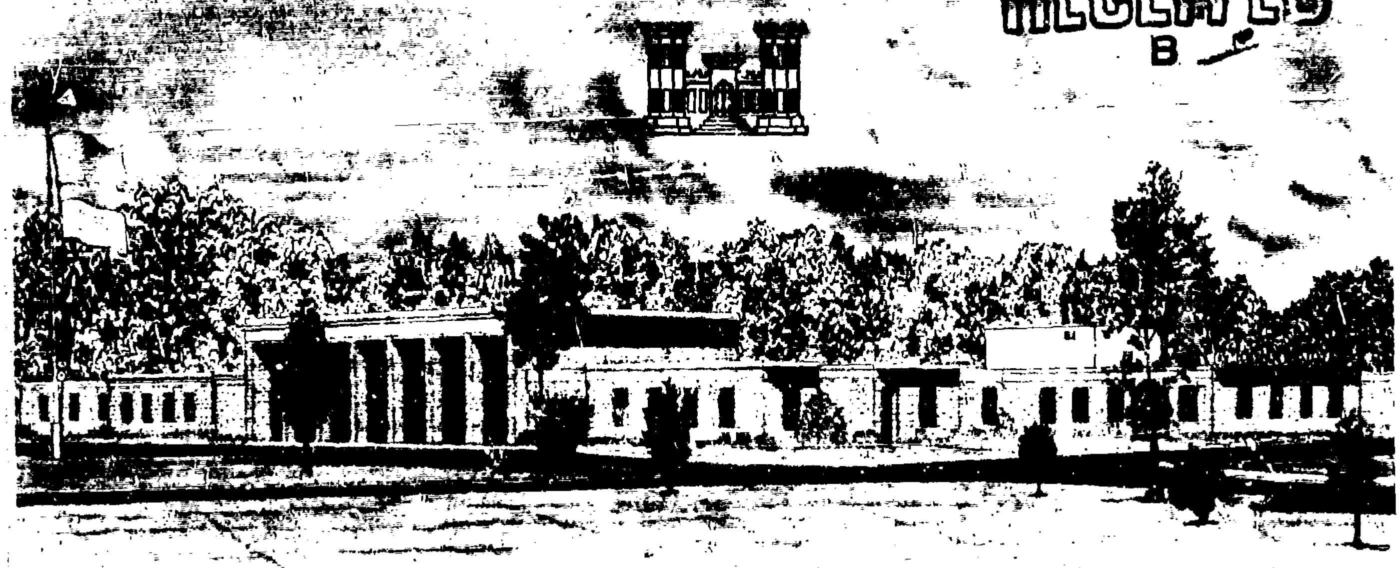
MISCELLANEOUS PAPER C-72-12

EFFECT OF METHOD OF PREPARATION OF ENDS OF CONCRETE CYLINDERS FOR TESTING

by

K. L. Saucier



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13. ABSTRACT The purpose of this program was to investigate the effects of (a) the strength and surface condition of the several materials commonly used for capping concrete cylinders and (b) various degrees of restraint of the capping material on the apparent strength of concretes of different strength levels. The program was divided into four phases. Phase I incorporated an experimental method of preparing specimens utilizing light steel rings to confine a gypsum plaster cap on the end of the specimen during testing. Variables included strength of concrete, use of rings, strength of capping material, and cleanliness of the cap surface. Phase II extended the investigation to very high-strength concrete and utilized medium-thick rings and a sulfur-silica capping compound. Unexpected results with the medium-thick rings dictated additional work with very thick rings, Phase III. In Phase IV, a high-strength sulfur capping compound was evaluated. Test results indicate that lubricant on the cap of a compressive test specimen has no effect on the compressive strength if there is only a slight film of oil. Low-strength capping material (<3000 psi) was suitable for capping only low-strength concrete specimens. It was not possible to practically confine a weak capping material sufficiently to produce a state of high stress resistance in the material and allow a high-strength concrete to demonstrate its maximum strength. High-strength gypsum and sulfur compounds (7500 psi) were found to be satisfactory for capping test specimens in the range of 10,000-psi compressive strength. If very thin caps are used, sulfur compounds with compressive strengths of 7000 psi or greater may be used for capping concrete cylinders the ultimate strength of which approaches 16,000 psi.

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ARMY-MRC VICKSBURG, MISS

Foreword

This investigation was conducted as ES Item 622.8, which forms a part of Civil Works Investigations Engineering Studies Item 622, and was authorized by first indorsement from the Office, Chief of Engineers (OCE), dated 30 September 1960, to a letter from the U. S. Army Engineer Waterways Experiment Station (WES), dated 23 September 1960, subject: Project Plan for Improved Method of Preparation of Ends of Concrete Cylinder for Testing.

The work was conducted during the period October 1960 to June 1965 at the Concrete Division (CD) of the WES under the direction of Messrs. Thomas B. Kennedy, former Chief, CD, and Bryant Mather, Chief, CD, and under the direct supervision of Messrs. J. M. Polatty, Chief, Engineering Mechanics Branch, W. O. Tynes, Chief, Concrete and Rock Properties Section, and K. L. Saucier. Mr. Saucier prepared this report.

COL Alex G. Sutton, Jr., CE, COL John R. Oswalt, Jr., CE, COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE, were Directors of the WES during the conduct of this study and the preparation of this report. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

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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 units as follows:

Multiply	By	To Obtain
bags* per cubic yard	55.768	kilograms per cubic meter
Fahrenheit degrees	5/9	Celsius or Kelvin degrees**
inches	25.4	millimeters
pounds (force)	4.448222	newtons
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	0.00689476	megapascals

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* 94-lb bag.

** 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: $K = (5/9)(F - 32) + 273.15$.

Summary

The purpose of this program was to investigate the effects of (a) the strength and surface condition of the several materials commonly used for capping concrete cylinders and (b) various degrees of restraint of the capping material on the apparent strength of concretes of different strength levels.

The program was divided into four phases. Phase I incorporated an experimental method of preparing specimens utilizing light steel rings to confine a gypsum plaster cap on the end of the specimen during testing. Variables included strength of concrete, use of rings, strength of capping material, and cleanliness of the cap surface. Phase II extended the investigation to very high-strength concrete and utilized medium-thick rings and a sulfur-silica capping compound. Unexpected results with the medium-thick rings dictated additional work with very thick rings, Phase III. In Phase IV, a high-strength sulfur capping compound was evaluated.

Test results indicate that lubricant on the cap of a compressive test specimen has no effect on the compressive strength if there is only a slight film of oil.

Low-strength capping material (<3000 psi) was suitable for capping only low-strength concrete specimens. It was not possible to practically confine a weak capping material sufficiently to produce a state of high stress resistance in the material and allow a high-strength concrete to

demonstrate its maximum strength. High-strength gypsum and sulfur compounds (7500 psi) were found to be satisfactory for capping test specimens in the range of 10,000-psi compressive strength. If very thin caps are used, sulfur compounds with compressive strengths of 7000 psi or greater may be used for capping concrete cylinders the ultimate strength of which approaches 16,000 psi.

EFFECT OF METHOD OF PREPARATION OF ENDS OF CONCRETE CYLINDERS FOR TESTING

Introduction

Background

1. The apparent strength of a concrete cylinder may be greatly influenced by the manner in which its ends are prepared before testing. There is no argument that the ends should be plane and normal to the axis of the cylinder. Planeness can be achieved for one end by casting against a machined base plate. The other end must be capped with a suitable material or ground smooth and plane. If the bottom is not cast against a machined base, both ends must be ground or capped. Capping is the commonly accepted method for preparing cylinders for testing; grinding is tedious and expensive. Ideally, the cap should be as strong as or stronger than the specimen and should have the same modulus of elasticity and Poisson's ratio. As a practical matter, the coefficient of friction between cap and machine platen should be large enough to prevent complete end restraint yet not allow total freedom that could result in radial movement (negative restraint) and possibly induced axial cleavage.

2. The increasing use of high-strength concrete for reinforced and prestressed elements makes it important to know accurately the strength of the concrete in the members as indicated by test cylinders. Present materials and methods of capping are deficient in a number of respects: (a) it is impossible to be certain that the elastic properties of the

cap match the concrete, (b) the effect of the strength of the cap on the indicated strength of high-strength concrete in unknown, and (c) the condition in the end due to lateral stress is unknown.

Purpose

3. The purpose of this program was to investigate the effects of: (a) the strength and surface condition of the several materials commonly used for capping of concrete cylinders and (b) various degrees of restraint of the capping material on the apparent strength of concretes of different strength levels.

Scope

4. The program was divided into four phases. Phase I incorporated an experimental method of preparing specimens utilizing light steel rings (1/8-in.-thick*) to confine a gypsum plaster cap on the end of the specimen during testing. Variables included strength of concrete, use of rings, strength of capping material, and cleanliness of the cap surface.

5. Phase II extended the investigation to very high-strength concrete (9000 to 10,000 psi) and utilized medium-thick steel rings (1/4 in.) and a sulfur-silica capping compound. Unexpected results with the medium-thick rings dictated additional work with very thick (1-in.) rings, Phase III. Phase IV completed the picture using very thick rings with the sulfur compound.

6. Given below is a summary of the work (Roman numerals indicate phase numbers):

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* A table of factors for converting U. S. customary units of measurement to metric units is given on page vii.

Strength Level of Concrete	Variable	Rings: None	Light	Medium	Heavy
Low (2500 psi)	Low-strength cap	I	I	--	--
	High-strength cap	I	I	--	--
	Cleanliness of cap	I	I	--	--
Medium (6500 psi)	Low-strength cap	I	I	--	--
	High-strength cap	I	I	--	--
	Cleanliness of cap	I	I	--	--
High (9500 psi)	Low-strength cap	III	III	III	III
	High-strength cap	II, III	II, III	II, III	III
	Sulfur-silica cap	II, IV	II	II	IV
	Mortar cap	II, IV	--	--	--

Phase I

Program

7. The experiment was set up on a statistical basis to utilize the minimum number of batches, rounds, and specimens. Medium- and low-strength concretes were used. Cylinders were made, capped, and tested using conventional materials and methods and were compared with cylinders from the same batches prepared by the experimental method.

8. The experimental method of preparing specimens consisted of using machined steel rings 1/2 in. high, 1/8 in. thick, 6-1/8 in. inside diameter (for 6-in.-diameter cylinder) to confine a gypsum plaster cap on the end of the specimen during testing. The steel ring was placed on a sheet of plate glass, then filled about one-half full of plaster mixed to proper consistency, after which the cylinder was placed upright in the ring, forcing the plaster up around the end of the cylinder. The ring remained in contact with the glass, and the excess plaster was removed

by wiping with the finger. The plaster was allowed to harden, and the specimen was tested with the ring inplace. A few preliminary tests to determine feasibility of the method indicated noticeable increase in strength of specimens thus tested. A high-strength gypsum plaster, designated plaster 1, and an ordinary plaster of paris gypsum plaster, designated plaster 2, usually of relatively low strength, were used for capping.

