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EVALUATION OF THE PULL-OUT TEST TO DETERMINE STRENGTH OF IN-SITU CONCRETE

by

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V. M. Malhotra*

SUMMARY OF RESULTS

A degree of correlation exists between compressive strength of 6 x 12-in.(15 x 30-cm) concrete cylinders cured under standard conditions and pull-out strength of concrete cured under field conditions.

For the same concrete mix, the pull-out strength increased with increasing age, indicating the possible usefulness of these tests for comparative studies.

The 28-day standard deviation and coefficient of variation of strength from pull-out test results varied from 15 to 45 psi (0.10 to 0.31 MN/m^2) and from 2.3 to 5.0 per cent respectively. The corresponding values from compressive strength test results were 4 to 120 psi (0.03 to 0.82 MN/m^2) and 0.2 to 3.0 per cent respectively, except for Mix No. 1 for which the above values were 682 psi (4.68 MN/m^2) and 11.4 per cent.

The ratio pull-out strength:compressive strength varies directly with the compressive strength of concrete. At 3 days, this ratio varies from 18 per cent for 4795 psi (32.93 MN/m^2) concrete to 46 per cent for 1145 psi (7.86 MN/m^2). However, for any strength level, the ratio does not change significantly with age.

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INTRODUCTION

The strength of concrete in structures is usually estimated by testing simultaneously cast test specimens in a laboratory. The disadvantages of this approach are well known; the main disadvantage is that the test specimens do not represent the concrete in a structure because they are cured and compacted under different conditions. A further complication is that the strength of a concrete specimen depends on its shape and size, so allowance must be made for these factors in estimating the strength of concrete in-situ. To overcome some of these problems, a number of attempts have been made to develop quick and inexpensive methods of testing concrete in structures.

In recent years, the pull-out tests, initially proposed in the U.S.S.R. in 1934, have come into vogue (2), and a number of patents have been registered in various countries. In the U.S.A., Richards (3) has been advocating the use of these tests on structural concrete members. Briefly, a pull-out test measures, with a special tension ram, the force required to pull-out a specially shaped steel rod whose enlarged end has been cast into the concrete. Because of its shape, the steel rod pulls out a cone of the concrete (4). The concrete is believed to be simultaneously in tension and in shear, and the shape of the cone is approximately 45 degrees. The pull-out force is related to the compressive strength of companion test cylinders.

Following the introduction of this test in the U.S.A., it was considered that the Mineral Processing Division should examine the usefulness of this new test. This investigation was, therefore, undertaken to evaluate the pull-out test as a means of estimating the strength of in-situ concrete.

SCOPE OF INVESTIGATION

In this study, five concrete mixes were investigated. The nominal water:cement ratio varied from 0.47 to 0.87 and corresponding cement contents varied from 630 to 320 lb/yd^3 (374 to 190 kg/m^3). From each mix, one 24 x 24 x 24-in. (61 x 61 x 61-cm) concrete cube and ten 6 x 12-in. (15 x 30-cm) cylinders were cast at an outdoor exposure site. The plywood form for the cube had six pull-out assemblies installed on each side. After an initial 3-day curing period at 65 $\pm$ 10°F (18.3 $\pm$ 6°C), the concrete cubes were exposed to the elements, while curing of the test cylinders was continued under standard laboratory conditions. The pull-out tests on cubes were made at 3, 28, and 91 days. Companion laboratory-cured test cylinders were also tested at the same age to obtain comparative compressive strength values.

THE PULL-OUT ASSEMBLY

The pull-out assembly consisted of a threaded steel shaft 3/4 in. (19 mm) in diameter and 4.25 in. (10.7 cm) long together with a 2.25 in. (57 mm) by 1/8-in. (2.8-mm) thick washer which was to serve as the embedded head. The assembly was held in position in the form work by nuts and washers, as shown in Figure 1. The critical dimensions were the diameter of the washer and the distance between the top of the washer and the inside of the form work. This distance was kept constant at 2.08 in (52.8 mm). The steel shaft and the embedded heads are pulled out of the hardened concrete by means of a hollow tension ram which exerts pressure through a bearing ring, inside diameter 5.00 in. (127.0 mm) and thickness 1/2 in. (12.5 mm). The inside diameter of the bearing ring, the outside diameter of the embedded head, and the distance between them control the size and the apex angle of the concrete frustrum that will be pulled out (Figure 2).

INSTALLATION OF THE PULL-OUT ASSEMBLIES

The pull-out assemblies were installed* in the 24 x 24 x 24-in. (61 x 61 x 61-cm) wooden moulds at the Mines Branch laboratory. Great care was taken to ensure that the height "h" was kept constant in each assembly. All threaded shafts, washers, and nuts were cleaned to ensure a satisfactory bond between steel and concrete. There were 24 pull-out assemblies in each mould, six on each face, excepting one mould which was to be used for concrete with a water:cement ratio of 0.47. No form oil of any kind was used on the inside of the moulds. Figure 3 shows one mould with pull-out assemblies installed.

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*The installation was supervised by Owen Richards, Mineral Consultant, Washington, D.C.

PREPARATION AND CURING OF TEST SPECIMENS

For each test series, a two-cubic-yard (1.53-cubic-meter) batch of concrete was obtained from a ready-mix concrete supplier. The physical properties and chemical analyses of the normal portland cement (ASTM Type 1) and the grading and physical properties of aggregates used for concrete are given in Tables 1 to 3. The mix proportions and the properties of fresh concrete are shown in Table 4.

Immediately before casting, the temperature, slump, unit weight and air content of fresh concrete were determined by ASTM standard methods.

A 24 x 24 x 24-in. (61 x 61 x 61-cm) wooden mould with pull-out assemblies was filled with concrete in one lift and compacted by an internal vibrator. Great care was taken to ensure that the pull-out assemblies were not disturbed during casting. Immediately after casting, the wooden moulds were covered with wet burlap and left undisturbed in an outdoor exposure plot at the University of Ottawa. The forms were removed after three days and the concrete blocks were exposed to the elements.

After casting the concrete block, the ready-mix truck was diverted to the Civil Engineering Materials Behaviour laboratory of the University of Ottawa where ten* 6 x 12-in. (15 x 30-cm) cylinders were cast in steel moulds using procedures outlined in ASTM Standard C 31-69. All cylinder moulds were filled in three equal layers, and each layer was compacted by hand rodding. Immediately after casting, the moulded specimens were covered with wet burlap and kept wet for the next 24 hours. The cylinders were then removed from the moulds and transferred to the standard moist-curing room at the Mines Branch Laboratory.

TESTING OF CONCRETE

Two 6 x 12-in. (15 x 30-cm) cylinders were tested in compression on a 600,000-lb (271,800-kg) Amsler testing machine at 3, 28, and 91 days**. All cylinders were capped with a sulphur and flint mixture before testing.

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* A large number of other test specimens were cast from each batch of concrete, the testing of which will be the subject of another report.

** The remaining four cylinders will be tested at later ages.

A hand-operated hydraulic pump and a 30-ton Enerpack tension ram were used for the pull-out tests. Before using, the tension ram was calibrated* against the Amsler testing machine for both 5000- and 10,000-psi (34.5- and 69.0-MN/m^2**) -capacity gauges. The calibration charts are shown in Figures 4 and 5.

With the threaded shaft of one of the pull-out assemblies as the centre, a 5-in. (12.6-cm)-diameter circle was drawn on the concrete surface with a marking pencil. Next, a 3-in (7.6-cm) long sleeve was screwed onto the exposed portion of the shaft (Figure 6). A 3/4-in. (19-mm)-diameter high-strength steel rod, approximately 16 in. (41-cm) long, was then threaded into the steel sleeve.

