TECHNICAL REPORT NO. 6-518

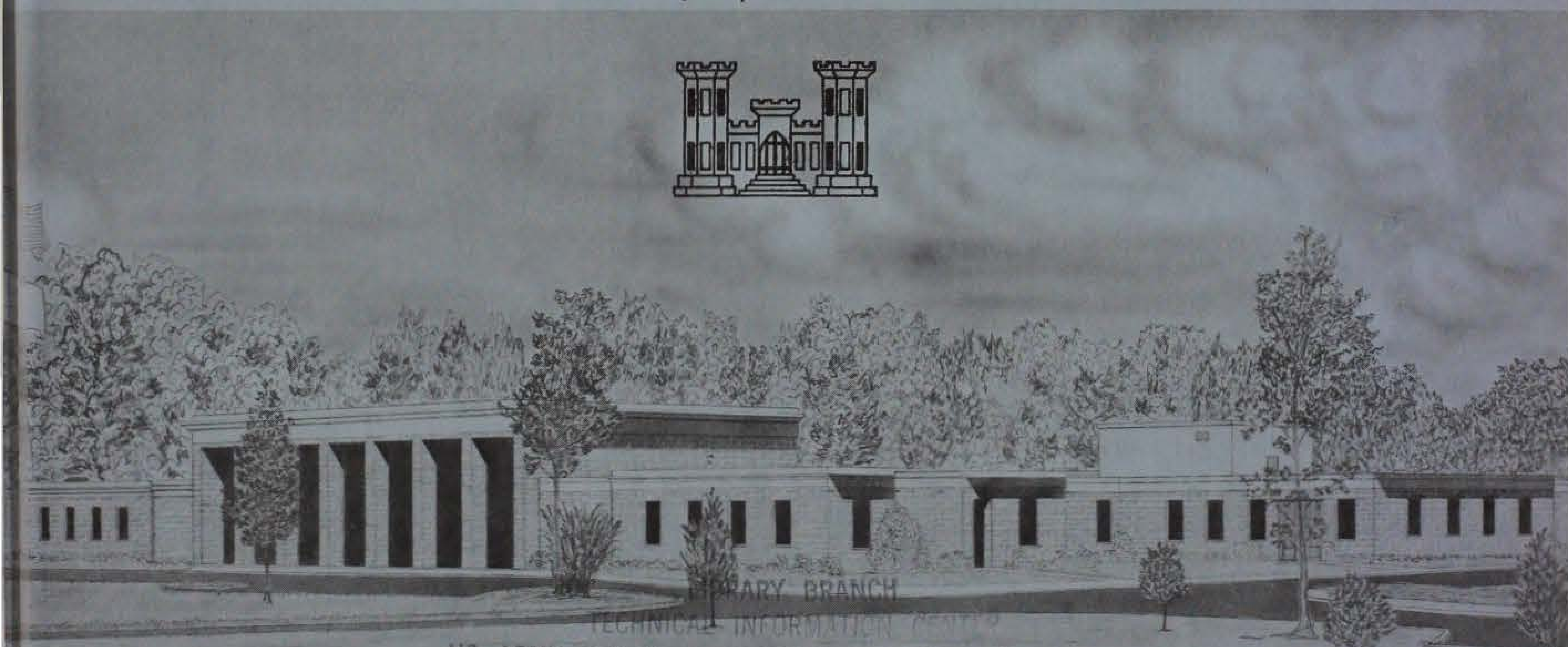
INVESTIGATION OF METHODS OF PREPARING HORIZONTAL CONSTRUCTION JOINTS IN CONCRETE

Report 4

EVALUATION OF HIGH-PRESSURE WATER JET AND JOINT PREPARATION PROCEDURES

by

W. O. Tynes, W. F. McCleese



August 1973

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station
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FOREWORD

The investigation reported herein was authorized by the Office, Chief of Engineers, by first indorsement, dated 11 July 1969, to U. S. Army Engineer Waterways Experiment Station (WES) letter, dated 9 June 1969, subject: "Project Plan for Construction Joint Study." The investigation forms a part of Engineering Studies (ES) Item No. 617, "Improvements in Construction Practice," of the ES Program of the Corps of Engineers.

This work is supplementary to the laboratory investigation of methods of preparing horizontal construction joints in concrete that was conducted by the WES in 1958-1959 and 1960-1962, the results of which are reported in Report 1, July 1959, and Report 2, July 1963, of Technical Report No. 6-518.

The work was conducted by the Concrete Laboratory of the WES during the period 1969-1972 under the direction of Messrs. Bryant Mather and J. M. Polatty. Staff members actively concerned with the work included Messrs. W. O. Tynes, W. F. McCleese, and W. B. Lee. This report was prepared by Messrs. Tynes and McCleese.

Directors of the WES during the investigation and the preparation and publication of this report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. Customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic yard	0.59327638	kilograms per cubic metre
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (force) per square inch per minute	0.006894757	megapascals per minute
gallons (U. S. liquid)	0.3785	cubic metres
gallons (U. S. liquid) per minute	0.00630902	cubic metres per second
feet per second	0.3048	metres per second

SUMMARY

This study was designed to investigate procedures for preparation of horizontal construction joints using a high-pressure water jet, to compare these procedures with the alternative practice of wet sandblasting, and to develop additional information on procedures and methods that have been utilized in horizontal construction joint practice.

The investigation was divided into two phases, laboratory and field. One 6-in. maximum size crushed limestone aggregate concrete mixture, with a cement content of 235 lb/cu yd, an air content of 6 $\pm$ 1 percent, and a slump of 2 $\pm$ 1/2 in. on the portion of the mixture passing the 1-1/2-in. sieve, was used to cast specimens for both phases. In the laboratory phase, thirty 3- by 3-ft by 18-in. concrete test specimens were cast for surface cleanup utilizing the high-pressure water jet, and five 3- by 3-ft by 18-in. specimens were cast for surface cleanup utilizing the wet sandblasting method. Two nozzle types and three water pressures (2000, 6000, and 10,000 psi) for each nozzle type were used to determine the effectiveness of the various combinations of nozzle and water pressure in cutting the surface of concrete specimens at each age of 2, 3, 7, 14, and 28 days. Wet sandblasting was used to cut the surface of concrete test specimens at each of the five test ages for comparison with the water jet cleanup. In the field phase, three concrete blocks, 10 by 20 by 5 ft high, were cast in two 30-in.-high lifts. The 10- by 20-ft joint plane of the first lift of each block was divided into four equal areas for four different types of cold joint preparation (dry with mortar, dry without mortar, wet with mortar, and wet without mortar). The joint cleanup technique (using the 6000-psi water jet) was common to all three blocks. A series of strength tests (shear, tensile, and flexural) were made of cores drilled from several areas of each block to evaluate the various methods of preparing the horizontal construction joints.

Results of the laboratory phase indicate that the 2000-psi pressure is not satisfactory, except possibly for very low strength concrete (less than 1500 psi), and that the water jet cutting efficiency with 6000- and 10,000-psi pressures is as satisfactory as the wet sandblasting method and requires less cutting time and less cleanup of the concrete surface after cutting.

Strength test results of the core specimens of the blocks during the field phase indicate that the dry joint without mortar is equal to the wet joint with mortar.

INVESTIGATION OF METHODS OF PREPARING HORIZONTAL CONSTRUCTION JOINTS IN CONCRETE

EVALUATION OF HIGH-PRESSURE WATER JET AND JOINT PREPARATION PROCEDURES

PART I: INTRODUCTION

Background

1. Horizontal construction joints in mass concrete structures are one of the most likely places for planes of weakness to exist and leakage and deterioration to occur. There is agreement on the importance of thoroughly cleaning the top surface of the lower lift prior to placement of fresh concrete, but differences of opinion remain as to the proper method of such treatment prior to placement of additional concrete, i.e., as to which method of treatment will best prevent weakness, leakage, and deterioration. Numerous methods of improving joint treatment have been tried, but the problem still exists. Questions have arisen as to whether the surface should be wet or dry and whether or not a layer of mortar should be used. It has been reported by Trinker[1] that the delay time between the casting of lifts has a significant effect on the quality of the joint. Trinker has furthermore stated that:

> The strength of connection of concrete with construction joints and interval between concreting up to 8 hr decreases up to 12%, in the case with no special treatment of the joint surface. The strength of connection of concrete with construction joints and interval between concreting of 16 hr to 15 days decreases by 18 to 29% by comparison with strength of test pieces without joints, in the case with correct and careful treatment of joint surfaces.[1]

2. In checking the wet and dry surfaces, mortar or no mortar conditions, two investigations[2,3] were conducted by the U. S. Army Engineer

Waterways Experiment Station (WES). However, the results of these investigations were regarded as not conclusive enough to accept without reservations. The results are, however, presently being cited as justification for the employment of specific construction practices. Therefore, it is important that ambiguities arising in these two investigations be resolved. Also, the development and extensive use of high-pressure water jets in cutting and cleaning concrete joint surfaces have created such unanswered questions as:

- a. Can such equipment be used on younger, weaker concrete without serious undercutting?
- b. Is there a combination of pressure and nozzle shape which will perform as effectively and economically on mature high-strength concrete as wet sandblasting?

3. This study was conducted to develop the data necessary to answer the above questions and to determine the best method of construction joint preparation prior to the placement of additional concrete.

Scope

4. This investigation was conducted in two phases, laboratory and field, to investigate the high-pressure water jet and to develop additional data on the wet versus dry and the grouted versus ungrouted effects on properly prepared joint surfaces.

- a. In the laboratory phase, a pump capable of developing 10,000 psi* of water pressure and of being adjusted to any selected lower pressure and two nozzles of the same water capacity but different shapes were obtained for use in this investigation. Thirty 3- by 3-ft by 18-in. specimens of mass concrete were cast for this phase to evaluate the effectiveness of the high-pressure water jet, and five such specimens were cast for wet sandblasting tests.
- b. In the field phase, three blocks of mass concrete, each approximately 5 by 10 by 20 ft, were cast. Each block was cast in two lifts of approximately 30 in. The lower

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* A table of factors for converting U. S. Customary units of measurement to metric (SI) units is presented on page ix.

lift of each block contained a coloring material (iron oxide) in order to properly locate the joint plane. Monfore gages were embedded in the dry and wet surfaces of the lower lift to measure the moisture content. The first lift of each block was divided into four equal areas, and the joint cutting method selected from the laboratory phase, i.e., using the 6000-psi water pressure and the No. SS2506 nozzle type, was used to cut all joint surfaces. The areas were prepared with and without mortar, dry and wet. The first lift of each block was moist cured 14 days. After this period of wet curing, the surfaces were kept dry until the surface was sufficiently dry (Monfore gage reading of 97); then, two surfaces were wetted 16 hr prior to casting the second lift. The four areas of each block were used to evaluate the effects of a layer of mortar on the joint and the drying effect of the joint surface prior to placement of the next lift.

Purpose

5. The purpose of this study was to investigate procedures for preparation of horizontal construction joints using a high-pressure water jet, to compare these procedures with the alternate practice of wet sandblasting, and to develop additional information on procedures and methods that have been utilized in horizontal construction joint practices.

PART II: MATERIALS, MIXTURES, EQUIPMENT SPECIMENS, AND TESTS

Materials

6. A type II portland cement (RC-622,-635) from Alabama was used in all the concrete for this investigation. The chemical and physical properties of this cement are given in table 1.

7. The aggregates used were crushed limestone from Tennessee. The fine aggregate was graded to comply with OCE Guide Specifications, alternate 1, and the coarse aggregate was graded to comply with OCE Guide Specifications.[4] The gradings and physical properties of the aggregates are given in table 2.

8. The air-entraining admixture (AEA 896) used in this investigation was a solution of neutralized vinsol resin.

Mixtures

9. One air-entrained concrete mixture was proportioned with 6-in. maximum size aggregate, 235 lb of portland cement per cubic yard, and an air content of 6 $\pm$ 1.0 percent and a slump of 2 $\pm$ 1/2 in. on the minus 1-1/2-in. portion of the mixture.