9. The effects of the lateral restraining rings, strength of capping material, and the presence of oil on caps were investigated using two strengths of concrete by making four batches of concrete, two of each strength, and three test cylinders per test condition per round as follows:

Low-Strength (4-bg*/cu yd) Mixture								Medium-Strength (8-bg/cu yd) Mixture							
Rings				No Rings				Rings				No Rings			
Plaster No. 1		Plaster No. 2		Plaster No. 1		Plaster No. 2		Plaster No. 1		Plaster No. 2		Plaster No. 1		Plaster No. 2	
Dry	Oil	Dry	Oil	Dry	Oil	Dry	Oil	Dry	Oil	Dry	Oil	Dry	Oil	Dry	Oil

* 94-lb bag.

10. The concrete was nonair-entrained and was made with type II cement and well-graded natural sand and well-graded, good-quality, 3/4-in. maximum size limestone. Slump was 2-1/2 ± 1/2 in. Cylinders were moist-cured for 28 days and tested at 28 days age. The results of physical and chemical tests of the cement are given in table 1, and the physical properties of the aggregates are given in table 2.

11. The type of break was observed, and in most cases an attempt was made to determine the angle of failure of both top and bottom sections of the cylinders by using a protractor to measure the angle between the plane of the cap and the sheared slope.

Results

12. The strengths of the high- and low-strength plasters, cast in 6- by 12-in. cylinders and tested at 4 hr age, were 5280 and 2025 psi, respectively. Initial tangent moduli of elasticity for the high- and low-strength plaster cylinders were 2.2×10^6 and 1.2×10^6 psi, respectively. Poisson's ratios from sonic measurements were 0.19 and 0.28, respectively.

13. The results of the capping tests are given in table 3, including descriptions of individual cylinder breaks, compressive strengths, standard deviations, and coefficients of variation. Tensile strain developed in the rings during test was monitored with electrical resistance strain gages affixed to the outer perimeter of the rings. Utilizing elastic theory, the strain was converted to stress. Table 4 gives the stress resulting in the rings when the specimens were tested.

14. The test results show no significant difference for the low-strength (2300- to 2900-psi) concrete whether the caps were made of high- or low-strength material, whether they were dry or oiled, or whether they were confined in rings or not. For the low-strength concrete, the average strength of all the high-strength-capped specimens was 2590 psi and that of the low-strength-capped specimens was 2550 psi. The low-strength

concrete cylinders tested with the caps dry had an average strength of 2580 psi; those tested with a thin film of oil on the caps averaged 2560 psi. The average strength of the low-strength concrete specimens with the caps unconfined was 2550 psi. When the caps were confined in the rings, the strength averaged 2590 psi.

15. Analysis of the data for the medium-strength concrete cylinders (approximately 6500 psi) also showed that the effect of oil on the caps did not have a significant effect on the strength (6640 versus 6690 psi). The effects of the cap strength and rings are given below (averaged from table 3):

Condition	Strength, psi: High-Strength Cap	Strength, psi: Low-Strength Cap	%
With rings	7150	6660	93
No rings	6810	6020	88
Percent	95	90	--

Obviously, the largest effect is realized by use of good capping material (88 percent effectiveness with low-strength plaster). Use of rings slightly improved the performance (93 percent). However, the rings were twice as effective with the low-strength material for increasing indicated strength (90 versus 95 percent). Perhaps the most significant point is the combined effect of rings and high strength cap, an improvement of 16% (6020 psi versus 7150 psi).

16. The exterior, circumferential stresses developed in the rings, given in table 4, may be considered indicative only of how capping materials of different strengths may deform under load. For example, with medium-strength concrete, deformation of the high-strength caps when the load

applied to the cylinder was 5000 psi resulted in 6000-psi tension in the steel ring, but the same load applied to the low-strength cap resulted in about 17,000-psi tension in the ring.

17. Measurement of the angle of break was difficult, and the angle of break was not measured for all tests; however, there appeared to be a slight tendency for the angle between the surface of the cap and the sheared surface of the remaining cone after test to be somewhat less for the low-strength (65-deg) than for the medium-strength (71-deg) concrete. There appeared to be a tendency for the angle to be flatter for the top half of the cylinders for both strength classes of concrete than for the bottom. The angle described by the low-strength concrete top sections was about 63 deg, and by the bottom sections 67 deg. The respective angles for the medium-strength concrete were about 69 and 73 deg. The stronger concrete (bottom halves of the cylinder and higher cement factor concrete) tended to fail at angles more nearly approaching the vertical. The presence of the rings seemed to have no effect on the angle of break.

Phase II

Program

18. The previous phase of this experiment indicated that when cylinders of low-strength concrete (near 2500 psi) were tested, the method of capping and the materials used for capping (within the scope of this experiment) made no significant difference in their apparent strength. When the strength of the concrete was near 7000 psi, the method of capping and the material used in the cap made an appreciable difference in indicated strength.

19. The purpose of Phase II was to determine if higher strength concrete (9,500-psi) than the 7000-psi concrete previously used will be benefited in apparent strength to a greater degree. The previous phase used two grades of gypsum plaster for capping, confined in light steel rings and free of rings. High stresses developed in rings surrounding plaster caps. Phase II utilized no rings and both light and medium steel rings with high-strength plaster and a sulfur-silica compound. Specimens were also cast against machined steel plates, plane within 0.001 in. across any diameter, and the top ends were capped with neat cement paste of type III cement formed against plate glass before the concrete set so that no caps were needed.

20. The concrete was nonair-entrained and was made with type III cement and well-graded natural sand and well-graded, good-quality 3/4-in. maximum size limestone coarse aggregate. Cement factor was 10 bg/cu yd. Slump was 2-1/2 ± 1/2 in. Concrete was consolidated by internal vibration. All specimens were moist-cured for 60 days, air-dried for 28 days, capped on the 29th day, and tested on the 30th day after removal from moist curing. Four rounds (batches) were cast.

Results

21. The results are given in table 5, including the round (batch) average strengths, standard deviations, and test condition averages. The data indicate that the concrete was only moderately uniform within batch. Variation between batches was not as consistent, generally ranging between 1500- and 2000-psi difference between rounds for each test condition.

22. A statistical analysis of the results was not made; a cursory examination reveals that no appreciable difference existed in the test condition averages--the maximum variation between round averages was only 400 psi irrespective of the capping material, whether sulfur or high-strength plaster, or the ring condition, either light, medium, or none. The test condition wherein cement caps were used resulted in a slightly lower average strength. This could possibly be the result of inexperience on the part of personnel applying the caps, since neat cement caps are seldom utilized at this laboratory.

23. Again, strains were measured in the rings on one specimen from each round during test and converted to stresses as given in table 6. Expectedly, the stresses increased as the load and stress in the cylinder increased. Since there appears to be little if any difference in the stresses developed in the top or bottom rings, the two were averaged in the following tabulation taken from table 6:

Type Ring	Capping Material	Circumferential, Exterior Stresses in Rings, psi, at Machine Load, 10^3 lb				
		60	120	180	240	300
Light	Plaster 1	2,600	4,500	6,950	9,350	12,850
Light	Sulfur	3,150	5,400	8,500	11,900	15,750
Medium	Plaster 1	3,200	4,700	6,350	8,250	10,350
Medium	Sulfur	4,750	6,300	8,150	10,500	13,350

24. In order to better understand the mechanics of the stresses developed in the confined caps, the circumferential stress measurements, given above, were used to compute the radial stresses imposed on the rings

by the capping material. Based on elastic theory for rings or hollow cylinders*, the radial stresses can be shown to be 4.25 percent of the exterior circumferential stress for 1/8-in.-thick rings and 8.68 percent for 1/4-in. rings. Theoretically, the radial stresses in the larger rings should be approximately twice those in the smaller rings for any one material. The results of the calculations, given in plate 1, confirm this analysis. Also, the stresses imposed on both the light and medium rings surrounding the sulfur-silica caps are approximately one-third higher than the stresses in the plaster-capped specimens. This would indicate that the plaster caps were more rigid, a premise supported by the moduli of elasticity determinations--2.2 x 10^6 psi for the plaster (para 12) and 1.5 x 10^6 psi for the sulfur-silica caps (para 32).

Phase III

Program

25. Phase II unexpectedly indicated that there was virtually no difference in the apparent strengths of cylinders capped with two strong materials, whether confined in medium or light rings, or whether unconfined. The purpose of Phase III was to determine if extra heavy rings would confine the capping material sufficiently to result in a higher apparent strength. Six rounds (batches) were cast utilizing the 10,000-psi mixture developed in Phase II. Three cylinders each were capped with low- and high-strength plasters. Tests were conducted at 90 days age after 60 days moist-curing and 30 days air-drying.

* Seely, F.B., and Smith, J.O., "Thick-Walled Cylinders," Advanced Mechanics of Materials, 2d ed., Wiley, New York, 1967, pp 295-304.

Results

26. The results are given in table 7. Obviously, the low-strength compound results in lower indicated strengths when compared to the higher strength capping material, irrespective of the ring condition. The difference (approximately 2300 psi) is very significant when no rings are used, less significant (approximately 1300 psi) with light rings, and evident (approximately 1000 psi) even with the medium and heavy rings. Significantly, also, the standard deviations are consistently larger with the lower strength compound, indicating a greater degree of variability in the results when this material is used. However, even with the 1-in.-thick rings, the restraint is not complete; some plastic flow or failure evidently affects the strength results. Therefore, it follows that there should be no substitute for a high-strength, high-modulus capping compound for high-strength concrete.

27. During this phase of the investigation, the effect of the various end conditions upon the strain gradient was questioned. Consequently, two diametrically opposed strain gages were placed on test specimens at three locations: approximately 1 in. each from the bottom and top and at the midheight of the test specimens. Specimens from batch 5 (high-strength plaster) and batch 6 (low-strength plaster) were gaged: one from each batch with light rings, one with heavy rings, and one without rings. The stress-strain curves are given in plates 2 and 3. The results indicate that relatively equal strains existed up to failure in the specimens capped with the high-strength compound both with and

without rings and in the specimens capped with the low-strength compound with rings. However, a very peculiar strain picture developed in the specimen capped with the low-strength material without rings (plate 3a). Excessive and erratic strains were recorded in the gages near the top and bottom of the test specimen. This very possibly is a result of premature yielding or localized failure of the cap.

28. Strain gages were affixed to the rings of one specimen each with light, medium, and heavy rings for both the high- and low-strength plasters. The results of the tests (plate 4) are from batch 4 (specimens 2, 3, and 4) for the low-strength compound and from batch 1 (specimens 1, 2, and 6) for the high-strength compound. An approximate linear relationship exists between the applied machine load and the ring stresses for all conditions. Erratic behavior occurred in two of the specimens capped with the low-strength compound, specimens 4-3 and 4-4. However, the curves from specimen 4-4 indicate that the rings on any one specimen act somewhat in conjunction with each other, i.e., if one ring is strained excessively, the strain in the other end is reduced a comparable amount. Since the caps of the test specimens are not connected physically in any way, some facet of the loading, possibly an eccentricity or misalignment, is assumed to cause such an interaction.