The tension ram was then mounted on the shaft so that the bearing plate which had been bolted to the bottom of the ram was flush with the concrete surface. The bearing plate was centered on the marked circle. Another washer with a short head was then screwed onto the exposed steel rod and tightened against the top of the piston opening of the ram (Figure 7). Pressure was applied with the hydraulic pump and continued until the gauge needle started to fall back. The maximum gauge reading was noted, then the pumping was continued until the pull-out assembly was free of the concrete block. The calibration charts, referred to above, were used to obtain the total load applied, and knowing the area of the frustrum, the pull-out strength was calculated. Figures 8 to 11 show views of the concrete blocks and the pull-out assemblies after the test.

PRESENTATION AND ANALYSIS OF TEST RESULTS

A total of 30 compressive-strength and 44 pull-out strength tests were made in this programme (Tables 5 to 7). Where possible, standard deviations and coefficients of variation for the tests were calculated (Tables 8 to 10).

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* The calibration is performed by placing the ram between the platens of the Amsler testing machine. The ram is loaded by means of the hand-operated hydraulic pump. The piston of the ram transfers the load on the testing machine. For each increment of 50 psi (0.344 MN/m^2) on the dial gauge connected to the ram, the load on the dial of the testing machine is noted.

** 1 MN/m^2 = 145.6 psi.

The relationships between compressive strengths of 6 x 12-in. (15 x 30-cm) test cylinders and the pull-out strengths of concrete are shown in Figures 12 to 14.

The paucity of the test results neither permitted nor justified regression analysis or other detailed statistical treatment.

DISCUSSION OF TEST RESULTS

The Pull-Out Test

The pull-out test equipment is simple to assemble and can be operated by an average laboratory technician. The principal parts of the equipment, i.e., the hollow tension ram* and the hand-operated hydraulic pump, are commercially available; the peripheral parts such as the sleeves , washers, and steel plates can be manufactured locally. The total cost of the test equipment is less than $500.00. There are no hazards in using the equipment, and the testing can be done in the field in a matter of minutes.

Calibration of the Test Equipment

The total pull-out force can be obtained by multiplying the pressure gauge reading by the effective cylinder area** of the tension ram. However, it is preferable to calibrate the pull-out system with the compression testing machine being used to test the companion cylinders. This will help keep the testing errors to a minimum.

Detection of Increase in Strength With Age

For the same concrete mix, the pull-out strengths increased with increasing age. As an example, average strength of Mix No. 2 (Tables 5 and 7) increased from 785 psi (5.40 MN/m^2) at 3 days to 985 psi (6.78 MN/m^2) at 91 days, an increase of about 26 per cent. Other mixes showed similar increases, so it appears that the pull-out tests are useful for comparative studies.

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* Available from: Black Hawk Industrial Company, Wisconsin, U.S.A.

** This varies with the capacity of the ram and is provided by the manufacturer. For the 30 ton ram in use this is equal to 7.216 sq.in.

Damage Caused by the Pull-Out Tests

The major disadvantage of the pull-out tests is that the damage to the concrete surface (Figure 8) must be repaired. Like the Windsor probe test, these tests are non-destructive in that the structural members need not be discarded. Furthermore, if a pull-out force of a given magnitude is applied and the load is released immediately, the gauge needle begins to fall back, it can be assumed that the recorded strength is a minimum for the in-situ concrete. The pull-out assembly is not removed from the concrete, and damage to the concrete surface is minimized.

Correlation between Compressive and Pull-Out Strengths

The correlation between the pull-out strengths and the compressive strengths of standard-cured test cylinders is shown in Figures 12 to 14. The tests were too few to permit regression analysis of data; nevertheless, the results at 3, 28, and 91 days can be correlated. Concrete made with limestone aggregate only was investigated in this study. It is probable that pull-out tests on concrete made with aggregate having different hardness and surface textures will correlate differently with compressive strength.

The usefulness of the pull-out test lies not in determining the relative quality of concrete in place but in using it as a means of quantitatively predicting the compressive strength of concrete.

Variation in Pull-Out Strength

The standard deviation (S.D.) and coefficient of variation (C.V.) for pull-out test results at 28 days varied from 15 to 45 psi (0.10 to 0.31 MN/m^2) and from 2.3 to 5.0 per cent respectively (Table 8). The corresponding values for the compression test were 4 to 120 psi (0.03 to 0.82 MN/m^2) and 0.2 to 3.0 per cent respectively except for Mix No. 1 for which the above values were 682 psi (4.68 MN/m^2) and 11.4 per cent respectively. Two pull-out tests at each strength level on 3-day old concrete gave lower S.D. and C.V. values than those on 28-day old concrete; the reverse was true for 91-day old concrete on which six pull-out tests were done at each strength level. It appears that three pull-out tests at a given strength level would give a satisfactory indication of the in-situ strength of concrete at that level.

Probably an automatic hydraulic pump could reduce within-batch variation because its rate of loading would be more uniform than loading by the hand operated pump.

Ratio Pull-Out Strength:Compressive Strength

The pull-out strength:compressive strength ratio varies directly with the compressive strength of concrete. At 3 days, the ratio varies from 18 per cent for 4795-psi (32.93-MN/m^2) concrete to 46 per cent for 1145-psi (7.86-MN/m^2) concrete (Table 5). At 28 and 91 days, the corresponding ratio varies from 20 to 29 per cent and 19 to 29 per cent respectively. However, for any strength level the ratio does not significantly change with age.

Field Use of the Pull-Out Test

The ideal way to use the pull-out tests in the field would be to cast one or two large concrete specimens, incorporating the pull-out assemblies, when the actual structural members are cast. These specimens could be tested at will during the construction period. Compaction and curing of the specimens cast for the pull-out tests must be identical to that received by the actual structural members.

Limitations of the Pull-Out Test

The pull-out tests do not measure the strength in the interior of mass concrete because the pull-out assembly does not extend more than 3 in. (7.6 cm) into the concrete. Another limitation of the test in its present form is that the test has to be planned in advance and the pull-out assemblies have to be set into the forms before placing concrete. This is a serious disadvantage compared to that of either the rebound hammer or the Windsor probe test which does not require pre-planning and can be done after the concrete has reached final set.

SUMMARY AND RECOMMENDATIONS

1. The pull-out test is satisfactory for estimating the strength of in-situ concrete at both early and late ages, and its results can be reproduced with an acceptable degree of accuracy.
2. The pull-out test is superior to the rebound hammer and the Windsor probe tests because a greater depth and volume of concrete is tested. However, unlike the latter two tests, the pull-out test has to be planned in advance and the pull-out assemblies have to be set in the form work before concrete is placed. This somewhat limits the usefulness of the technique.

3. It is recommended that the pull-out tests be incorporated in any new concrete strength evaluation programme.

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to Mr. Owen Richards, Mineral Consultant, Washington, D.C., for supplying the pull-out assemblies and for supervising their installation in the plywood forms. Also, Professor Carl Berwanger, Department of Civil Engineering, University of Ottawa was most helpful for allowing the use of the exposure site.

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3. Richards, Owen, "Pull-Out Strength Tests of Concrete" Paper Presented at the Research Session, 1972 Annual Meeting of American Concrete Institute, Dallas, Texas.

4. Malhotra, V.M. "Recent Developments in Test Methods and Equipment for Evaluation of In-Situ Concrete", Mines Branch Internal Report MPI(A) 72-9, May, 1972, pp30.