10. One mortar mixture was proportioned with the same proportion of sand and cement as in the concrete but with the water-cement ratio (W/C) decreased to produce a material of medium stiff consistency.

Equipment

11. The high-pressure water jet pump used in this investigation (fig. 1) was rented from a commercial source. The pump consisted of a single 1-in.-diameter piston with a 2-1/2-in. stroke. The pump was capable of supplying 13.0 gal/min of water with a nozzle pressure of 10,000 psi.

12. Two nozzles were used in this investigation, one of which gave a 15-degree broom type pattern and the other, a 25-degree spread. The two nozzles utilized approximately the same quantity of water when

Fig 1. High-pressure water jet pump

the same water pressures were used. The quantity of water utilized for each pressure was approximately 6.0 gal/min for 2000-psi, 9.0 gal/min for 6000-psi, and 13.0 gal/min for 10,000-psi pressure.

13. The portable wet sandblasting apparatus used in this investigation had a capacity of 1 cu ft for abrasive material. In this investigation the apparatus utilized a water pressure of 50 psi, an air pressure of 95 psi, and size No. 30 natural silica sand.

Preparation of Specimens

Laboratory phase

14. As stated earlier, a total of thirty-five 3- by 3-ft by 18-in. test specimens were cast for this phase. Three water pressures (2000, 6000, and 10,000 psi), five cutting ages (2, 3, 7, 14, and 28 days), and two nozzle types were used for 15 specimens, making a total of 30 specimens for the water-jet cutting effort. The top 3- by 3-ft surface plane was cut for each specimen on the designated testing dates. The remaining five specimens were wet sandblasted on the top 3- by 3-ft

surface plane at each of the cutting ages stated above for comparable observations. An examination of the water-jet cutting job and wet sandblasted cutting job for each specimen was made, and the cutting time required and the height of the cutting nozzle above the concrete surface were recorded. Photos 1, 2, and 3 show specimens after cutting with water pressures of 2000, 6000, and 10,000 psi, respectively; photo 4 shows a specimen after cutting with the wet sandblast method.

15. The 3- by 3-ft by 18-in. test specimens were cast and cured according to CRD-C 10[5]; however, the surface was not struck off and finished. Consolidation was accomplished by the use of internal vibration, and all specimens were moist cured until tested.

16. Three 6- by 12-in. companion cylinders were cast from the minus 1-1/2-in. portion of the concrete mixture for three of the five 3- by 3-ft by 18-in. test specimens cast on any specified day. These cylinders were tested at various ages to provide strength data of the concrete in companion specimens being cut with the high-pressure water jet and the wet sandblast method. The cylinders were cast and cured according to CRD-C 10[5].

Field phase

17. As stated earlier, three 5- by 10- by 20-ft test blocks were cast for the field phase of the study. Each block was cast in two 30-in. lifts, and the lower lift contained a coloring agent (iron oxide). Twenty 1-cu-yd batches of concrete were made for each lift. The 10- by 20-ft joint plane of each of the blocks was divided into four equal areas for different types of joint preparation. The blocks were designated 1, 2, and 3, and the four joint areas of each block were designated A1 through A4. Copper wells at depths of 1/2, 3/4, and 1 in. below the surface were embedded in each of the four quadrants of the first lift of the first block and at depths of 1/2 and 3/4 in. in each of the two areas (wet and dry) of the second and third blocks for later insertion of Monfore gages.

18. All joints were left rough, as in actual dam construction, as shown in photo 5. The concrete joint surface areas of the first lift of each block were cut using the high-pressure water jet with 6000-psi

water pressure and a nozzle with 25-degree spread at 48 ± 4 hr after casting (see photo 6). All joints were cleared of loose cuttings immediately prior to placement of the second lift, the wet joints with air and water, and the dry joints only with air.

19. Steel forms, 5 by 10 by 20 ft, were used to form the blocks. The forms were loosened to permit cleanup, then tightened and kept in place during the curing period. During the drying period, the blocks were protected from rainfall by a temporary shelter.

20. The first lift of each block was wet-cured for 48 ± 4 hr, cut utilizing the high-pressure water jet with 6000-psi water pressure, and then moist-cured an additional 12 days for a total of 14 days wet curing. After this period of moist curing, one half of the surface of the bottom lift of block 1 was allowed to dry for 29 days, and the other half was allowed to dry for 28-1/4 days; this second half was kept wet for 3/4 day. Blocks 2 and 3 were the same as block 1, except for the drying time. The drying times for the two halves of block 2 were 79 and 78-1/4 days, and for the two halves of block 3 were 126 and 125-1/4 days. The reason for the variation in length of drying time was based on Monfore gage readings. Monfore gage readings of 97 obtained from block 1 were used as the criteria for adequate dryness. Low temperatures caused difficulties with the Monfore gage readings for block 3, and the second lift was cast when the readings were 98. The medium stiff consistency mortar was broomed onto the cleaned surface of one wet and one dry area of each block with a minimum amount of brooming for a coverage thickness of approximately 1/2 in. The procedures used in preparing each of the four areas on the surface of the lower half of each block are given below.

Block 1

Quadrant No.	Curing Condition After 14-Day Moist Curing	Mortar
A1	Dry 29 days	None
A2	Dry 29 days	Yes
A3	Dry 28-1/4 days, wet 16 hr	None
A4	Dry 28-1/4 days, wet 16 hr	Yes

Block 2

Quadrant No.	Curing Condition After 14-Day Moist Curing	Mortar
A1	Dry 79 days	None
A2	Dry 79 days	Yes
A3	Dry 78-1/4 days, wet 16 hr	None
A4	Dry 78-1/4 days, wet 16 hr	Yes

Block 3

Quadrant No.	Curing Condition After 14-Day Moist Curing	Mortar
A1	Dry 126 days	None
A2	Dry 126 days	Yes
A3	Dry 125-1/4 days, wet 16 hr	None
A4	Dry 125-1/4 days, wet 16 hr	Yes

21. After the surfaces of the lower lifts had been treated as described above, the second lifts were placed and wet-cured for 14 days. Following this curing period, the blocks were air-dried in the open for 14 days or longer before the cores for the strength tests were drilled.

Cores and Types of Tests Used

22. Four nominal 10-in.-diameter by 60-in.-long cores were drilled vertically (normal to the joint plane) from each quarter of each of the blocks (see fig. 2) after the upper lift had reached 28 days age. Three top and bottom portions of each of these 10-in. cores were used to test concrete on each side of the plane for compressive, flexural, tensile, and shear strength. Six nominal 10-in.-diameter by approximately 26-in.-long cores were drilled with the diameter of the core formed by the joint plane, three each for tensile splitting and shear strength tests, from each quarter of each of the blocks. Six nominal 6-in.-diameter by 60-in.-long cores were drilled vertically (normal to the joint plane) for direct tensile test from each quarter of block 1 only (fig. 2).

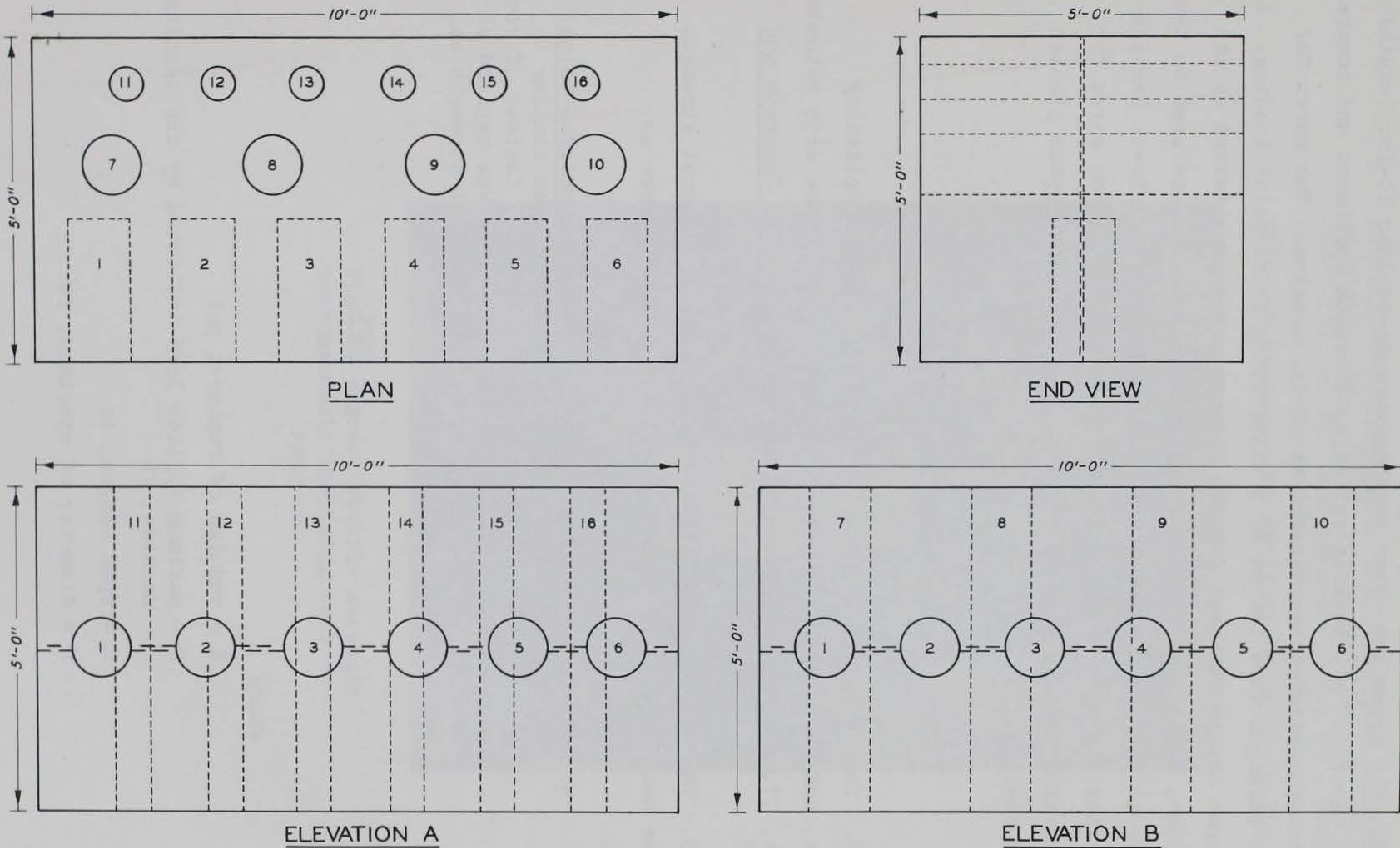

Fig. 2. Core layout for joint studies (one-quarter block)

23. All cores for shear testing were sawed into 10-in. lengths prior to testing. All tensile splitting strength specimens and compressive strength specimens were sawed to 20-in. lengths. The cores for flexural strength were tested as drilled using third-point loading. A 26-in. span length was used for all flexural specimens tested at the joint plane, and a span length of approximately 24 in. was used to test the concrete above and below the joint. The cores for direct tensile strength testing were sawed to 12-in. lengths. All of the cores for shear strength testing were capped with high-strength gypsum plaster prior to testing.

Test Methods

24. The tests for compressive strength, tensile splitting strength, and shear strength were conducted in accordance with methods CRD-C 14, 77, and 90, respectively, of the _Handbook for Concrete and Cement._[5]

25. The methods used for direct tension and flexural strength tests are not included in the _Handbook_; however, they were as follows:

a. _Flexural strength test of cylindrical specimens using third-point loading._ This test method was similar to method CRD-C 16, except that cylindrical instead of rectangular specimens were used. The load was applied at a rate of 150 psi per min, and the flexural strength was calculated using the formula

$$R = \frac{16PL}{3\pi D^3}$$

where

R = modulus of rupture, psi

P = maximum applied load indicated by the testing machine, lb

L = span length, in.

D = diameter of specimen, in.

b. <u>Direct tensile strength test of nominal 6- by 12-in. concrete cores.</u> This test method was similar to method CRD-C 149, except that concrete cores of a larger size instead of rock cores were used. The test assembly used including a test specimen is shown in fig. 3.