29. If, during loading, the capping material acted as a completely plastic or fluid substance, it can be shown that the radial stresses should be in the ratio of 1.00, 2.04, and 9.15 for the 1/8-, 1/4-, and 1-in.-thick rings, respectively*, for any one material at a given

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* Ibid, Seely and Smith.

circumferential stress. However, the circumferential stresses were allowed to increase with load up to failure. Therefore, the light and medium rings strained more, allowing the cap to yield and build up less radial stress than the heavy rings. Given below are the approximate radial stresses at 10,000-psi cylinder stress imposed on the six cylinders gaged (from plate 4c):

Radial Stresses at 10,000-psi Cylinder Stress

Ring Type	Low-Strength Cap	High-Strength Cap
Light	1100	500
Medium	1300	700
Heavy	2000	1900

The greater rigidity of the high-strength caps apparently prevented buildup of radial stresses in the light and medium rings comparable to those obtained with the low-strength material. However, with the heavy rings, radial stresses are approximately equal, as are circumferential stresses (plates 4a and 4b). This would indicate that the heavy rings confined the low-strength caps as effectively as the high-strength caps. The ultimate strength results, given in table 7, indicate no difference in strength obtained through use of different size rings for either material. Lower strength (8660 psi) was obtained with the weaker material (plaster 2) when rings were not used. Indications are, therefore, that even slight confinement (light rings) will increase effectiveness of a weak capping material by increasing cap strength and/or preventing radial movement (negative restraint). Unfortunately, strength comparison between the two materials for respective ring types is not possible due to the batch variations. However, the standard deviations are generally larger for the specimens capped with the weaker material. This should reinforce the argument for use of a high-quality capping material at all times.

Phase IV

Program

30. Phase IV was conducted to complete the information for the study; i.e., test specimens (a) capped with sulfur-silica compound in heavy rings and (b) capped with a mortar paste of stiff consistency made from the same materials used in the concrete. Utilizing the nominal 10,000-psi mixture previously used, three rounds (batches) were mixed, and three cylinders were cast and tested for compressive strength at 90 days age for each round. Strain measurements were not made on the ring capped cylinder; however, five 2-in. cubes of the sulfur-silica capping compound were cast, instrumented with electrical resistance strain gages, and tested at 1 day age.

Results

31. The results given in table 8 represent individual breaks. Since between-round differences were not significant, the standard deviations and coefficients of variation were computed for each test condition utilizing data from all rounds. Obviously, the variation was very slight for all test conditions. Also, there is no significant difference between the three methods of capping used in this phase. The use of heavy rings or a matching mortar cap did not increase the indicated strength. Unpublished work at this laboratory on test specimens which were cast from

a comparable 10-bg/cu-yd mixture and which had the ends ground prior to testing also yielded strengths in the range of 9000 to 11,000 psi. One might therefore postulate that the maximum strength of the concrete for the conventional compressive test as conducted herein had been attained. Other methods which tend to neutralize the effects of end restraint or produce a uniform stress condition throughout might yield higher indicated strengths, but such methods were not within the scope of this study.

32. Six 2-in. cubes of the sulfur compound were cast and tested for compressive strength at 1 day age. Average compressive strength was approximately 7000 psi. Electrical resistance strain gages affixed to the cubes yielded stress-strain curves not unlike a conventional concrete curve, i.e., linear to approximately one-half the ultimate strength, then becoming curvilinear to failure. Initial tangent modulus was approximately 1.5×10^6 psi. Ultimate strain was approximately 6000 μin./in.

Discussion and Conclusions

Discussion

33. With respect to the stated objectives of this program, the study may be described as having been successfully completed. However, as with many research efforts, questions were raised which could not be answered from the results obtained or pursued further with the funds available.

34. The long accepted practice requiring caps for compressive test specimens to be free from grease and oil appears to be unjustified--at least to the extent that a light coat of lubricant has little or no perceptible effect on the failure stress of concrete up to 7000-psi

compressive strength. Apparently, the light coat of lubricant either did not reduce the end restraint sufficiently to produce a significant degree of freedom on the ends or the caps nullified whatever effect a slight lubricant may have on indicated strength.

35. Understandably, the quality of capping material made no detectable difference as long as the concrete was of rather low strength (<3000 psi). Although the weak gypsum plaster had a compressive strength of only 2000 psi when tested in a 6- by 12-in. cylinder, the concrete strengths obtained were equal to those obtained with the higher strength material. When a good-quality concrete (7000 psi) was used, a weak capping compound gave strengths only 88 percent of those obtained with a good-quality capping material; with high-strength concrete (10,000 psi), the figure was only 81%. This should be sufficient evidence to signal the need for high-strength capping material on all except very low-strength concrete test specimens.

36. The 5000-psi capping material (6- by 12-in. cylinder) was used successfully with the excellent-quality concrete (10 bg/cu yd) to obtain strengths equal to those obtained on specimens capped with high-strength mortar (approximately 10,000 psi). The explanation may lie in the extremely thin section used in the capping procedure. Additional proof of the increased strength of capping materials when used in thin applications may be seen in plate 5.* The curve shown therein for plaster of paris indicates a basic strength for a conventional test specimen (h = 2d) of 2000 psi, which was equivalent to the weak gypsum plaster used in this

* Joint Technical Information Letter, National Sand and Gravel Association No. 227, and National Ready-Mix Concrete Association No. 216, 27 November 1964.

study. The strength of a 1/8-in.-thick section of this same material was approximately 6000 psi, equivalent to the good-quality concrete tested in Phase I. The high-strength gypsum plaster utilized herein, roughly equivalent in a standard test specimen to the 3-day neat cement shown in plate 5, could therefore be expected to possess strength in excess of 10,000 psi in a 3/8-in. thickness. All of the caps fabricated in this investigation were less than 3/8 in. thick. Moreover, the sulfur compound utilized herein had a strength approximating the 325 F sulfur compound curve shown in plate 5. In very thin sections, this material could apparently be expected to possess strength in excess of 16,000 psi and should be satisfactory for capping of concrete test specimens approaching this strength.

37. For 7000-psi concrete the use of rings to confine the caps was logically more effective with lower strength capping compound--strengths of standard unconfined specimens averaged only 90 percent of those with light rings (Phase I). For the high-strength gypsum plaster, the ratio was 95 percent. For 10,000-psi concrete, however, results with the high-strength gypsum showed no effects of utilization of either light or medium rings. This was substantiated by the work in Phase III where confinement in very heavy rings had no effect on the test specimens utilizing high-strength gypsum and in Phase IV where a different (sulfur) compound is used. Phase III also indicated that rings of all three sizes improved low-strength caps equally when used on high-strength concrete. Apparently, confinement of the capping material is effective only if the material attempts to flow a

substantial amount as with the low-strength material. Since concrete strengths obtained with unconfined high-strength caps were equal to those with very heavy, rigid rings, a state of plastic flow had apparently not been attained at 10,000 psi in the capping material.

38. Stresses and strains in the rings were inversely proportional to the size ring and the elastic modulus of the capping material. Stresses approaching the yield limit were obtained in the light rings with the weak material. However, even very thin rings appear to strengthen weak capping material to a significant degree. When very heavy rings were used, ultimate ring stresses and concrete strengths were approximately equal for either grade capping material (Plate 4, Table 7). Therefore, confinement was apparently effective, but large internal (radial) stresses developed in the caps which could be of significance in very high-strength tests.

Conclusions

39. Based on the results of this investigation, the following conclusions appear justified:

a. Lubricant on the cap of a compressive test specimen has no effect on the compressive strength if the thickness is very slight as would result from wiping with a greasy cloth.

b. Low-strength capping material (<3000 psi) should be used only for capping low-strength concrete specimens and then only if high-strength material is not available. It is not practical to confine a weak capping material sufficiently to produce a state of high stress resistance in the material and allow high-strength concrete cylinders to attain maximum strength.

c. High-strength gypsum and sulfur compounds (7500 psi) are satisfactory for capping test specimens by conventional means in the range to 10,000-psi compressive strength. If very thin caps are used, sulfur compounds with compressive strengths of 7000 psi or greater may be used for capping concrete cylinders the ultimate strength of which approaches 16,000 psi.

d. Very high circumferential stresses are likely to develop in light rings placed around the ends of test specimens to confine the caps. The magnitude of stresses developed is inversely proportional to the size of the rings and quality of the capping material.

e. Relatively large internal (radial) stresses were developed in the specimen caps surrounded with heavy rings. Confinement with the heavy rings, although not complete, was approximately equal for weak and strong capping materials.

f. Confinement in rings does not improve the performance of high-strength caps on high-strength concrete, but may enhance cap performance under other conditions, i.e. weak capping material on high-strength concrete, although not necessarily to a degree adequate to mobilize the full strength of the specimen.

TABLE 1

Results of Physical and Chemical Tests of RC-474 Type II Portland Cement

Results of Physical Tests	
Specific gravity	3.15
Fineness, air permeability, cm^2/g	3450
Normal consistency, water requirement, %	27.2
Time of setting, Gillmore test:	
Initial, hr:min	4:00
Final, hr:min	6:00
Mortar expansion, autoclave test, %	0.07
Air content, %	7.7
Compressive strength, psi	
3 days	2500
7 days	3770
28 days	5220

Results of Chemical Tests, %	
SiO_2	22.15
Al_2O_3	4.20
Fe_2O_3	3.31
CaO	62.96
MgO	3.06
SO_3	2.00
Loss on ignition	1.15
Insoluble residue	0.36
Na_2O	0.20
K_2O	0.39
Total alkali as Na_2O	0.46
C_3S	49
C_3A	6

TABLE 2

Physical Properties and Gradings of Aggregates

Tests	Limestone No. 4 to 3/4 in. VICKS-3 G-1(23)	Natural Fine CRD S-4(15)
Physical Properties		
Bulk specific gravity, saturated surface dry	2.69	2.61
Absorption, %	0.9	0.7
Soft particles, %	0	--
Mortar-making properties,* %		
Strength at 3 days	--	--
Strength at 7 days	--	--
Flat and elongated particles, %	7.8	--
Abrasion loss (Los Angeles), %	24.2	--

Gradings

Sieve Size	Cumulative Percent Passing Standard Sieve	
	Limestone No. 4 to 3/4 in. VICKS-3 G-1(23)	Natural Fine CRD S-4(15)
3/4 in.	100	
1/2 in.	84	
3/8 in.	58	
No. 4	4	99
No. 8		87
No. 16		72
No. 30		57
No. 50		25
No. 100		4

* CRD-C 116, Handbook for Concrete and Cement, Aug 1949 (with quarterly supplements), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

TABLE 3

Results of Phase I Tests

Cylinder	Type Cap	Type Ring	End Condition	Type Break Top	Type Break Bottom	Angle of Break, deg Top	Angle of Break, deg Bottom	28-day Compressive Strength, psi	σ, psi	V, %
Low-Strength Mixture, Round 1										
1154	Plaster 1	None	Dry	Cone	Cone	55	63	2800	75	2.61
1155				Cone	Inclined	56	64	2950		
1156				Cone	Cone	57	68	2860		
Avg						56	65	2870		
1157	Plaster 1	None	Oiled	Cone	Inclined	55	62	2800	50	1.82
1158				Inclined	Inclined	63	65	2700		
1159				Cone	Cone	57	63	2760		
Avg						58	63	2750		
1160	Plaster 2	None	Dry	Cone	Inclined	53	68	2640	59	2.25
1161				Inclined	Inclined	--	--	2660		
1162				Cone	Vertical	55	--	2550		
Avg						54	68	2620		
1163	Plaster 2	None	Oiled	Cone	Vertical	63	--	2730	110	4.12
1164				Cone	Vertical	57	--	2540		
1165				Cone	Vertical	58	--	2730		
Avg						59	--	2670		
1166	Plaster 1	Light	Dry	Cone	Cone	66	70	2860	132	4.78
1167				Cone	Cone	64	68	2830		
1168				Cone	Cone	71	71	2590		
Avg						67	70	2760		