VMM/ec

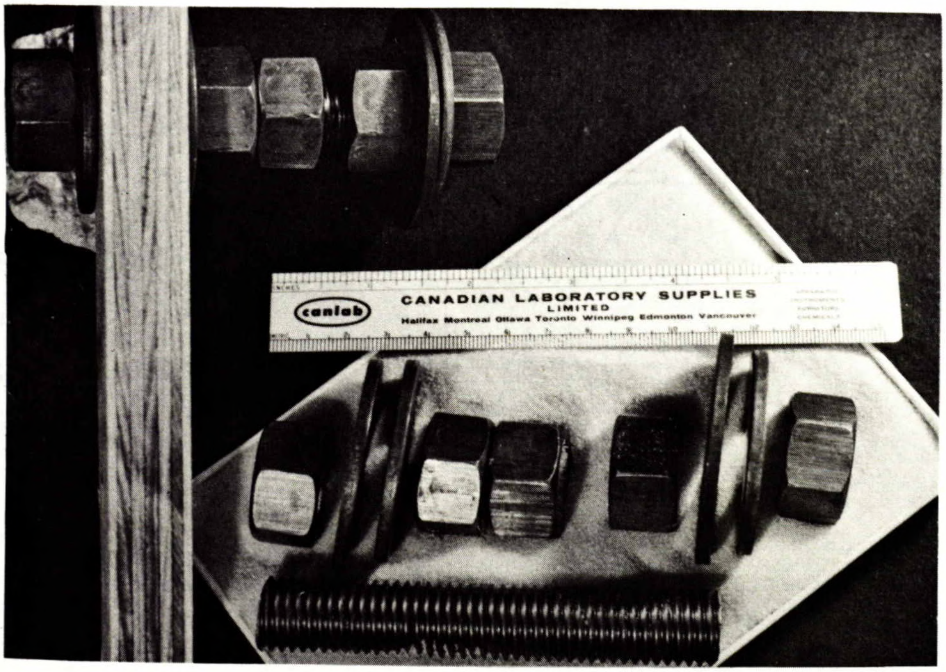
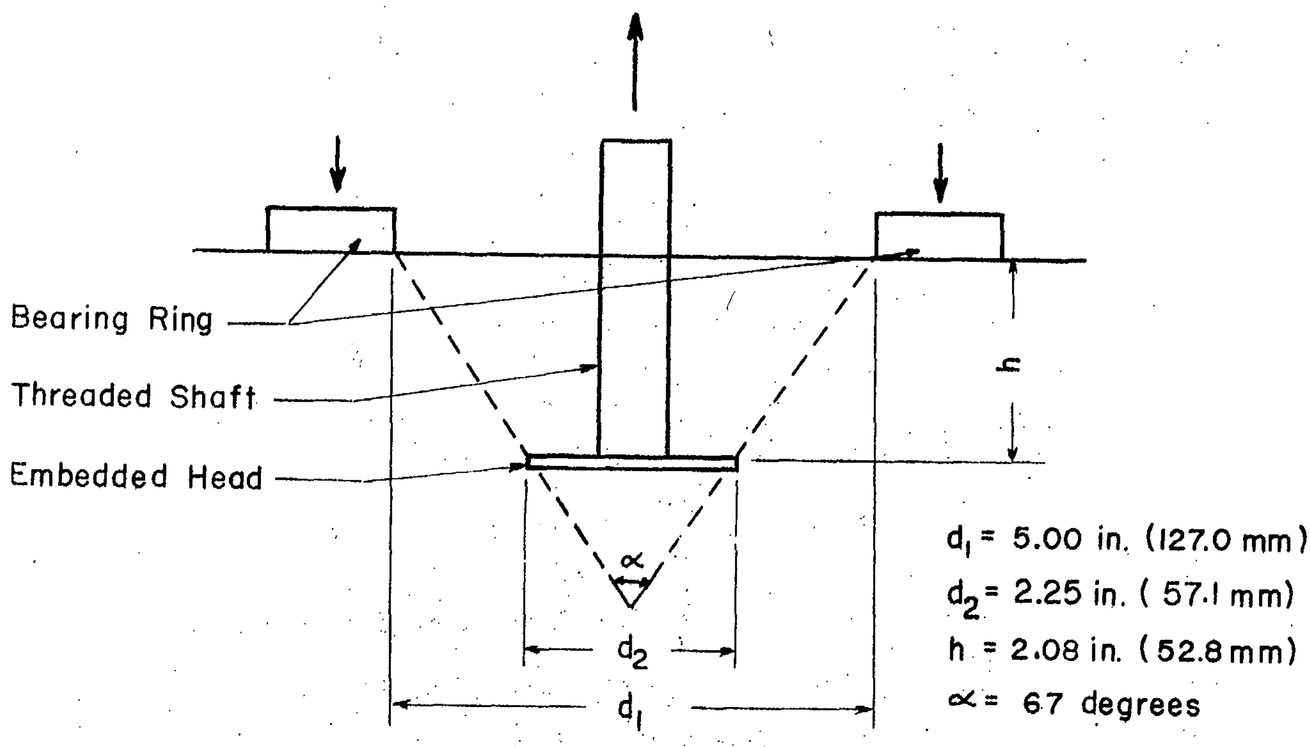


Figure 1. A pull-out assembly with plywood form (exploded view) on the right. The diameter of the threaded shaft is 3/4 in. (19 mm).



Note 1: Experience indicates that the above dimensions are most suitable.

Note 2: Total area "A" of convex surface of a frustrum of a right circular cone is equal to i.e.

$$A = \pi\, s\left(d_1/2 + d_2/2\right)$$

where $s = \sqrt{h^2 + (d_1/2 - d_2/2)^2}$

substituting for s, d_1, and d_2, we get:

$A = 28.40$ in.^{2} (181.8 cm^2)

Figure 2. Sketch showing position and dimensions of the bearing plate, threaded shaft, and the embedded head.

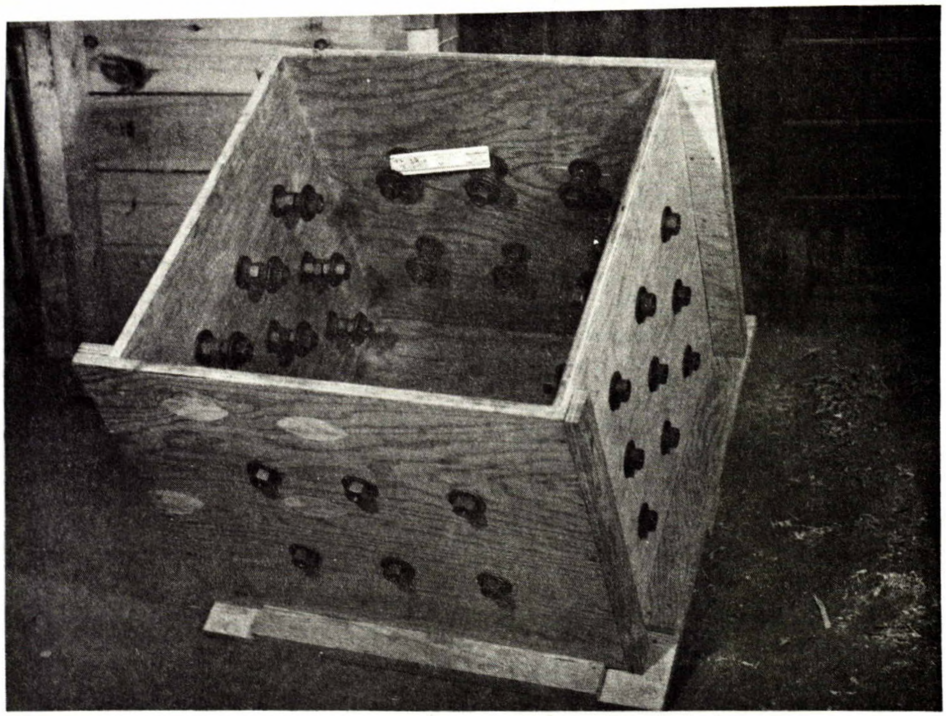


Figure 3. Pull-out assemblies in position in a 2 x 2 x 2-ft (61 x 61 x 61-cm) plywood form.

