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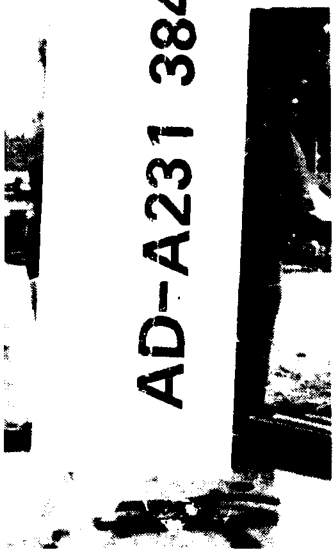

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-33

ANCHOR EMBEDMENT IN HARDENED CONCRETE UNDER SUBMERGED CONDITIONS

by

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP— Injecting bulk resin into a submerged drill hole.

BOTTOM— Pullout test on a vertical anchor.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Anchors embedded in hardened concrete under submerged conditions with prepackaged adhesive capsules exhibit significant reductions in tensile load capacity compared to anchors installed under dry conditions. This relatively poor performance of anchors with embedment lengths up to 24 in. is the result of water in the drill hole mixing with adhesive. Although insertion of the adhesive capsule or cartridge into a submerged drill hole will displace the majority of the water in the hole, water will remain between the walls of the adhesive container and the drill hole. Insertion of the anchor traps this water in the drill hole and causes it to become mixed with the adhesive.

An anchor installation procedure that eliminates the problem of resin and water mixing in the drill hole is described ~~herein~~. Basically, this procedure uses resin in both bulk and capsule form to displace the water in a drill hole prior to anchor insertion and spinning. Pullout tests on vertical and horizontal anchors embedded in vinylester

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resin with this revised installation procedure resulted in tensile capacities near the yield load of the anchors for both dry and submerged installations.

Tests to date on anchors installed with the revised procedure have been limited to short-duration loadings at relatively early ages. Additional testing should be conducted to determine the long-term performance of vinylester resin under wet, alkaline conditions. Also, creep tests should be conducted to evaluate the effect of sustained loads on anchors installed with the revised procedure. The potential for eliminating the resin capsule and injecting all of the adhesive in bulk shculd also be investigated.

PREFACE

The work described in this report was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32303, "Application of New Technology to Maintenance and Minor Repair," for which Mr. James E. McDonald, Research Civil Engineer, Concrete Technology Division (CTD), Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), was Principal Investigator. Dr. Tony C. Liu (CECW-EG) was the REMR Technical Monitor for this work.

Mr. Jesse A. Pfeiffer, Jr. (CERD-C) was the REMR Coordinator at the Directorate of Research and Development, HQUSACE; Mr. James E. Crews (CECW-OM) and Dr. Liu served as the REMR Overview Committee; Mr. William F. McCleese, WES, SL, CTD, was the REMR Program Manager. Mr. McDonald was the Problem Area Leader.

The work was performed at WES under the general supervision of Mr. Bryant Mather, Chief, Structures Laboratory (SL), and Mr. Kenneth L. Saucier, Chief, CTD, and under the direct supervision of Mr. McDonald, who prepared this report. Testing activities were monitored by Mr. Roy L. Campbell, Sr., CTD, and Mr. Ray H. Smith, Jones County Junior College, on Intergovernmental Personnel Act assignment to CTD. Mr. Gary W. Powers, Hilti, Inc., also assisted in testing activities.

Commander and Director of WES was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
kips (force) per square inch	6.894757	megapascals
pounds (force) per square inch	0.006894757	megapascals

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain Kelvin (K) readings, use: K = (5/9) (F - 32) + 273.15.

ANCHOR EMBEDMENT IN HARDENED CONCRETE UNDER SUBMERGED CONDITIONS

PART I: INTRODUCTION

Background

1. Rehabilitation of hydraulic structures usually requires removal of deteriorated concrete and replacement with new concrete. Steel dowels are normally used to anchor the replacement material to the existing concrete. Typically, small-diameter holes are drilled into the remaining sound concrete, and dowels are embedded in the holes with prepackaged polyester resin (Figure 1). Early-age field pullout tests on anchors installed in this manner under dry conditions indicate this to be a satisfactory procedure. However, a number of failures of anchors embedded in polyester resin under wet conditions have been reported (McDonald 1980 and Krysa 1982). Consequently, a study was initiated as part of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program to evaluate the effectiveness of selected grout systems for embedment of anchors in concrete.

2. Cement, epoxy resin, and polyester resin were evaluated under a variety of wet and dry casting and curing conditions (Best and McDonald 1990).

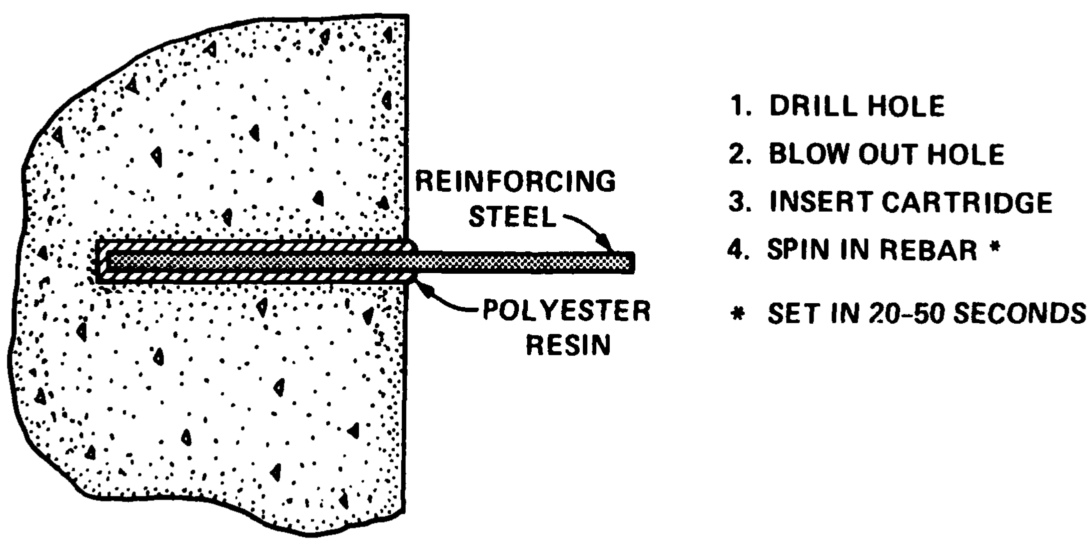


Figure 1. Typical anchor installation in concrete

Pullout test specimens consisted of 6- by 18-in. concrete cylinders into which 3/4-in.-diam reinforcing bars were embedded to a depth of 15 in. in nominal 1-1/8-in.-diam percussion drilled holes. Pullout tests were conducted at eight different ages ranging from 1 day to 32 months. Beyond 1 day, all pullout strengths were approximately equal to the ultimate strength of the reinforcing-bar anchor when the anchors were installed under dry conditions, regardless of the type of embedment material or curing conditions. With the exception of the anchors embedded in polyester resin under submerged conditions, pullout strengths were essentially equal to the ultimate strength of the anchor when the anchors were installed under wet or submerged conditions. The overall average pullout strength of anchors embedded in polyester resin under submerged conditions was 35 percent less than the strength of similar anchors installed and cured under dry conditions. The largest reductions in pullout strength, approximately 50 percent, occurred at ages of 6 and 16 months. Also, the overall average pullout strength of anchors embedded in polyester resin installed under submerged conditions was approximately one-third less than the strength of anchors embedded in epoxy resin and cement under wet and submerged conditions, respectively, and cured under submerged conditions. Although the epoxy resin performed well in these tests when placed in wet holes, it should be noted that the manufacturer does not recommend placement under submerged conditions.

3. Creep tests were conducted by subjecting pullout specimens to a sustained load of 60 percent of the anchor-yield strength and periodically measuring anchor slippage at the end of the specimen opposite the loaded end. After 6 months under load, anchors embedded in cement and epoxy resin, installed and tested under dry conditions, exhibited very low anchor slippage, averaging 0.0013 and 0.0008 in., respectively. Under similar conditions, slippage of anchors embedded in polyester resin was approximately 30 times higher. Results of creep tests on specimens fabricated and tested under wet conditions followed a similar trend. The average slippage for anchors embedded in cement and epoxy resin was 0.0028 and 0.0033 in., respectively, or two to four times higher than results under dry conditions. Anchors embedded in polyester resin, installed and cured under submerged conditions, exhibited significant anchor slippage; in fact, in one case the anchor pulled completely out of the concrete after 14 days under load. After 6 months under load, the

two remaining specimens exhibited an average anchor slippage of 0.0822 in., approximately 30 times higher than anchors embedded in cement under the same conditions.

4. Long-term durability of the embedment materials was evaluated by periodic compressive strength tests on 2-in. cubes stored in both submerged and laboratory air conditions. After 32 months, the average compressive strength of polyester resin and epoxy specimens stored in water was 37 and 26 percent less, respectively, than that of companion specimens stored in air. The strength of cement cubes stored in water averaged 5 percent higher than that of companion specimens stored in air during the same period.

5. A 1987 review of available manufacturers' literature on concrete anchor grouting systems revealed that a vinylester resin, prepackaged in glass capsules, was being promoted for use under submerged conditions. According to the manufacturers' representatives, the performance of anchors embedded in vinylester resin under submerged conditions was similar to that of comparable anchors installed in the dry. Since no test data were furnished to substantiate this claim, the US Army Engineer District, New Orleans, initiated testing by the US Army Engineer Waterways Experiment Station (WES) to evaluate the performance of anchors embedded in vinylester resin under dry and submerged conditions (McDonald 1989).

6. Anchors were 1-1/4-in.-diam threaded rods installed in holes drilled to depths of 12 and 15 in. with a 1-1/2-in.-outside-diameter core barrel. Pullout tests were conducted at four different ages ranging from 1 to 28 days. Results of pullout tests on anchors installed in dry holes (15-in. embedment length) were remarkably consistent with an overall average tensile capacity of 105 kips at 0.1-in. displacement and an average ultimate load of approximately 125 kips, near the yield load of the anchors. In comparison, results of pullout tests on anchors installed under submerged conditions were relatively erratic, with an overall tensile capacity of 36 kips at 0.1-in. displacement and an average ultimate load of 48 kips. Obviously, the tensile load capacity of anchors embedded in concrete with vinylester resin capsules is significantly reduced when the anchors are installed under submerged conditions. At a displacement of 0.1 in., the tensile capacity of anchors embedded under submerged conditions was approximately one-third that of similar anchors embedded in dry holes.

7. The reduced tensile capacity of anchors embedded in concrete under submerged conditions with prepackaged polyester resin and vinylester resin cartridges is primarily attributed to the anchor installation procedure. Resin extruded from dry holes during anchor installation was very cohesive, and a significant effort was required to obtain the full embedment depth. In comparison, anchor installation required significantly less effort under submerged conditions. Also, the extruded resin was much more fluid under wet conditions, and the creamy color contrasted with the black resin extruded under dry conditions. All of these factors indicated that the water in the drill hole was mixing with the resin when the cartridges were ruptured by insertion of the anchor.