(Continued)

TABLE 3 (CONTINUED)

Cylinder	Type Cap	Type Ring	End Condition	Type Break		Angle of Break, deg		28-day Compressive Strength, psi	σ, psi	V, %
				Top	Bottom	Top	Bottom			
1169	Plaster 1	Light	Oiled	Cone	Cone	61	70	2860	26	0.92
1170				Cone	Cone	63	67	2810		
1171				Cone	Cone	65	68	2820		
Avg						63	68	2830		
1172	Plaster 2	Light	Dry	Cone	Cone	70	75	2860	188	6.89
1173				Cone	Cone	65	77	2500		
1174				Cone	Cone	65	65	2830		
Avg						67	72	2730		
1175	Plaster 2	Light	Oiled	Cone	Cone	66	73	2730	31	1.13
1176				Cone	Cone	67	69	2770		
1177				Cone	Cone	70	75	2710		
Avg						68	72	2740		
				Low-Strength Mixture, Round 2						
1440	Plaster 1	None	Dry	Cone	Cone	63	70	2410	46	1.95
1441				Cone	Cone	65	67	2350		
1442				Inclined	Cone	70	66	2320		
Avg						66	68	2360		
1443	Plaster 1	None	Oiled	Inclined	Inclined	67	64	2510	157	6.57
1444				Inclined	Inclined	67	64	2440		
1445				Cone	Inclined	69	64	2210		
Avg						68	64	2390		
1446	Plaster 2	None	Dry	Cone	Cone	71	63	2320	130	5.42
1447				Cone	Cone	65	67	2330		
1448				Cone	Cone	65	65	2550		
Avg						67	65	2400		

(Continued)

TABLE 3 (CONTINUED)

Cylinder	Type Cap	Type Ring	End Condition	Type Break: Top	Type Break: Bottom	Angle of Break, deg: Top	Angle of Break, deg: Bottom	28-day Compressive Strength, psi	σ, psi	V, %
1449	Plaster 2	None	Oiled	Inclined	Inclined	65	67	2550	171	7.28
1450				Cone	Inclined	63	67	2240		
1451				Inclined	Cone	65	69	2270		
Avg						64	68	2350		
1452	Plaster 1	Light	Dry	Cone	Cone	60	68	2340	125	5.08
1453				Cone	Cone	63	63	2450		
1454				Cone	Cone	64	62	2590		
Avg						62	64	2460		
1455	Plaster 1	Light	Oiled	Cone	Cone	56	63	2330	72	3.14
1456				Cone	Cone	60	65	2210		
1457				Cone	Cone	57	61	2340		
Avg						58	63	2290		
1458	Plaster 2	Light	Dry	Cone	Cone	65	66	2260	204	8.46
1459				Cone	Cone	60	61	2640		
1460				Cone	Cone	70	68	2320		
Avg						65	65	2410		
1461	Plaster 2	Light	Oiled	Cone	Cone	57	66	2370	99	3.99
1462				Cone	Cone	56	59	2530		
1463				Cone	Cone	56	64	2550		
Avg						56	63	2480		
Medium-Strength Mixture, Round 1										
1416	Plaster 1	None	Dry	Cone	Vertical	68	--	6510	166	2.61
1417				Cone	Vertical	67	--	6180		
1418				Cone	Cone	70	77	6380		
Avg						68	77	6360		

(Continued)

TABLE 3 (CONTINUED)

Cylinder	Type Cap	Type Ring	End Condition	Type Break Top	Type Break Bottom	Angle of Break, deg Top	Angle of Break, deg Bottom	28-day Compressive Strength, psi	σ, psi	V, %
1419	Plaster 1	None	Oiled	Cone	Vertical	70	--	6290	26	0.41
1420				Cone	Vertical	68	--	6340		
1421				Cone	Vertical	72	--	6330		
Avg						70	--	6320		
1422	Plaster 2	None	Dry	Cone	Vertical	70	--	5500	22	4.03
1423				Cone	Vertical	69	--	5690		
1424				Cone	Inclined	67	--	5250		
Avg						69	--	5480		
1425	Plaster 2	None	Oiled	Cone	Vertical	69	--	5800	16	0.28
1426				Cone	Vertical	69	--	5820		
1427				Cone	Vertical	72	--	5790		
Avg						70	--	5800		
1428	Plaster 1	Light	Dry	Cone	Vertical	--	--	6990	155	2.27
1429				Vertical	Cone	--	--	6680		
1430				Cone	Vertical	--	--	6820		
Avg						--	--	6830		
1431	Plaster 1	Light	Oiled	Cone	Vertical	--	--	6270	295	4.46
1432				Vertical	Vertical	--	--	6790		
1433				Cone	Cone	--	--	6770		
Avg						--	--	6610		
1434	Plaster 2	Light	Dry	Cone	Cone	--	--	6560	251	3.92
1435				Cone	Cone	--	--	6550		
1436				Cone	Vertical	--	--	6120		
Avg						--	--	6410		

(Continued)

TABLE 3 (CONTINUED)

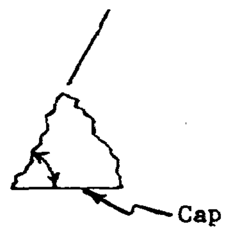
Cylinder	Type Cap	Type Ring	End Condition	Type Break		Angle of Break, deg		28-day Compressive Strength, psi	σ, psi	V, %
				Top	Bottom	Top	Bottom			
1437	Plaster 2	Light	Oiled	Cone	Cone	--	--	6270	347	5.57
1438				Cone	Inclined	--	--	6550		
1439				Cone	Cone	--	--	5960		
Avg						--	--	6230		
Medium-Strength Mixture, Round 2										
1464	Plaster 1	None	Dry	Cone	Cone	70	67	7460	200	8.76
1465				Inclined	Cone	45	72	7070		
1466				Cone	Cone	66	66	7190		
Avg						60	68	7240		
1467	Plaster 1	None	Oiled	Cone	Vertical	73	--	7460	132	1.80
1468				Inclined	Cone	72	76	7290		
1469				Inclined	Cone	70	70	7200		
Avg						72	73	7320		
1470	Plaster 2	None	Dry	Inclined	Inclined	78	75	6620	221	3.46
1471				Cone	Inclined	72	72	6360		
1472				Cone	Inclined	78	68	6180		
Avg						76	72	6390		
1473	Plaster 2	None	Oiled	Cone	Cone	80	80	6600	236	3.68
1474				Cone	Cone	76	80	6500		
1475				Inclined	Vertical	71	--	6150		
Avg						76	80	6420		
1476	Plaster 1	Light	Dry	Cone	Cone	72	70	7650	163	2.10
1477				Cone	Inclined	68	70	7690		
1478				Cone	Inclined	64	70	7950		
Avg						68	70	7760		

(Continued)

TABLE 3 (CONTINUED)

Cylinder	Type Cap	Type Ring	End Condition	Type Break		Angle of Break, deg		28-day Compressive Strength, psi	[illegible], psi	J, %
				Top	Bottom	Top	Bottom			
1479	Plaster 1	Light	Oiled	Cone	Cone	63	74	7210	175	2.36
1480				Cone	Inclined	70	75	7550		
1481				Inclined	Inclined	63	70	7450		
Avg						65	73	7400		
1482	Plaster 2	Light	Dry	Inclined	Cone	70	78	6920	125	1.78
1483				Cone	Inclined	76	76	6950		
1484				Cone	Cone	73	73	7180		
Avg						73	76	7020		
1485	Plaster 2	Light	Oiled	Cone	Cone	70	74	6990	140	2.00
1486				Inclined	Inclined	73	73	6860		
1487				Cone	Cone	60	71	7140		
Avg						68	73	7000		

NOTES: Dry end condition = cleaned with acetone; oiled end condition = thin coat of oil applied to cap.
Type of break: Cone = conical; inclined = inclined splitting; vertical = vertical splitting.
Angle of break measured as:



(Continued)

TABLE 3 (CONCLUDED)

Analysis of Variance

Variable	Low-Strength Concrete	Medium-Strength Concrete	Variables	Low-Strength Concrete	Medium-Strength Concrete
	Significance			Interaction	
1. Rings	No	Yes*	3-4	No	No
2. Capping Material	No	Yes*	2-4	Yes**	No
3. Dry or Oiled	No	No	1-2	No	Yes**
4. Batch	Yes*	Yes*	2-3	No	No
			1-3	No	Yes**
			1-4	No	No
			2-3-4	No	No
			1-3-4	No	No
			1-2-4	No	No
			1-2-3	No	No
			1-2-3-4	No	No

* 99 percent level.
** 95 percent level.

TABLE 4

Exterior, Circumferential
Stress in Rings' Confining Caps During Phase I Compression Testing

Cylinder	Type Cap	End Condition	Stress in Cylinder, psi 850	1,700	2,550	Cylinder	Type Cap	End Condition	Stress in Cylinder, psi 700	1,420	2,120
Low-Strength Mixture, Round 1						Low-Strength Mixture, Round 2					
1168	Plaster 1	Dry	675	1,800	4,315	1454	Plaster 1	Dry	600	1,770	3,240
1171	Plaster 1	Oiled	675	2,050	3,675	1457	Plaster 1	Oiled	660	2,070	4,200
1174	Plaster 2	Dry	1350	3,635	10,375	1460	Plaster 2	Dry	1380	2,460	6,750
1177	Plaster 2	Oiled	1235	3,485	9,245	1463	Plaster 2	Oiled	1800	3,600	9,150
			1700	3,400	5,100				1400	2,840	4,240
Medium-Strength Mixture, Round 1						Medium-Strength Mixture, Round 2					
1430	Plaster 1	Dry	1170	3,030	5,280	1478	Plaster 1	Dry	1680	3,660	6,480
1433	Plaster 1	Oiled	1200	2,580	4,920	1481	Plaster 1	Oiled	1830	3,300	6,180
1436	Plaster 2	Dry	2730	13,020	16,950	1484	Plaster 2	Dry	6570	14,640	17,640
1439	Plaster 2	Oiled	2520	11,820	20,220	1487	Plaster 2	Oiled	5730	14,250	16,260

TABLE 5

Results of Phase II Tests

Type Ring	Capping Material	Average Compressive Strength 4 Rounds, psi	Standard Deviation psi	Test Condition Average Strength, psi
None	Type III Cement	11,260	920	10,600
		10,110	880	
		10,370	690	
		10,650	700	
None	Plaster 1	11,160	370	11,520
		10,790	480	
		11,970	850	
		12,160	550	
None	Sulfur	11,420	320	11,250
		10,240	1030	
		11,610	680	
		11,730	990	
Light	Plaster 1	10,590	350	11,480
		10,920	700	
		12,110	310	
		12,320*	160*	
Light	Sulfur	11,220	240	11,670
		10,750	450	
		11,900	690	
		12,820*	100*	
Medium	Plaster 1	10,680	230	11,480
		11,340	970	
		12,310	250	
		11,600	570	
Medium	Sulfur	10,000	450	11,400
		11,080	1130	
		12,580	260	
		11,960	530	

* Average of two breaks only; all other values are averages of three cylinder breaks.