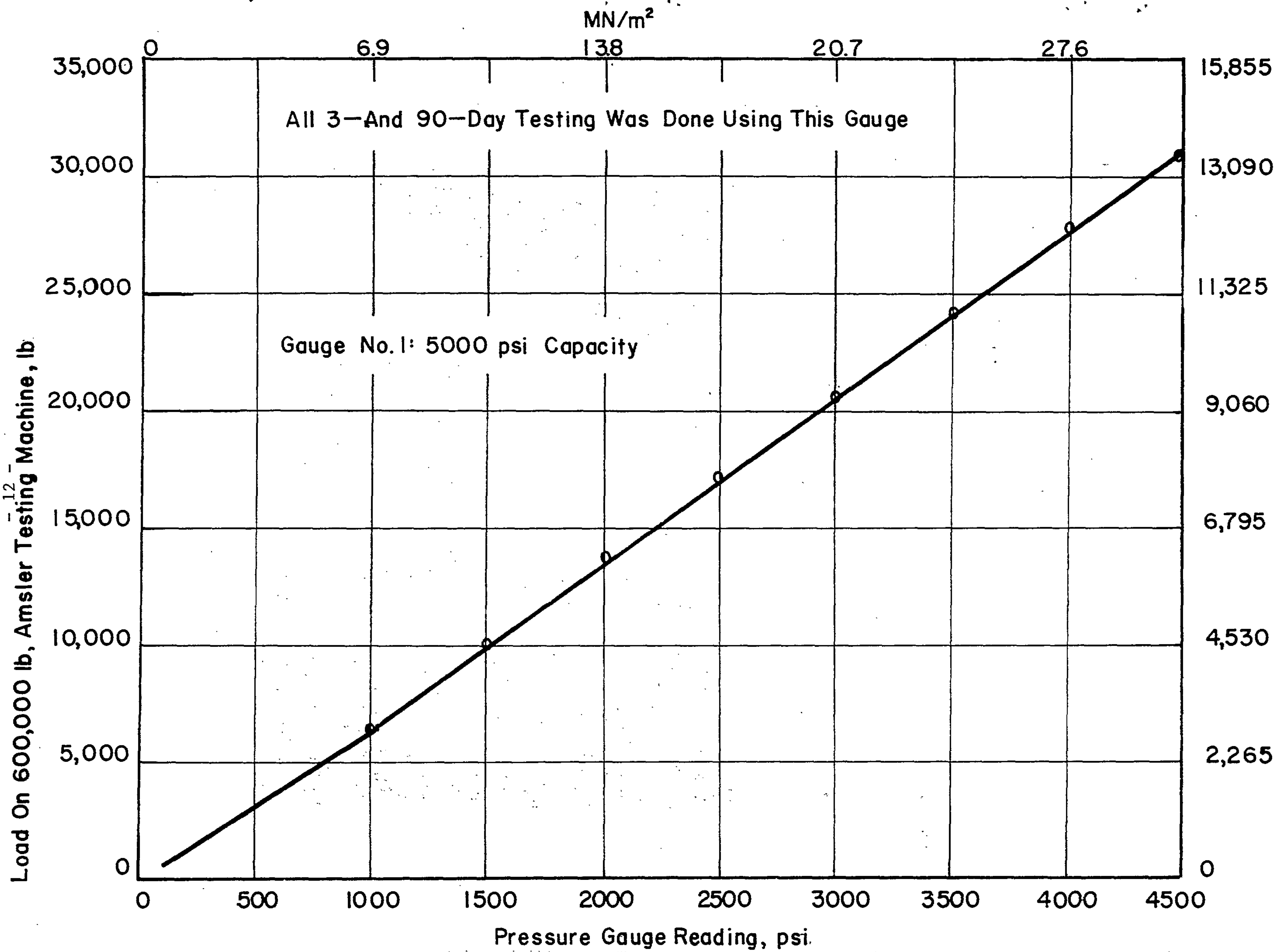


Figure 4. Calibration Chart for Pressure Gauge, Capacity-5000 psi (34.5 MN/m^2)

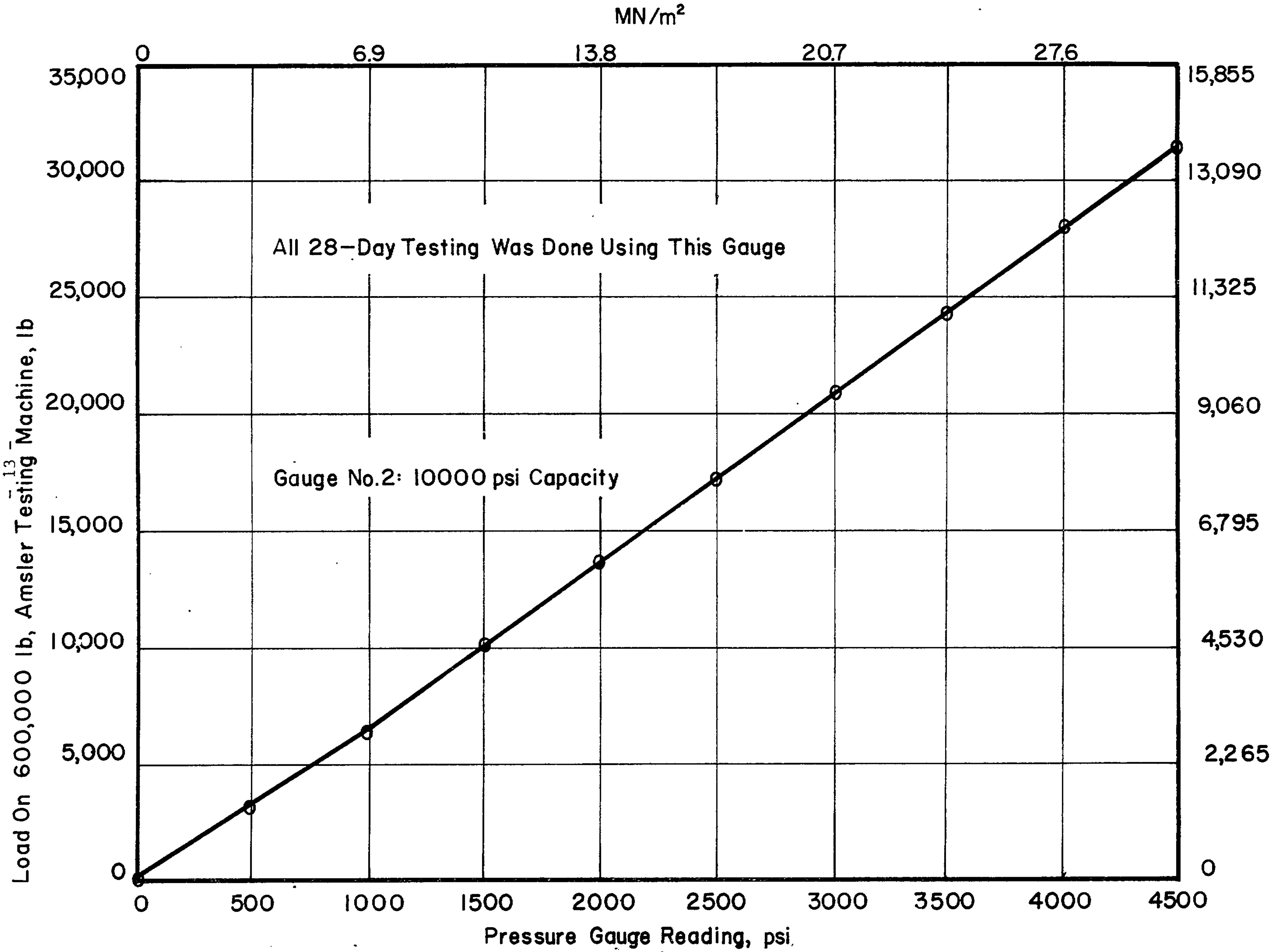


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Figure 5.- Calibration Chart for Pressure Gauge, Capacity-10,000 psi (69.0 MN/m²)

(a) With sleeve in position

(b) With sleeve and steel rod in position

Figure 6. A view of a concrete block showing the sleeve and the steel rod in position.