Fig. 3. Direct tensile strength test assembly including test specimen

PART III: DISCUSSION OF TEST RESULTS

Laboratory Phase

26. The results of each individual test for high-pressure water jet cutting showing nozzle type, cutting time, cutting height, job rating, size of specimen, concrete slump, air content, concrete strength, and comparable wet sandblasted specimens are presented in table 3.

27. Test data obtained from the high-pressure water jet cutting were not sufficient to determine any discernible difference between the efficiency of nozzle types (25-degree spread and 15-degree spread). However, it is the opinion of the project leader that the nozzle with the 15-degree spread is slightly more likely to cause grooving of the concrete surface and undercutting of the aggregate, especially at high water pressures. This opinion is based on personal observations during testing and not on any measurable data. In analyzing the test data obtained, no distinction was made as to which nozzle was used.

28. As stated earlier, three 6- by 12-in. companion cylinders were cast for three of the five 3- by 3-ft by 18-in. test specimens cast on any specified day. The compressive strength of the concrete in the test specimens was assumed to be equal to the average compressive strength of the three companion cylinders (table 3). In order to estimate the compressive strength of the remaining two test specimens, the following procedure was used:

<u>a</u>. The average compressive strengths of all 6- by 12-in. cylinders tested at 2, 3, 7, 14, and 28 days age were determined to be 1918, 2359, 2877, 3330, and 3766 psi, respectively. The percentages of the 28-day strength at 2, 3, 7, and 14 days were then determined to be 50.9, 62.6, 76.4, and 88.4 percent, respectively.

<u>b</u>. Since companion cylinders were tested at 28 days for each round of casting, the 28-day strength was used as a base, and the missing compressive strengths were determined by multiplying the appropriate percentage by the 28-day compressive strength of a particular round. For example, the 3-day strength of the round cast on 6 April 1970 was determined as follows: 3780 psi × 62.6 percent = 2366 psi.

29. The cutting job on the surface of each specimen tested was rated by the project leader based on a personal observation of the concrete surface after cutting. The cutting job was rated as "excellent," "very good," "good," "fair," or "bad" based on the observation. The following guide was used in rating each specimen tested:

a. Excellent - all laitance removed from the surface of the test specimen without undercutting more than 5 percent of all exposed aggregate.

b. Very good - 95 percent of all laitance removed from the surface of the test specimen.

c. Good - 90 percent of all laitance removed from the surface of the test specimen.

d. Fair - 80 percent of all laitance removed from the surface of the test specimen.

e. Bad - less than 80 percent of the laitance removed from the surface of the test specimen.

30. In the tests with the high-pressure water jet, the cutting height, cutting time, cutting pressure, and the concrete strength were all variables which had to be considered in obtaining an excellent cutting job. For a given concrete strength and cutting pressure, the cutting height could be varied to some degree, while still maintaining an excellent cutting job, by varying the speed at which the water jet was moved over the concrete surface. The closer the cutting height (distance of the nozzle above the concrete surface), the faster the water jet had to be moved across the concrete surface to prevent undercutting of the aggregate or grooving of the surface. Similarly, the cutting height had to be decreased and/or the cutting speed reduced when the concrete strength was increased or the cutting pressure was decreased in order to obtain an excellent cutting job. For all of the specimens cut during this project, the speed at which the water jet was moved across the concrete surface was fairly constant and was the speed with which the operator felt comfortable and in control of the high-pressure water jet. This speed was estimated to be approximately 1 to 1-1/2 fps.

31. It was intended that all specimens would be cut until all laitance was removed, without excessive undercutting of aggregate particles. The cutting height was held constant once the cutting process

was started, and the cutting nozzle was moved over the surface of the specimen until the operator felt an excellent cutting job had been obtained or additional laitance could not be removed at the set cutting height within a reasonable time period. In most cases, an excessive cutting height or insufficient cutting pressure was the cause of a specimen receiving a less than excellent cutting job. However, in a few instances when the operator felt an excellent job had been done, a closer inspection revealed that the cutting job could only be rated as good. This could be attributed to the inexperience of the operator, a fear of undercutting the aggregate, or the fact that the concrete surface was wet making it difficult to judge the cutting job. None of the specimens tested were considered to have been overcut.

32. The cutting height plotted against the concrete compressive strength for all specimens cut with a 6000-psi water jet is shown in plate 1. The rating of the cutting job done on each specimen is denoted next to the plotted point. A line of best visual fit has been drawn through the points that denote an excellent cutting job. This line provides a suggested cutting height for a given compressive strength concrete cut with a 6000-psi water jet.

33. Plates 2 and 3 are similar plots for a water jet cutting pressure of 10,000 psi and the wet sandblasting method, respectively. In plate 2, the number of data points representing an excellent cutting job are rather limited but a line of the same slope as that in plate 1 appears to be the best line of fit for cutting height versus compressive strength for a 10,000-psi water jet. Assuming that a line of the same slope would also be the best fit for the wet sandblasting method, a line was drawn through the one point representing an excellent cutting job in plate 3.

34. None of the specimens cut with a 2000-psi water pressure were rated excellent. Plate 4 is a plot of the cutting height versus the compressive strength for the data that were obtained using this pressure level. From these data, it was apparent that a cutting pressure of 2000 psi could not be considered sufficient for the removal of laitance from concrete with a compressive strength of 2000 psi or greater.

35. Plate 5 combines the data shown in plates 1, 2, and 3 for excellent cutting jobs and gives the suggested cutting height for various strengths of concrete cut with 6000- and 10,000-psi water jets and with the wet sandblast method.

36. As stated earlier, the cutting time required to cut satisfactorily a given area of concrete is dependent on the compressive strength of the concrete and the cutting height and cutting pressure used. Plate 6 is a plot of the concrete compressive strength over the cutting height used versus the time required to cut with the 6000-psi water jet the 3- by 3-ft surface of those specimens for which the cutting job was rated excellent.

37. The same line drawn through the points on plate 6 was drawn on plates 7 and 8, and the data from those specimens with excellent cutting jobs from the 10,000-psi water jet and the wet sandblasting method were respectively plotted on plates 7 and 8. Plate 9 shows all the data plotted in plates 6, 7, and 8 on one graph. It should be noted that the line drawn through the points is applicable only when the suggested cutting heights presented in plate 5 are used.

38. The efficiency of the cutting operation is dependent on the time required to cut a given surface area. From plate 9, the minimum time required to cut a 3- by 3-ft surface area is found to be 1-1/2 to 2 min. Considering a cutting time of 2 min or less to cut a 3- by 3-ft surface area, the ratio of the concrete compressive strength in pounds per square inch to the cutting height in inches required is approximately equal to or less than 700. Using plate 5 and noting again that the data contained in plate 9 are applicable only when the suggested cutting heights in plate 5 are used, it can be concluded that a 6000-psi water jet is efficient for cutting concrete with a compressive strength up to approximately 2100 psi and that a 10,000-psi water jet is efficient for cutting concrete with a compressive strength up to approximately 3000 psi.

39. Concrete with higher compressive strengths than that indicated in paragraph 38 can be cut satisfactorily with 6000- and 10,000-psi water jets, but the higher strength concrete will require longer cutting times

as a result of reduced nozzle height and a slower nozzle movement.

40. For a given compressive strength concrete, the suggested cutting height for the high-pressure water jet and the wet sandblasting method can be obtained from plate 5. Using the suggested cutting height and the compressive strength of the concrete, it can readily be determined from plate 9 that the time required to cut a 3-ft-square area of concrete is less when a high-pressure water jet is used (with a water pressure of 6000 psi or greater) than when the wet sandblast method is used. For example: Using 2000-psi concrete, the cutting heights required for the wet sandblast, the 6000-psi water jet, and the 10,000-psi water jet would be 2, 3-1/4, and 4-1/2 in., respectively (plate 5). The time required to cut a 3- by 3-ft surface, determined from plate 9, would be 2 min 30 sec for the wet sandblast method, 1 min 55 sec for the 6000-psi water jet, and 1 min 40 sec for the 10,000-psi water jet.

Field Phase

41. The strength tests of the joint specimens of the three blocks were made when the first and second lift ages were as follows:

Block No.	Lift No.	Age When Strength Tests Made, days
1	1	123
	2	80
2	1	243
	2	150
3	1	280
	2	140

42. The results of each individual test for strength in shear, tensile splitting, flexure, and direct tension are presented in table 4. A comparison of the results of tests of individual blocks is made below, since there was considerable difference in testing age between the blocks.

Effect of dry versus wet surface

43. The effect on joint strength of allowing the surface of the hardened concrete to dry before the new concrete was placed, as compared with placement on a wet surface, is shown in the following tabulation (values taken from table 4).

Block Quarter	Surface Treatment	Condition of Joint After 14 Days of Moist Curing	Average Strength of Joint, psi: Shear	Flexure	Tensile Splitting	Direct Tension
		Block 1				
A3	No mortar	Dry 28-1/4 days, wet 16 hr	395	390	180	155
A1	No mortar	Dry 29 days	455	405	270	205
		Ratio, dry to wet	1.15	1.04	1.50	1.32
A4	Mortar	Dry 28-1/4 days, wet 16 hr	360	385	220	150
A2	Mortar	Dry 29 days	435	380	250	200
		Ratio, dry to wet	1.21	0.99	1.14	1.33
		Block 2				
A3	No mortar	Dry 78-1/4 days, wet 16 hr	470	520	280	--
A1	No mortar	Dry 79 days	580	575	310	--
		Ratio, dry to wet	1.23	1.11	1.11	
A4	Mortar	Dry 78-1/4 days, wet 16 hr	505	550	260	--
A2	Mortar	Dry 79 days	510	575	250	--
		Ratio, dry to wet	1.01	1.05	0.96	
		Block 3				
A3	No mortar	Dry 125-1/4 days, wet 16 hr	540	540	255	--
A1	No mortar	Dry 126 days	580	560	290	--
		Ratio, dry to wet	1.07	1.04	1.14	
A4	Mortar	Dry 125-1/4 days, wet 16 hr	430	420	215	--
A2	Mortar	Dry 126 days	500	435	245	--
		Ratio, dry to wet	1.16	1.04	1.14	

In 18 of 20 comparisons, the average strengths of the dry joint surface specimens were slightly greater than those of the wet joint surface specimens. These findings, in general, agree with those of previous investigations,[2,3] and with the findings of Waters,[6] in that the dry surface was as effective as the wet surface.

Effect of mortar between lifts

44. The average data showing the effect on joint strength of a layer of mortar between the hardened lift and fresh concrete are tabulated below (values taken from table 4).

Block Quarter	Surface Treatment	Condition of Joint Prior to Placement of 2d Lift	Average Strength of Joint, psi: Shear	Flexure	Tensile Splitting	Direct Tension
			Block 1			
A4	Mortar	Wet	360	385	220	150
A3	No mortar	Wet	395	390	180	155
	Ratio, no mortar to mortar		1.10	1.01	0.82	1.03
A2	Mortar	Dry	435	380	250	200
A1	No mortar	Dry	455	405	270	205
	Ratio, no mortar to mortar		1.05	1.07	1.08	1.03
			Block 2			
A4	Mortar	Wet	505	550	260	--
A3	No mortar	Wet	470	520	280	--
	Ratio, no mortar to mortar		0.93	0.95	1.08	
A2	Mortar	Dry	510	575	250	--
A1	No mortar	Dry	580	575	310	--
	Ratio, no mortar to mortar		1.14	1.00	1.24	

(Continued)

Block Quarter	Surface Treatment	Condition of Joint Prior to Placement of 2d Lift	Average Strength of Joint, psi Shear	Flexure	Tensile Splitting	Direct Tension
			Block 3			
A4	Mortar	Wet	430	420	215	--
A3	No mortar	Wet	540	540	255	--
	Ratio, no mortar to mortar		1.26	1.29	1.19	
A2	Mortar	Dry	500	435	245	--
A1	No mortar	Dry	580	560	290	--
	Ratio, no mortar to mortar		1.16	1.29	1.18	

In 17 of 20 comparisons, the average strengths of the no mortar joint surface specimens were slightly greater than those of the joint surface specimens with mortar. The data indicate no definite superiority of joints made with mortar, a determination which agrees with the findings of Wuerpel.[7] In general, these findings also agree with those of the previous laboratory work[2] in which there appeared to be no significant difference between joint surfaces treated with or without mortar. Results of field tests under a value-engineering proposal at Dworshak Dam[8] also agree with the findings of this investigation.