TABLE 6

Exterior, Circumferential
Stresses in Rings' Confining Caps During Phase II Compression Testing

Type Ring	Capping Material	Batch	Stress in Cylinder, psi									
			2140		4280		5430		8570		10,710	
			Stress in Rings, thousands of psi									
			Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Light	Plaster 1	1	3.0	2.4	4.4	4.2	6.8	6.5	8.6	8.6	--	--
		2	3.0	2.7	5.3	4.8	7.4	6.5	10.4	8.6	14.0	13.1
		3	1.6	3.0	3.9	4.8	6.2	6.5	9.1	8.6	12.5	11.6
		4	1.8	3.3	4.2	4.8	6.5	7.4	9.4	11.3	--	12.8
		Avg	2.4	2.8	4.4	4.6	6.7	6.7	9.4	9.3	13.2	12.5
Light	Sulfur	1	3.3	3.3	5.6	5.3	8.3	7.4	11.0	10.4	14.2	13.1
		2	2.4	5.0	5.3	7.1	6.5	9.5	15.1	12.8	23.8	16.9
		3	2.4	3.3	4.8	5.0	7.0	6.8	10.0	9.2	14.1	11.6
		4	0.3	5.0	2.7	7.4	12.3	10.4	--	14.6	--	14.8
		Avg	2.1	4.2	4.6	6.2	8.5	8.5	12.0	11.8	17.4	14.1
Medium	Plaster 1	1	2.1	2.1	3.9	3.3	5.9	5.0	8.0	6.8	9.8	9.2
		2	3.4	3.3	5.2	4.5	6.7	5.9	8.4	7.7	10.5	9.8
		3	4.2	4.2	6.2	5.3	8.2	7.1	10.1	8.6	12.2	10.4
		4	2.1	3.9	3.7	5.3	5.3	6.8	7.7	8.6	10.0	11.0
		Avg	3.0	3.4	4.8	4.6	6.5	6.2	8.6	7.9	10.6	10.1
Medium	Sulfur	1	4.2	5.9	6.8	7.1	9.5	8.9	13.7	10.7	17.8	--
		2	3.9	5.3	5.3	6.8	7.7	8.6	10.5	11.0	14.8	14.2
		3	3.3	6.2	5.2	6.8	7.1	8.9	9.8	10.1	12.8	11.9
		4	7.3	1.8	8.6	3.6	9.5	5.3	10.5	7.7	12.2	10.7
		Avg	4.7	4.8	6.5	6.1	8.4	7.9	11.1	9.9	14.4	12.3

TABLE 7

Results of Phase III Tests

Type Ring	Capping Material	Round (Batch)	Average Compressive Strength, psi	Standard Deviation, psi	Test Condition Average Strength, psi
None	Plaster 1	1	9,430	170	
		3	11,520	250	10,970
		5	11,950	180	
Light	Plaster 1	1	9,620	240	
		3	11,620	360	10,980
		5	11,690	270	
Medium	Plaster 1	1	10,220	110	
		3	11,830	250	11,190
		5	11,520	80	
Heavy	Plaster 1	1	10,210	10	
		3	10,990	180	10,870
		5	11,420	120	
None	Plaster 2	2	7,590	530	
		4	8,800	640	8,660
		6	9,580	850	
Light	Plaster 2	2	8,390	670	
		4	9,820	720	9,720
		6	10,960	620	
Medium	Plaster 2	2	9,280	510	
		4	10,240	210	9,990
		6	10,460	210	
Heavy	Plaster 2	2	9,260	230	
		4	10,240	460	9,820
		6	9,960	360	

NOTE: Each value given is an average of three cylinder breaks.

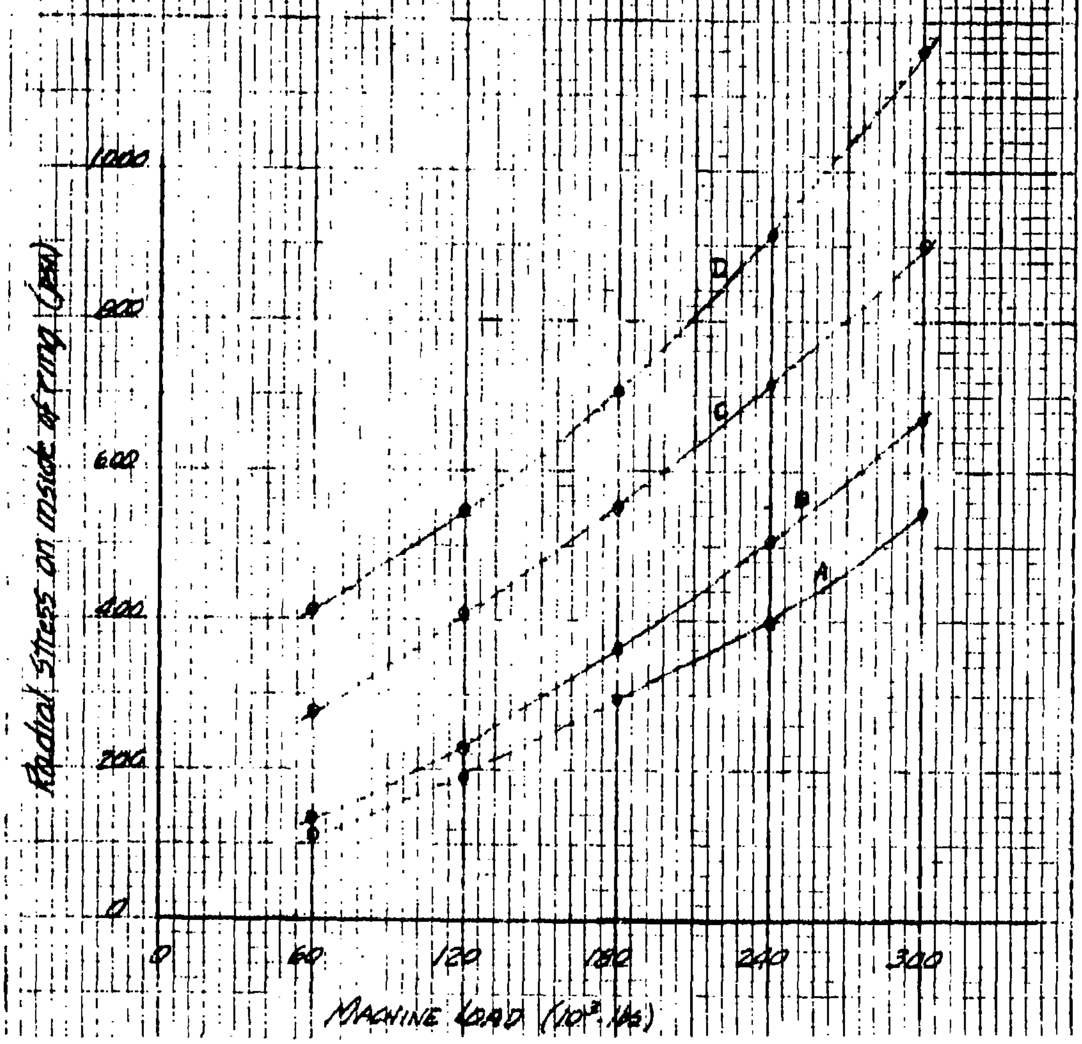
TABLE 8

Results of Phase IV Tests

Type Ring	Capping Material	Round (Batch)	Average Compressive Strength, psi	Standard Deviation, psi	Coefficient of Variation, %	Test Condition Average Strength, psi
None	Sulfur	1	10,120	480	4.7	10,190
		1	11,040			
		1	10,730			
		2	9,330			
		2	10,010			
		2	10,200			
		3	10,280			
		3	10,080			
		3	9,930			
Heavy	Sulfur	1	9,140	540	5.2	10,300
		1	10,590			
		1	10,340			
		2	10,620			
		2	10,680			
		2	9,690			
		3	10,380			
		3	10,400			
		3	10,840			
None	Mortar	1	10,550	380	3.6	10,460
		1	10,840			
		1	10,800			
		2	10,210			
		2	10,080			
		2	10,050			
		3	10,010			
		3	10,760			
		3	10,880			

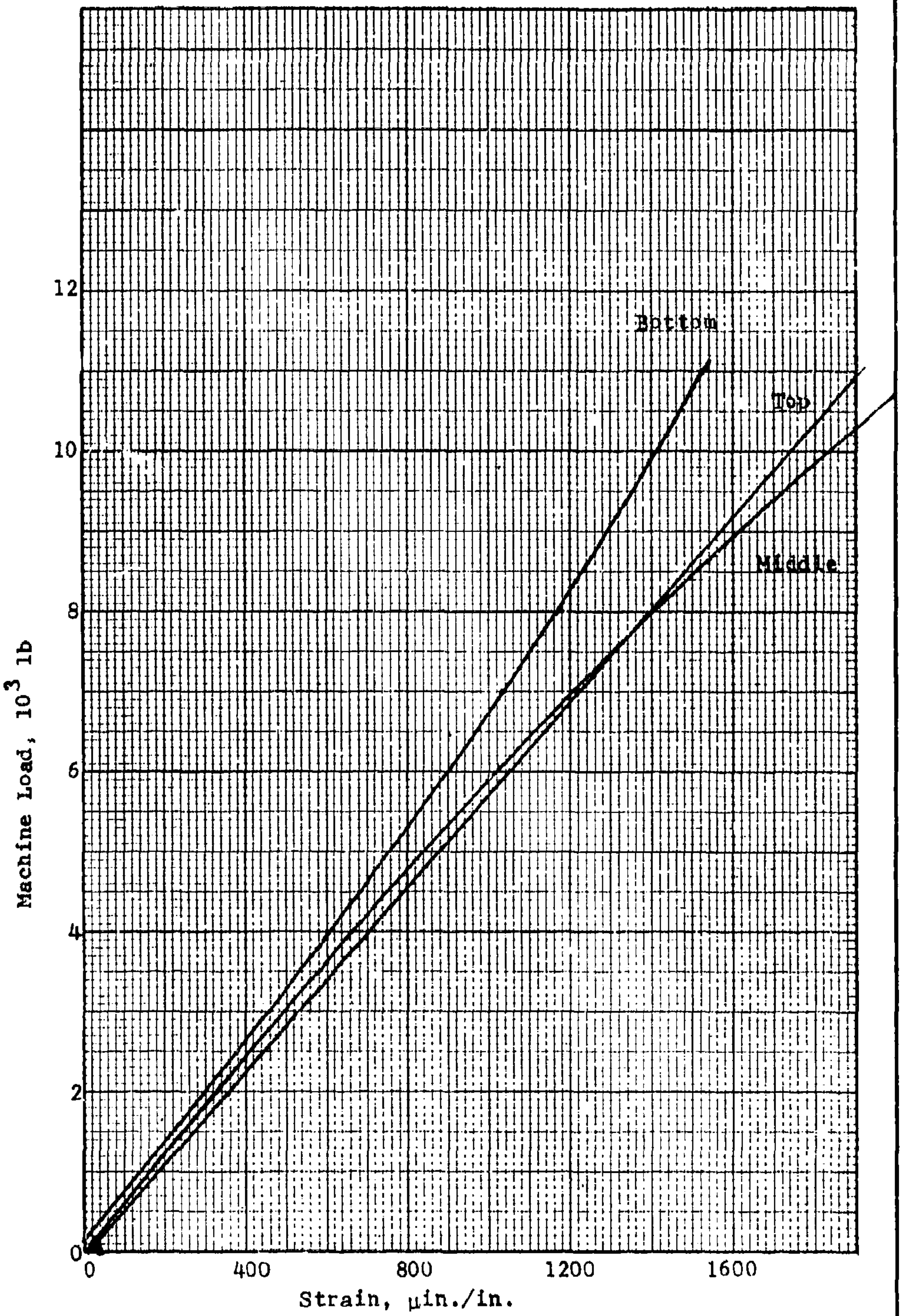
NOTE: Each value given is an average of three cylinder breaks.