(a) Tension ram in position

(b) Washer in position against the top of the piston opening of the ram

Figure 7. A view of the 30-ton tension ram being positioned on the pull-out assembly.

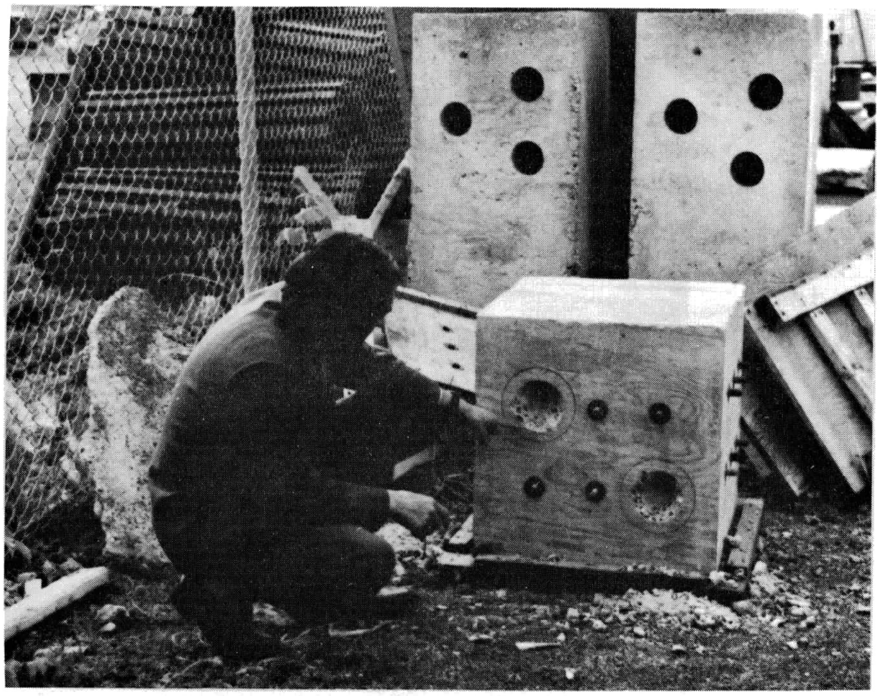

Figure 8. Concrete block after pulling-out two of the assemblies 3 days after casting.

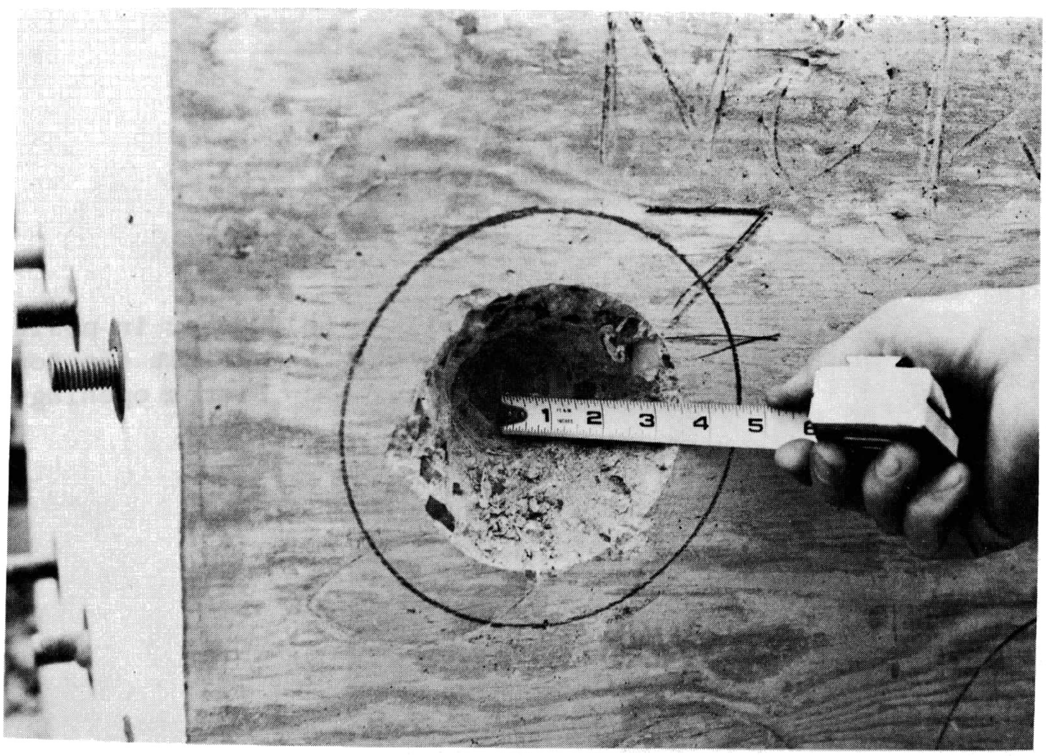

Figure 9. A close-up view of the hole left in concrete after the pull-out test.

Figure 10. The 30-ton tension ram immediately after the pull-out test. The dial gauge can be seen at the top.

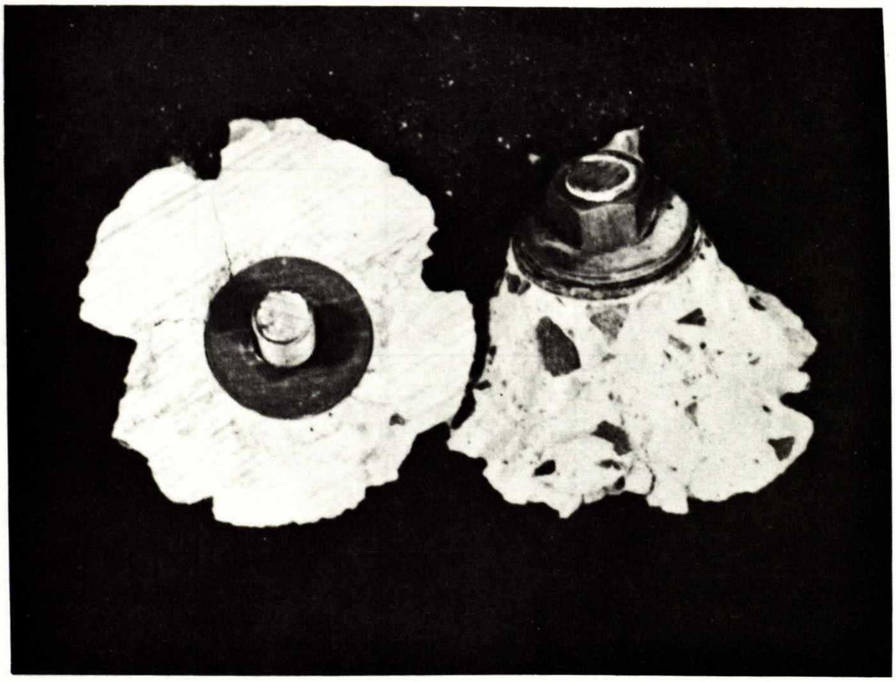

Figure 11. Pull-out assemblies with adhering cones of concrete, immediately after the test.