Statistical analysis

45. For these analyses all data for each type of strength test were grouped together, i.e., test results for dry versus wet comparison included all wet and dry specimens with and without mortar, and the no mortar versus mortar comparison included all mortar and no mortar specimens both wet and dry.

46. An f test was used to check variance in the test data between the dry and wet joint surfaces and between the no mortar and mortar on joint surfaces. All four types of strength tests for each of the comparisons mentioned above were so checked. The results clearly showed that the ratio of the two variances was not larger than might have been expected by chance if they had been drawn from the same

population. These calculations were made using a 0.05 probability level. The f values are given in table 5.

47. The results of the f test warranted a t test to determine if the means of the two different samples could have come from the same population. The test data for the dry and wet and the no mortar and mortar were checked for t values. Again, all four types of strength tests for each comparison were included in the analysis.

48. The t tests showed that there was no significant difference between the dry and wet joint surfaces when these surfaces were tested in flexure. There was, however, a significant difference for the shear, tensile splitting, and direct tension tests of these same surfaces. The t tests between the no mortar and mortar showed that there was no significant difference for any of the strength tests conducted on the joint surfaces.

49. Table 6 presents the statistical values of arithmetic mean, standard deviation, range, and coefficient of variation which describe the test data obtained in this study. The statistical data were calculated using the formula described in reference 10. The standard deviation values shown in table 6 were rather low for all strength tests except the flexural test, in which the values were somewhat higher. These values indicated moderate dispersion for the test data. The coefficient of variation values in table 6 indicated excellent control for general construction and good control for laboratory work using the standards of concrete control for 28-day compressive strengths as given in ACI proceedings.[11]

50. All horizontal construction joints appeared to be well formed regardless of surface treatment. It was difficult to discern between the two lifts, i.e., to locate the contact between the two lifts. A typical construction joint is illustrated in photo 7; the joint lies between the two vertically drawn arrows. The well-formed joints show that adequate joint cleanup was obtained during this study.

PART IV: CONCLUSIONS

51. The 2000-psi high-pressure water jet is not satisfactory, except perhaps for very low strength concrete. It appears that the high-pressure water jet cutting with 6000- to 10,000-psi pressures is more efficient than the wet sandblasting method and requires less cleanup after cutting. The 6000-psi pressure is efficient for cutting concrete with a compressive strength up to approximately 2000 psi, and the 10,000-psi pressure is efficient for cutting concrete with a compressive strength up to approximately 3000 psi. Concrete with higher strengths than those mentioned can be adequately cut, but the cutting time will be increased. No measurable difference was found between the nozzle with the 15-degree spread and the nozzle with the 25-degree spread. However, the 15-degree nozzle seemed to be slightly more likely to cause grooving of the concrete surface when the higher water pressures were used.

52. The absence of mortar on the construction joint generally improved the strength of the joints. The strength of the joint was improved in almost every case when the joint surface was dry prior to receiving the new concrete. The t tests for the strength data obtained from no mortar and mortar specimens show that there was no significant difference for any of these tests. The t tests also show that there was no significant difference between the dry and wet joint surfaces when these surfaces were tested in flexure. However, there was a significant difference for the shear, tensile splitting, and direct tension tests of these same surfaces.

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Table 1

Chemical and Physical Properties of Type II Portland Cement

	Type II Portland Cement RC-622	RC-635
Chemical Data		
SiO_2, %	21.0	21.5
Al_2O_3, %	5.7	5.3
Fe_2O_3, %	4.7	4.7
CaO, %	64.3	63.1
MgO, %	0.8	0.9
SO_3, %	2.2	2.0
Loss on ignition, %	1.1	1.3
Insoluble residue, %	0.35	0.37
Na_2O, %	0.08	0.08
K_2O, %	0.42	0.40
Total alkalies, Na_2O, %	0.36	0.34
C_3S, %	--	45.4
C_2S, %	--	27.4
C_3A, %	7.1	6.2
C_4AF, %	--	14.2
Physical Data		
Specific gravity	3.15	3.15
Fineness, air permeability, cm^2/g	3560	3610
Time of set, Gilmore:		
Initial, hr:min	3:05	3:05
Final, hr:min	5:10	6:05
Mortar expansion, autoclave test, %	0.03	0.01
Air content, %	9.4	7.8
Compressive strength, psi		
3 days	2710	2340
7 days	3785	3060
28 days	--	--

Table 2

Physical Properties and Gradings of Crushed Coarse and Fine Aggregates

	Fine Aggregate CRD MS-17(8)	Coarse Aggregate Passing Indicated Sieve Size: No. 4 to 3/4 in. CRD G-31(15)	3/4 to 1-1/2 in. CRD G-31(9)	1-1/2 to 3 in. CRD G-31(15)	3 to 6 in. CRD G-31(15)
Physical Properties					
Bulk specific gravity, saturated surface dry	2.66	2.71	2.71	2.69	2.68
Absorption, %	1.2	0.4	0.5	0.4	0.3
Fineness modulus (FM)	2.82	--	--	--	--

Cumulative Percent Passing Standard Sieve

Sieve Size	Fine Aggregate CRD MS-17(8)	Coarse Aggregate Passing Indicated Sieve Size: No. 4 to 3/4 in. CRD G-31(15)	3/4 to 1-1/2 in. CRD G-31(9)	1-1/2 to 3 in. CRD G-31(15)	3 to 6 in. CRD G-31(15)	Recombined Grading* 6-in. Max
6 in.					100	100
5 in.				100	89	96
4 in.				97	73	89
3 in.				90	39	74
2 in.			100	32	4	49
1-1/2 in.			97	8		41
1 in.		100	40	2		28
3/4 in.		99	11			22
1/2 in.		52	4			11
3/8 in.	100	22	3			5
No. 4	100	2				
No. 8	88					
No. 16	58					
No. 30	36					
No. 50	24					
No. 100	12					

* Percentages used in recombined grading were: No. 4 to 3/4 in., 20%; 3/4 to 1-1/2 in., 20%; 1-1/2 to 3 in., 25%; 3 to 6 in., 35%.

Table 3

Construction Joint Investigation Strength and Cutting Results

Casting Dates	Cutting Method	Nozzle Type Deg Spread	Test Age Days	Cutting Height in.	Cutting Time min:sec	Job Rating	Air Content %	Slump in.	Compressive Strength psi*	Specimen Size
4-6-70	2,000-psi water jet	15	2	2	5:20	Good	5.9	1-3/4	2100	3 by 3 ft by 18 in.
			3	1-3/4	6:25	Bad	5.8		2366**	
			7	1-1/4	7:30	Bad	6.0		2990	
			14	1	9:04	Bad	5.7		3340**	
			28	1	9:30	Bad	6.2		3780	
4-28-70		25	2	1-1/2	6:35	Good	5.5	1-3/4	2100**	
			3	1-1/2	7:00	Fair	5.5	1-1/2	2330	
			7	3/4	8:45	Fair	5.8	2	3155**	
			14	1/4	10:32	Bad	5.9	1-3/4	3650**	
			28	1/4	8:15	Bad	5.5	1-3/4	4130	
4-14-70	6,000-psi water jet	15	2	5-1/2	1:45	Good	5.8	1-1/2	2000**	
			3	4-1/2	2:54	Fair	6.0	1-3/4	2350	
			7	3-1/2	3:32	Good	6.0	1-1/2	3000**	
			14	2-1/2	4:43	Very Good	6.0	1-1/2	3490	
			28	1-1/2	4:55	Excellent	6.0	2	3930	
5-5-70		25	2	3-1/2	1:45	Excellent	5.6	1-1/2	1800	
			3	2-1/2	2:30		5.5	1-3/4	2480**	
			7	1-1/2	4:07		5.7	2	2970	
			14	1-1/2	4:30		5.4	1-3/4	3500**	
			28	1-1/2	4:45		5.9	2	3960	
4-21-70	10,000-psi water jet	15	2	7	0:54	Good	5.8	1-3/4	1840	
			3	5-1/2	1:12	Very Good	5.7	1-1/2	2150**	
			7	4-1/2	1:40	Good	6.0	2	2600	
			14	4-1/2	2:00	Good	5.8	1-3/4	3030**	
			28	4-1/2	1:25	Fair	6.0	2	3430	
5-25-70		25	2	4-1/2	1:20	Excellent	5.6	1-3/4	1840**	
			3	6	1:30	Bad	5.5	1-3/4	2400	
			7	4	1:45	Excellent	5.5	2	2770**	
			14	3	2:35	Excellent	5.7	2	3170	
			28	4	4:15	Fair	5.6	1-3/4	3620	
6-2-70	WSB†	Sanstrom wet sandblasting nozzle	2	2	2:14	Excellent	5.7	1-3/4	1930	
			3	2	3:18	Good	5.8	2	2200**	
			7	3	3:21	Fair	5.8	1-3/4	2950	
			14	3	2:27	Bad	5.8	1-3/4	3100**	
			28	3	3:02	Bad	5.8	1-3/4	3510	

* Average of three tests (6- by 12-in. cylinders).
** See text, paragraph 28.
† WSB = Wet sandblasting.

Table 4

Strength of Horizontal Construction Joints and Concrete

Joint Condition	Block Quarter	Shear Strength psi, Block No.			Flexural Strength psi, Block No.			Tensile Split psi, Block No.			Direct Tension psi, Block No.	Compressive Strength psi, Block No.		
		1	2	3	1	2	3	1	2	3	1	1	2	3
Wet, mortar	A4	275	450	505	435	450	450	200	205	195	185	--	--	--
		375	520	400	440	545	565	240	230	220	100	--	--	--
		425	550	385	275	580	340	215	350	230	180	--	--	--
		--	--	--	--	620	325	--	--	--	145	--	--	--
	Average	360	505	430	385	550	420	220	260	215	150	--	--	--
Dry, mortar	A2	500	510	365	420	600	245	300	295	255	195	--	--	--
		375	510	580	365	580	580	240	200	230	235	--	--	--
		435	515	560	355	570	310	205	255	255	145	--	--	--
		--	--	--	--	550	610	--	--	--	225	--	--	--
	Average	435	510	500	380	575	435	250	250	245	200	--	--	--
Wet, no mortar	A3	455	395	530	455	635	590	195	275	255	145	--	--	--
		390	560	585	430	420	570	165	295	230	155	--	--	--
		345	450	510	285	435	500	175	265	280	130	--	--	--
		--	--	--	--	590	500	--	--	--	200	--	--	--
	Average	395	470	540	390	520	540	180	280	255	155	--	--	--
Dry, no mortar	A1	480	555	605	360	560	505	280	210	320	265	--	--	--
		500	620	645	450	630	545	270	375	230	155	--	--	--
		390	570	495	410	560	600	260	340	325	175	--	--	--
		--	--	--	--	545	595	--	--	--	230	--	--	--
	Average	455	580	580	405	575	560	270	310	290	205	--	--	--
Average concrete strength, psi, lifts 1 and 2		550	660	670	540	700	690	330	330	415	190	2720	3640	3950

Specimens from block 1 tested when concrete from upper lift was 80 days age.
Specimens from block 2 tested when concrete from upper lift was 150 days age.
Specimens from block 3 tested when concrete from upper lift was 140 days age.