8. These findings generated concern in the geotechnical community regarding the ultimate performance of rock bolts previously installed under similar conditions. Because of this concern, the Geotechnical Laboratory at WES contracted with the Bureau of Mines, Denver Research Center, to determine what effect water present during installation would have on longer anchors embedded in polyester resin. Anchors were headed bolts (No. 6 Grade 60 steel) with embedment lengths ranging from 17 to 38 in. Anchor holes were drilled in concrete blocks with a masonry diamond-core bit that had a nominal 1-in. outside diameter. Pullout tests were conducted on anchors installed under "dry, damp, displaced, and submerged" conditions. As a result of these tests, Avery (1989) concluded that in a submerged borehole, water appears to affect the resin by mixing with the top 12 to 14 in. to form an emulsion which may be too diluted to catalyze effectively. He also concluded that water is detrimental to the successful curing of polyester resins only in situations involving very short anchors (less than 2 ft). To solve this problem, Avery recommended drilling the anchor hole 1 ft deeper than desired and adding an additional cartridge of resin.

Purpose

9. The purpose of this study was to determine the pullout capacity of anchors with increased embedment lengths and to evaluate the potential of a revised anchor installation procedure to eliminate the problem of resin and water mixing in the drill hole during anchor insertion.

Scope of Work

10. Pullout tests were conducted on five anchors installed under submerged conditions in vertical drill holes 24 in. deep for comparison with previous tests on similar anchors with shorter embedment lengths. Also, pullout tests were conducted on 42 anchors embedded in vertical and horizontal drill holes with the revised installation procedure. These anchors were equally divided between dry and submerged holes with 15-in. embedment lengths.

PART II: TESTING PROGRAM

Anchor Installation

11. A total of 53 vertical and horizontal holes were drilled in a mass concrete block to depths of 15 and 24 in. with a 1-1/2-in.-outside-diameter core barrel. After the concrete cores were removed, the 24-in.-deep vertical holes were filled with water. Also, one-half of the 15-in.-deep vertical and horizontal holes were filled with water. Drilling water in the remainder of the 15-in.-deep holes was removed with pressurized air. These holes were allowed to dry for a minimum of 3 days before anchors were installed.

12. High-strength threaded steel rods were used as anchors. The anchors were 1-1/4-in. in diameter and 30 or 40 in. long, depending on required embedment length. One end of each anchor had a flat chisel point.

13. HEA capsules furnished by Hilti, Inc., were used to embed the anchors with 24-in. embedment lengths. These capsules contained quartz sand, benzol peroxide hardening agent, and vinylester resin, all self-contained in a glass vial. Two 1-1/4-by 12-in. capsules, placed cap-end down, were used in each hole. Anchors were installed under the direct supervision of Hilti personnel and with the exception of the embedment length, anchor installati ... were identical to those used in previous tests (McDonald 1989). An average of 70 sec was required to spin the anchors into the drill holes.

14. It was obvious during these installations that water in the drill hole was actually mixing with the vinylester resin during the anchor installation process. Similar conditions were noted in previous tests, and the relatively poor performance of these anchors was attributed to this mixing of the resin and water (McDonald 1989). Although insertion of the adhesive capsule or cartridge into a submerged drill hole will displace the majority of the water in the hole, water will remain between the walls of the container and the drill hole (Figure 2). Insertion of the anchor traps this water in the drill hole and causes it to become mixed with the adhesive.

15. In an attempt to improve the pullout capacity of anchors installed under submerged conditions, a revised procedure was used to install the remaining anchors. The initial step in the revised installation procedure (Figure 3) was to inject a small volume of adhesive into the drill hole. The next step in the revised procedure was insertion of a 1-1/4- by 15-in. HEA

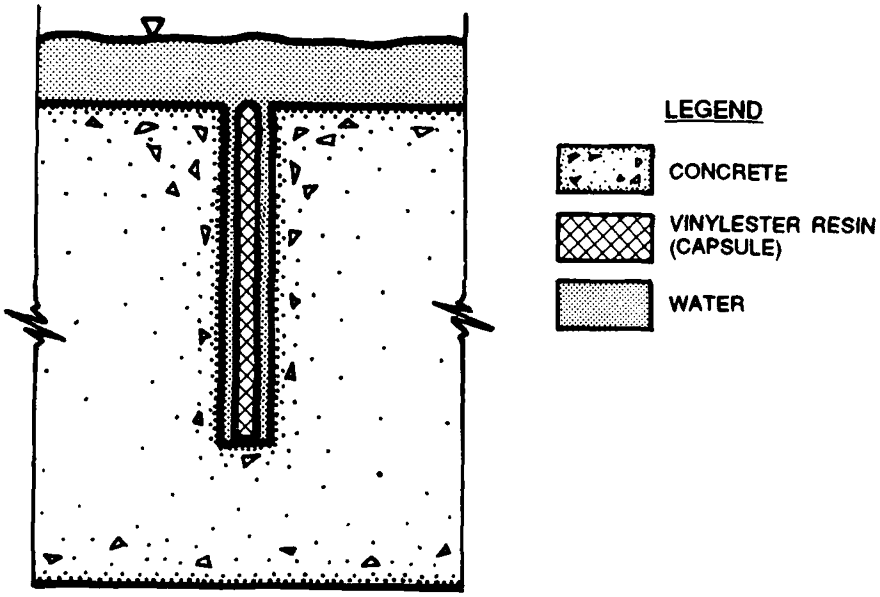
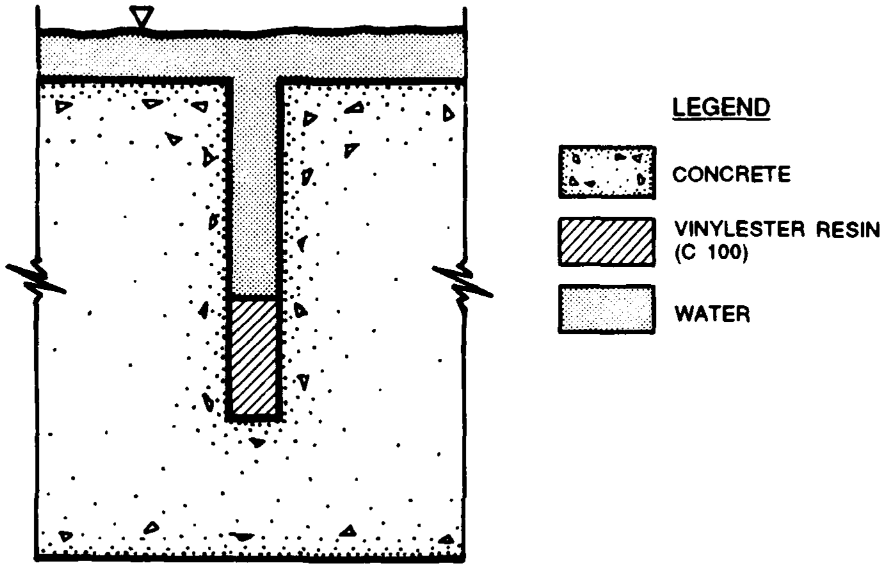
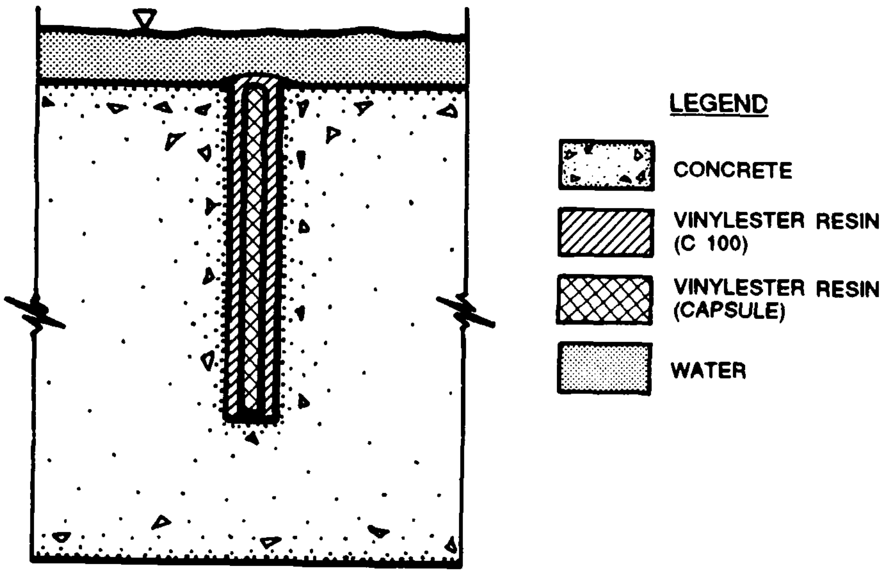


Figure 2. Water surrounding the adhesive capsule in the original anchor installation procedure



a. Step 1



b. Step 2

Figure 3. Revised anchor installation procedure

capsule into the drill hole. This insertion displaced the remainder of the water in the drill hole prior to spinning the anchor into the drill hole.

16. According to Hilti, the injection adhesive is a "modified vinyl-ester resin with essentially the same chemical composition as the resin in the capsules." The system, designated by Hilti as HIT C-100, is packaged in paired plastic cartridges (Figure 4) containing the resin and a hardener. These disposable cartridges fit into a specially designed injection tool similar to a caulking gun which forces the two components through a spiral, static mixing tube. As a result, the two-component adhesive is precisely dispensed at the desired ratio and thoroughly mixed immediately prior to injection into the drill hole.

17. Thirty vertical anchors were installed with the revised procedure, fifteen each under dry and submerged conditions (Figures 5 and 6). The resin extruded from dry holes was more fluid than that extruded in previous installations with the original procedure under the same conditions. There was some obvious mixing of the resin and water under submerged conditions; however, this mixing appeared to be limited to the excess resin outside of the drill hole.

18. Eighteen horizontal anchors were installed with the revised procedure. Plywood boxes mounted on the concrete block and filled with water were used to maintain submerged conditions for one-half of the horizontal anchors.

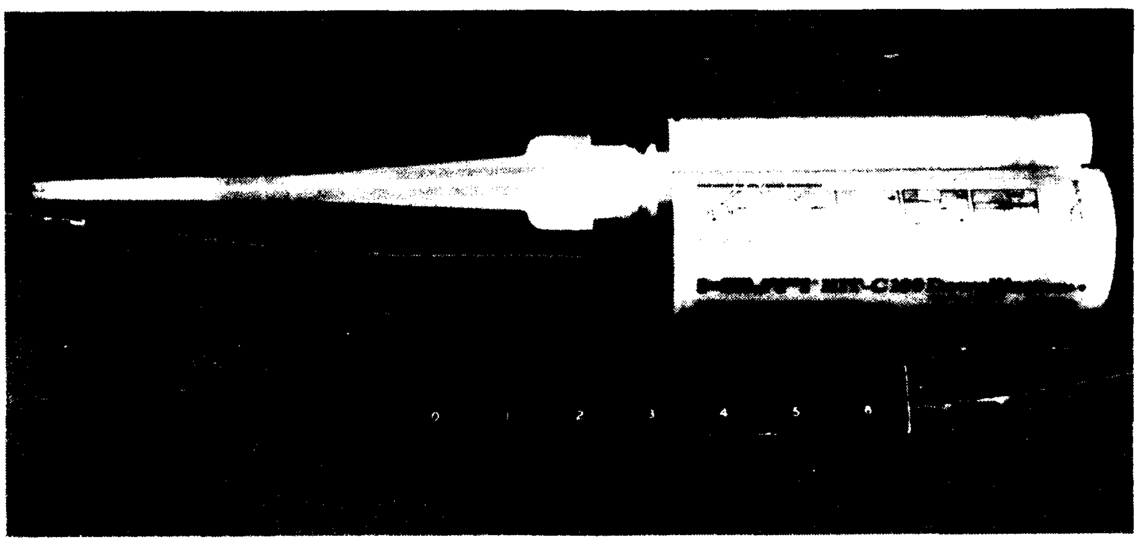
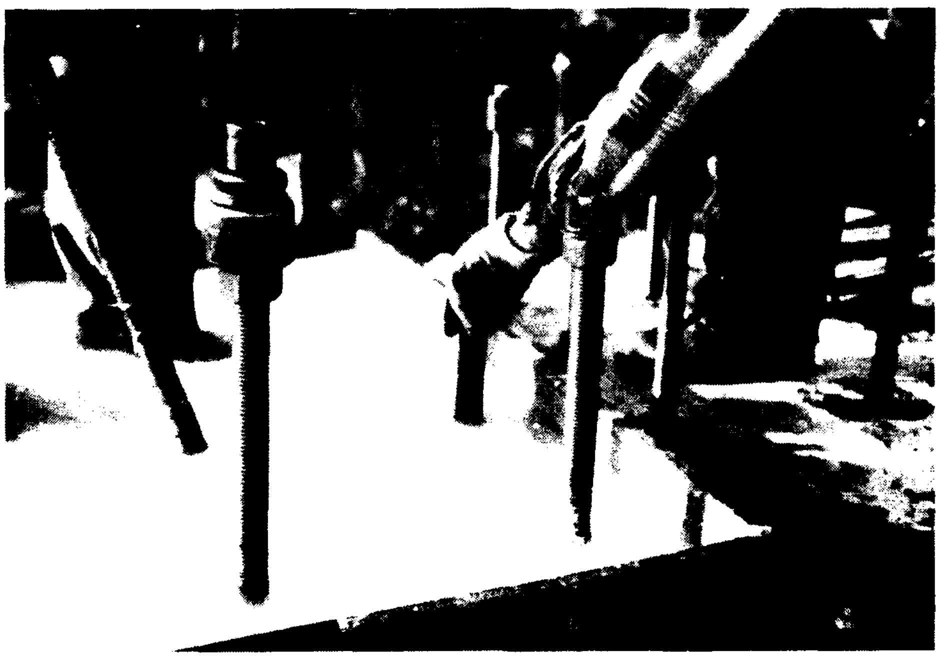