Curve	Ring Type	Cap Mat'l	60	120	180	240	300
A	Light	Plaster I	110	191	295	397	525
B	Light	Sulfur	134	230	361	505	670
C	Medium	Plaster I	278	408	551	716	900
D	Medium	Sulfur	412	546	707	912	1160



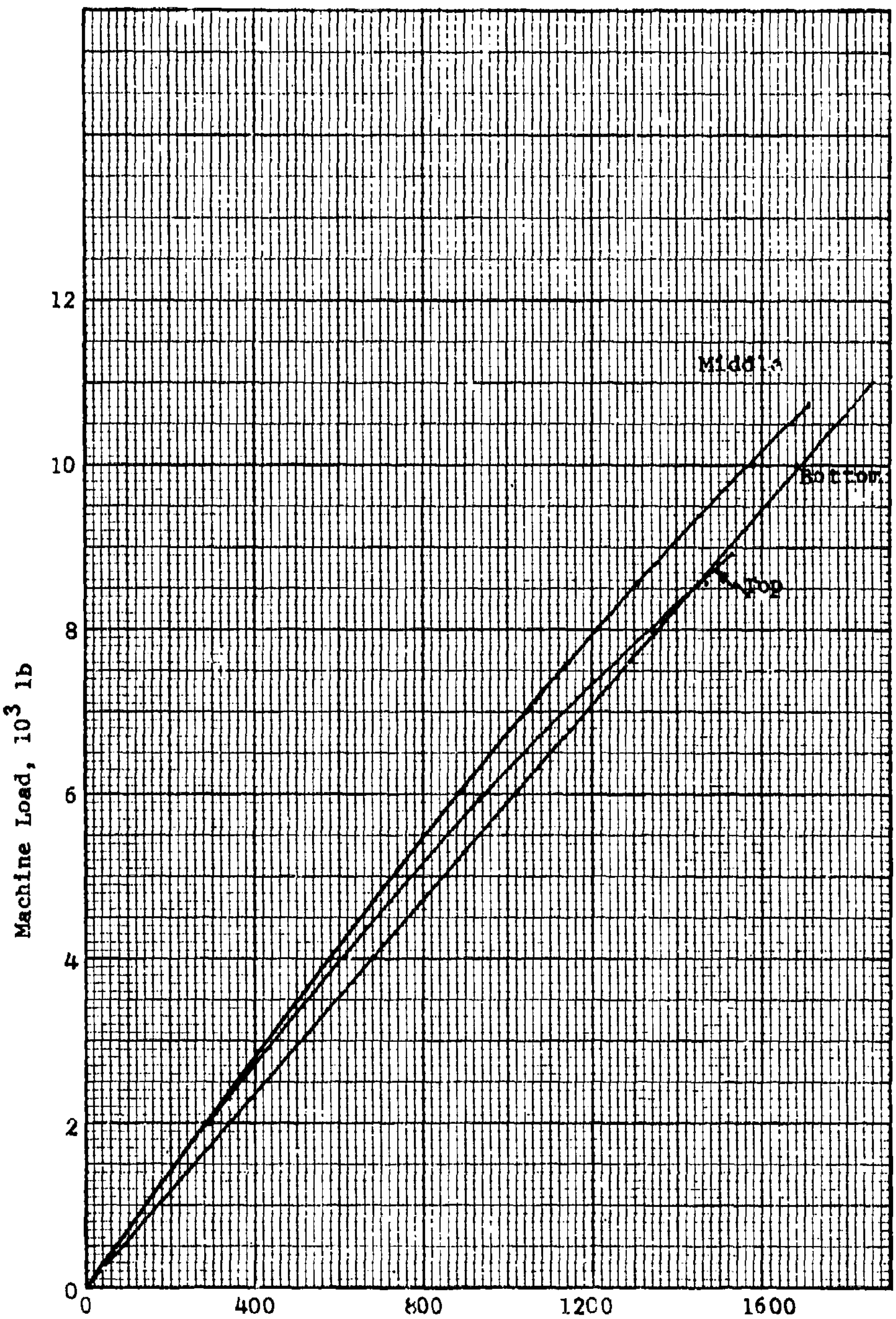
RADIAL STRESS NORMAL TO INSIDE SURFACE OF RING (PSI), AT MACHINE LOAD (10^3 LB)