Table 5

Results of f and t Tests

	Flexure		Shear		Tensile Split		Direct Tension	
	Calculated	Tabulated*	Calculated	Tabulated*	Calculated	Tabulated*	Calculated	Tabulated*
				Dry Versus Wet				
f	1.132	2.080	0.945	2.280	1.120	2.280	1.70	3.79
t	0.704	2.019	2.227	2.034	2.190	2.034	2.547	2.145
				No Mortar Versus Mortar				
f	0.580	2.080	1.110	2.280	2.040	2.280	1.050	3.790
t	1.344	2.019	1.654	2.034	0.844	2.034	0.272	2.145

if $f_{tab} > f_{cal}$; not significant

if $t_{tab} > t_{cal}$; not significant

* Values tabulated from reference 8.

Table 6

Statistical Analysis

	Flexure		Tensile Split		Shear		Direct Tension	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
$\bar{X}$	497.5	474.3	269.2	234.4	511.7	450.3	203.1	155.0
s	112.6	105.8	48.9	46.2	81.5	83.8	42.4	32.5
R	385	360	175	185	280	310	120	100
v	4.44	4.51	5.50	5.09	6.28	5.37	4.83	4.77

	No Mortar	Mortar	No Mortar	Mortar	No Mortar	Mortar	No Mortar	Mortar
$\bar{X}$	507	464	258	244.7	504	457	181.8	175.6
s	92	120.9	58	40.8	87	82.7	46	45
R	350	345	210	155	255	305	135	135
v	5.51	3.84	4.45	6.00	5.79	5.53	3.95	3.90

$\bar{X}$ = arithmetic mean, $\frac{\sum_{i=1}^{n} Xi}{n}$

s = standard deviation of a single observation, $\frac{\Sigma(X-\bar{X})^2}{n-1}$ when $n < 30$

and $\frac{\Sigma(X-\bar{X})^2}{n}$ when $n > 30$

R = range

v = coefficient of variation, $\frac{100S}{\bar{X}}$

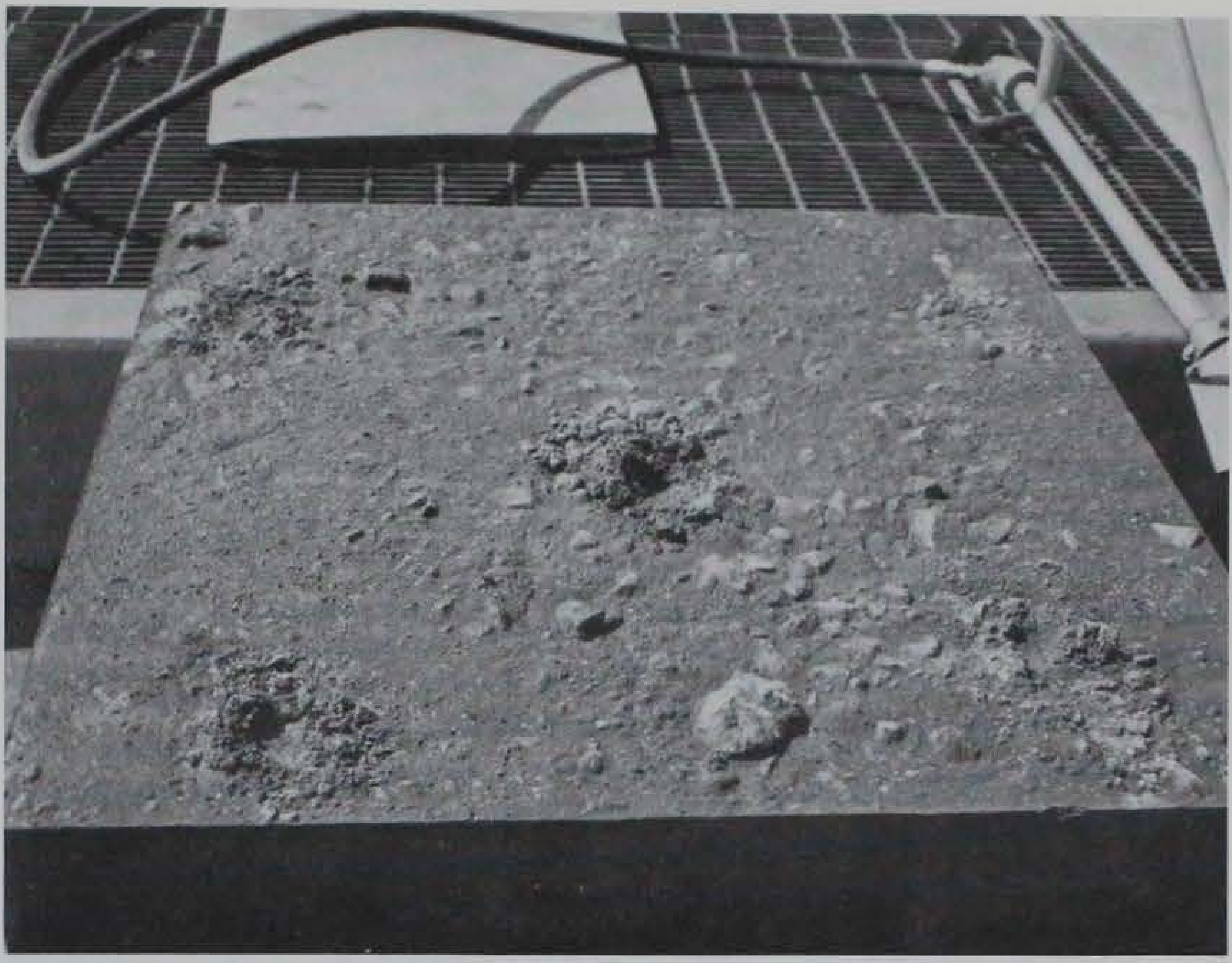


Photo 1. Joint surface after cutting with high-pressure water jet (2000 psi), using 15-deg nozzle, cutting height of 2 in., concrete specimen of 2 days of age, and compressive strength of 2100 psi. Cutting job rated "good"

Photo 2. Joint surface after cutting with high-pressure water jet (6000 psi), using 25-deg nozzle, cutting height of 3-1/2 in., concrete specimen of 2 days of age, and compressive strength of 1800 psi. Cutting job rated "excellent"

Photo 3. Joint surface after cutting with high-pressure water jet (10,000 psi), using 25-deg nozzle, cutting height of 4 in., concrete specimen of 7 days of age, and compressive strength of 2770 psi. Cutting job rated "excellent"

Photo 4. Joint surface after wet sandblasting, using cutting height of 2 in., concrete specimen of 2 days of age, and compressive strength of 1930 psi. Cutting job rated "excellent"

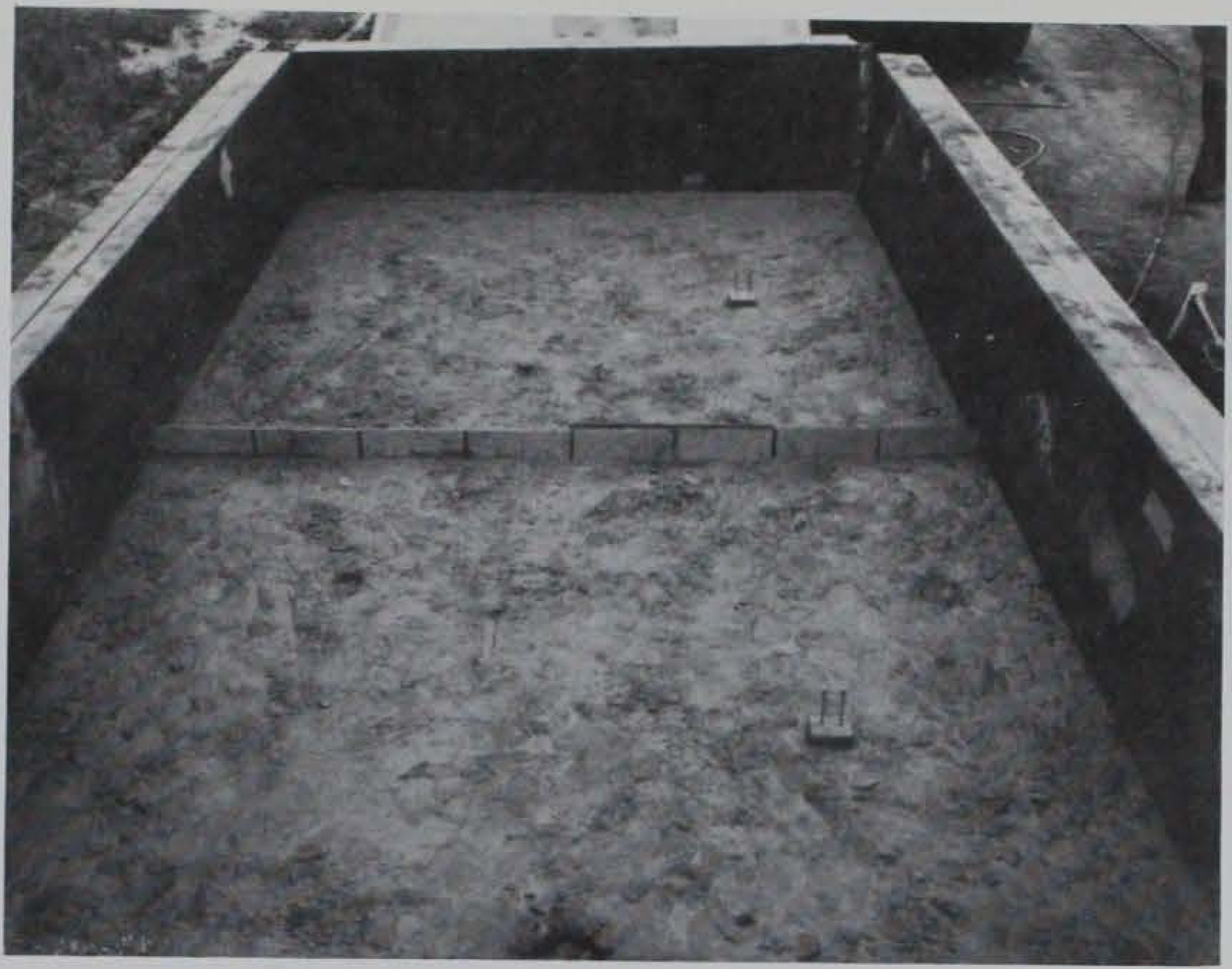
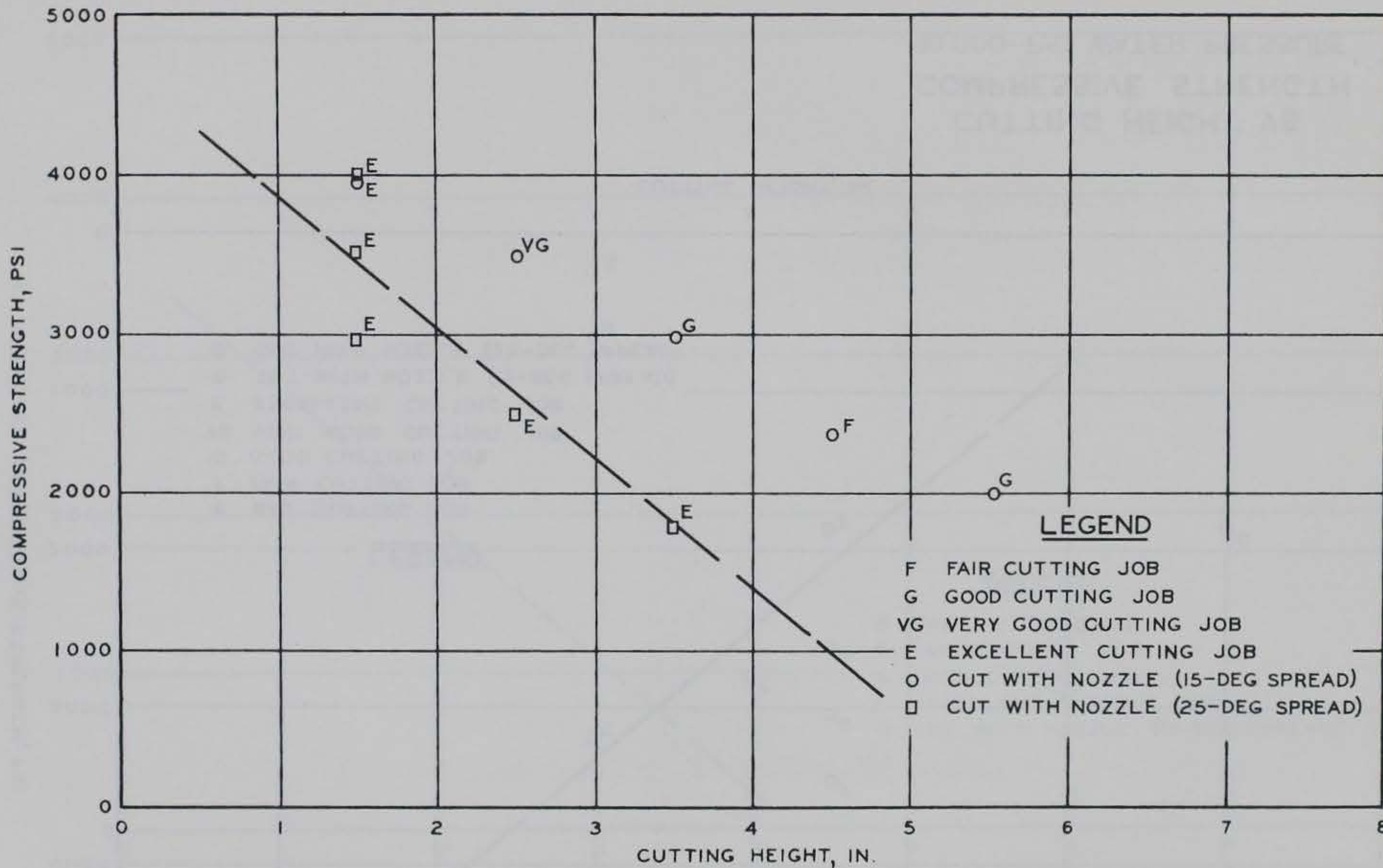