Figure 4. Paired plastic cartridges and static mixing tube

a. Resin injection



b. Capsule insertion

Figure 5. Placing the adhesives in a submerged drill hole

Figure 6. Anchor installed or spun into a submerged hole

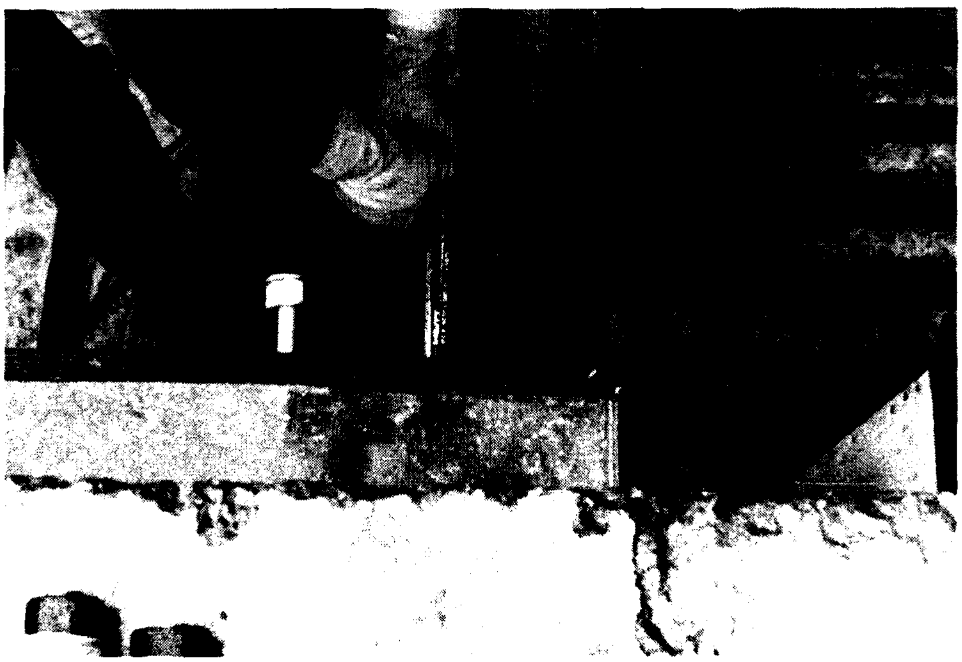
Holes in the box coinciding with drill hole locations were sealed with flexible rubber gaskets. The installation of horizontal anchors under submerged conditions is shown in Figures 7 and 8. The time required to spin the anchors into the drill holes ranged from 40 to 60 sec for both dry and submerged installations.

Testing Equipment and Procedures

19. A hollow-core hydraulic ram was used to load the anchors. Hydraulic pressure was supplied by a hand pump or an electrically powered pump. A universal laboratory testing machine was used to calibrate the loading system with results as shown in Figure 9.

20. In the pullout tests, the hydraulic ram was centered over the anchor to be tested and secured with a nut threaded onto the end of the anchor. A mechanical dial gage was positioned on the exposed end of the anchor to measure displacement of the anchor relative to the concrete surface (Figure 10). A linear variable differential transformer (LVDT) gage was used in lieu of the mechanical gage in one series of tests in an attempt to obtain a continuous plot of load versus displacement. However, the configuration of

