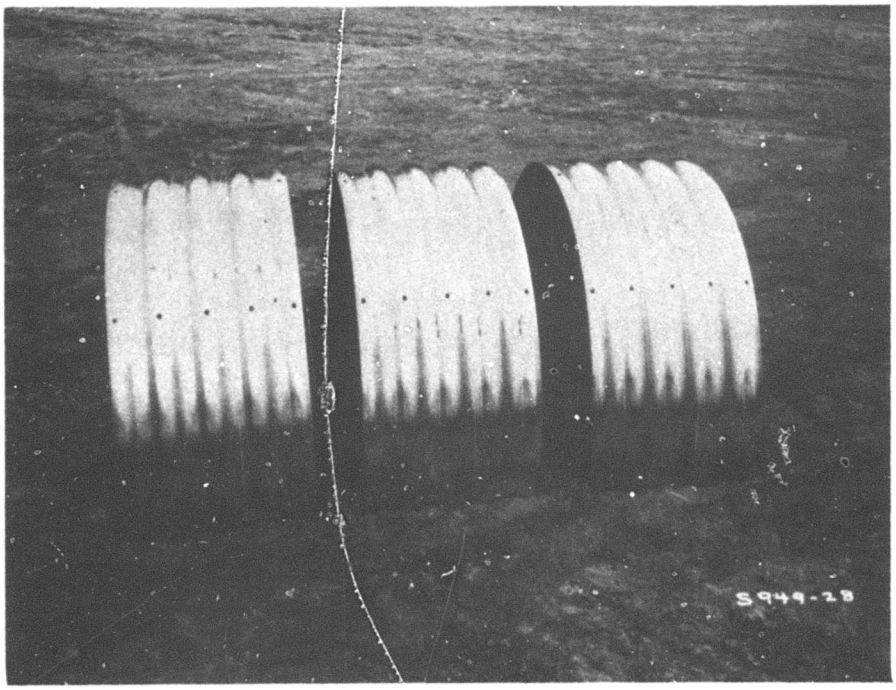
Photograph 32. Failure of crimp along 20-gage ARMCO II panel edge

Photograph 33. ARMCO II disassembly operations



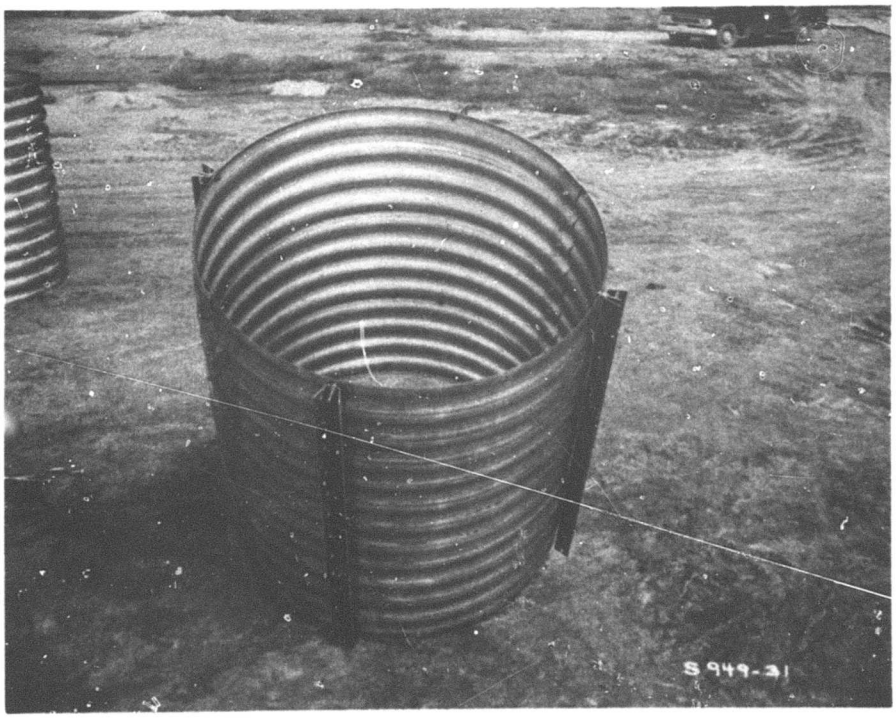
Photograph 34. ARMCO II disassembly operations

Photograph 35. Packaged Kaiser Aluminum revetment as received



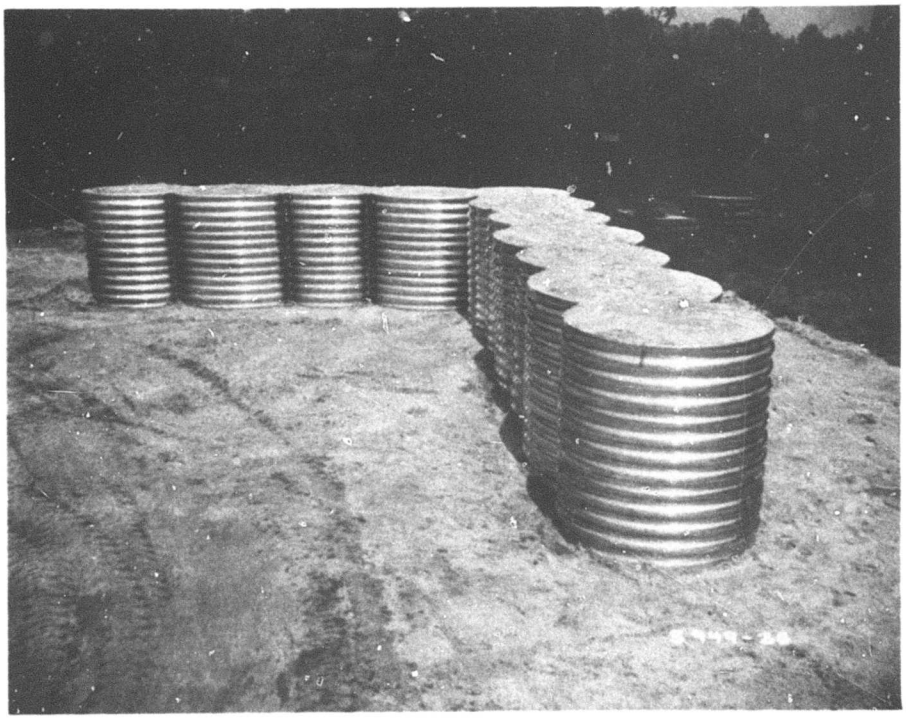
Photograph 36. View of separated Kaiser Aluminum half-culverts

Photograph 37. Joining Kaiser Aluminum culvert halves



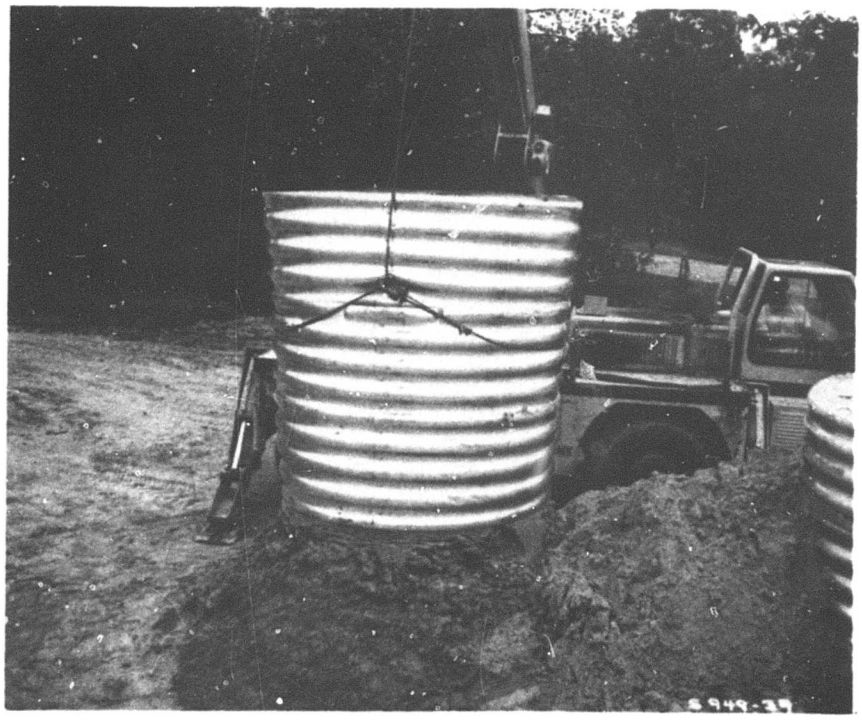
Photograph 38. Completed Kaiser Aluminum culvert with side rails attached