Photo 5. Joint surface before cutting and cleaning with high-pressure water jet

Photo 6. Joint surface after cutting with high-pressure water jet (6000 psi)

Photo 7. Core drilled parallel to horizontal construction joint

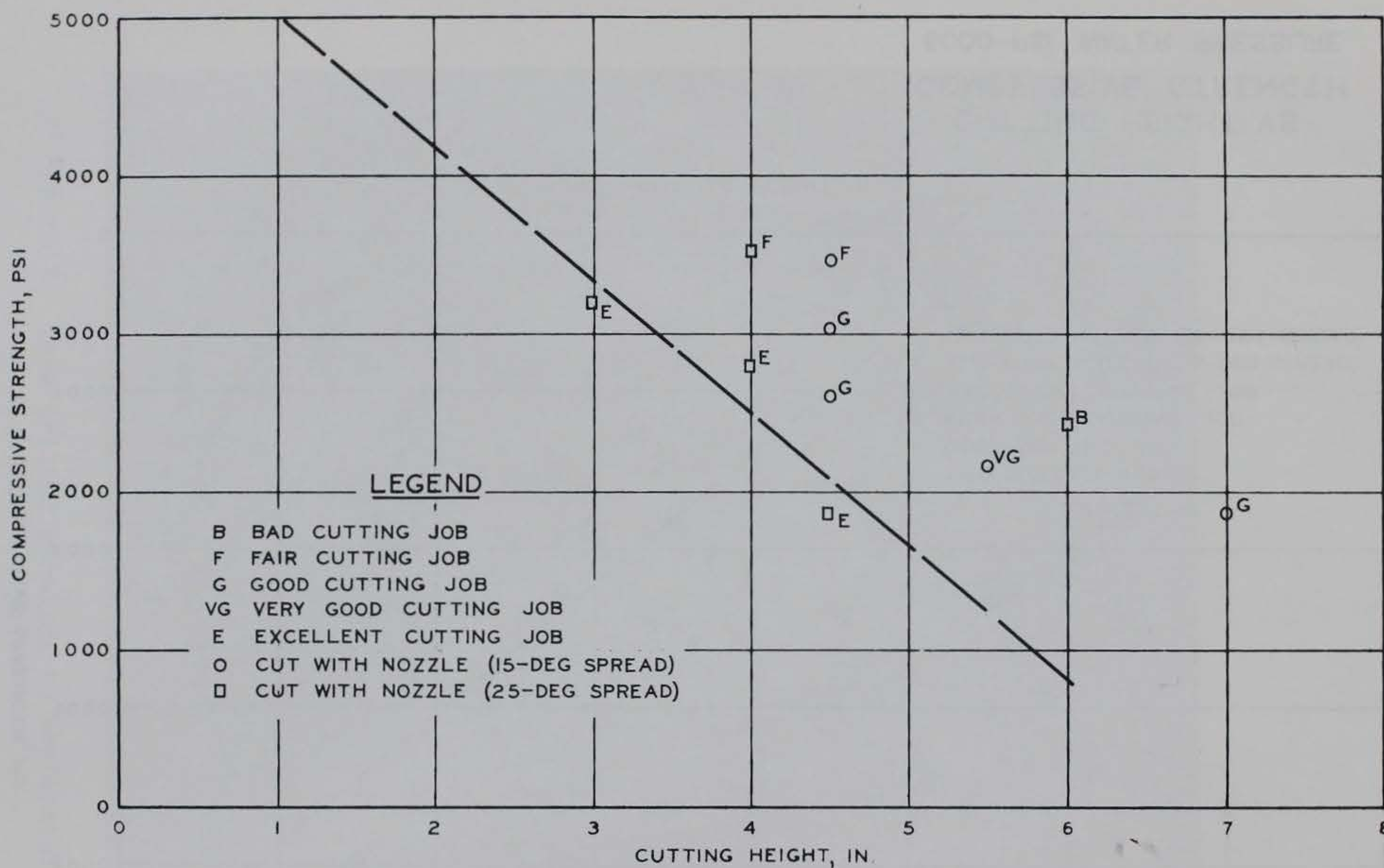


CUTTING HEIGHT VS COMPRESSIVE STRENGTH

6000-PSI WATER PRESSURE

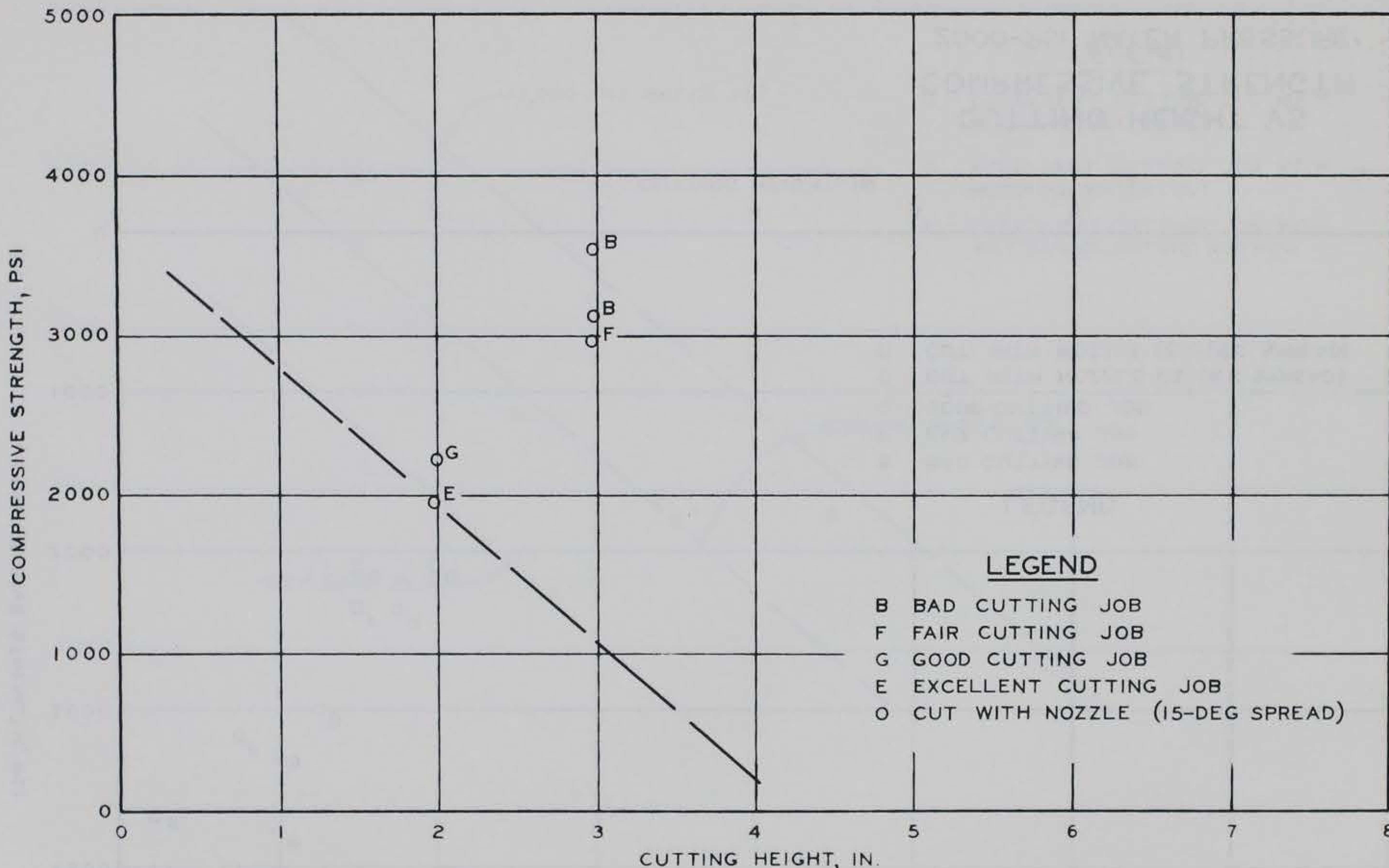
PLATE 1

PLATE 2



CUTTING HEIGHT VS COMPRESSIVE STRENGTH

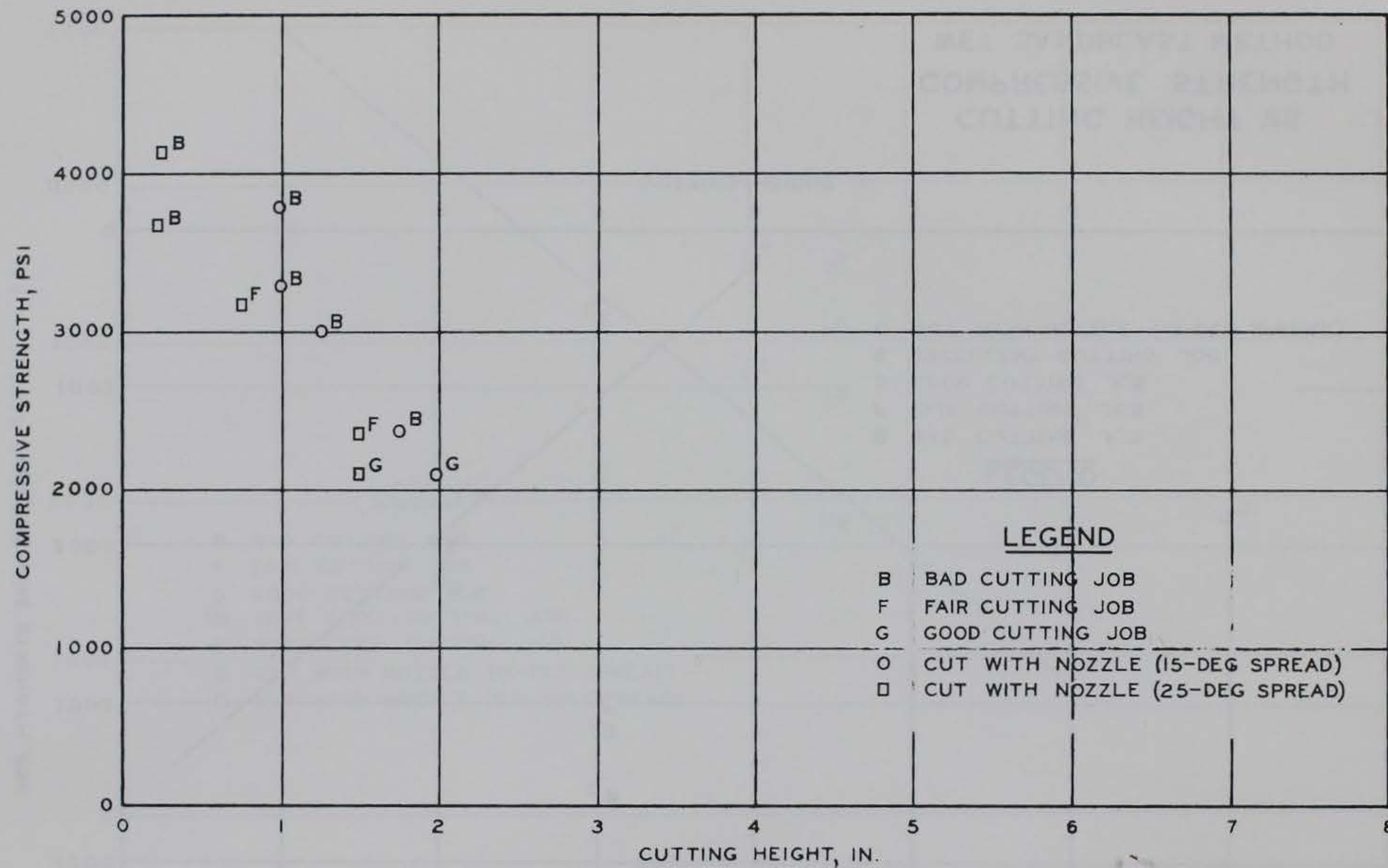
10,000-PSI WATER PRESSURE



CUTTING HEIGHT VS
COMPRESSIVE STRENGTH
WET SANDBLAST METHOD

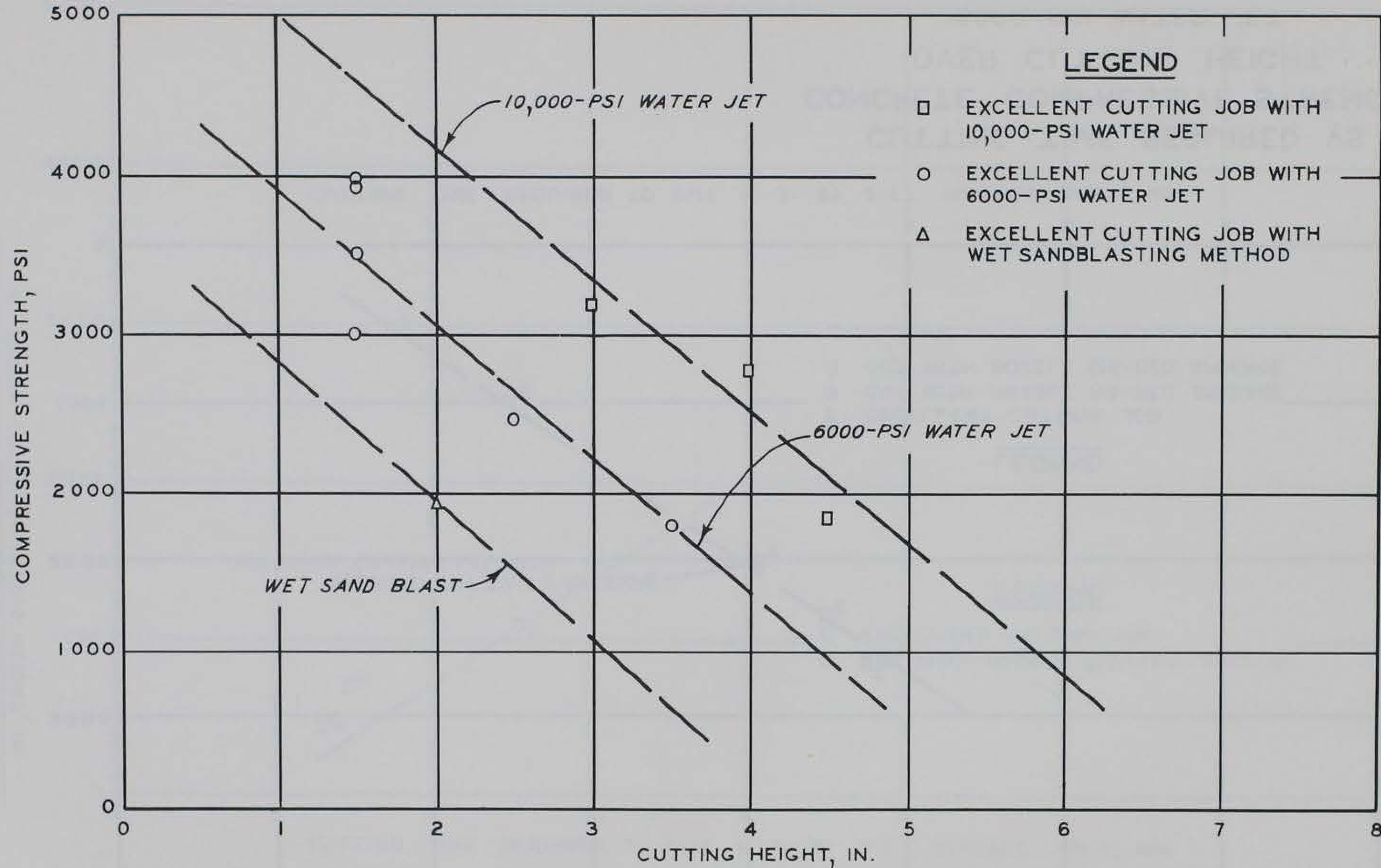
PLATE 3

PLATE 4

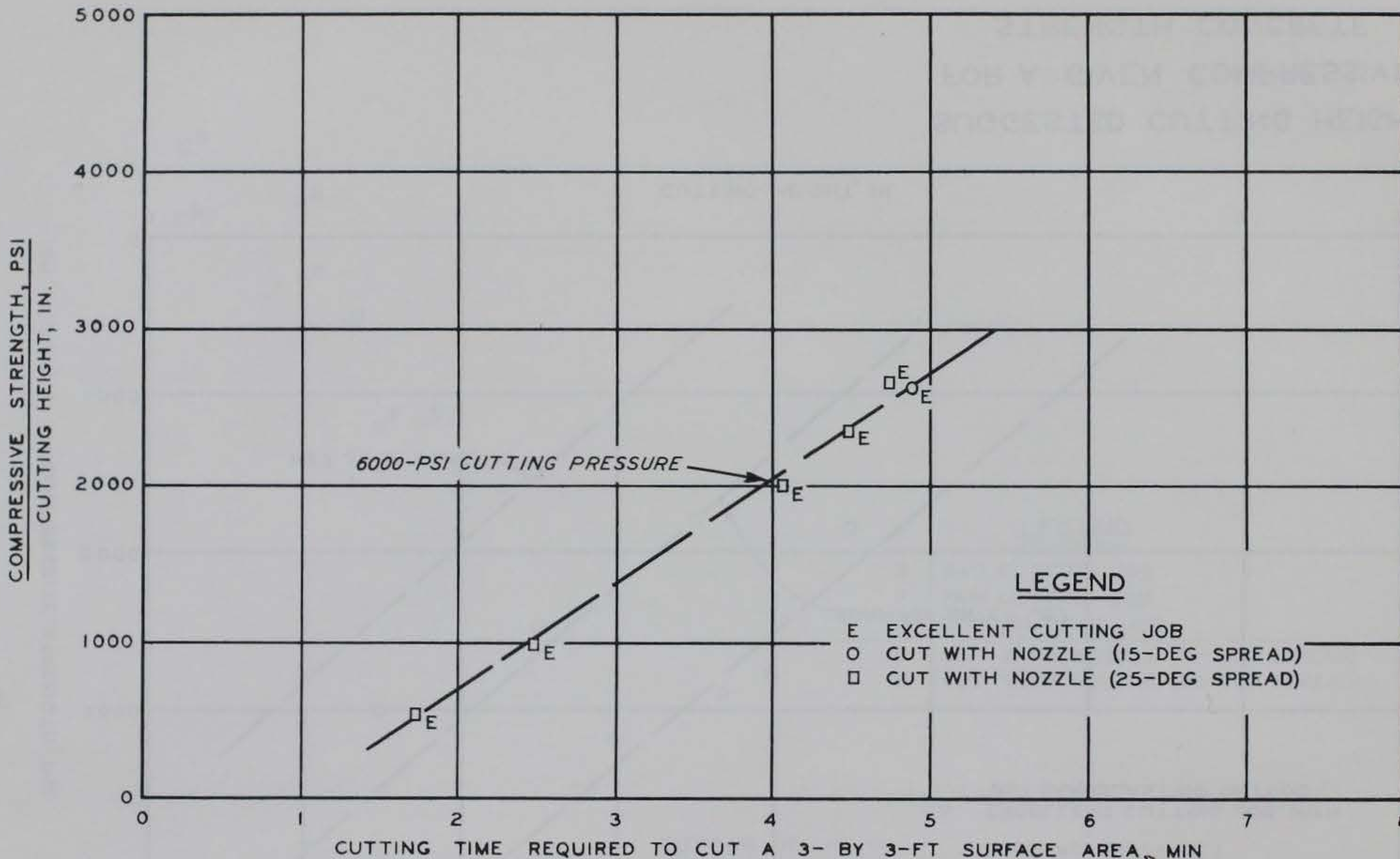


CUTTING HEIGHT VS COMPRESSIVE STRENGTH

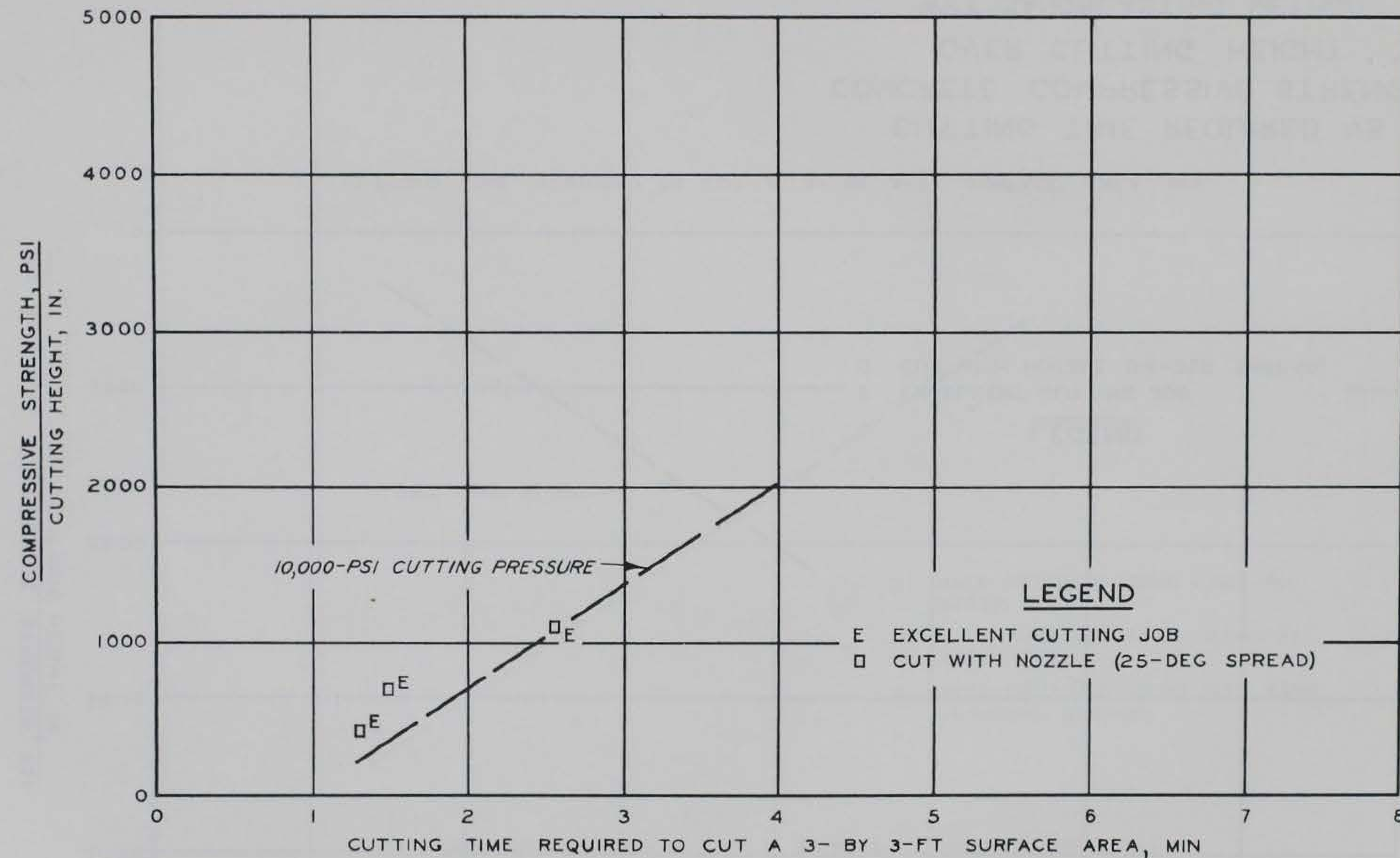
2000-PSI WATER PRESSURE



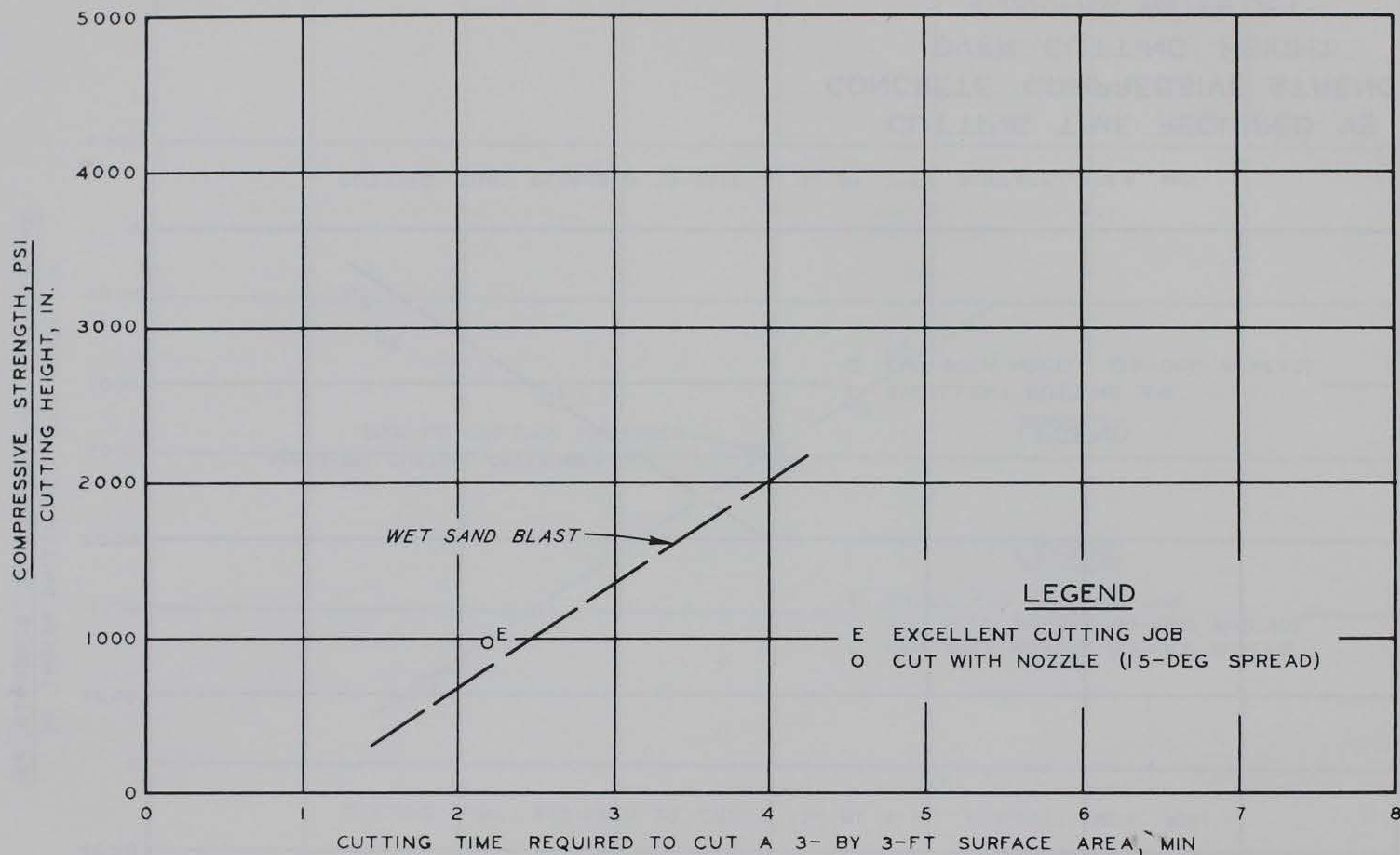
SUGGESTED CUTTING HEIGHT FOR A GIVEN COMPRESSIVE STRENGTH CONCRETE



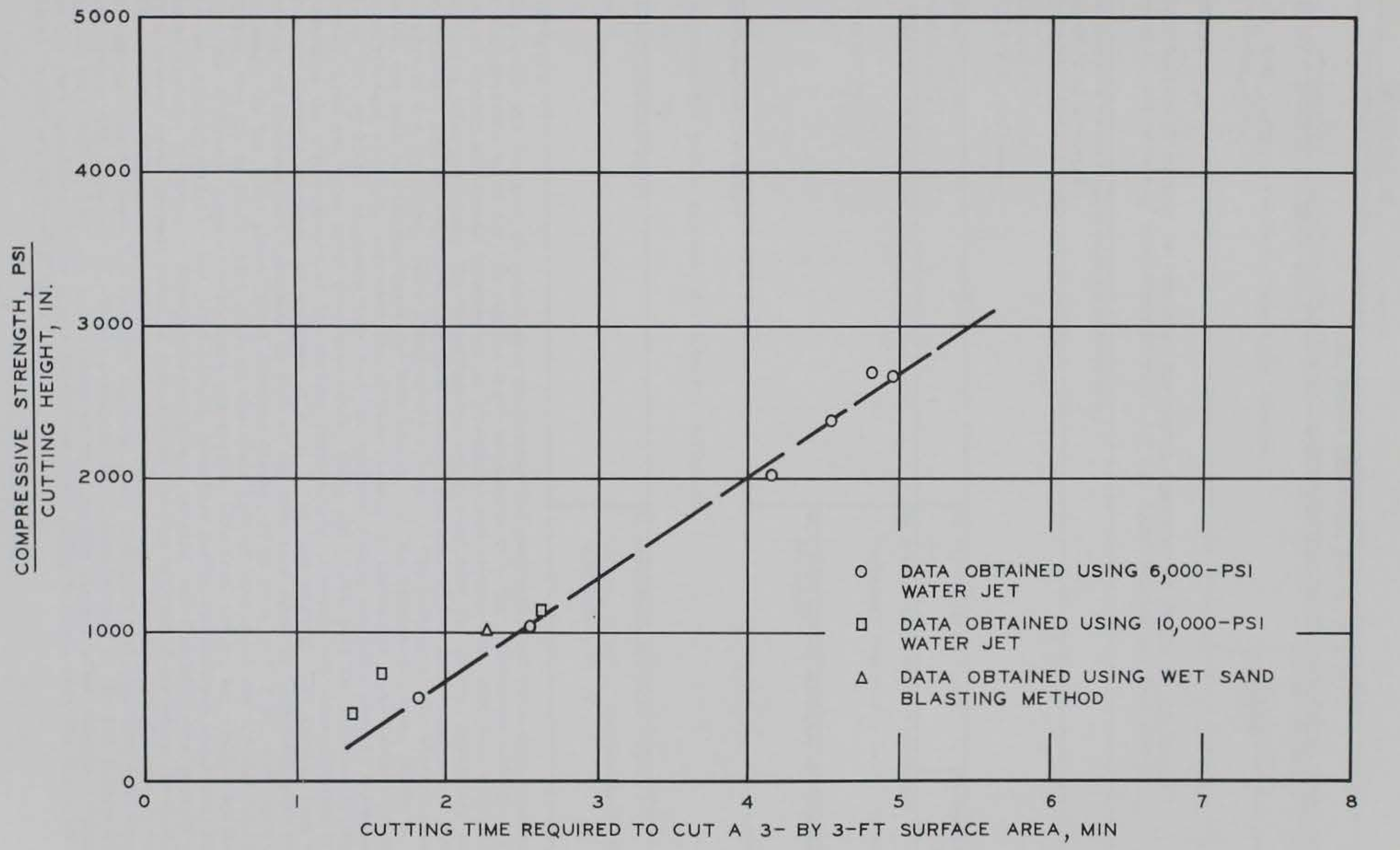
CUTTING TIME REQUIRED VS
CONCRETE COMPRESSIVE STRENGTH
OVER CUTTING HEIGHT
6000-PSI WATER JET



CUTTING TIME REQUIRED VS
CONCRETE COMPRESSIVE STRENGTH
OVER CUTTING HEIGHT
10,000-PSI WATER JET



CUTTING TIME REQUIRED VS
CONCRETE COMPRESSIVE STRENGTH
OVER CUTTING HEIGHT
WET SANDBLASTING METHOD



CUTTING TIME REQUIRED VS CONCRETE COMPRESSIVE STRENGTH OVER CUTTING HEIGHT OF NOZZLE ABOVE CONCRETE SURFACE