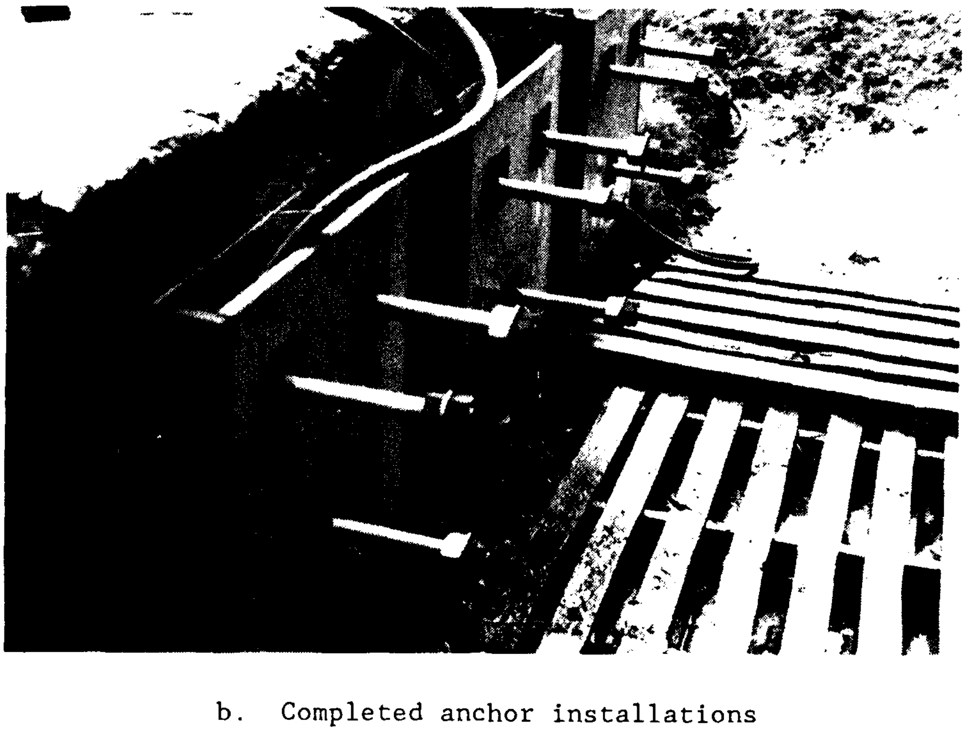
a. Resin injection



b. Capsule insertion

Figure 7. Placing the adhesives in a submerged, horizontal drill hole

a. Anchor being spun into a submerged hole



b. Completed anchor installations

Figure 8. Horizontal anchors installed under submerged conditions

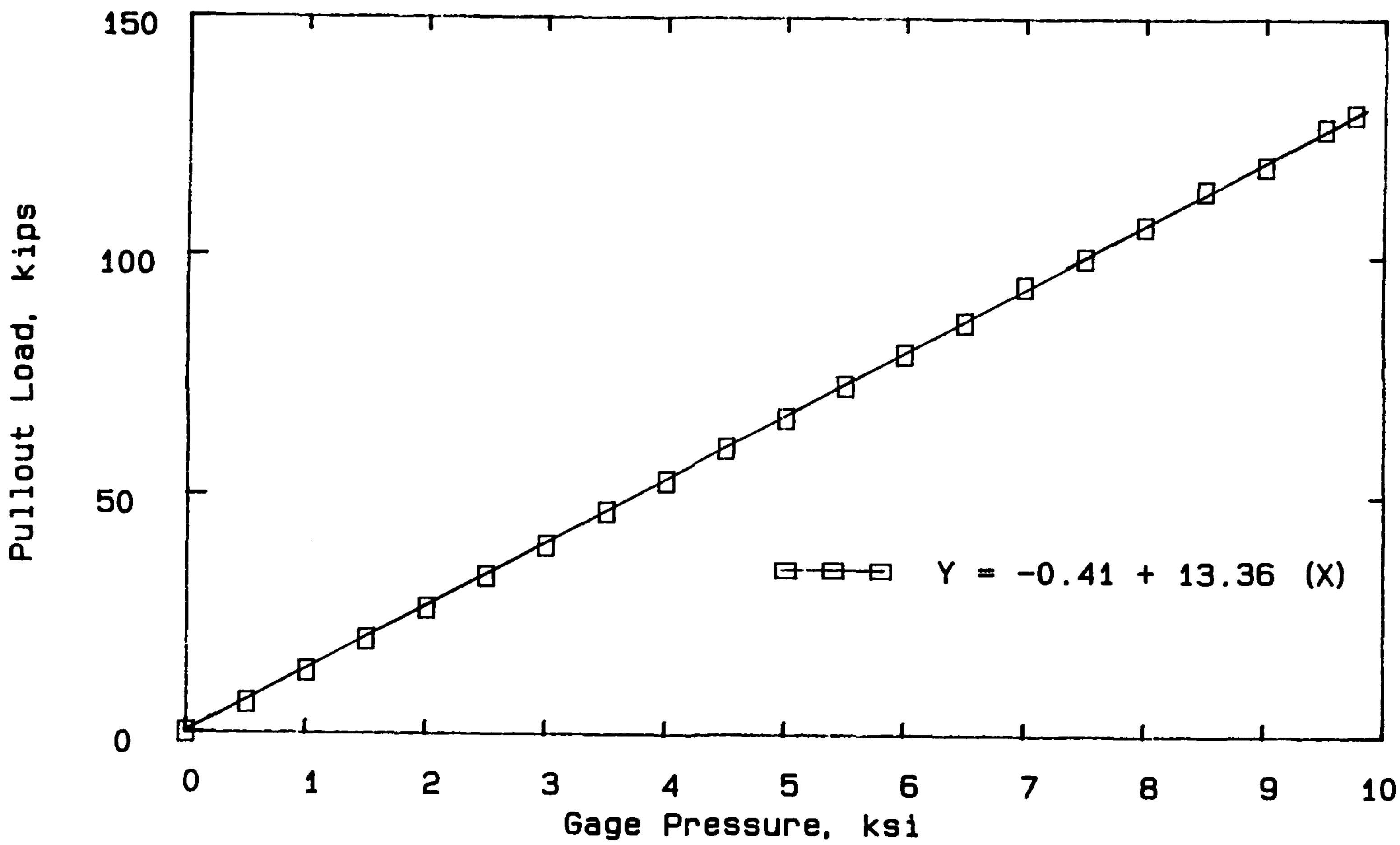
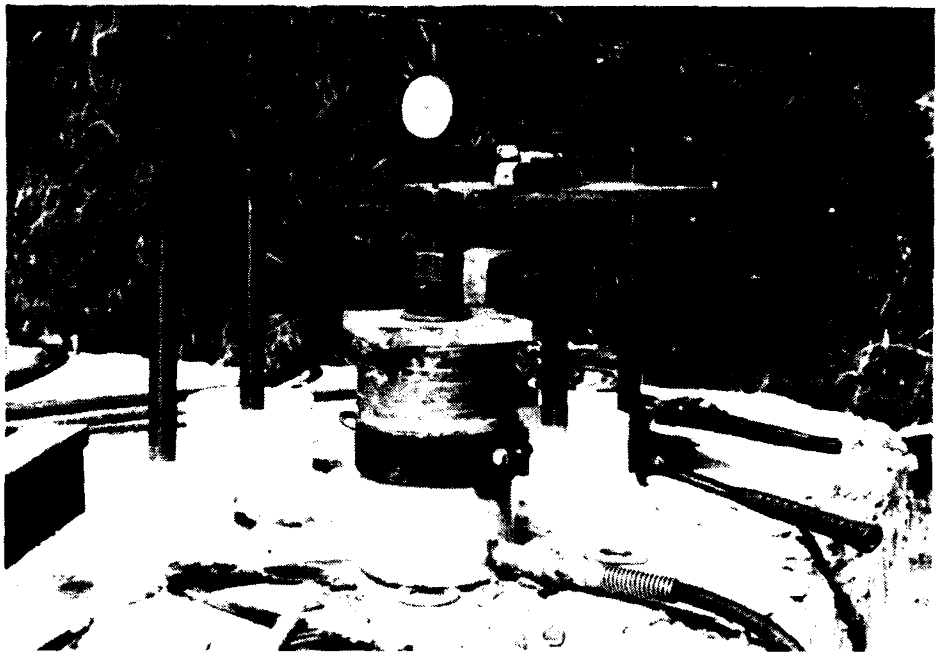
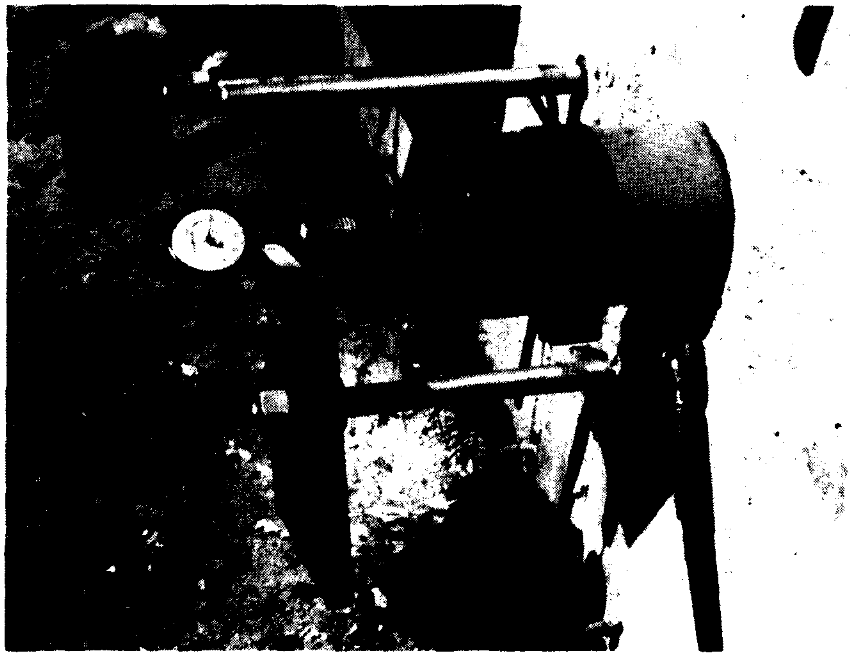


Figure 9. Calibration curve for hydraulic loading system



a. Vertical anchor



b. Horizontal anchor

Figure 10. Pullout tests in progress

the LVDT gage was such that it was difficult to maintain the gage in proper alignment when bending of the anchor occurred during the test.

21. In pullout tests on vertical anchors with 24-in. embedment lengths, the loading rate was approximately 3 kips/min. Typically, anchor displacements were measured at 5-kip load increments up to displacements of 0.1 in. and at smaller increments thereafter. In pullout tests on vertical anchors installed with the revised procedure, loads were applied in increments of 1,000-psi gage pressure up to 9,000 psi with smaller increments thereafter, depending on the magnitude of anchor displacement. Generally, two initial-load increments were applied to the anchors. The loading rate in these tests was approximately 3.5 kips/min with 3-min intervals at each increment of load. In pullout tests on horizontal anchors, the loading rate was approximately 10 kips/min. Typically, anchor displacements were measured at 5-kip load increments up to 100 kips and at smaller increments thereafter, depending on the magnitude of anchor displacement.

PART III: TEST RESULTS AND DISCUSSION

Vertical Anchors

22. Results of pullout tests conducted at 3 and 7 days on anchors with 24-in. embedment lengths are shown in Figure 11. These anchors were installed under submerged conditions with the original installation procedure. Pullout loads at displacements of 0.1 and 0.2 in., in addition to the maximum load, were selected as a basis for comparison of anchor performance. On this basis, results of the tests on anchors with 24-in. embedment lengths are summarized as follows:

Anchor No.	Testing Age, days		Load, kips 0.1-in. Displacement	0.2-in. Displacement	Maximum
1	3		48.3	58.1	80.0
3	3		52.8	65.4	75.C
5	3		64.5	91.2	95.0
		Avg	55.2	71.6	83.3
2	7		65.0	87.5	92.0
4	7		52.9	69.7	72.6
		Avg	59.0	78.6	82.3

To evaluate the effect of embedment length on tensile load capacity, these results are compared with the results of previous tests (McDonald 1989) on similar anchors with 12-in. embedment lengths (Figure 12).

23. In tests conducted at 3 days on anchors installed under submerged conditions with the original installation procedure, increasing the embedment length from 12 to 24 in. resulted in a 60-percent increase in tensile capacity at 0.1-in. displacement. However, this increased tensile capacity of anchors installed under submerged conditions was still significantly less than the load capacity of anchors with 12-in. embedment lengths installed in dry holes. While it may be possible to improve anchor performance under submerged conditions by further increasing embedment lengths, significant additional material and labor costs are associated with increasing embedment lengths of anchors in concrete. Therefore, the development of improved anchor installation procedures which do not require excessive embedment lengths was necessary.

24. An anchor installation procedure that eliminates the problem of resin and water mixing in the drill hole was described previously. This

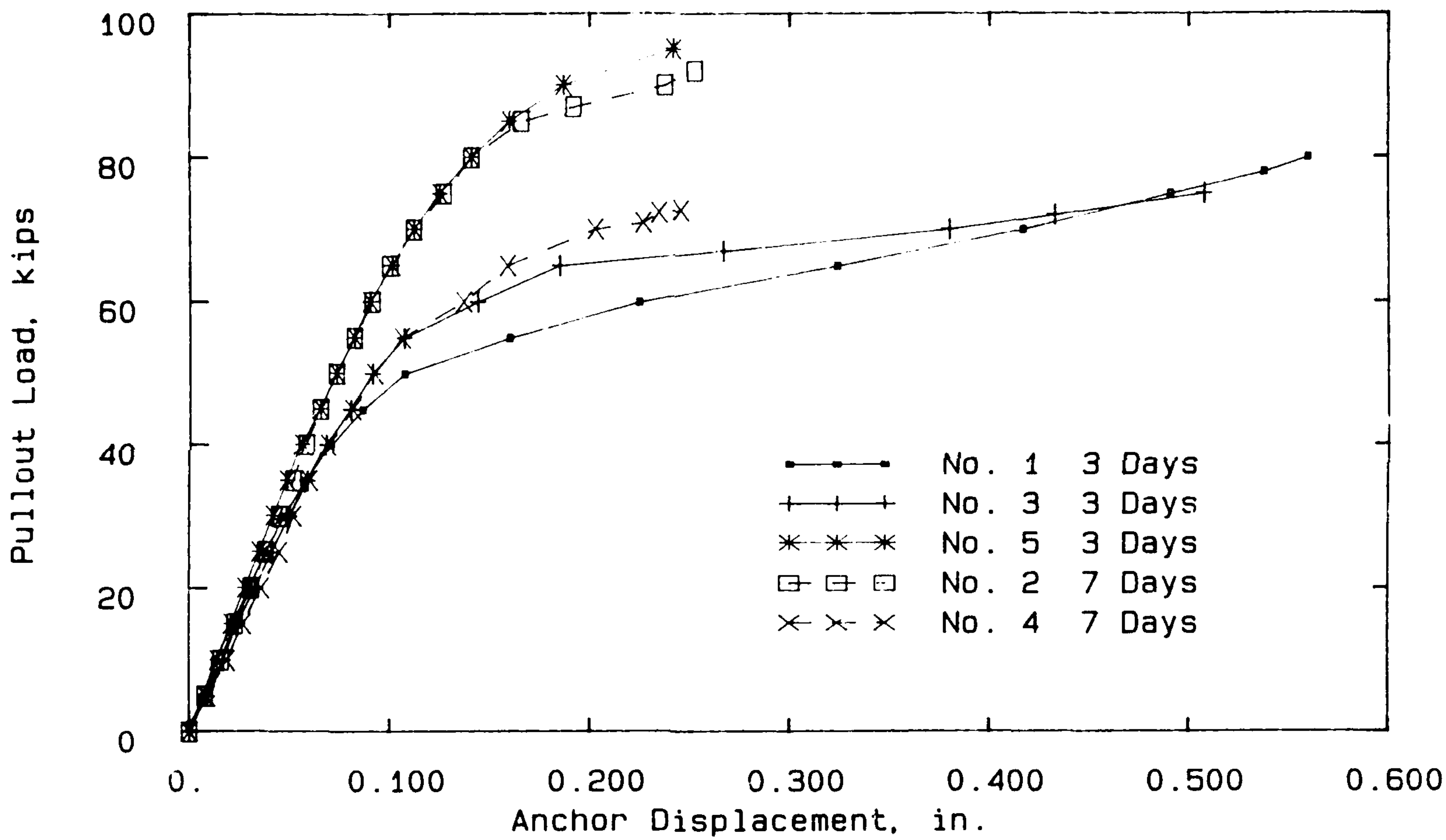


Figure 11. Results of pullout tests conducted on anchors (24-in. embedment) installed under submerged conditions with the original procedure

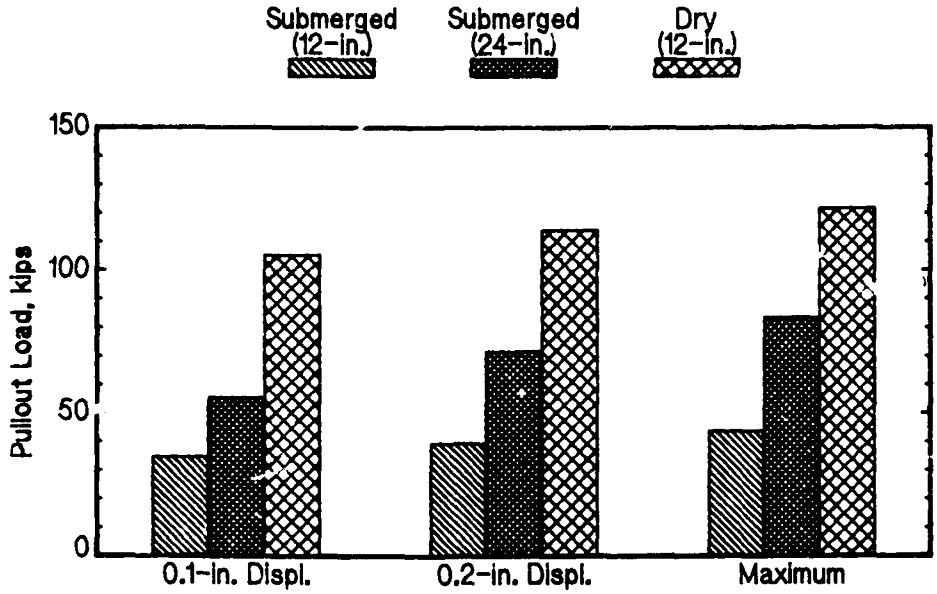


Figure 12. Effect of embedment length on tensile capacity

procedure, which uses resin in both bulk and capsule form to displace the water in a drill hole prior to anchor insertion and spinning, was used to install a number of anchors with 15-in. embedment lengths. Results of pullout tests conducted at 1, 3, 7, and 28 days on vertical anchors installed in this manner are shown in Figures 13 through 16, respectively. The variations in anchor displacement for a given load in the 1-day tests are attributed to difficulties with the measuring system in these tests.