Photograph 39. Assembly of Kaiser Aluminum arch sections

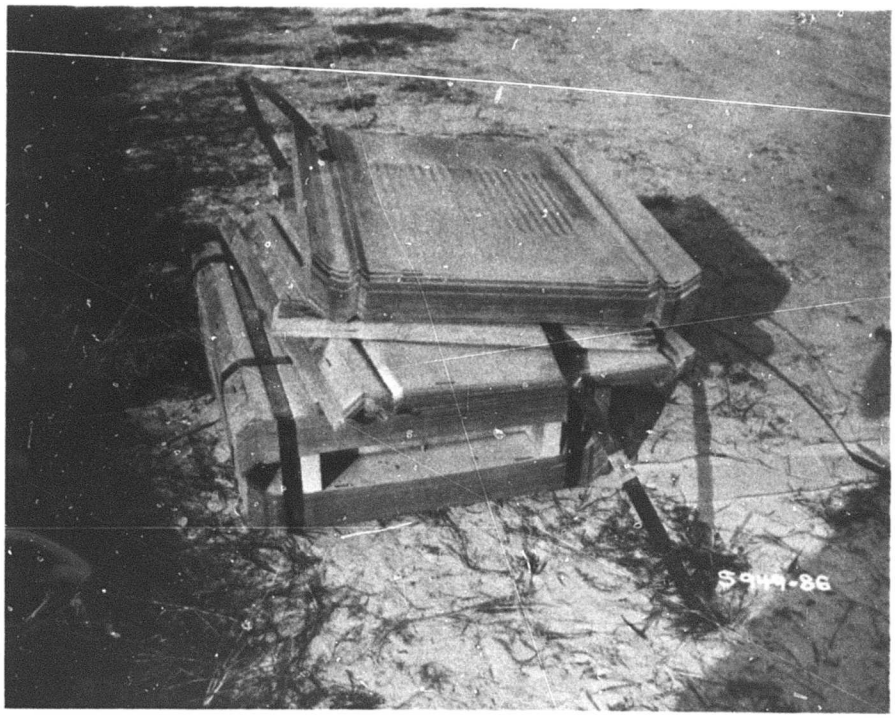


Photograph 40. View of completed Kaiser Aluminum revetment

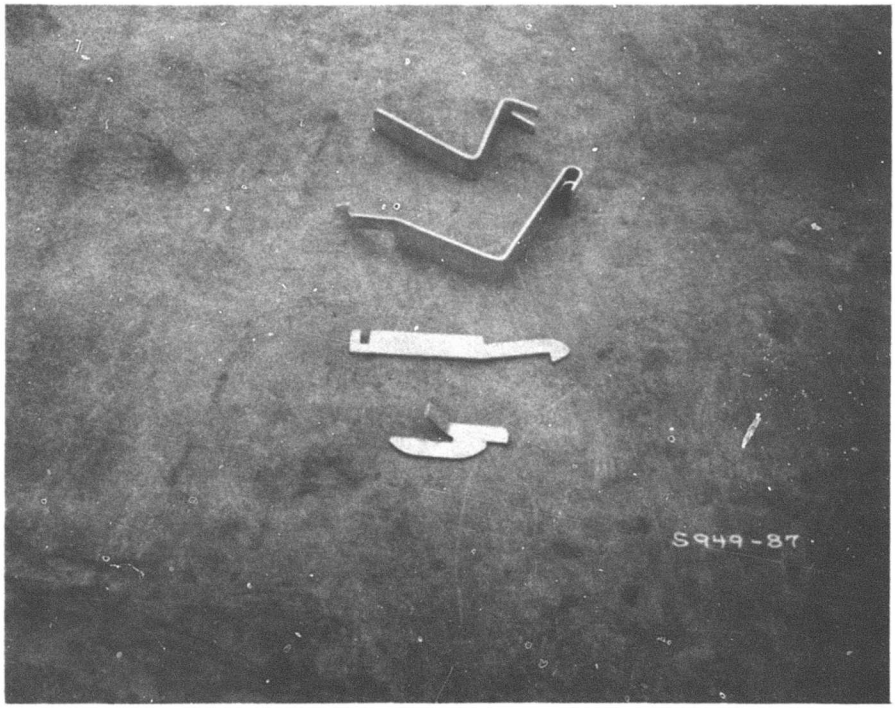
Photograph 41. Disassembly of Kaiser Aluminum arch sections



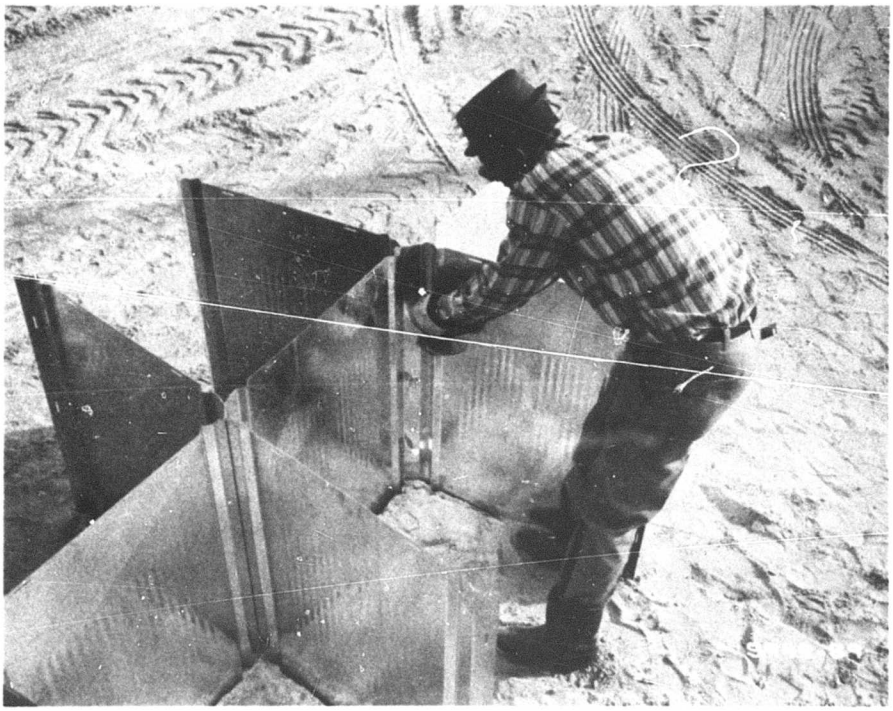
Photograph 42. Pulling Kaiser Aluminum full culverts



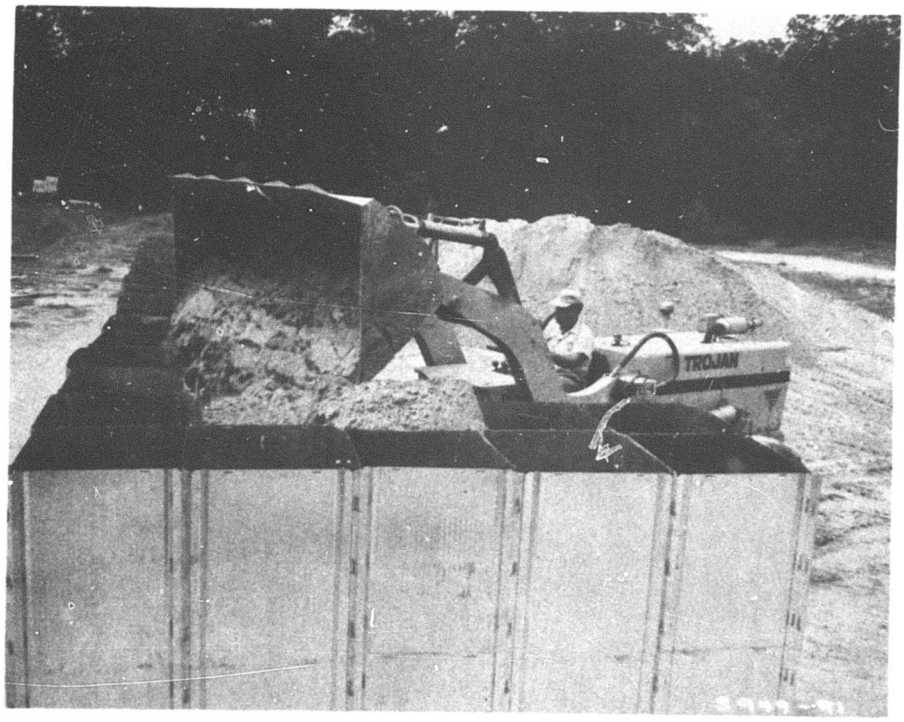
Photograph 43. Packaged Kaiser Steel Corporation Type I revetment as received



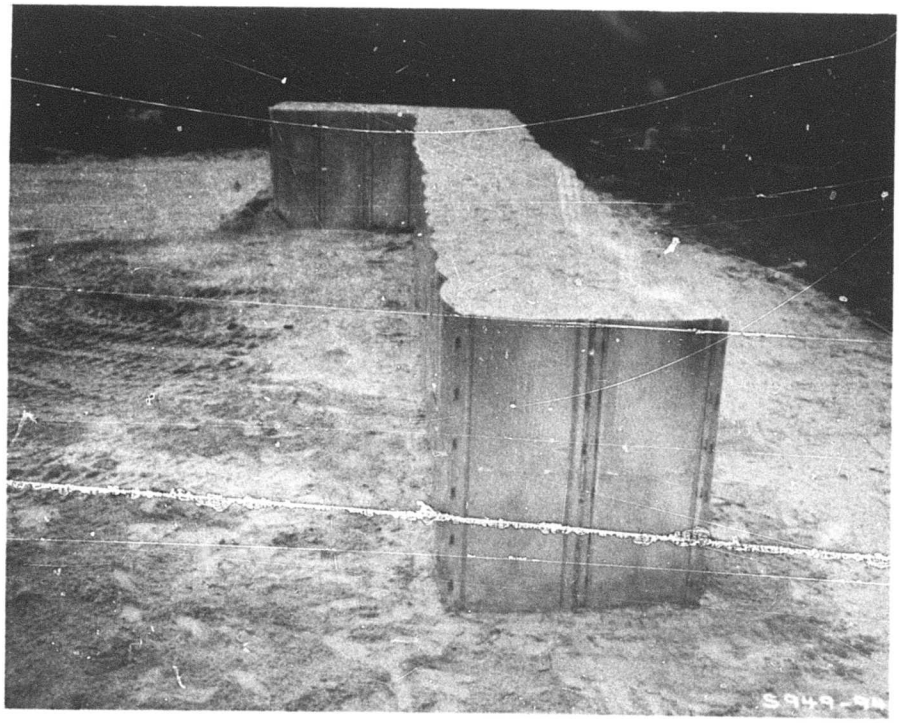
Photograph 44. Assembly tools and clip for Kaiser I revetment