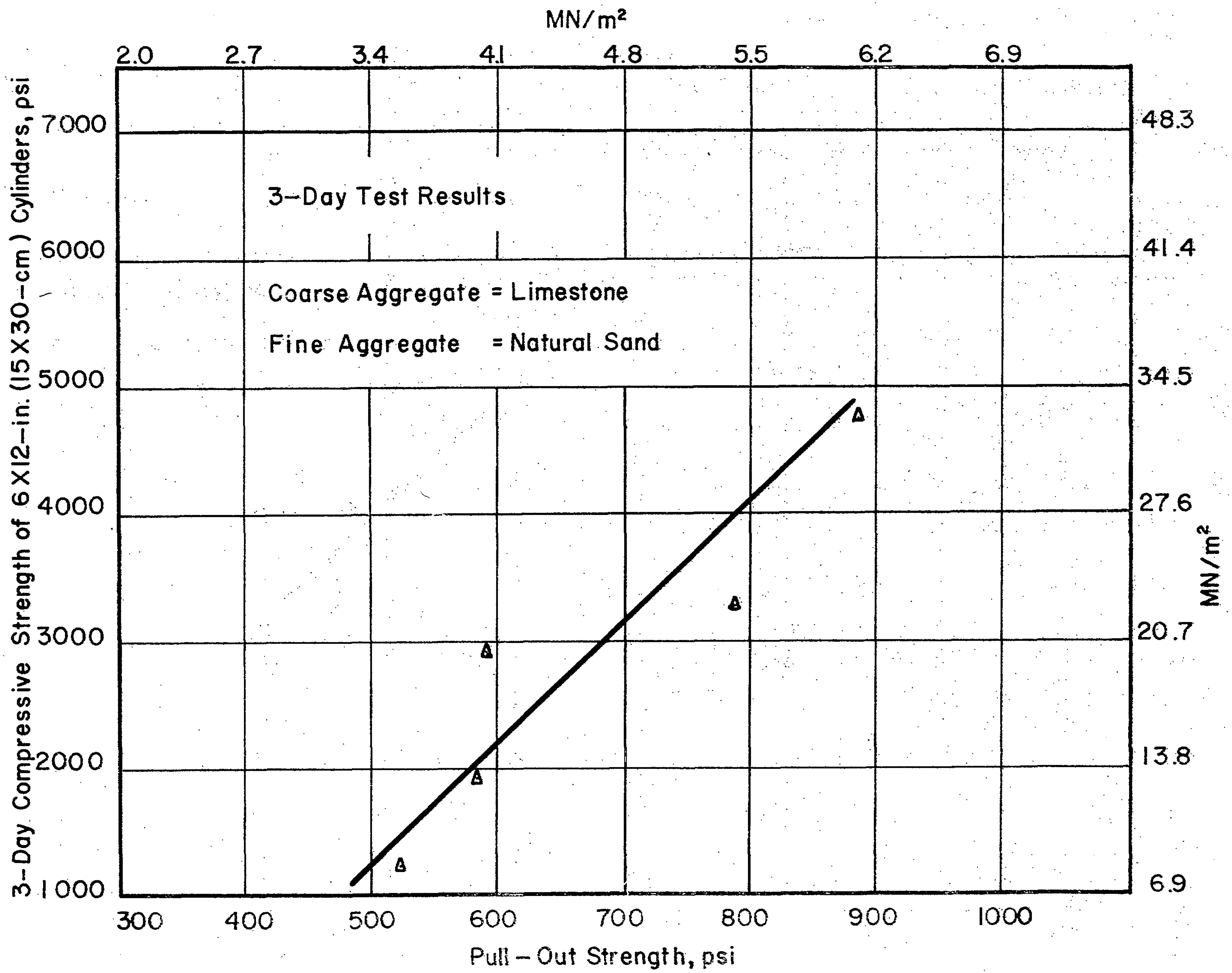

Figure 12. Relationship between compressive and pull-out strengths for 3-day old concrete

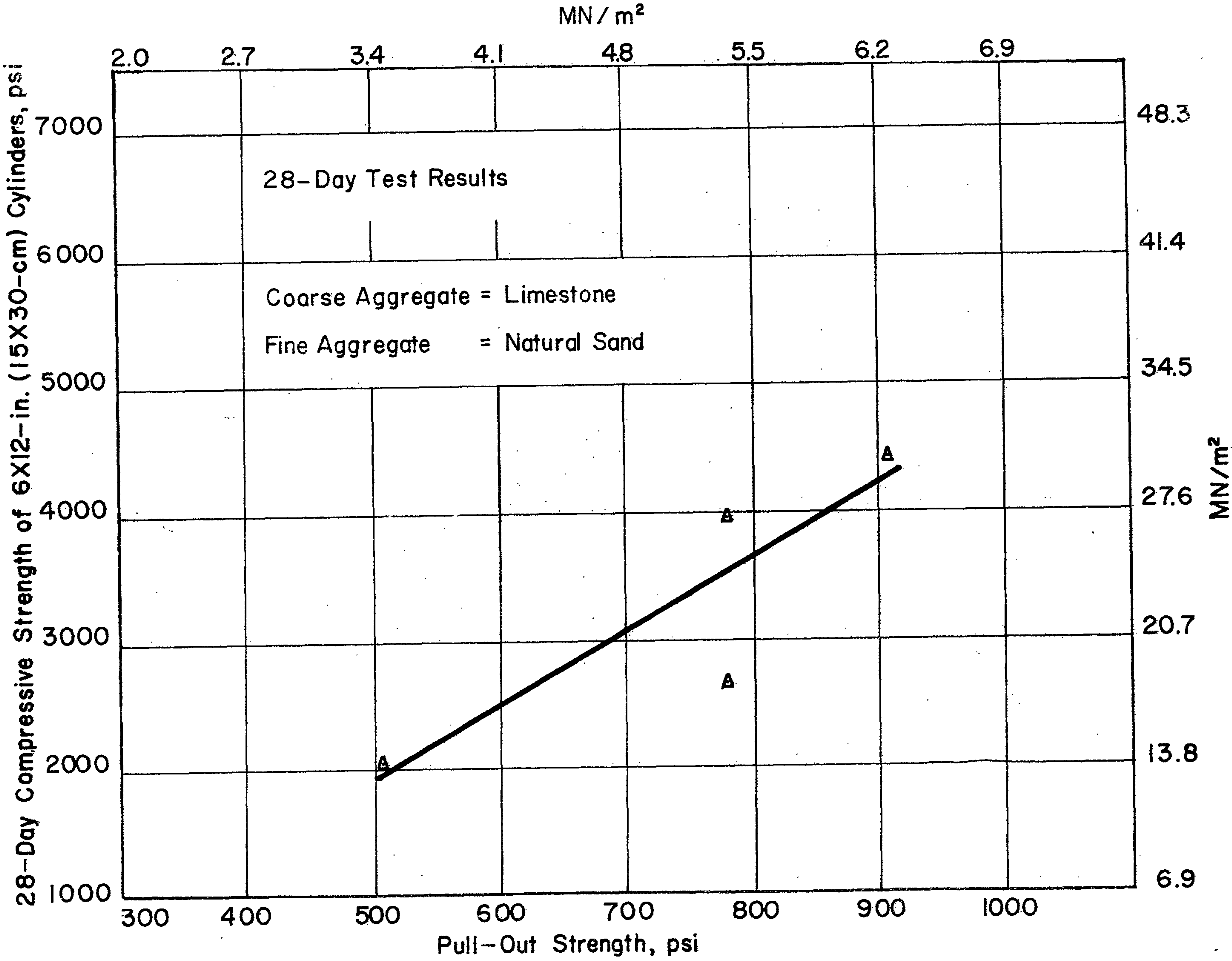

Figure 13. Relationship between compressive and pull-out strengths for 28-day old concrete