25. With one exception, the ultimate tensile capacity of all anchors exceeded the loading capacity of the testing system. The maximum loading capacity was slightly less than the yield load of the anchors. The exception was Anchor No. 18 which failed through loss of bond at the concrete-grout interface. Vertical anchor tests are summarized in the tabulation following Figure 16.

26. The tensile capacity was essentially the same for anchors with 15-in. embedment lengths installed with the revised procedure under dry and submerged conditions (Figure 17). Anchors installed under submerged conditions with the revised procedure exhibited significant increases in tensile capacity compared to results of previous tests (McDonald 1989) on similar anchors installed with the original procedure (Figure 18). At 0.1-in. displacement, the tensile capacity of anchors installed with the revised procedure averaged more than three times greater than that of anchors installed

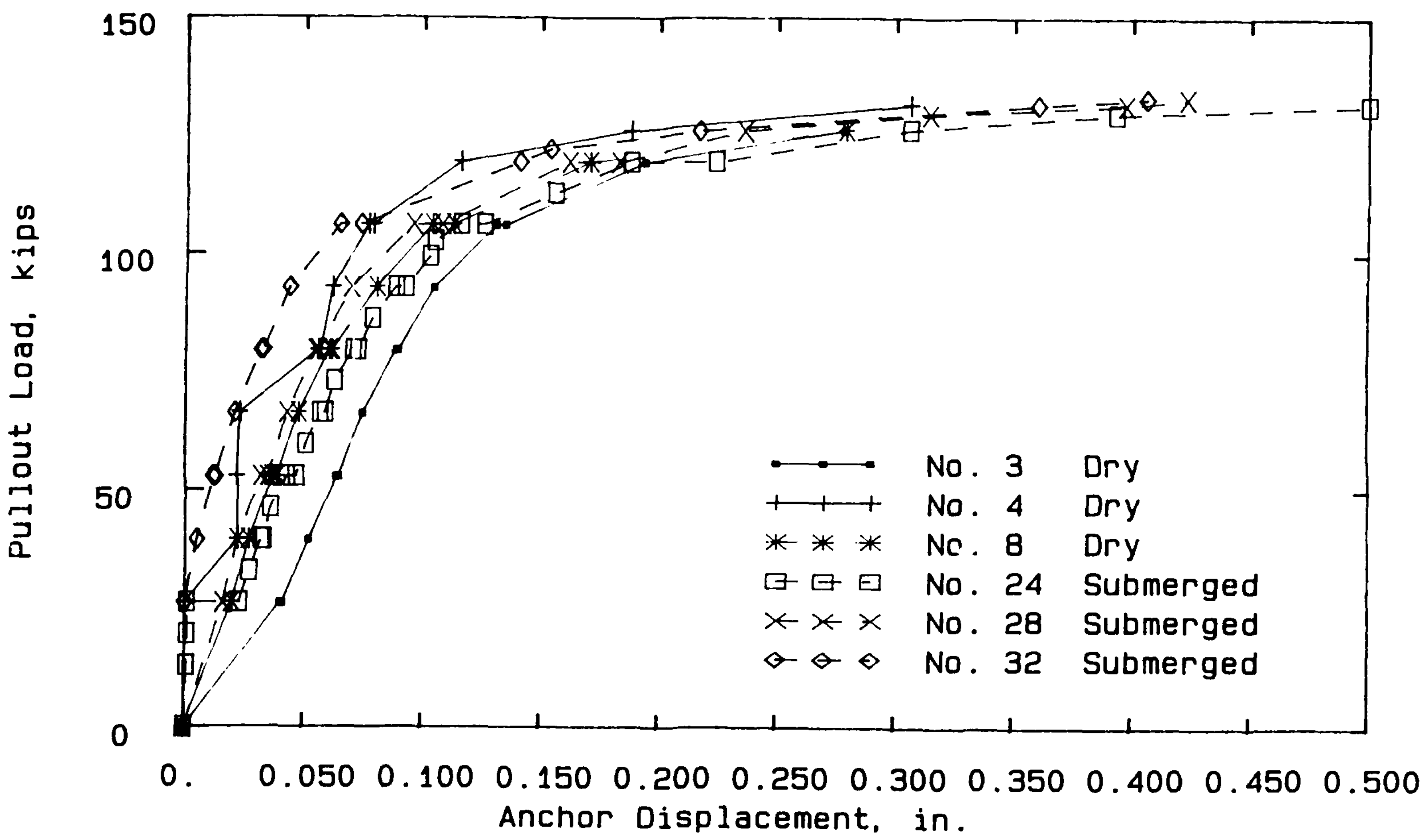


Figure 13. Results of pullout tests conducted at 1 day on vertical anchors (15-in. embedment) installed with the revised procedure

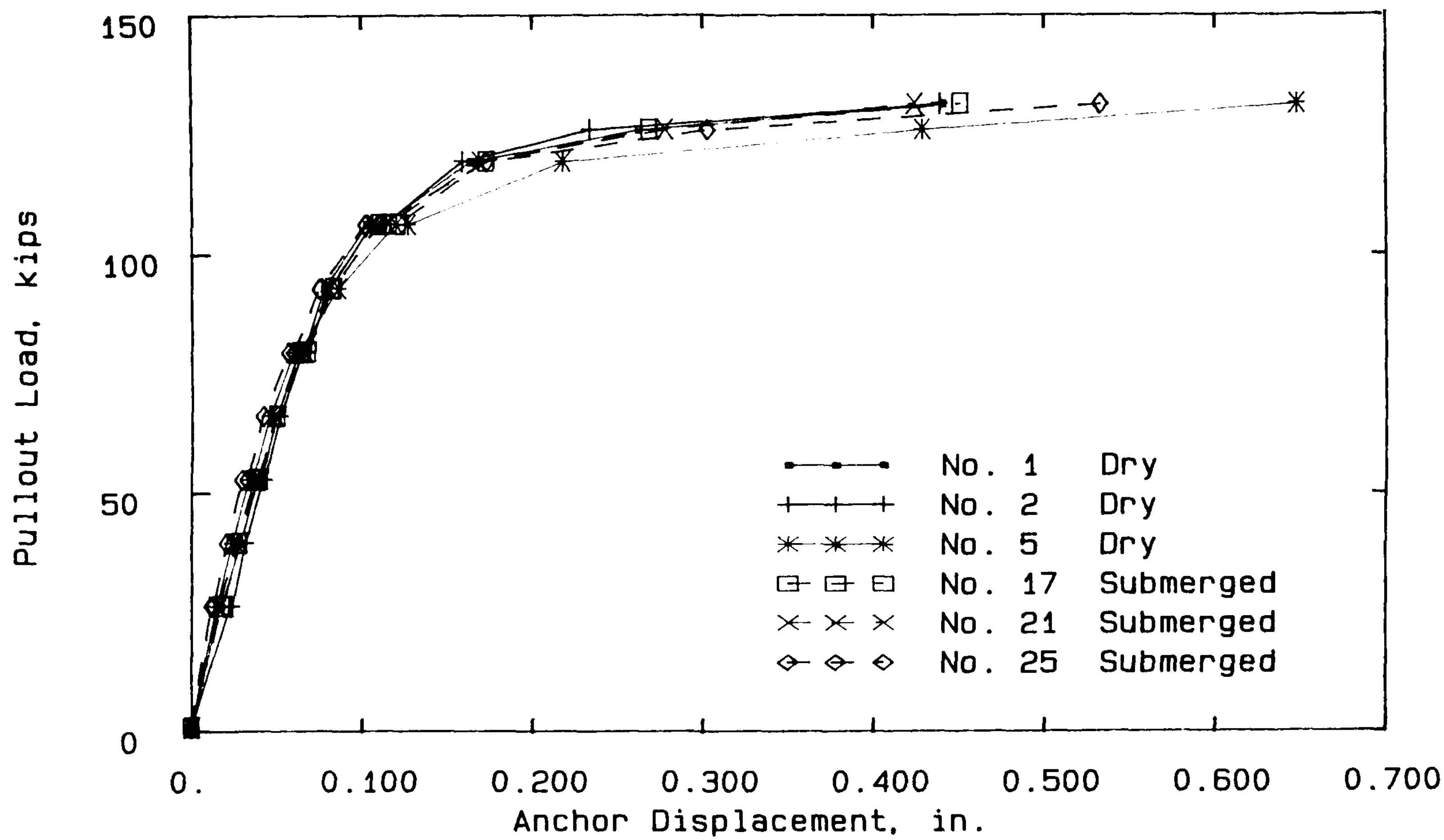


Figure 14. Results of pullout tests conducted at 3 days on vertical anchors (15-in. embedment) installed with the revised procedure