Photograph 45. Assembly of Kaiser I revetment

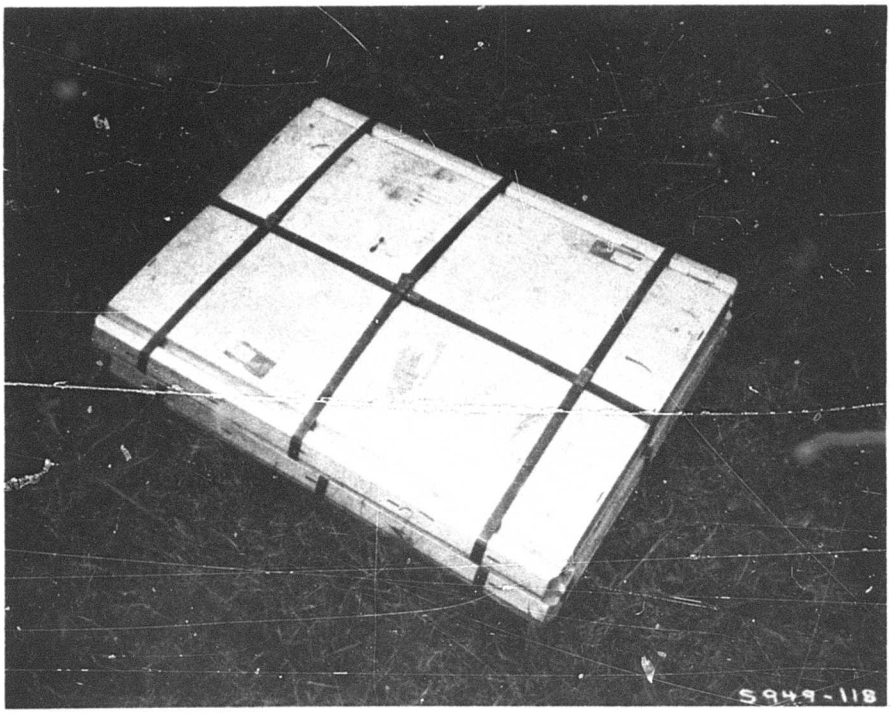


Photograph 46. Filling Kaiser I revetment

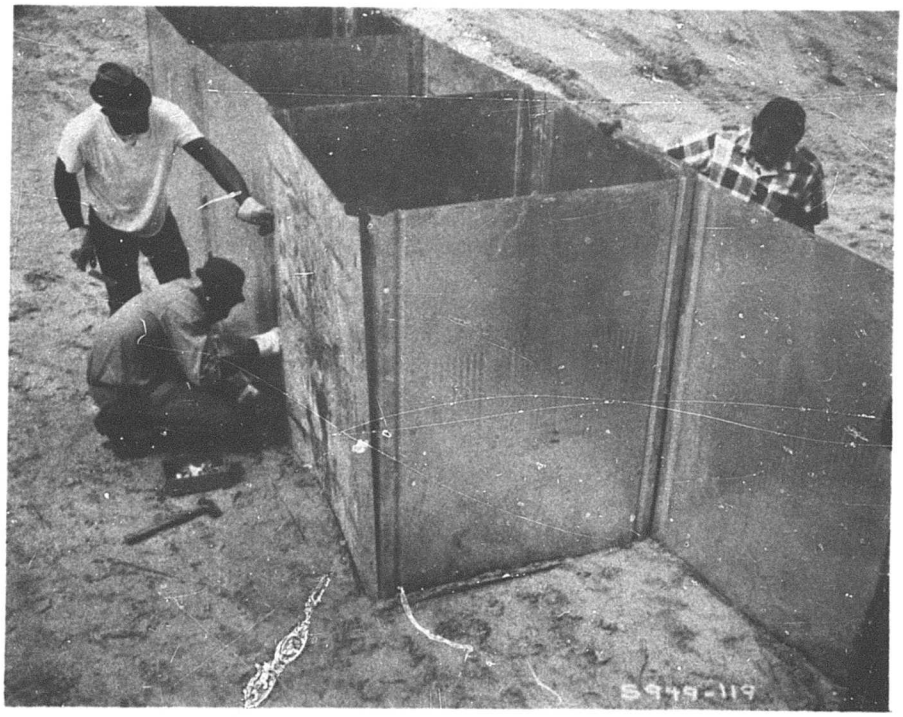


Photograph 47. Completed Kaiser I revetment

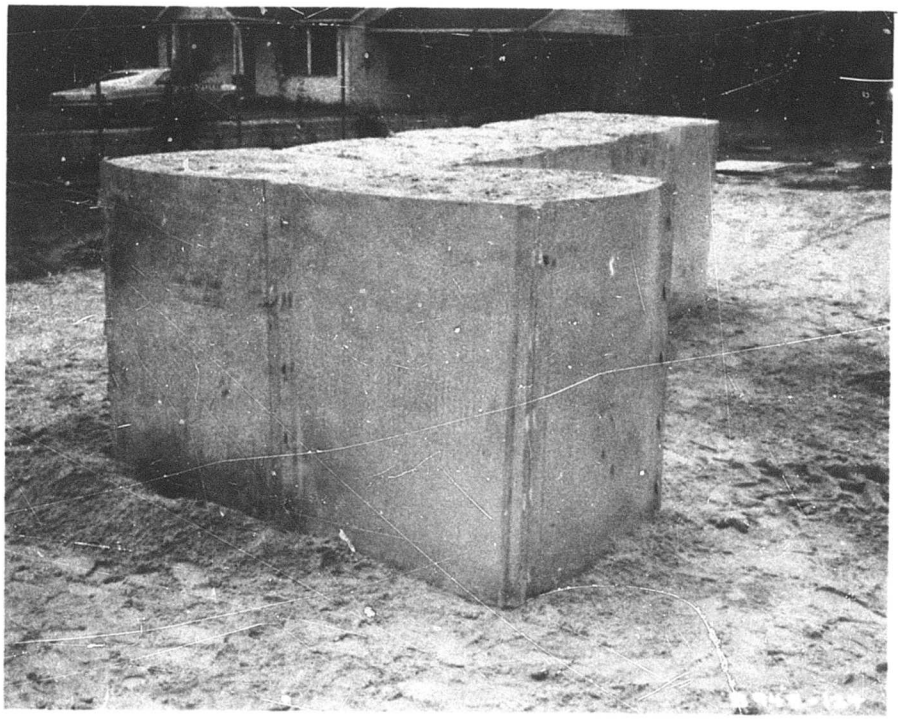
Photograph 48. Disassembly of Kaiser I revetment



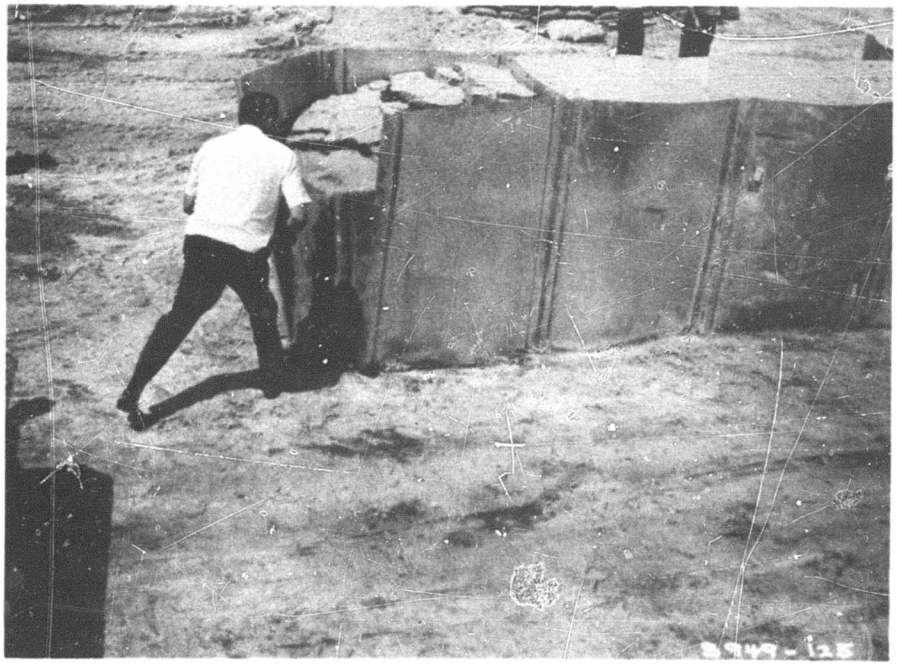
Photograph 49. Packaged Kaiser Steel Corporation Type II revetment as received



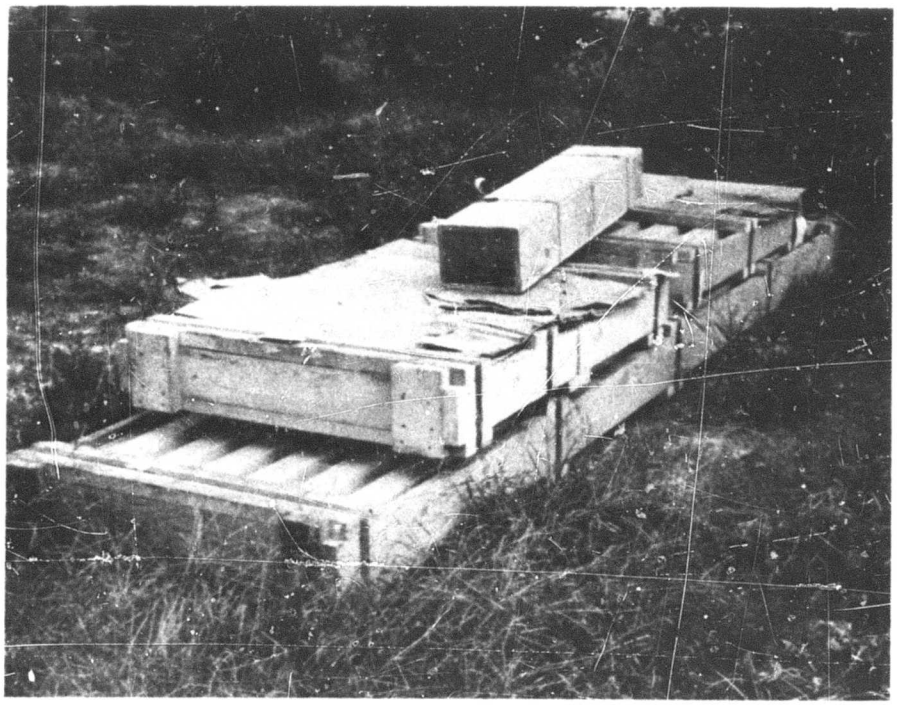
Photograph 50. Assembly of Kaiser II revetment