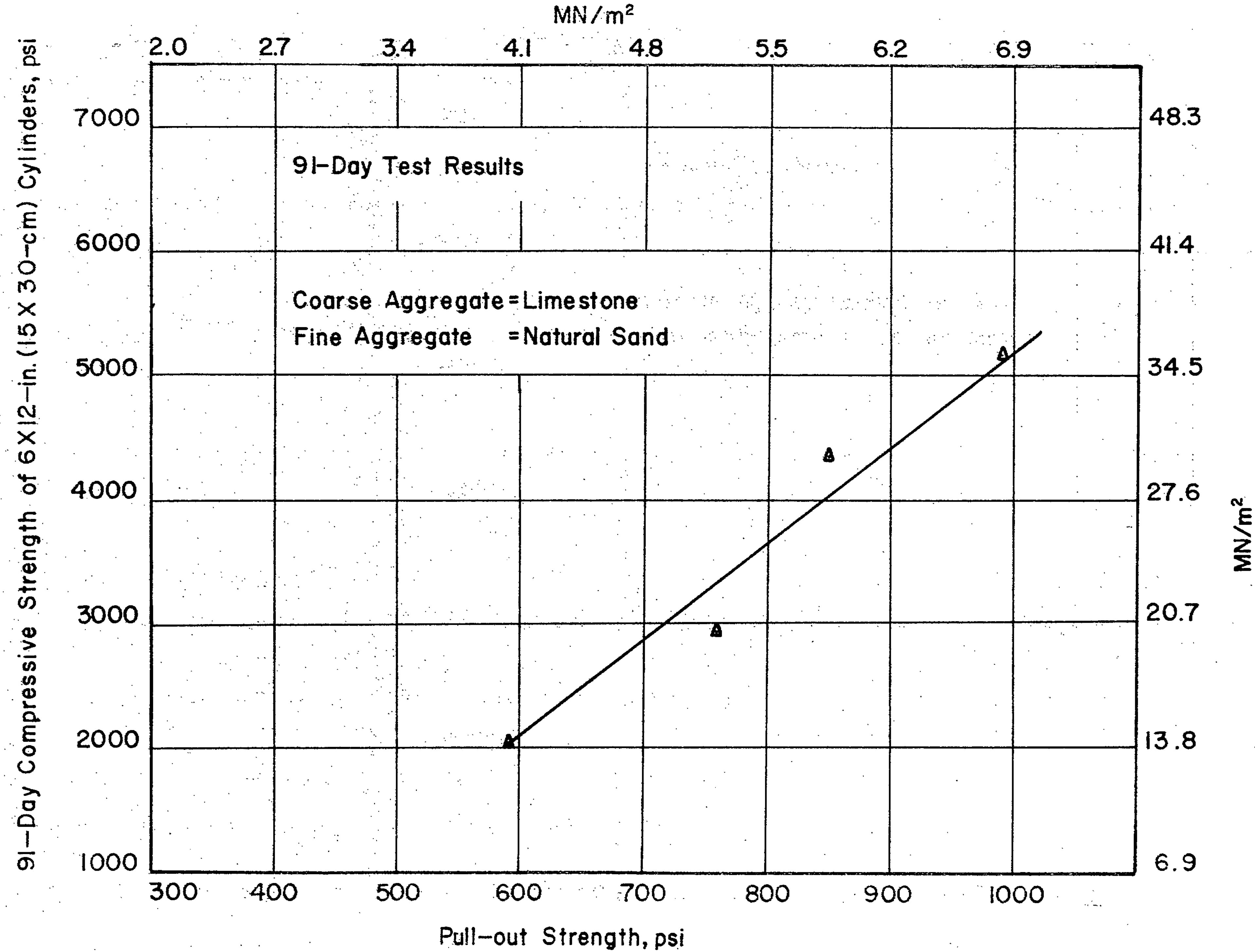
MN/m²
2.0
2.7
3.4
4.1
4.8
5.5
6.2
6.9
91-Day Test Results
Coarse Aggregate = Limestone
Fine Aggregate = Natural Sand
7000
6000
5000
4000
3000
2000
1000
48.3
41.4
34.5
27.6
20.7
13.8
6.9
MN/m²
300
400
500
600
700
800
900
1000
Pull-out Strength, psi
91-Day Compressive Strength of 6X12-in. (15X30-cm) Cylinders, psi

TABLE 1

Physical Properties and Chemical Analyses of Cement*

Description of Test	
Time of Set (Gillmore needle): Initial	2 hr 18 min
Final	4 hr 20 min
Specific Surface (Blaine)	3370 cm^2/gm
Soundness - Autoclave	0.076 per cent
Physical Tests - Mortar Strength	
Compressive strength of 2-in. (5-cm) cubes	**
3-day	3315 psi (22.8MN/m^2)
7-day	3865 psi (26.5 MN/m^2)
28-day	4670 psi (32.1 MN/m^2)
Chemical Analysis	
Insoluble residue	Not available
Tricalcium Silicate (C_3S)	49.3 per cent
Tricalcium Aluminate (C_3A)	20.7 per cent
Magnesium Oxide (MgO)	11.6 per cent
Sulphur Trioxide (SO_3)	7.3 per cent
Loss on Ignition	1.6 per cent

* Test results and chemical analyses supplied by the cement manufacturing company.

** One mega Newton per square meter = 145.6 psi.

TABLE 2

Grading of Aggregates*

Coarse Aggregate			Fine Aggregate	
Sieve Size		Cumulative percentage retained	Sieve Size	Cumulative percentage retained
in.	mm			
3/4	19	3	No. 4	0
1/2	13	29	No. 8	7.8
3/8	9.5	68	No. 16	24.1
No. 4	-	97	No. 30	42.4
			No. 50	82.0
			No. 100	96.4
			No. 200	99.1

*Supplied by the aggregate producer.

TABLE 3

Physical Properties of Coarse and Fine Aggregates*

	Crushed Limestone	Natural Sand
Specific gravity	2.75	2.68
Absorption, %	0.60	0.93

*Supplied by the aggregate producer.

TABLE 4

Mix Proportions and Properties of Fresh Concrete

Date Cast	Mix No.	Mix Proportions, lbs/yd^3(kg/m^3)				Properties of Fresh Concrete						
		Free Water Content,	Cement Content	Fine Aggregate	Coarse Aggregate	Temp		Slump		Unit Weight		Air Content, %
						°F	°C	in	cm	lb/cu ft	kg/cu m	
June 12	1	294 (174)	630 (374)	1270 (753)	1920 (1140)	70	21.1	2.5*	6.4	148.0	2371	3.6*
June 15	2	287 (170)	500 (296)	1405 (831)	1880 (1115)	76	24.4	5.0	12.8	144.8	2320	4.2
June 19	3	283 (167)	410 (243)	1525 (904)	1850 (1100)	73	22.8	3.0	7.6	143.6	2300	5.5
June 21	4	282 (166)	360 (213)	1565 (929)	1840 (1090)	72	22.2	2.5	6.4	144.8	2320	5.2
June 26	5	279 (165)	320 (190)	1630 (965)	1830 (1085)	67	19.4	2.25*	2.7	144.4	2310	2.7*

* Measurement of slump and air were taken 45 minutes after the arrival of the truck.

Note: W.R.D.A (7.4 oz per 100 lb of cement) and Darex air entraining agent admixtures were used.

TABLE 5

Summary of Test Results for 3-Day Old Concrete

Mix No.	Compressive strength of 6x12-in. (15x30-cm) cylinders		Pull-out Tests done on 2 x 2 x 2-ft (61 x 61 x 61-cm) concrete cubes						Ratio of Pull-out to compressive strength, %
	psi	MN/m²	Gauge Reading		Load from calibration chart		Pull-out strength		
			psi	MN/m²	lb f	kgf	psi	MN/m²	
1	4750	32.62	5970*	35.51	25,400	11,506	900	6.18	18
	4840	33.24	5780*	39.70	24,600	11,144	870	5.97	
	Av=4795	Av=32.93					Av=885	Av=6.07	
2	3350	23.01	3250	22.32	22,300	10,102	790	5.43	24
	3295	22.63	3175	21.81	22,000	9,966	780	5.36	
	Av=3325	Av=22.84					Av=785	Av=5.40	
3	2940	20.19	2425	16.65	16,700	7,565	590	4.05	20
	3010	20.67	2425	16.65	16,700	7,565	590	4.05	
	Av=2975	Av=20.43					Av=590	Av=4.05	
4	1930	13.25	2425	16.65	16,700	7,565	590	4.05	30
	1960	13.46	2425	16.65	16,700	7,565	590	4.05	
	Av=1945	Av=13.36					Av=590	Av=4.05	
5	1165	8.00	2175	14.95	14,600	6,614	515	3.54	46
	1125	7.73	2225	15.28	15,000	6,795	530	3.64	
	Av=1145	Av=7.86					Av=525	Av=3.	