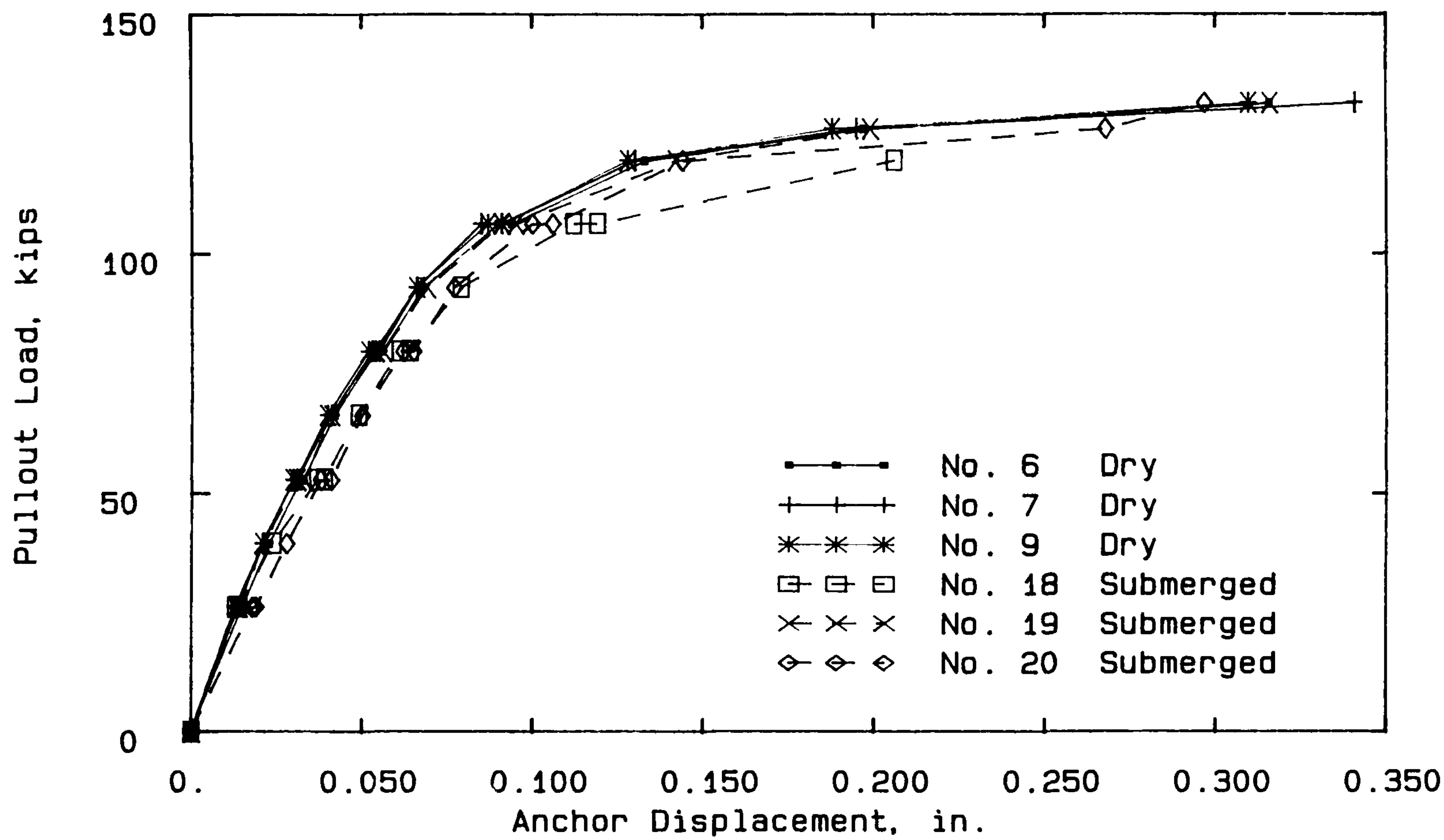


Figure 15. Results of pullout tests conducted at 7 days on vertical anchors (15-in. embedment) installed with the revised procedure

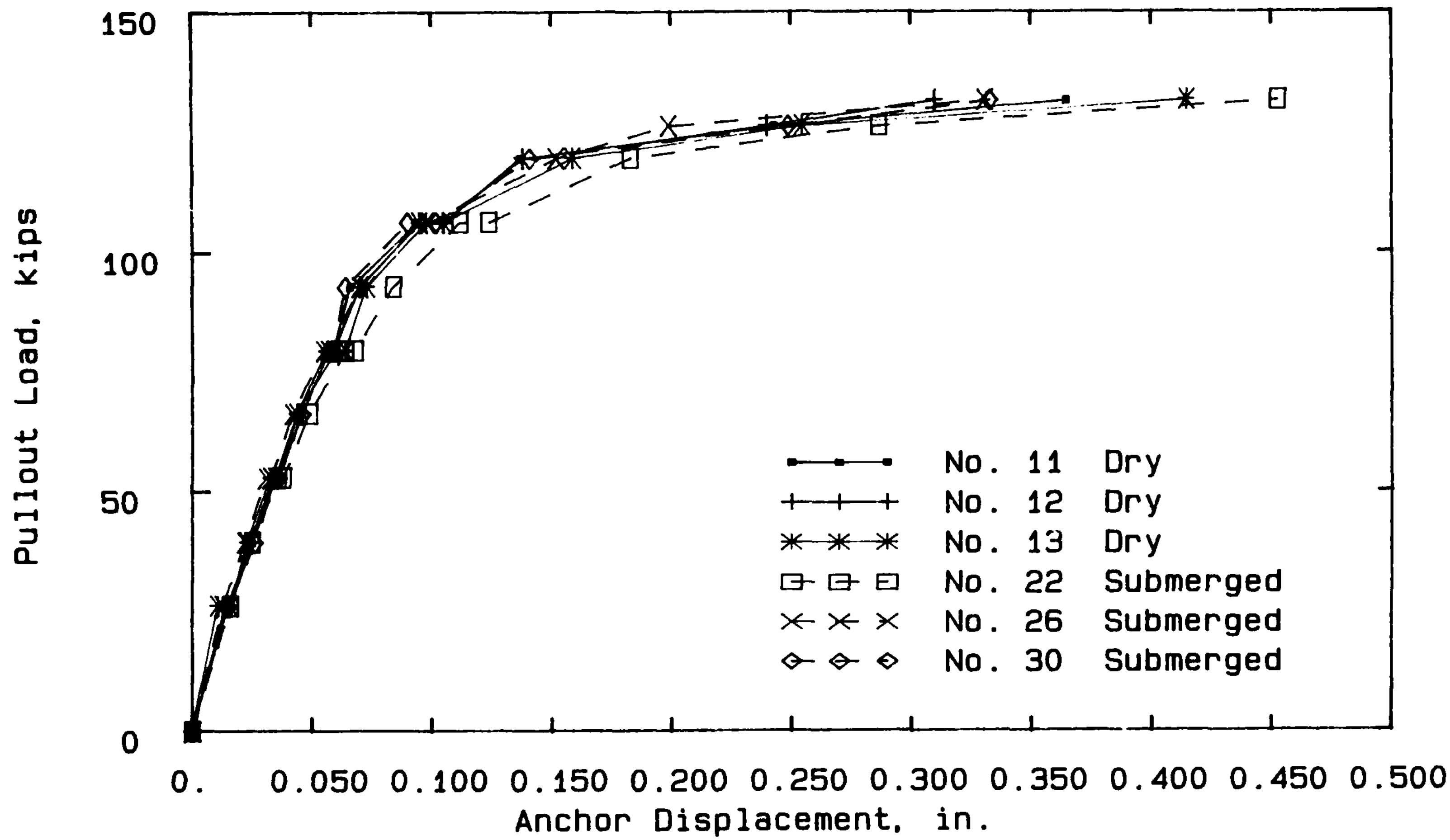


Figure 16. Results of pullout tests conducted at 28 days on vertical anchors (15-in. embedment) installed with the revised procedure

Anchor No.	Installation Condition		Load, kips 0.1-in. Displacment	0.2-in. Displacement	Maximum
			1 Day		
3	Dry		88.5	120.1	126.3
4	Dry		113.9	126.9	131.6
8	Dry		104.0	121.4	126.3
		Avg	102.1	122.8	128.1
24	Submerged		97.6	119.6	131.6
28	Submerged		106.3	121.8	133.0
32	Submerged		112.2	125.5	133.0
		Avg	105.4	122.3	132.5
			3 Days		
1	Dry		104.7	122.1	131.6
2	Dry		103.1	123.3	131.6
5	Dry		98.5	117.0	131.6
		Avg	102.1	120.8	131.6
17	Submerged		101.4	121.5	126.3
21	Submerged		102.8	121.5	131.6
25	Submerged		105.3	119.9	131.6
		Avg	103.2	121.0	129.8
			7 Days		
6	Dry		108.4	126.4	131.6
7	Dry		109.4	126.5	131.6
9	Dry		109.5	126.8	131.6
		Avg	109.1	126.5	131.6
18	Submerged		101.4	118.7	125.2
19	Submerged		107.7	126.4	131.6
20	Submerged		106.3	122.7	131.6
		Avg	105.1	122.6	129.5
			28 Days		
11	Dry		106.3	123.3	131.6
12	Dry		106.3	123.7	131.6
13	Dry		106.3	122.5	131.6
		Avg	106.3	123.2	131.6
22	Submerged		100.6	120.7	131.6
26	Submerged		106.6	126.4	131.6
30	Submerged		106.3	123.3	131.6
		Avg	104.5	123.5	131.6

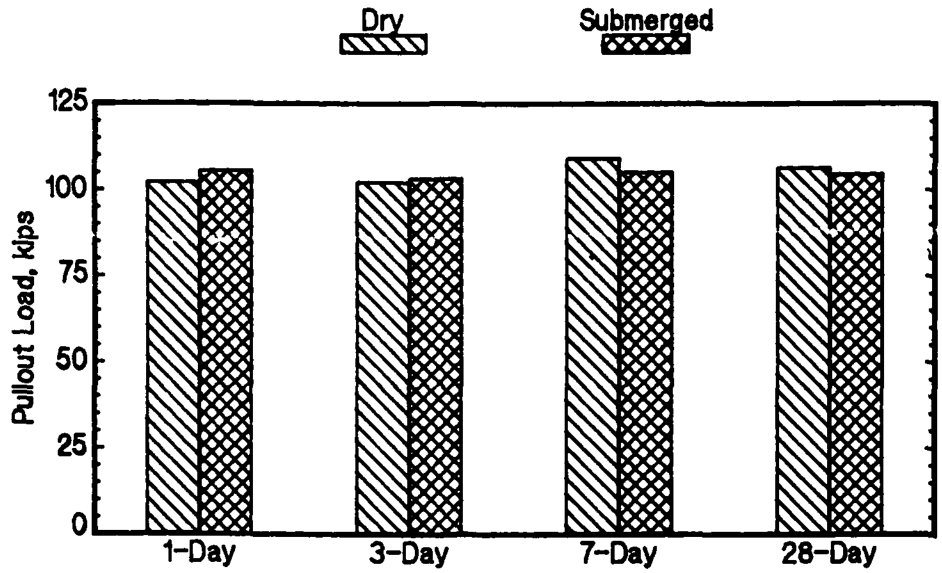


Figure 17. Average tensile capacity at 0.1-in. displacement of anchors installed with the revised procedure under dry and submerged conditions

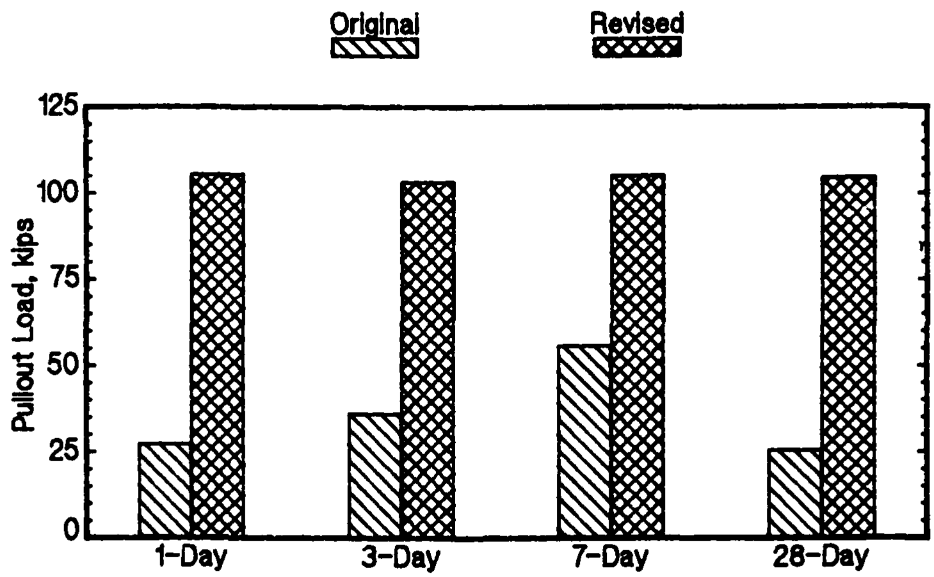


Figure 18. Average tensile capacity at 0.1-in. displacement of anchors installed under submerged conditions with the original and revised procedures

with the original procedure. Also, the ultimate tensile capacity of anchors installed under submerged conditions with the revised procedure averaged more than 130 kips compared to an average ultimate capacity of less than 50 kips for similar anchors installed with the original procedure.