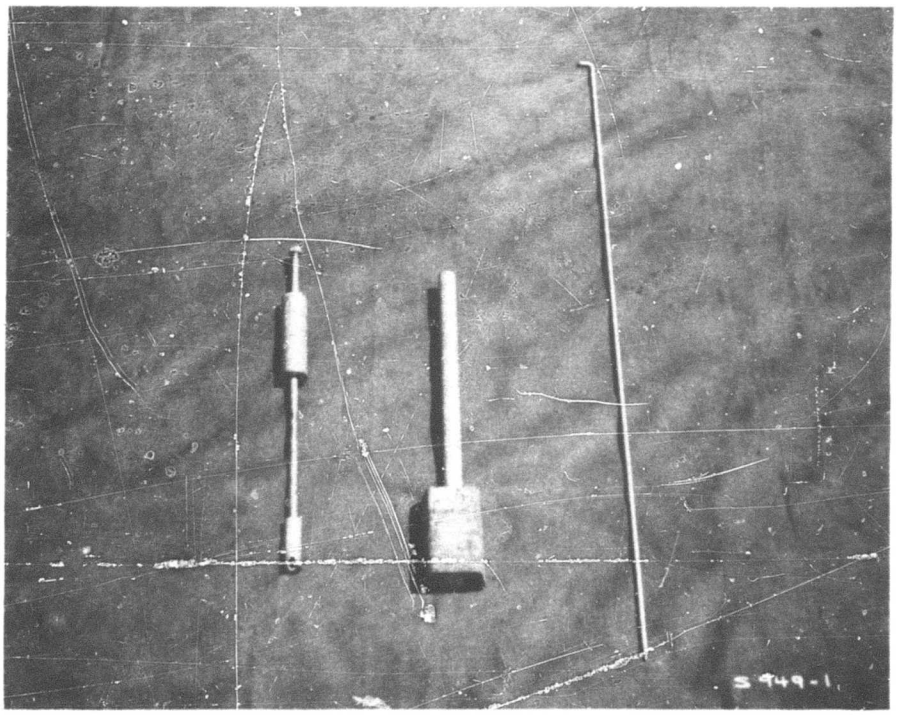
Photograph 51. Completed Kaiser II revetment



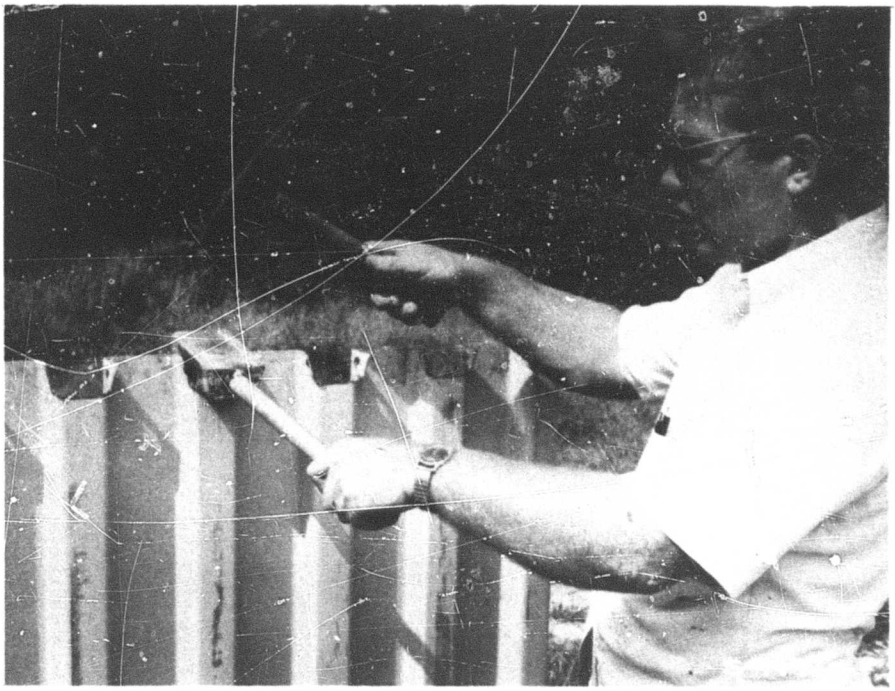
Photograph 52. Disassembly of Kaiser II revetment



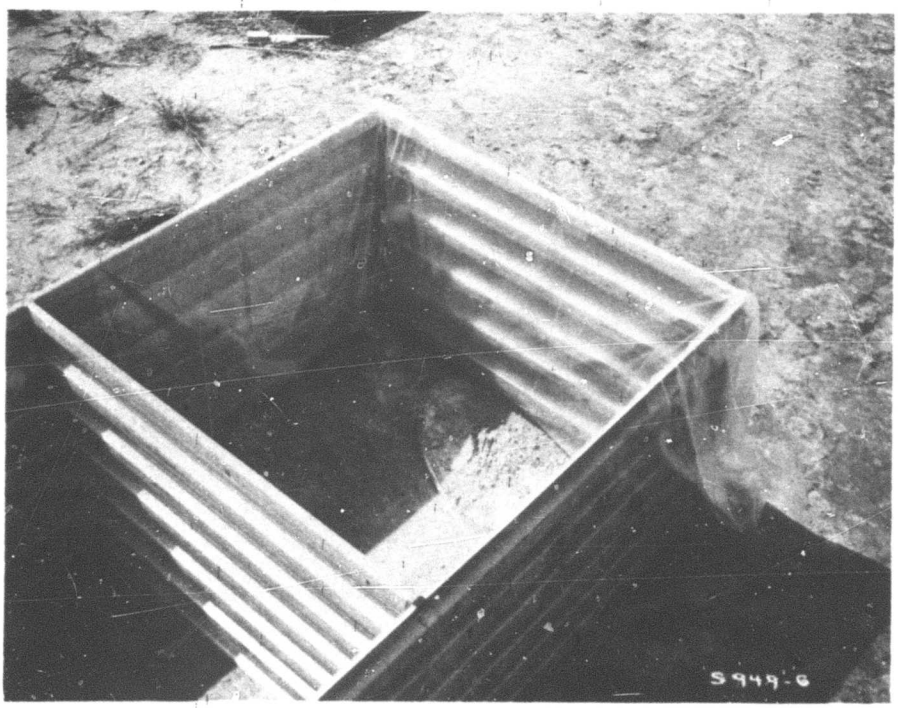
Photograph 53. Packaged Republic Steel Corporation revetment as received



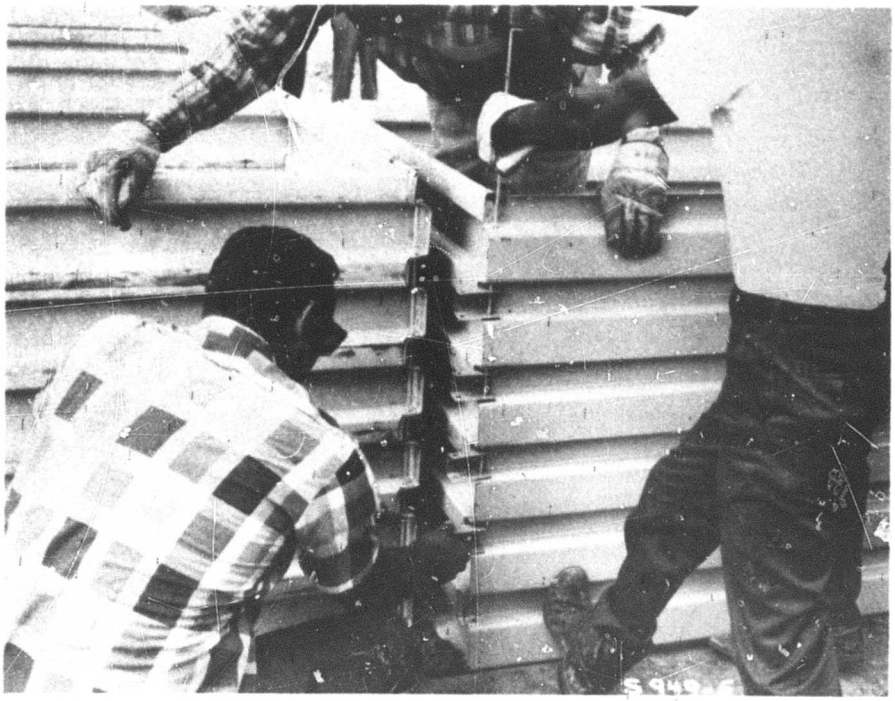
Photograph 54. Accessories for Republic Steel revetment