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13. ABSTRACT

This study was designed to investigate procedures for preparation of horizontal construction joints using a high-pressure water jet, to compare these procedures with the alternative practice of wet sandblasting, and to develop additional information on procedures and methods that have been utilized in horizontal construction joint practice. The investigation was divided into two phases, laboratory and field. One 6-in. maximum-size crushed limestone aggregate concrete mixture, with a cement content of 235 lb/cu yd, an air content of 6 ± 1 percent, and a slump of 2 ± 1/2 in. on the portion of the mixture passing the 1-1/2-in. sieve, was used to cast specimens for both phases. In the laboratory phase, thirty 3- by 3-ft by 18-in. concrete test specimens were cast for surface cleanup utilizing the high-pressure water jet, and five 3- by 3-ft by 18-in. specimens were cast for surface cleanup utilizing the wet sandblasting method. Two nozzle types and three water pressures (2000, 6000, and 10,000 psi) for each nozzle type were used to determine the effectiveness of the various combinations of nozzle and water pressure in cutting the surface of concrete specimens at each age of 2, 3, 7, 14, and 28 days. Wet sandblasting was used to cut the surface of concrete test specimens at each of the five test ages for comparison with the water jet cleanup. In the field phase, three concrete blocks, 10 by 20 by 5 ft high, were cast in two 30-in.-high lifts. The 10- by 20-ft joint plane of the first lift of each block was divided into four equal areas for four different types of cold joint preparation (dry with mortar, dry without mortar, wet with mortar, and wet without mortar). The joint cleanup technique (using the 6000-psi water jet) was common to all three blocks. A series of strength tests (shear, tensile, and flexural) were made of cores drilled from several areas of each block to evaluate the various methods of preparing the horizontal construction joints. Results of the laboratory phase indicate that the 2000-psi pressure is not satisfactory, except possibly for very low strength concrete (less than 1500 psi), and that the water jet cutting efficiency with 6000- and 10,000-psi pressures is as satisfactory as the wet sandblasting method and requires less cutting time and less cleanup of the concrete surface after cutting. Strength test results of the core specimens of the blocks during the field phase indicate that the dry joint without mortar is equal to the wet joint with mortar.

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