Horizontal Anchors

27. There was some concern about the performance of the revised installation procedure when used in horizontal drill holes. Consequently, the revised procedure was used to install 18 horizontal anchors, 9 each under dry and submerged conditions. Results of pullout tests conducted at 1, 3, and 7 days on horizontal anchors are shown in Figures 19 through 21.

28. At anchor displacements of 0.1 in., the average tensile capacity of horizontal anchors installed under submerged conditions was slightly higher than that of similar anchors installed in dry holes when tested at 1 and 7 days (Figure 22). Overall, the difference in tensile capacity between horizontal anchors installed under dry and submerged conditions was less than 2 percent at 0.1-in. displacement. Similar results were obtained at 0.2-in. and maximum anchor displacements.

29. At 1 day, the average tensile capacity of anchors installed under submerged conditions was essentially the same for horizontal and vertical anchors at displacements of 0.1 in. (Figure 23). Under the same installation conditions, the tensile capacity of vertical anchors was slightly higher than that of horizontal anchors at 3 and 7 days. Under submerged conditions, the overall average tensile capacity of vertical anchors was 3 percent higher than that of comparable horizontal anchors. Similar results were obtained in tests on anchors installed in dry holes (Figure 24). Under these conditions, the overall average tensile capacity of vertical anchors was almost 5 percent higher than that of comparable horizontal anchors at 0.1-in. displacements. Results of these tests are summarized and the tabulation follows Figure 24.

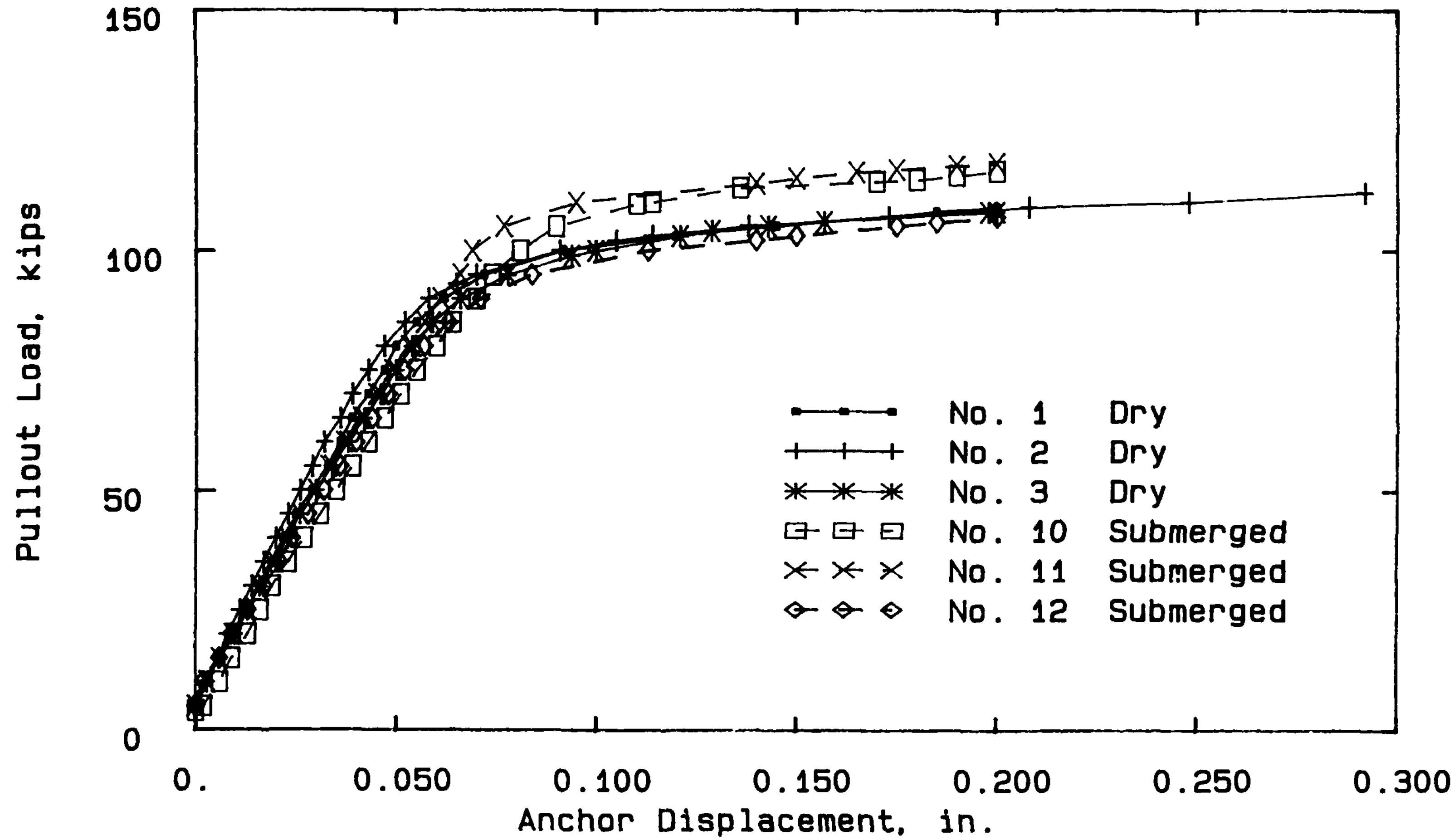


Figure 19. Results of pullout tests conducted at 1 day on horizontal anchors (15-in. embedment) installed with the revised procedure

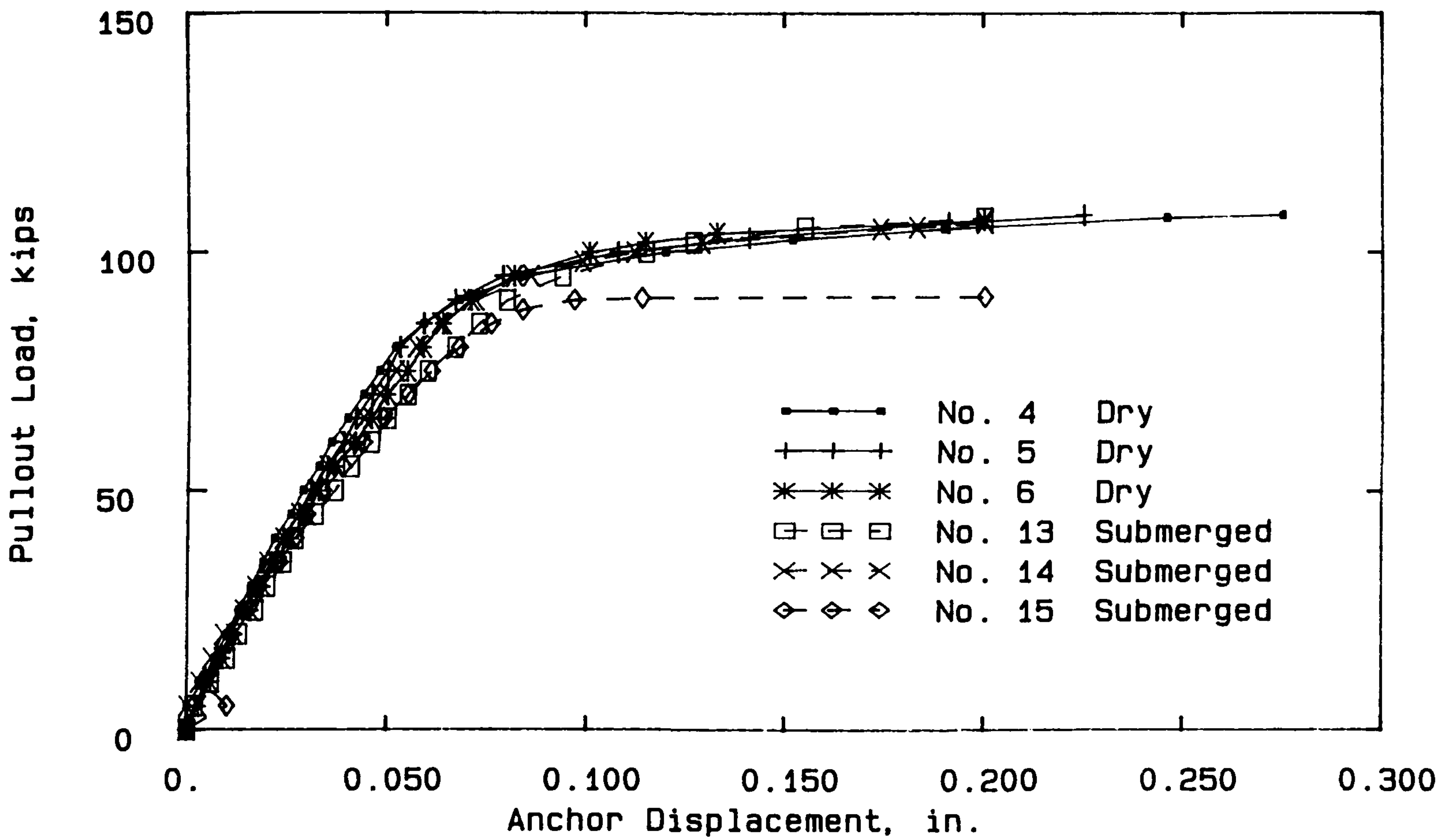


Figure 20. Results of pullout tests conducted at 3 days on horizontal anchors (15-in. embedment) installed with the revised procedure