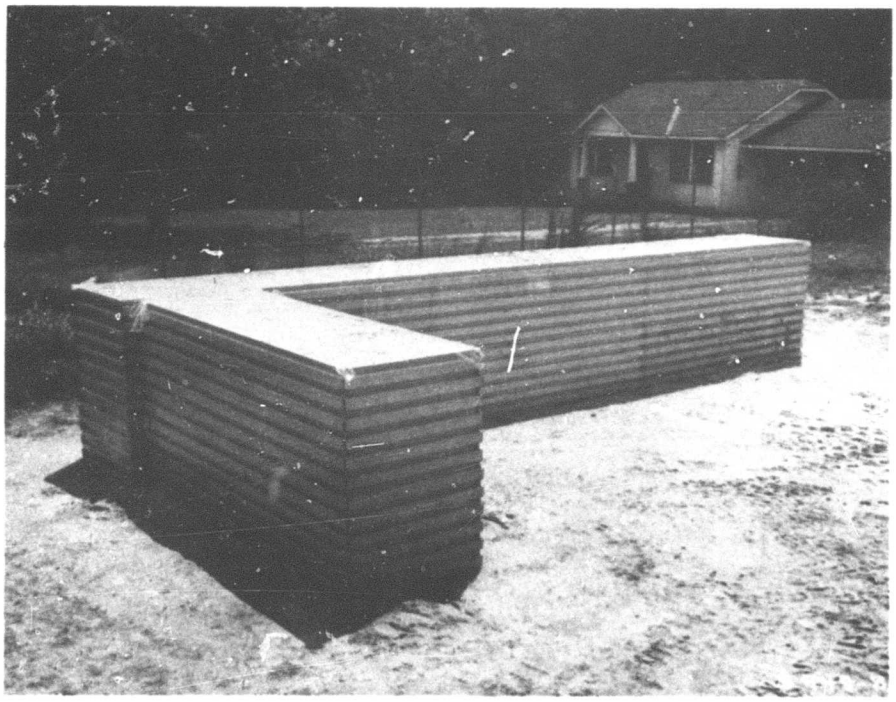
Photograph 55. Flaring cross-panel ends of Republic Steel revetment



Photograph 56. Polyethelene sand barrier at end of Republic Steel revetment

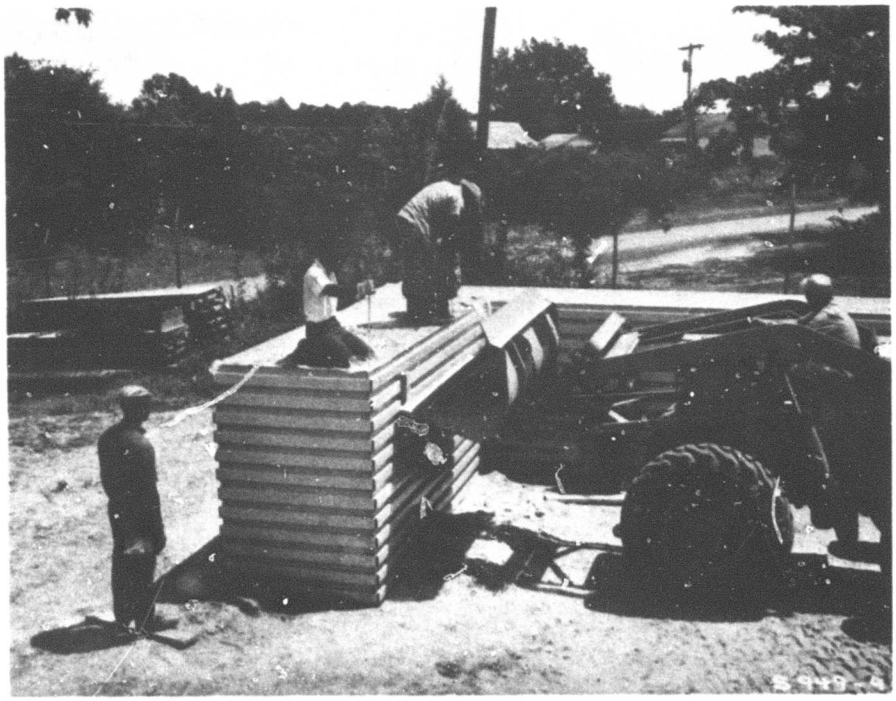


Photograph 57. Turning right angle with special clips for Republic Steel revetment

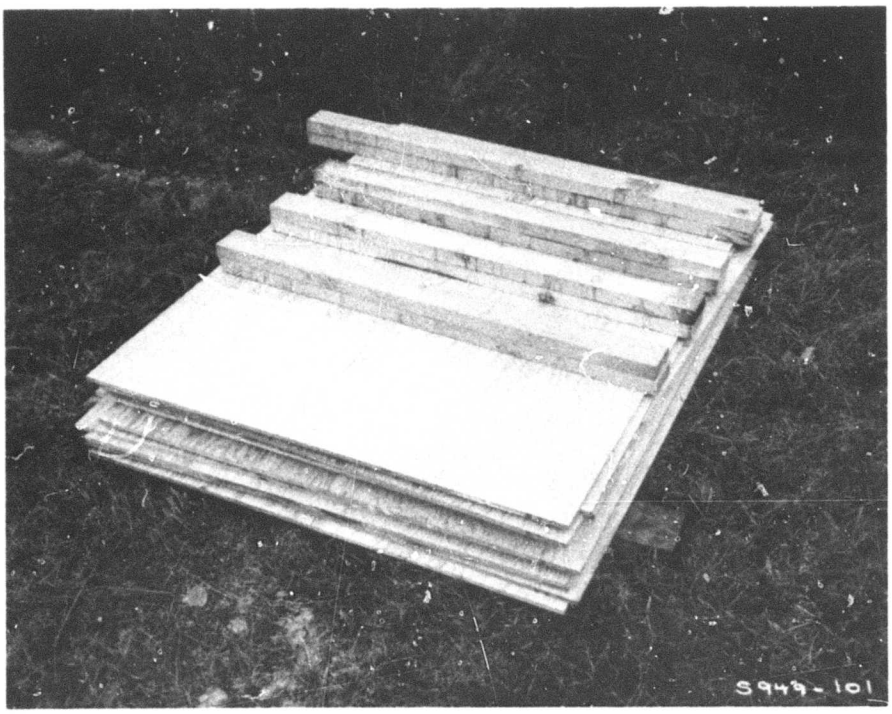


Photograph 58. Completed Republic Steel revetment

Photograph 59. Disassembly of Republic Steel revetment

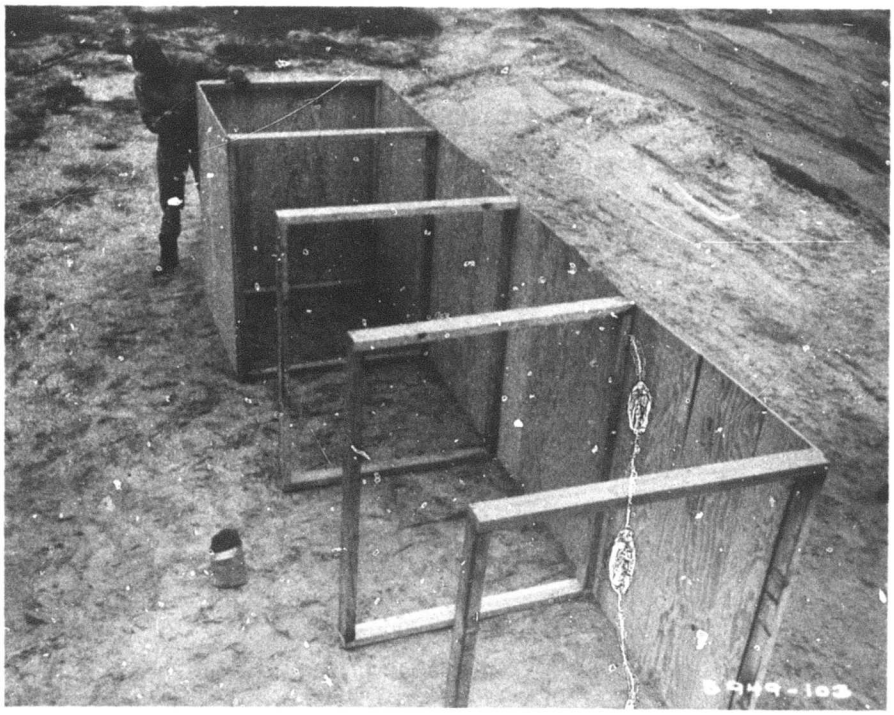


Photograph 60. Disassembly of Republic Steel revetment



Photograph 61. Materials used for plywood revetment

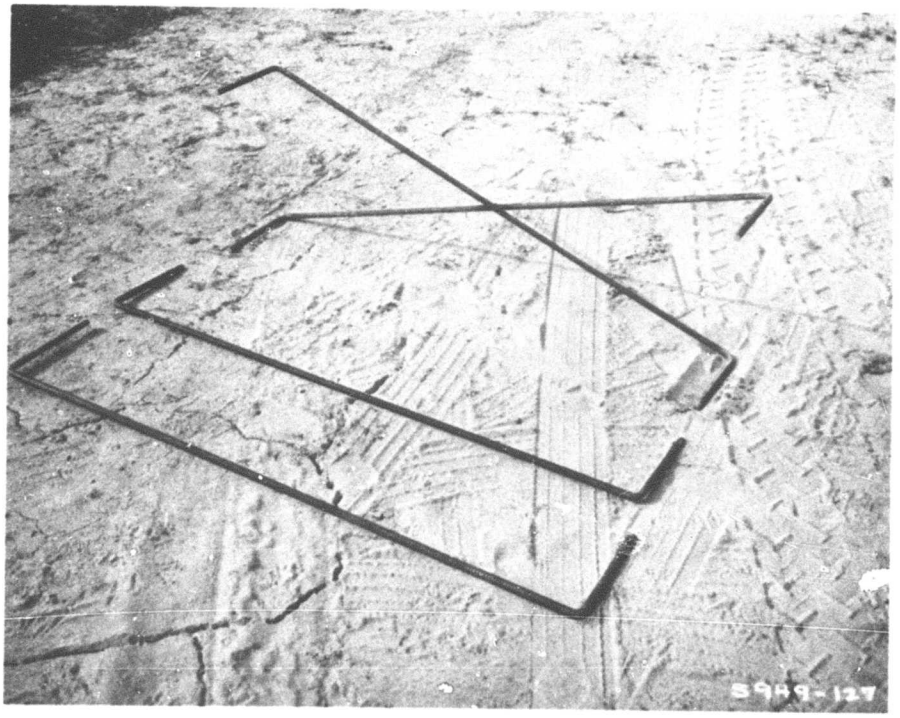
Photograph 62. Assembly of timber framework for plywood revetment