*This test was performed using a 20 ton hollow tension ram as provided by Owen Richards and therefore a different calibration chart has been used to obtain the load. This explains the difference in the magnitude of numbers.

TABLE 6

Summary of Test Results for 28-Day Old Concrete

Mix No.	Compressive strength of 6x12-in. (15x30-cm) cylinders		Pull-out tests done on 2 x 2 x 2 ft (61 x 61 x 61-cm) concrete cubes						Ratio of Pull-out to compressive strength, %
			Gauge reading		Load from calibration chart		Pull-out strength		
	psi	MN/m²	psi	MN/m²	lbf	kgf	psi	MN/m²	
1	6475	44.47	*	*	*	*	*	*	*
	5510	37.84							
	Av=5990	Av=41.15							
2	4480	30.77	3500	24.04	24,300	11,008	860	5.90	20
	4460	30.63	3850	26.44	26,800	12,140	950	6.52	
			3700	25.41	25,700	11,642	910	6.25	
	Av=4470	Av=30.70					Av=905	Av=6.22	
3	3860	26.51	3100	21.29	21,500	9,739	760	5.22	20
	4030	27.68	3200	21.98	22,200	10,057	785	5.39	
			3250	22.32	22,500	10,192	795	5.46	
	Av=3945	Av=27.09					Av=780	Av=5.36	
4	2690	18.47	3050	21.63	21,100	9,558	745	5.12	29
	2670	18.34	3200	21.98	22,200	10,057	785	5.39	
			3300	22.66	22,900	10,374	810	5.56	
	Av=2680	Av=18.41					Av=780	Av=5.36	
5	2015	13.84	2075	14.25	14,500	6,568	510	3.50	26
	2010	13.80	2200	15.11	15,000	6,795	530	3.64	
			2050	14.08	14,000	6,387	500	3.43	
	Av=2010	Av=13.82					Av=515	Av=3.52	

*Concrete cube had been damaged during testing at 3-days, therefore no pull-out tests were possible at 28-days and later.

TABLE 7

Summary of Test Results for 91-Day Old Concrete

Mix No.	Compressive strength of 6x12-in. (15x30-cm) cylinders		Pull-out tests done on 2 x 2 x 2-ft (61 x 61 x 61-cm) concrete cubes						Ratio of Pull-out to compressive strength, %
	psi	MN/m²	Gauge Reading		Load from calibration chart		Pull-out strength		
			psi	MN/m²	lb	kg	psi	MN/m²	
1	7345 7980 Av=7665	50.44 54.60 Av=52.64	-	-	-	-	-	-	
2	5165 5230 Av=5195	35.47 35.92 Av=35.68	4175 4100 4100 4025 3950 3950	28.67 28.16 28.16 27.64 27.13 27.13	28,750 28,300 28,300 27,750 27,250 27,250	13,024 12,820 12,820 12,571 12,344 12,344	1015 1000 1000 980 965 965 Av=985	6.97 6.87 6.87 6.73 6.63 6.63 Av=6.78	19
3	4260 4440 Av=4350	29.26 30.49 Av=29.87	3300 3550 3300 3800 3400 3750	22.66 24.38 22.66 26.10 23.35 25.75	22,600 24,400 22,600 26,100 23,400 25,800	10,237 11,053 10,237 11,823 10,600 11,687	800 865 800 925 830 910 Av=855	5.49 5.94 5.49 6.35 5.70 6.25 Av=5.87	19
4	2920 2965 Av=2940	20.05 20.36 Av=20.19	3175 M 2900 M 3250 M 3200 3100 M 3150 M	21.81 19.92 22.32 21.98 21.29 21.63	21,750 19,800 22,250 22,000 21,200 21,500	9,853 8,969 10,079 9,966 9,604 9,739	770 700 785 780 750 760 Av=755	5.29 4.81 5.39 5.36 5.15 5.22 Av=5.20	26
5	1965 2110 Av=2040	13.50 14.49 Av=14.01	2400 M 2325 M 2625 M 2500 M 2500 M 2400 M	16.48 15.97 18.03 17.17 17.17 16.48	16,300 15,750 17,750 17,000 17,000 16,300	7,384 7,135 8,041 7,701 7,701 7,384	575 555 630 600 600 575 Av=590	3.95 3.81 4.33 4.12 4.12 3.95 Av=4.05	29

M Threaded shaft of mild steel instead of high strength steel.

TABLE 8

Within-Batch Standard Deviations and Coefficients of Variation for 3-Day Test Results

Mix No.	6 x 12-in. (15 x 30-cm) cylinders Average * Strength psi(MN/m²)	S.D. psi	S.D. MN/m²	C.V. per cent	Pull-Out Tests Average Strength* psi (MN/m²)	S.D. psi	S.D. MN/m²	C.V., per cent
1	4795 (32.93)	64	0.44	1.3	885 (6.08)	21	0.14	2.4
2	3325 (22.84)	39	0.27	1.2	785 (5.39)	7	0.05	0.9
3	2975 (20.43)	49	0.34	1.7	590 (4.05)	0	0	0.0
4	1945 (13.36)	21	0.14	1.1	590 (4.05)	0	0	0.0
5	1145 (7.86)	28	0.19	2.5	520 (3.57)	11	0.07	2.0

*Average of two test results.

TABLE 9

Within-Batch Standard Deviations and Coefficients of Variation for 28-Day Test Results

Mix No.	Compressive Tests on 6 x 12-in. (15 x 30-cm) Cylinders				Pull-Out Tests			
	Average * Strength psi(MN/m²)	S.D. psi	S.D. MN/m²	C.V. per cent	Average Strength** psi (MN/m²)	S.D. psi	S.D. MN/m²	C.V., per cent
1	5990 (40.14)	682	4.68	11.4	-	-	-	-
2	4470 (30.70)	14	0.09	0.3	907 (6.23)	45	0.31	5.0
3	3945 (27.09	120	0.82	3.0	780 (5.36)	18	0.12	2.3
4	2680 (18.41	14	0.09	0.5	780 (5.36)	33	0.23	4.2
5	2010 (13.80)	4	0.03	0.2	515 (3.54)	15	0.10	3.0

* Average of two test results.
** Average of three test results.

TABLE 10

Within-Batch Standard Deviations and Coefficients of Variation for 91-Day Test Results

Mix No.	6 x 12-in. (15 x 30-cm) cylinders				Pull-out Tests			
	Average Strength* psi(MN/m²)	S.D.		C.V. per cent	Average Strength** psi (MN/m²)	S.D.		C.V. per cent
		psi	MN/m²			psi	MN/m²	
1	7665 (52.64)	449	3.08	5.9	—	—	—	—
2	5195 (35.68)	46	0.32	0.9	990 (6.80)	21	0.14	2.1
3	4350 (29.87)	127	0.87	2.9	855 (5.87)	54	0.37	6.3
4	2940 (20.19)	32	0.22	1.1	760 (5.22)	31	0.21	4.1
5	2040 (14.01)	103	0.71	5.0	590 (4.05)	26	0.18	4.5

* Average of two test results.
**Average of six test results.