PLATE 1

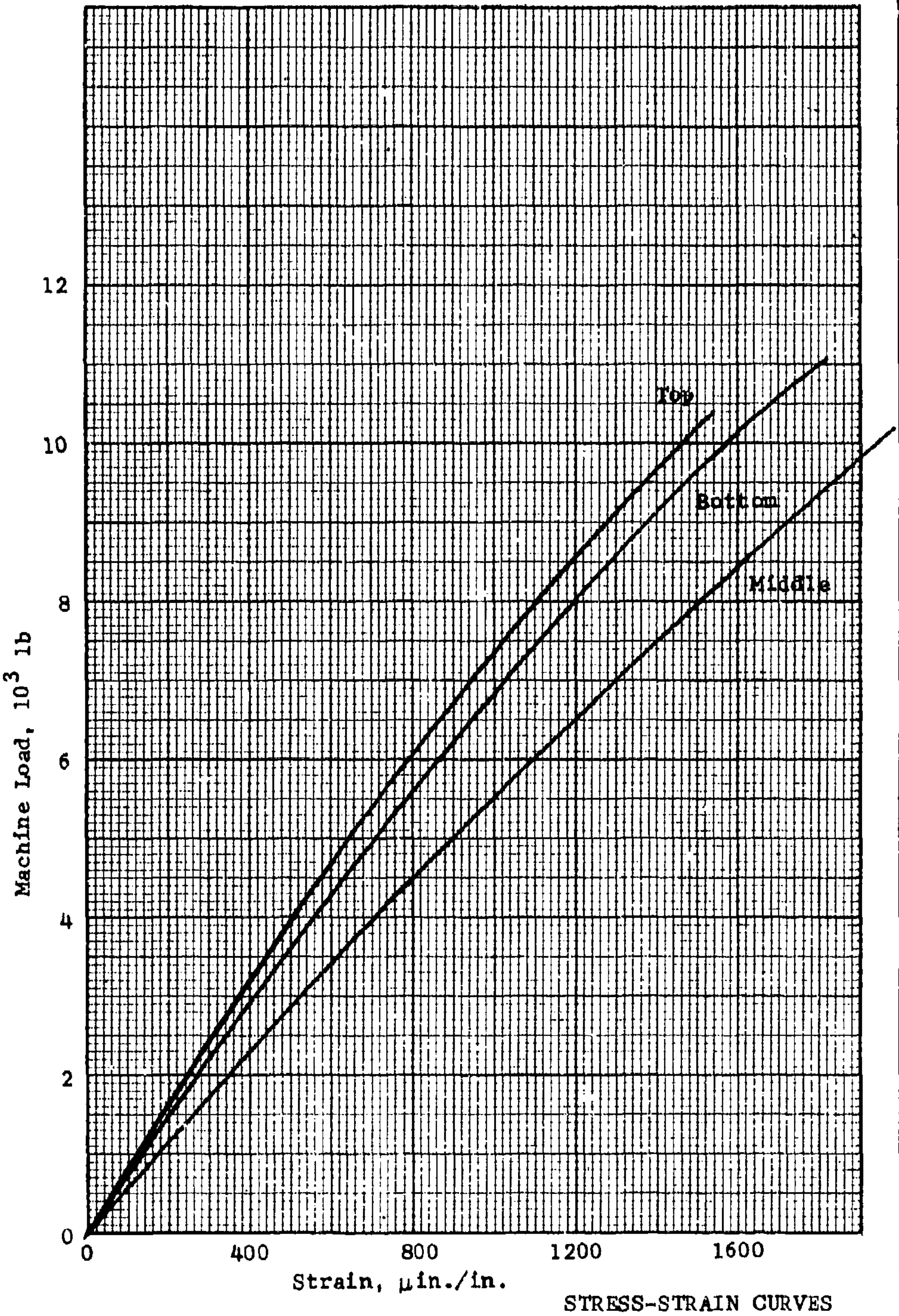


STRESS-STRAIN CURVES
PHASE III
High-Strength Cap
Specimen 5-2, No Rings

WES FORM NO. 1779
JULY 1968



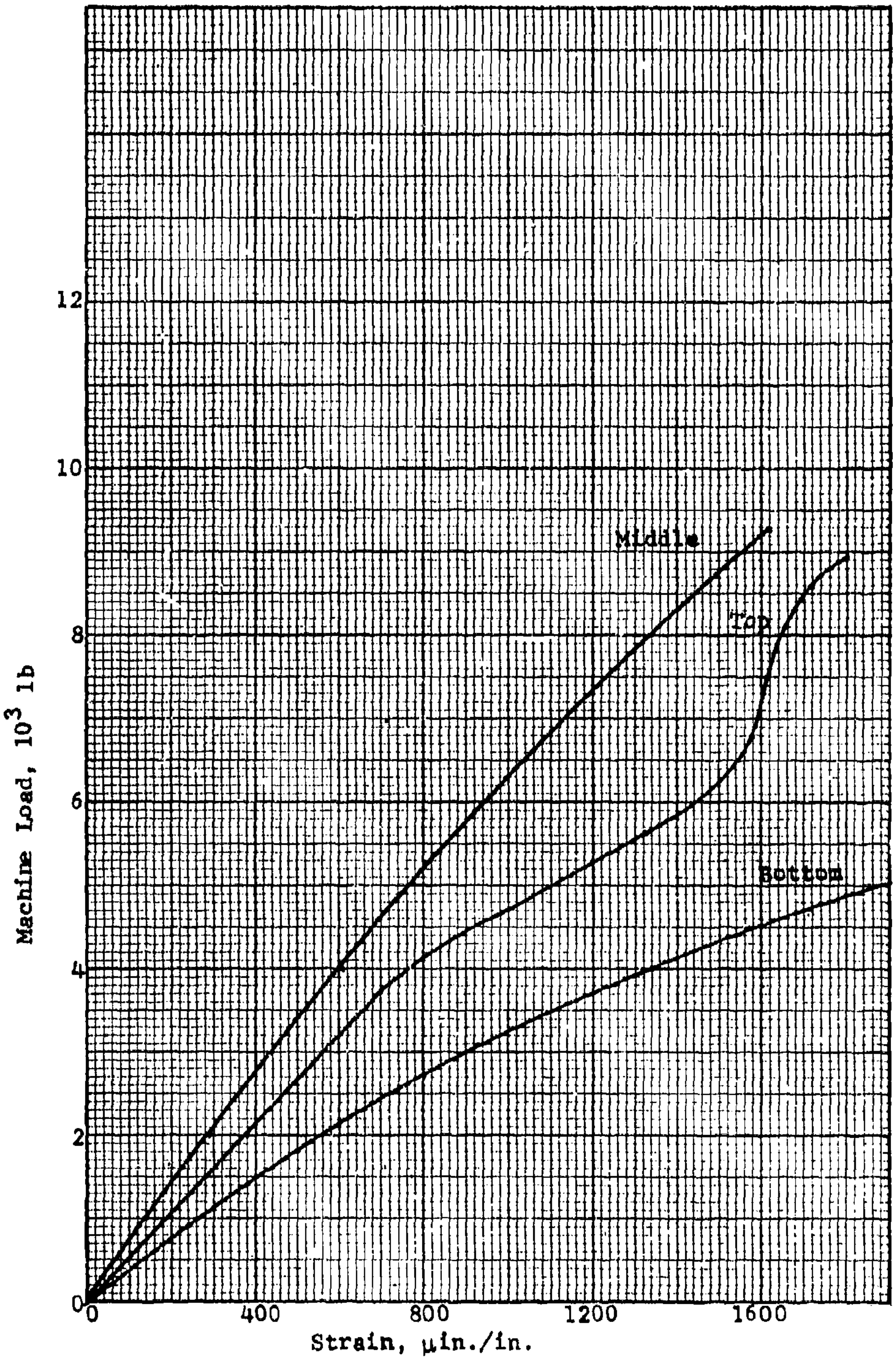
STRESS-STRAIN CURVES
PHASE III
High-Strength Cap
Specimen 5-1, Light Rings



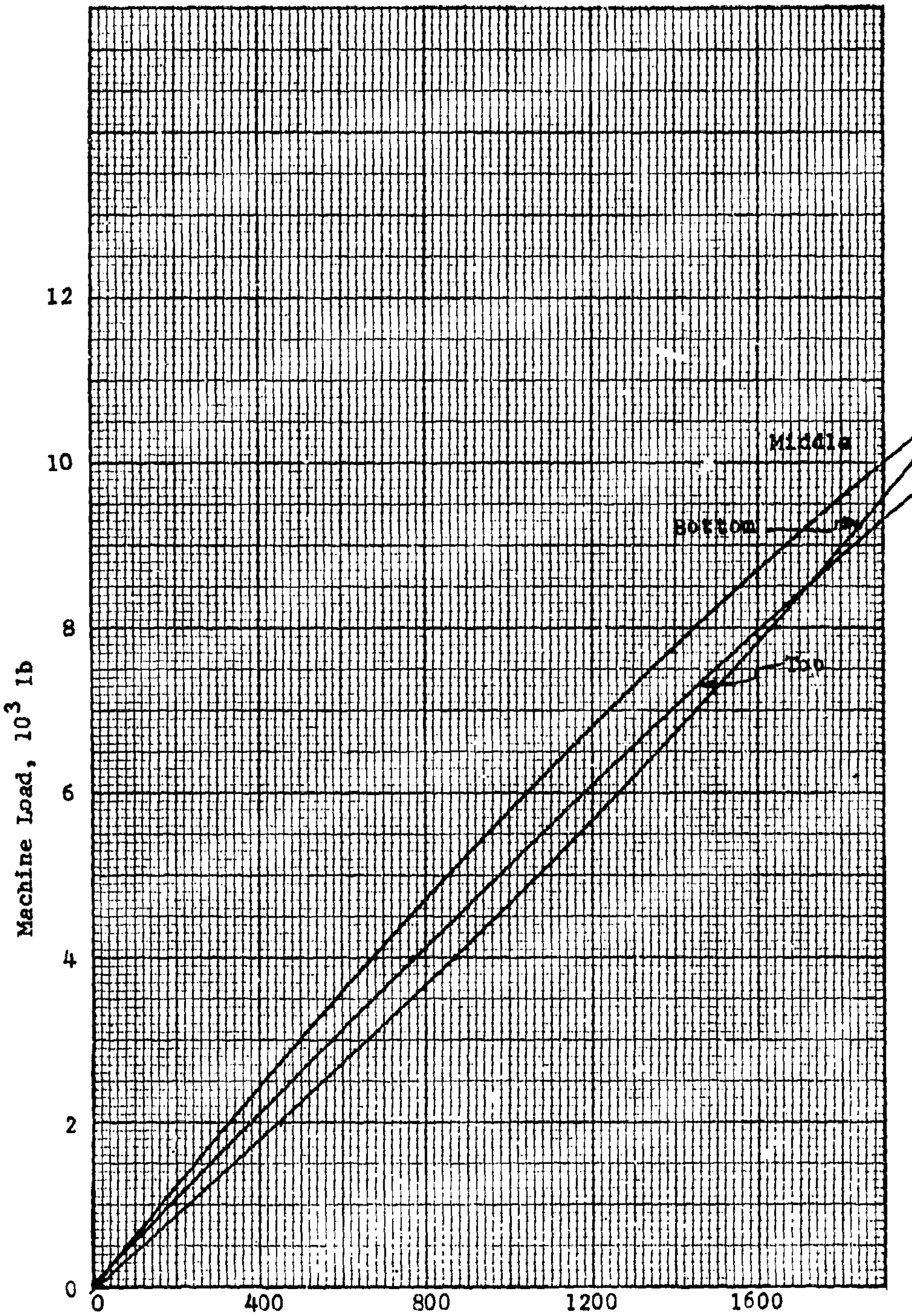
STRESS-STRAIN CURVES
PHASE III
High-Strength Cap
Specimen 5-4, Heavy Rings