Photograph 63. Assembly of plywood revetment

Photograph 64. View of right-angle turn in plywood revetment

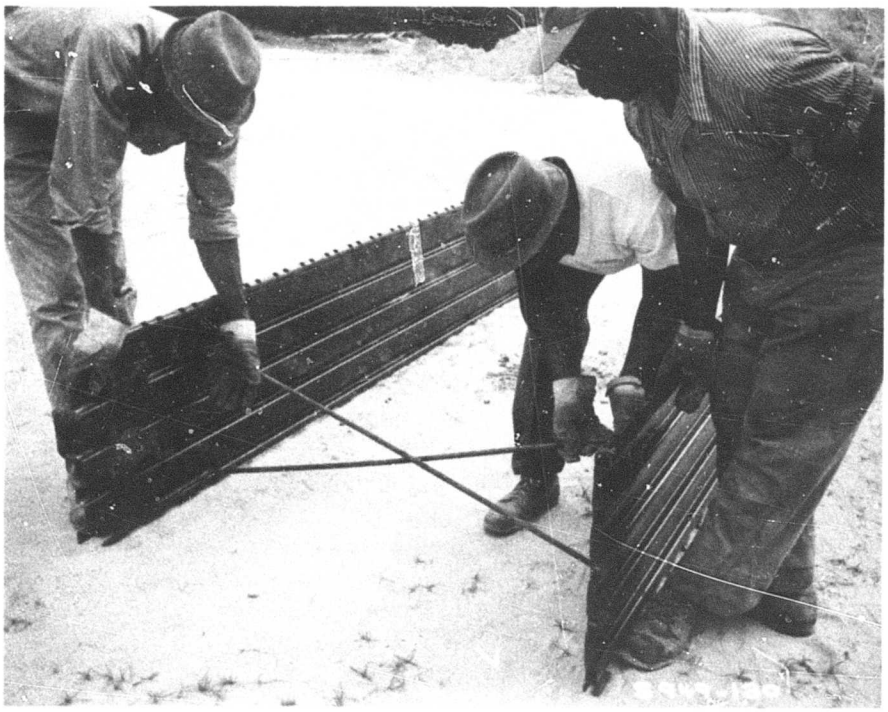
Photograph 65. Disassembly of plywood revetment



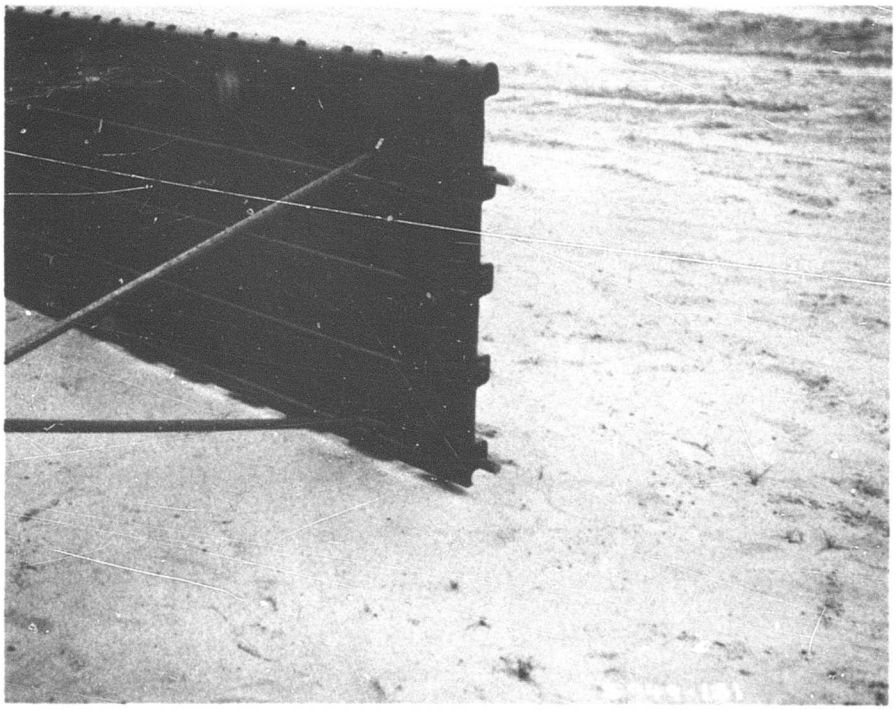
Photograph 66. Components and completed reinforcing bar frame for M8A1 revetment

Photograph 67. Removing locking pins to clear frame of M8A1 mat

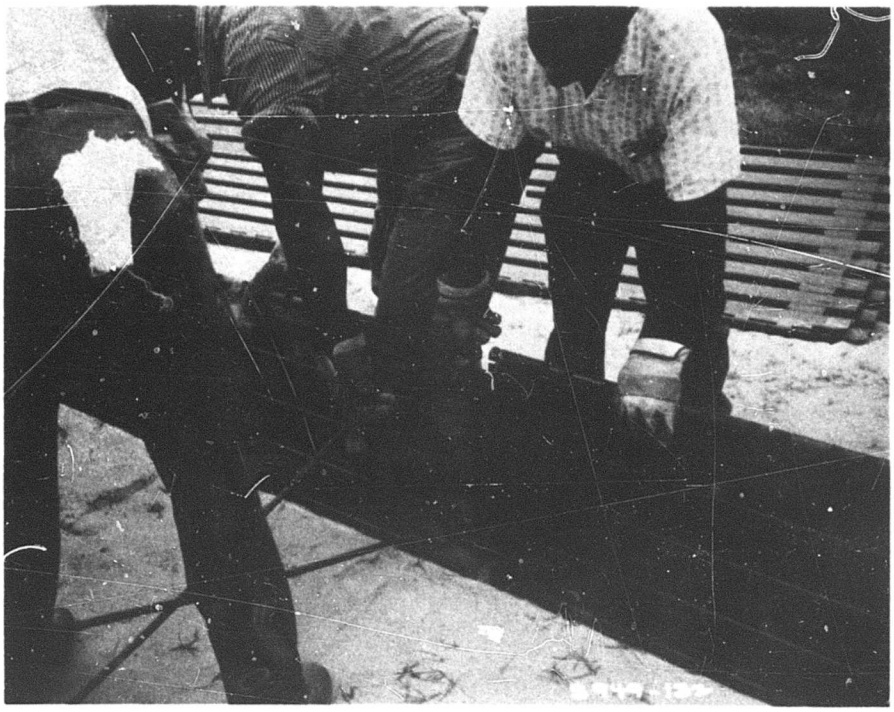
Photograph 68. Bending tabs to clear frame of M8A1



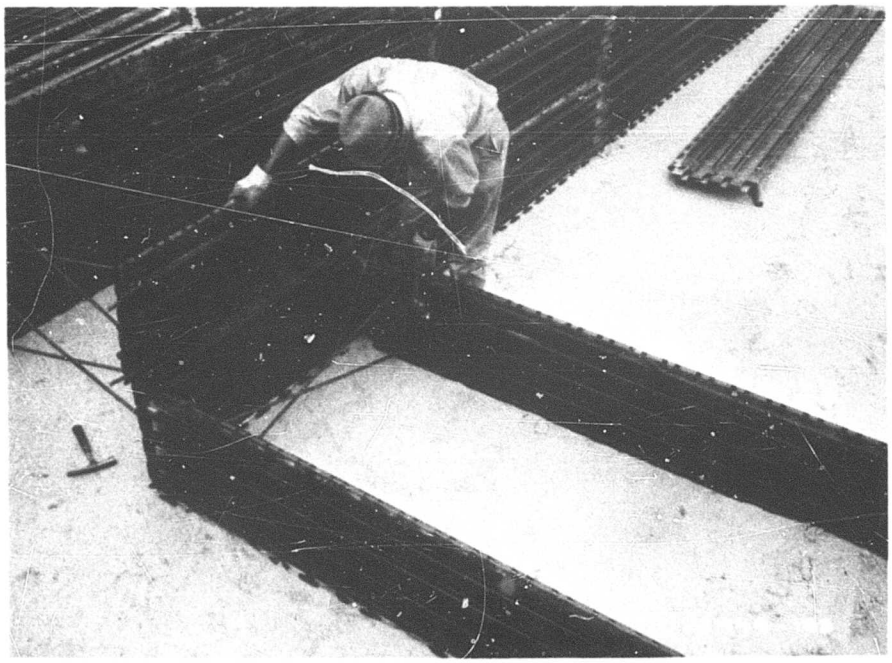
Photograph 69. Connecting reinforcing bar frame to M8A1 mat



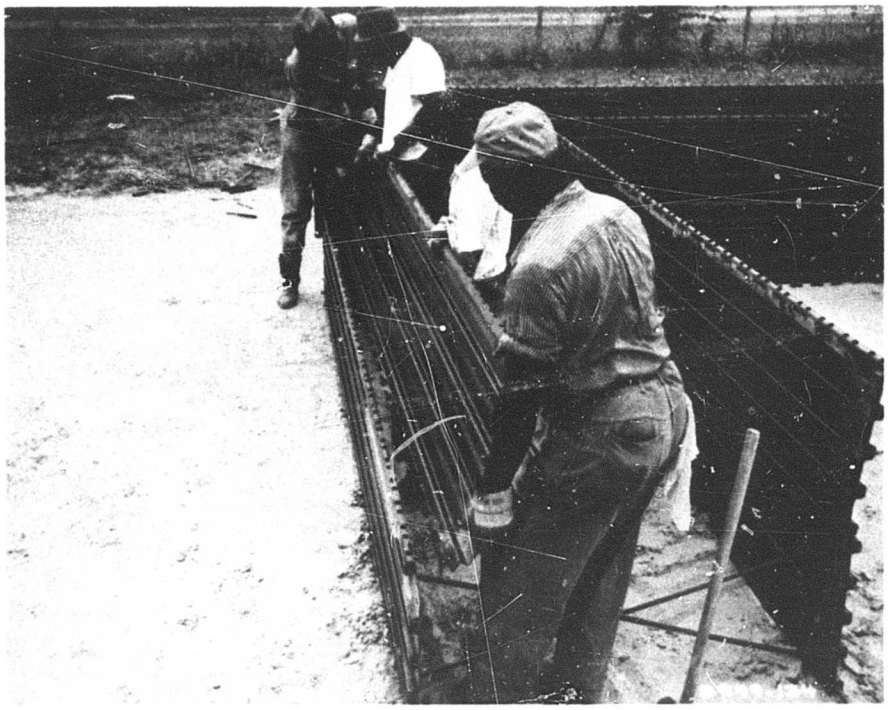
Photograph 70. Closeup view of reinforcing bar frame connected to M8A1