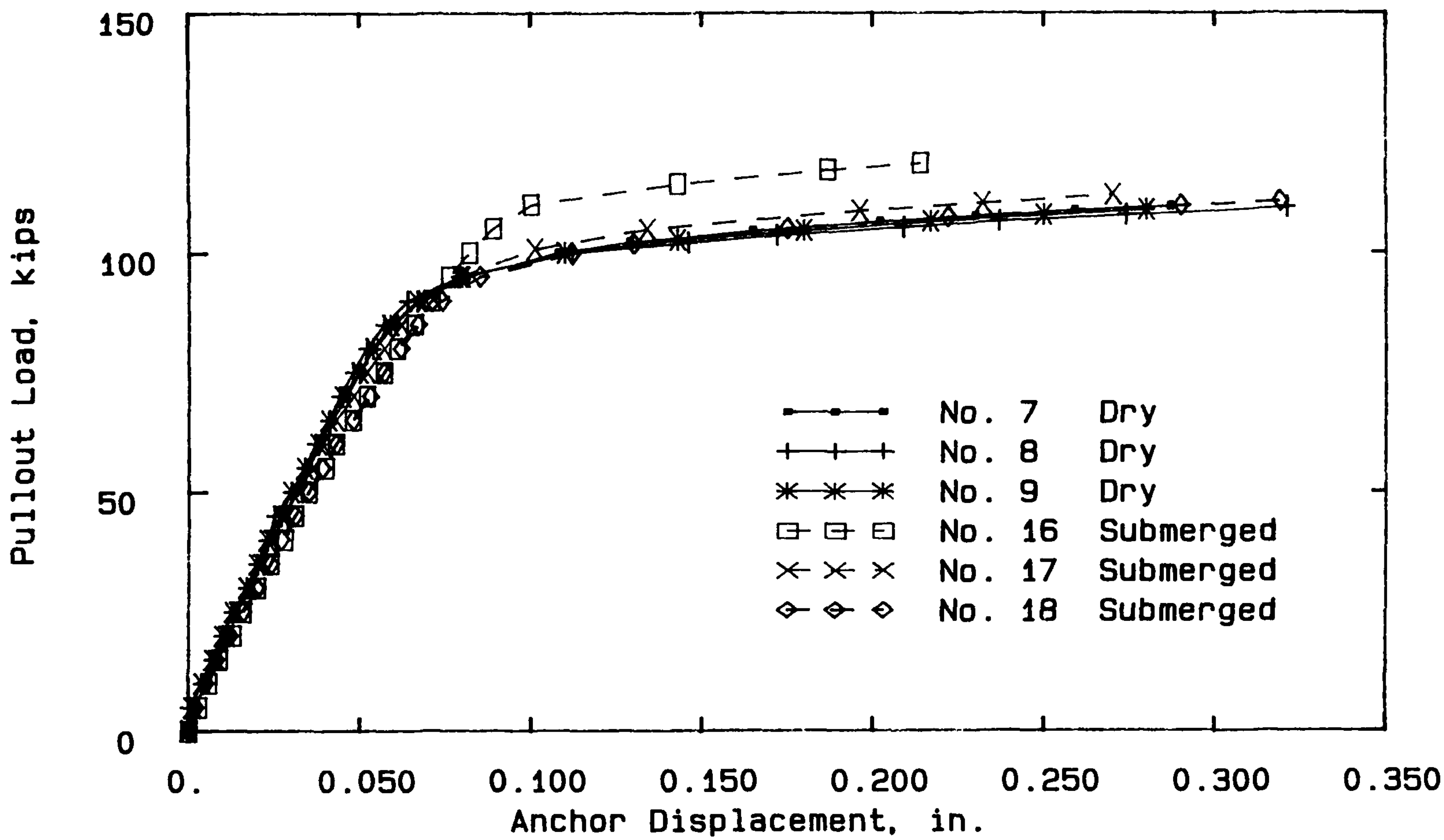


Figure 21. Results of pullout tests conducted at 7 days on horizontal anchors (15-in. embedment) installed with the revised procedure

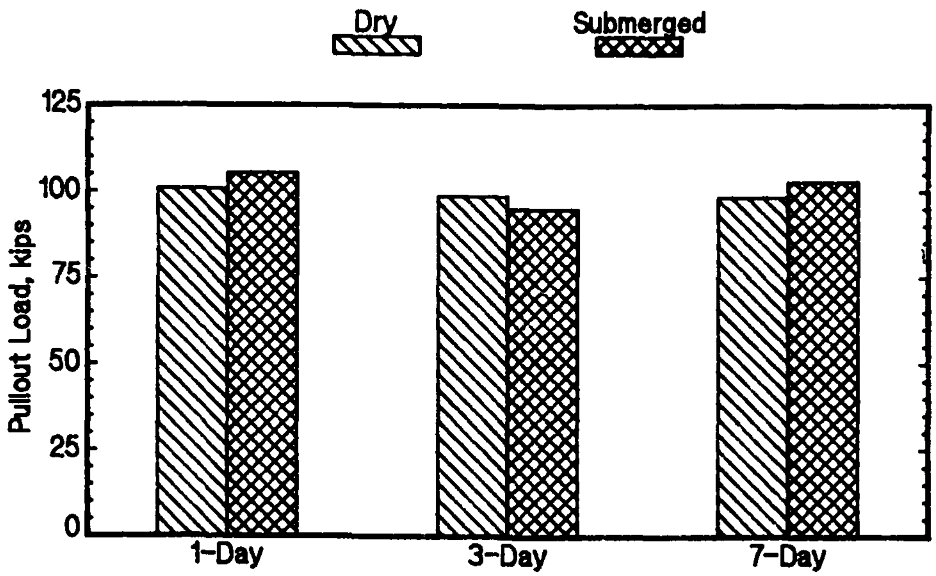


Figure 22. Average tensile capacity at 0.1-in. displacement of horizontal anchors installed under dry and submerged conditions with the revised procedure

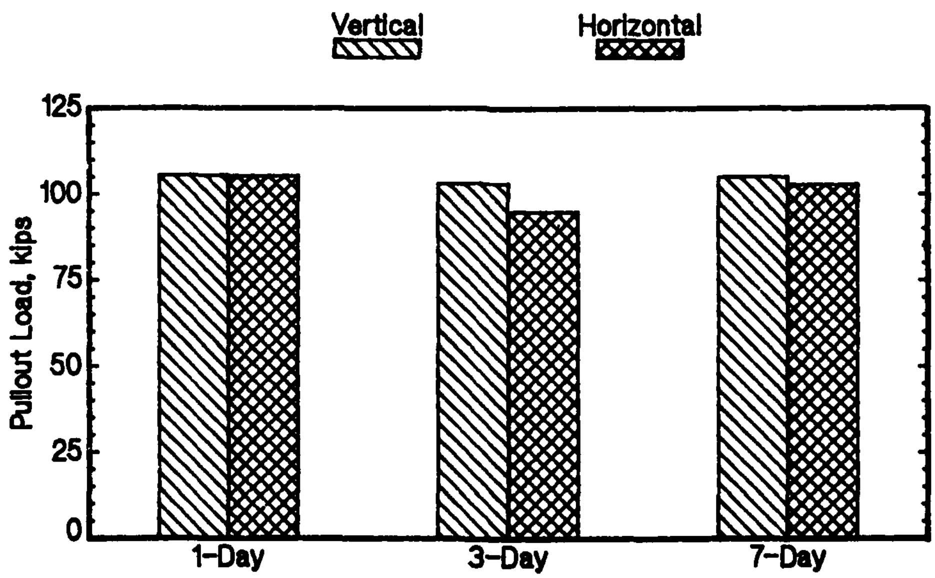


Figure 23. Average tensile capacity at 0.1-in. displacement of vertical and horizontal anchors installed under submerged conditions with the revised procedure

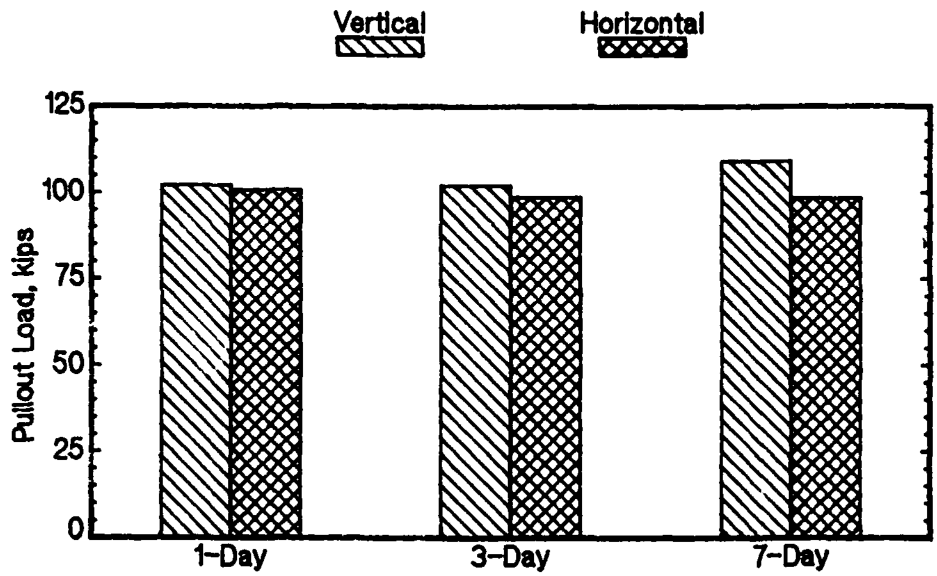


Figure 24. Average tensile capacity at 0.1-in. displacement of vertical and horizontal anchors installed under dry conditions with the revised procedure

Anchor No.	Installation Condition		Load, kips		
			0.1-in. Displacement	0.2-in. Displacement	Maximum
			1 Day		
1	Dry		100.9	109.0	109.0
2	Dry		101.3	108.5	112.0
3	Dry		100.0	108.1	108.1
		Avg	100.7	108.5	109.5
10	Submerged		107.4	116.4	116.4
11	Submerged		110.4	118.1	118.1
12	Submerged		97.8	106.9	106.9
		Avg	105.2	113.8	113.8
			3 Days		
4	Dry		97.2	105.2	107.6
5	Dry		98.6	106.4	107.5
6	Dry		100.0	106.5	106.5
		Avg	98.6	106.0	107.2
13	Submerged		96.4	107.0	107.2
14	Submerged		98.2	105.9	105.9
15	Submerged		90.1	90.5	90.5
		Avg	94.9	101.1	101.2
			7 Days		
7	Dry		98.5	106.3	109.6
8	Dry		98.2	104.9	109.4
9	Dry		98.3	105.6	108.9
		Avg	98.3	105.6	109.3
16	Submerged		110.0	118.0	118.6
17	Submerged		100.7	108.9	112.0
18	Submerged		97.6	106.0	110.6
		Avg	102.8	111.0	113.7

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

30. Typically, anchors are installed by (a) drilling a small-diameter hole into sound concrete, (b) cleaning the hole, (c) inserting a capsule containing polyester resin or vinylester resin, and (d) spinning the anchor into the hole. This procedure produces satisfactory results under dry conditions. However, anchors installed under submerged conditions with this procedure exhibit significant reductions in tensile load capacity. Although insertion of the adhesive capsule or cartridge into the drill hole displaces the majority of the water in the hole, water will remain between the walls of the adhesive container and the drill hole. Insertion of the anchor traps this water in the drill hole and causes it to become mixed with the adhesive, resulting in an anchor with reduced tensile capacity.

31. Increasing the embedment length from 12 to 24 in. resulted in a 60-percent increase in tensile load capacity of anchors installed under submerged conditions. However, this increased tensile capacity was still about one-half the load capacity of anchors with 12-in. embedment lengths installed in dry holes. While it may be possible to improve anchor performance under submerged conditions by further increasing embedment lengths, significant additional material and labor costs are associated with increasing embedment lengths of anchors in concrete. Therefore, improved anchor installation procedures which do not require excessive embedment lengths were desirable.

32. An anchor installation procedure that eliminates the problem of resin and water mixing in the drill hole is described herein. Basically, this procedure uses resin in both bulk and capsule form to displace the water in a drill hole prior to anchor insertion and spinning. Anchors with 15-in. embedment lengths installed with the revised procedure exhibited essentially the same tensile capacity under dry and submerged conditions. At 0.1-in. displacement, the tensile capacity of vertical anchors installed with the revised procedure under submerged conditions averaged more than three times greater than that of similar anchors installed with the original procedure. Also, the

ultimate tensile capacity of anchors installed under submerged conditions with the revised procedure averaged more than 130 kips compared to an average ultimate capacity of less than 50 kips for similar anchors installed with the original procedure.

33. Horizontal anchors installed with the revised procedure under both dry and submerged conditions also exhibited excellent tensile load capacities. Overall, the difference in tensile capacity between horizontal anchors installed under dry and submerged conditions was less than 2 percent at 0.1-in. displacement. Similarly, the average difference in tensile capacity between horizontal and vertical anchors was only 3 and 5 percent for anchors installed under submerged and dry conditions, respectively.

Recommendations

34. Tests to date on anchors installed with the revised procedure have been limited to short-duration loadings at relatively early ages. Additional testing should be conducted to determine the long-term performance of vinyl-ester resin under wet, alkaline conditions. Also, creep tests should be conducted to evaluate the effect of sustained loads on anchors installed with the revised procedure. The potential for eliminating the resin capsule and injecting all of the adhesive in bulk should also be investigated.

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