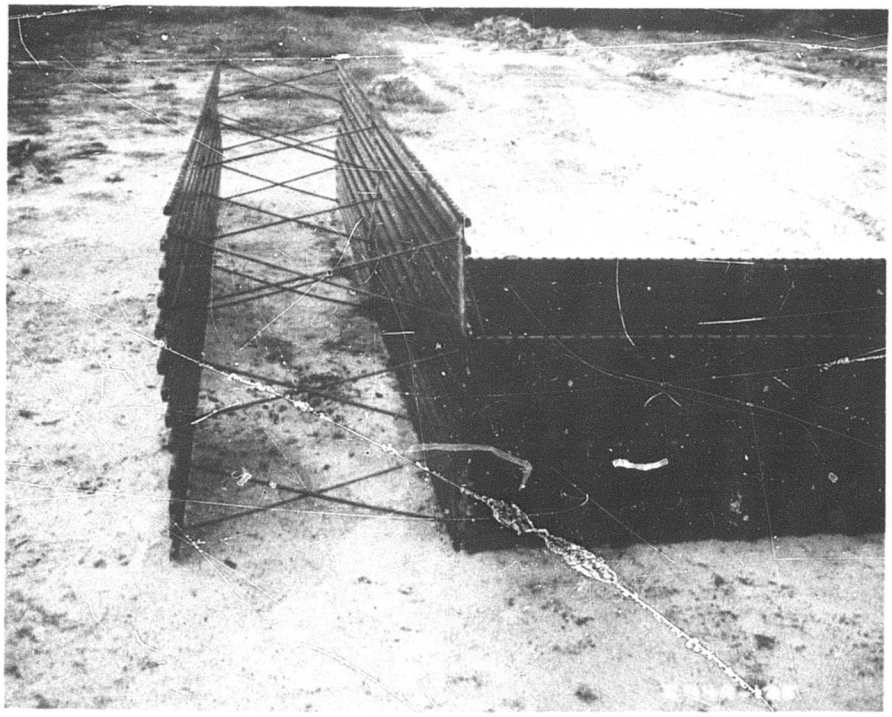
Photograph 71. Locking M8A1 internal joints



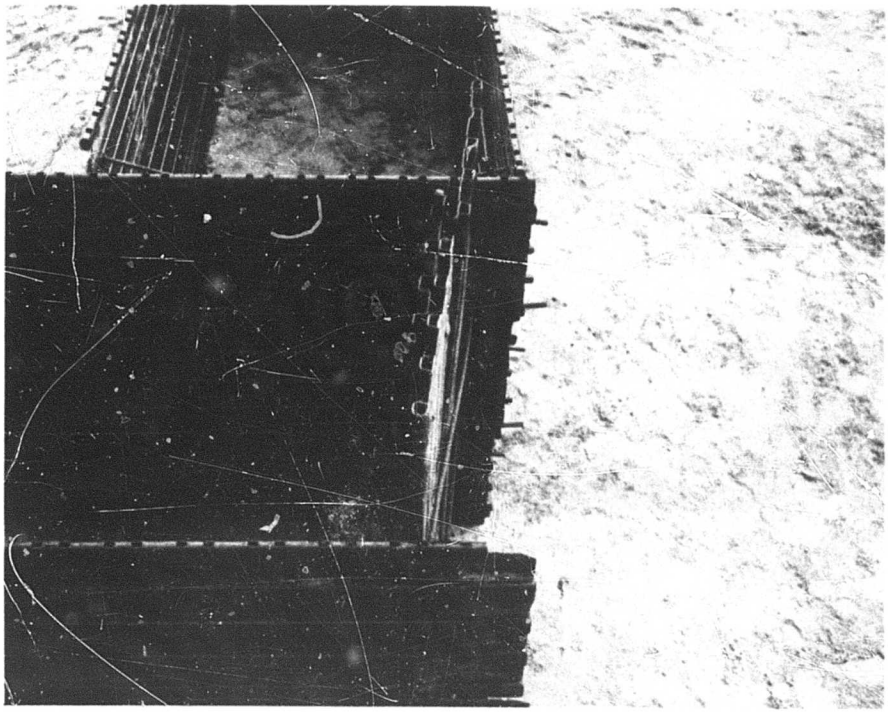
Photograph 72. M8A1 revetment assembly operation



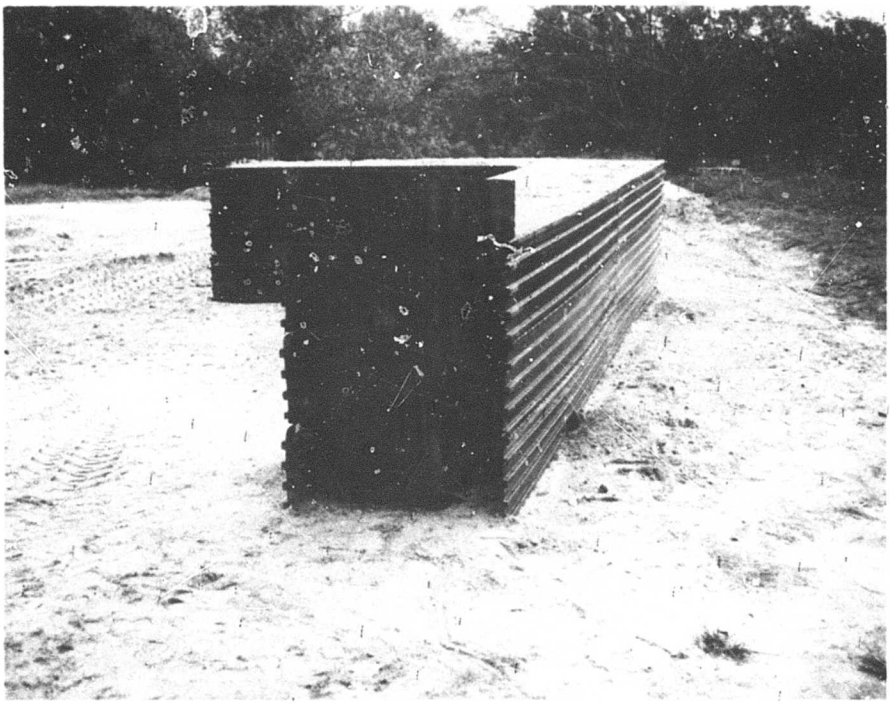
Photograph 73. M8A1 assembly operation, connecting panels



Photograph 74. Corner assembly and internal framework of M8A1 revetment

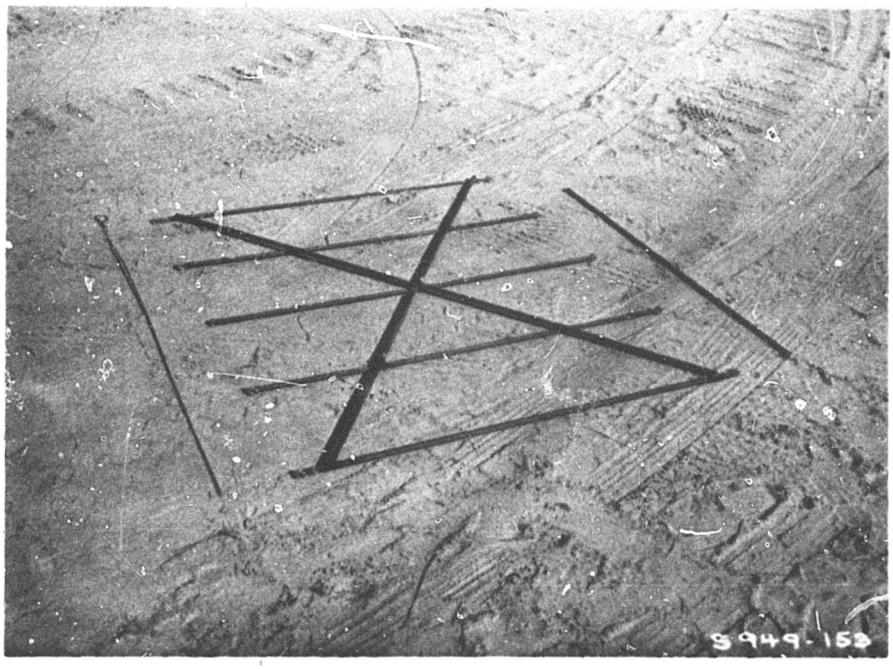


Photograph 75. M8A1 end panel and corner assembly



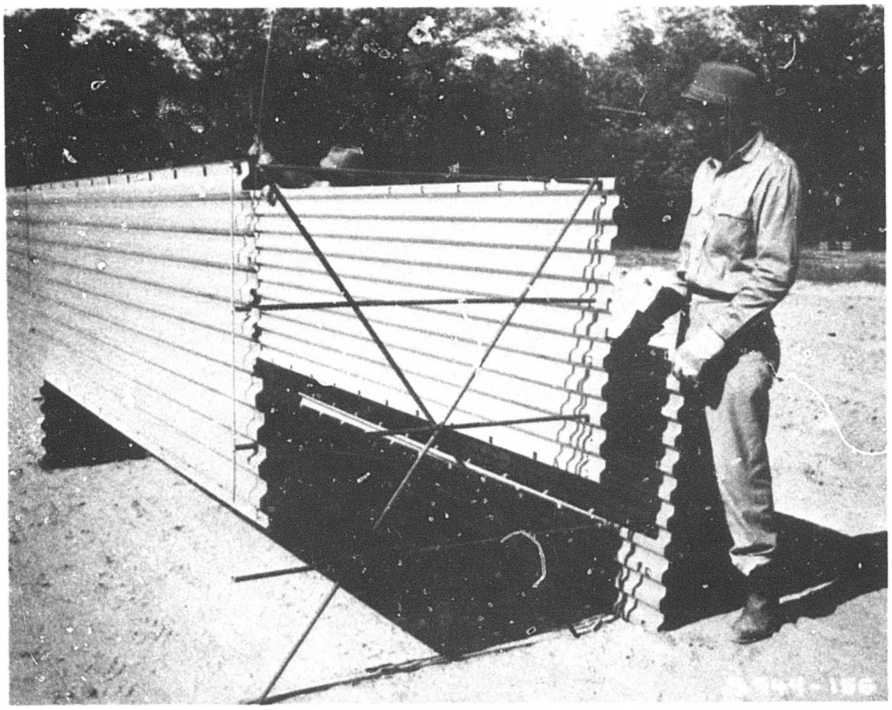
Photograph 76. Completed M8A1 revetment

Photograph 77. Disassembly of M8A1 revetment using sheet metal clamp

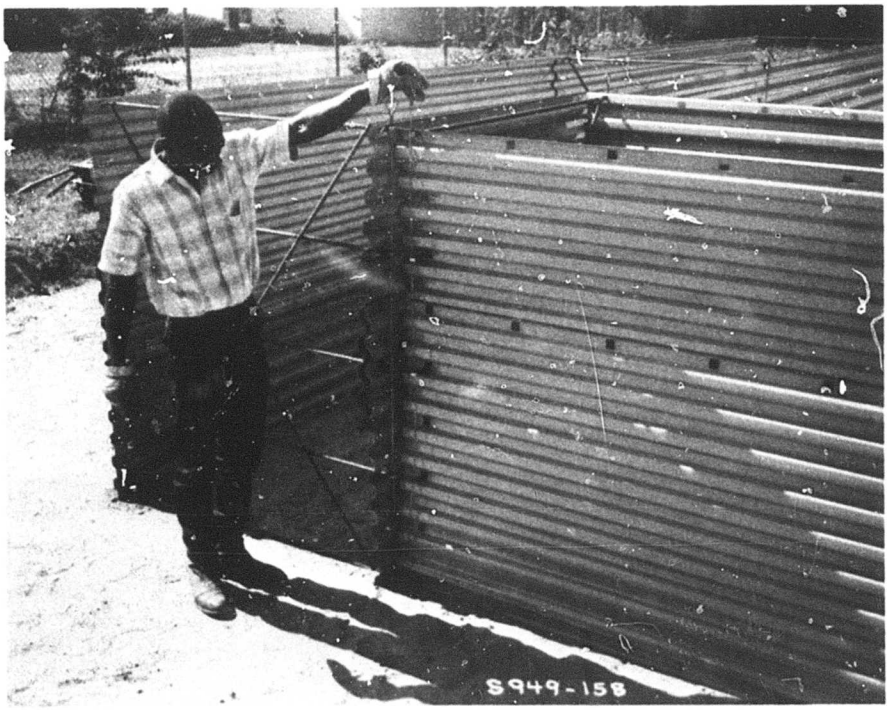


Photograph 78. Pin and frame assembly for Republic Steel ground mat revetment

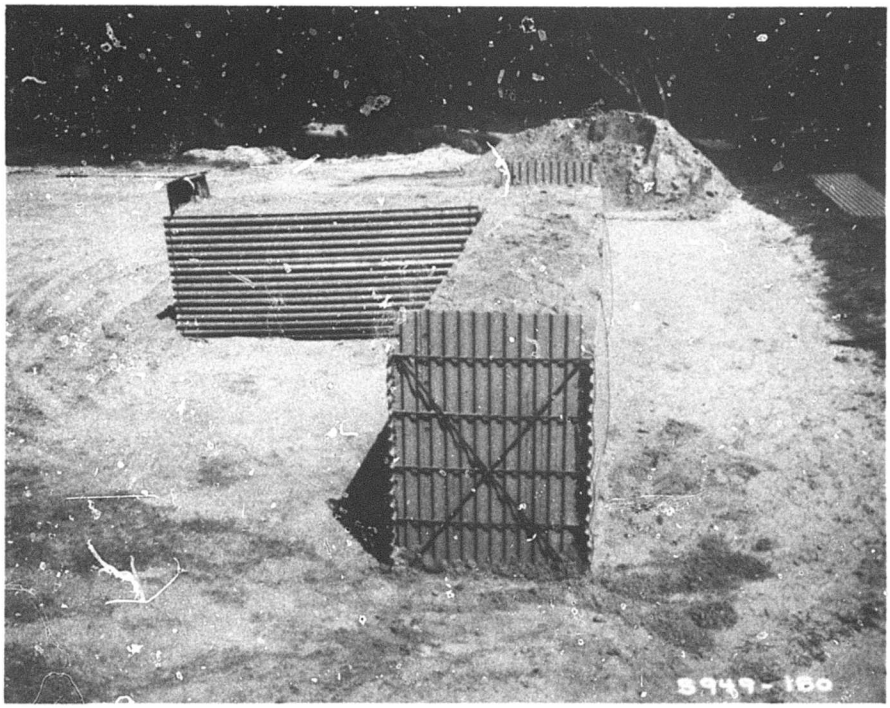
Photograph 79. Banding ground mat tab to accept frame



Photograph 80. Construction operation, ground mat revetment



Photograph 81. Pin connection and corner assembly for ground mat revetment



Photograph 32. Completed ground mat revetment

Photograph 33. Disassembly, ground mat revetment

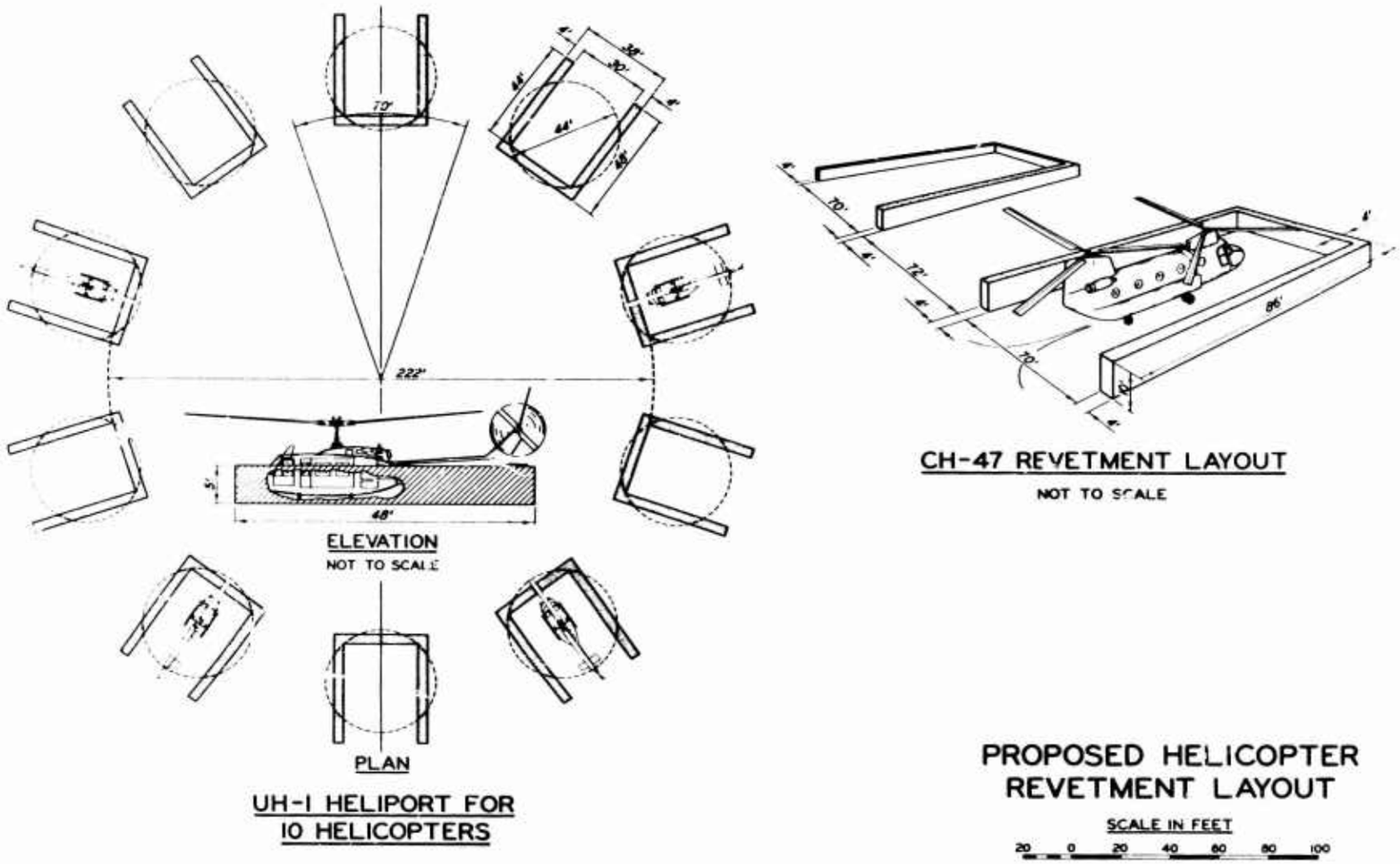

70'
222'
48'
ELEVATION
NOT TO SCALE
PLAN
UH-1 HELIPORT FOR
10 HELICOPTERS
CH-47 REVETMENT LAYOUT
NOT TO SCALE
PROPOSED HELICOPTER
REVETMENT LAYOUT
SCALE IN FEET
20 0 20 40 60 80 100

PLATE 1