WES FORM NO. 1779
JULY 1968

PLATE 2c

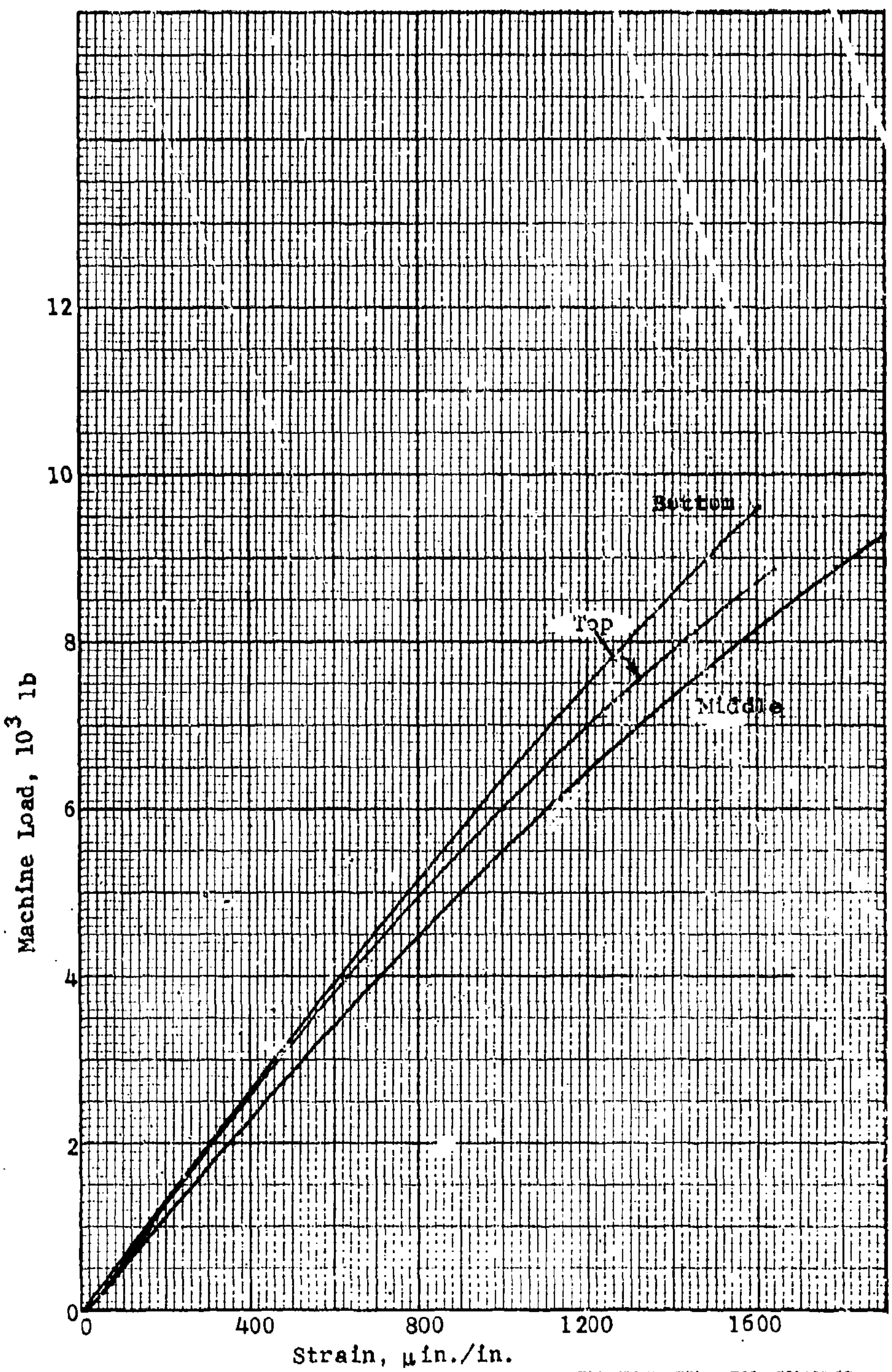


STRESS-STRAIN CURVES
PHASE III
Low-Strength Cap
Specimen 6-2, No Rings



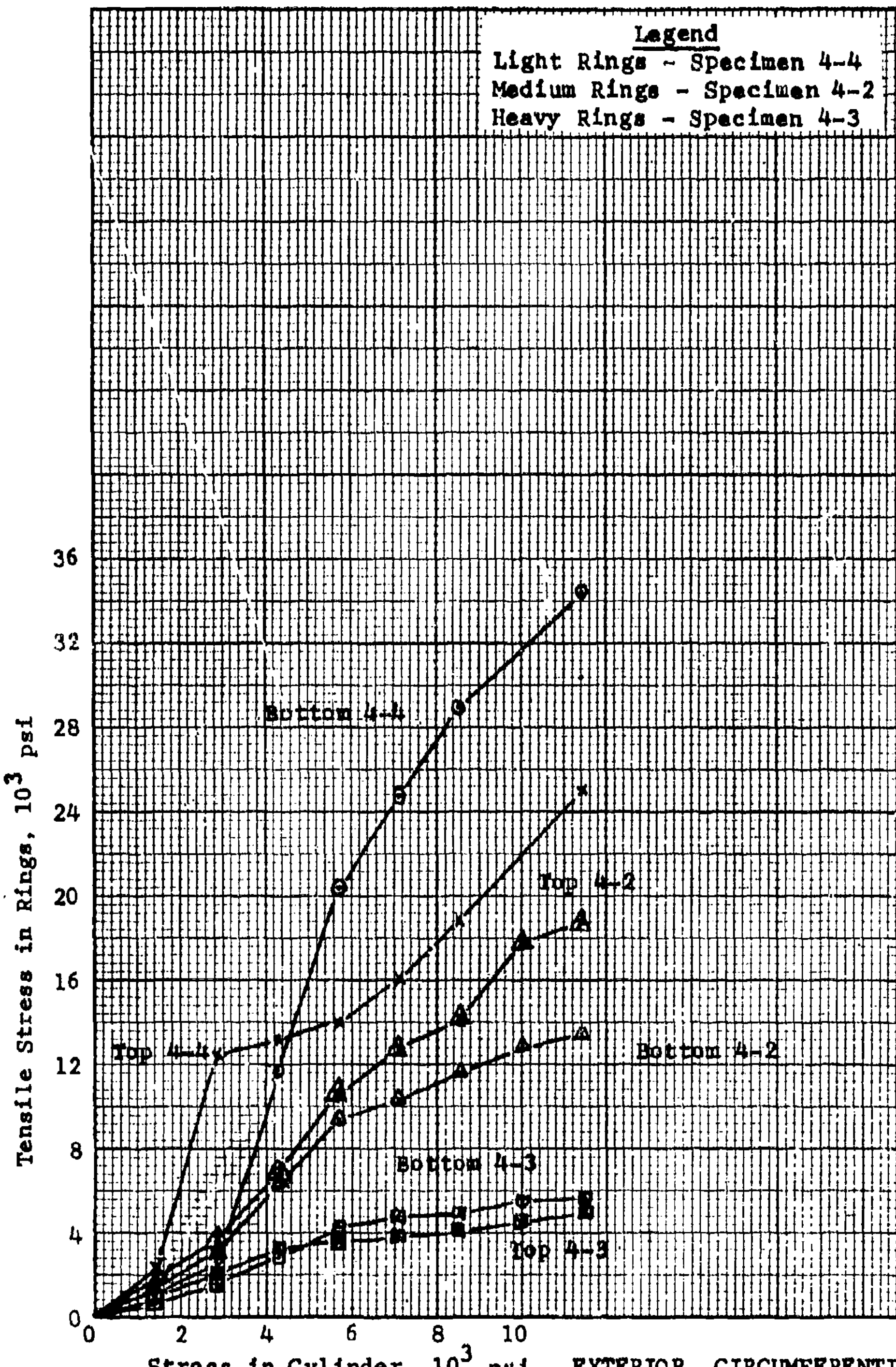
STRESS-STRAIN CURVES
PHASE III
Low-Strength Cap
Specimen 6-1, Light Rings

WES FORM NO. 1779
JULY 1968

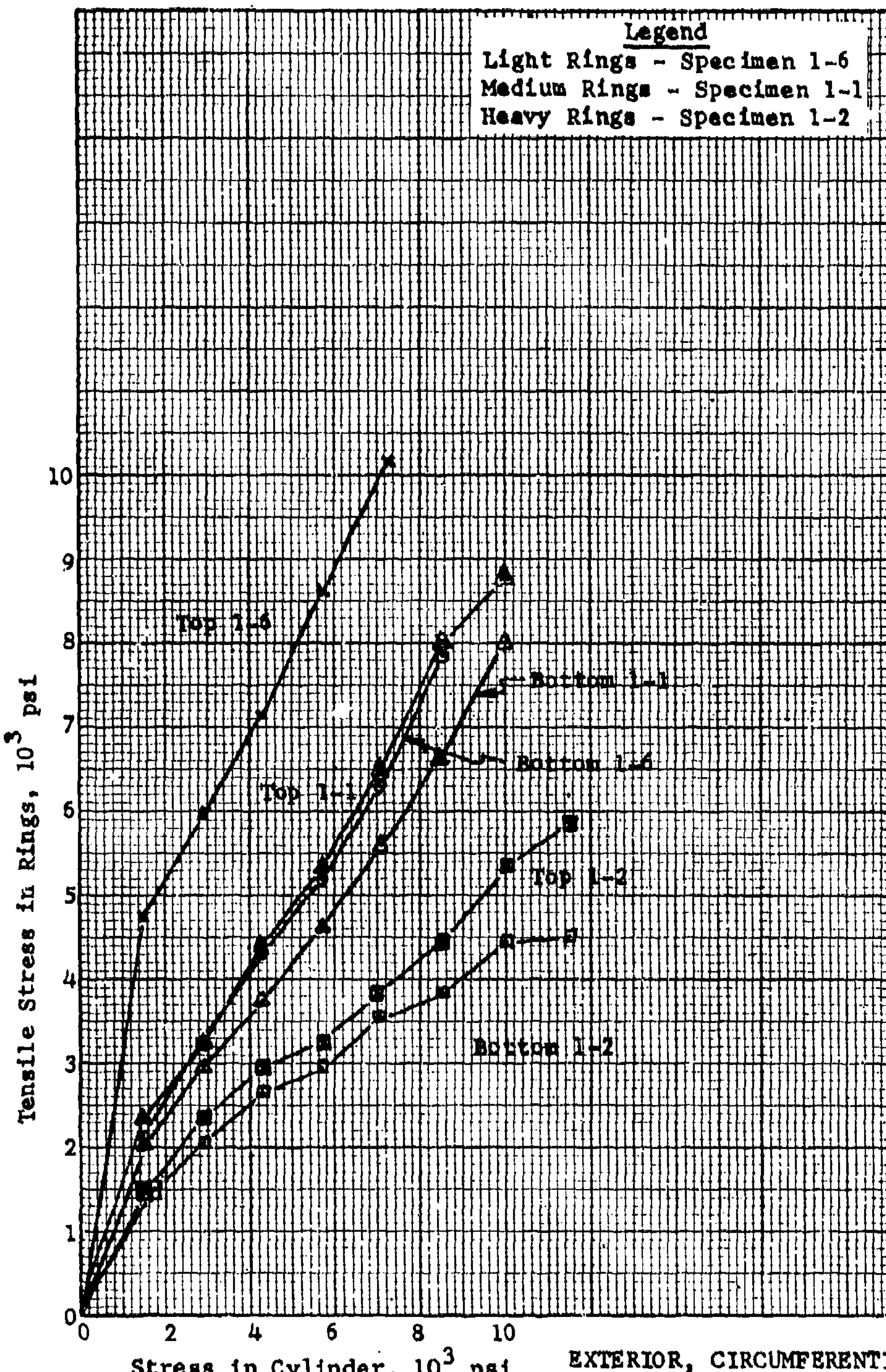


STRESS-STRAIN CURVES
PHASE III
Low-Strength Cap
Specimen 6-4, Heavy Rings

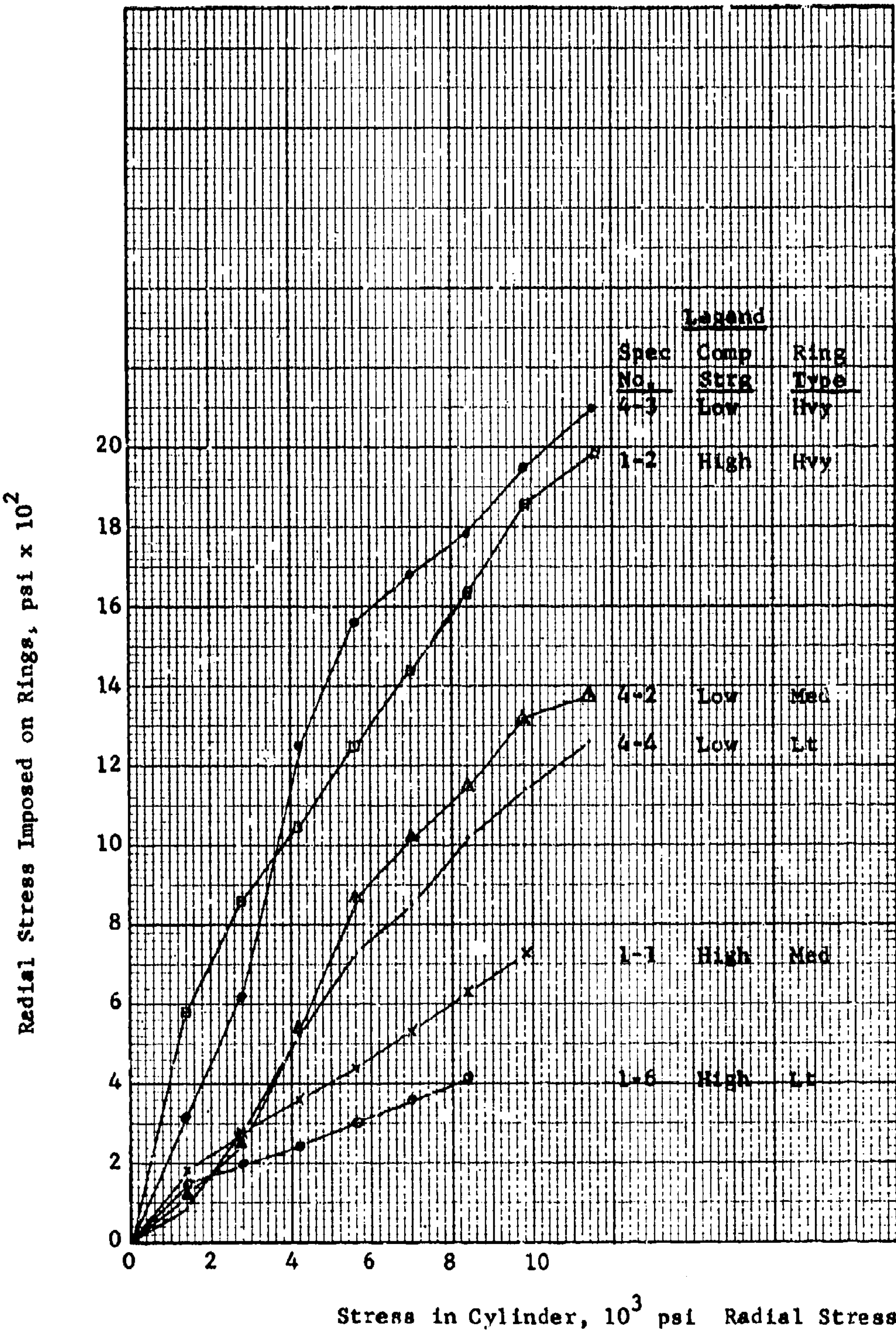
WES FORM NO. 1779
JULY 1968



EXTERIOR, CIRCUMFERENTIAL STRESSES IN RINGS
PHASE III
Low-Strength Compound



EXTERIOR, CIRCUMFERENTIAL STRESSES IN RINGS
PHASE III
High-Strength Compound



Radial Stresses in Rings Phase III

WES FORM NO. 1779
JULY 1958

PLATE 4c

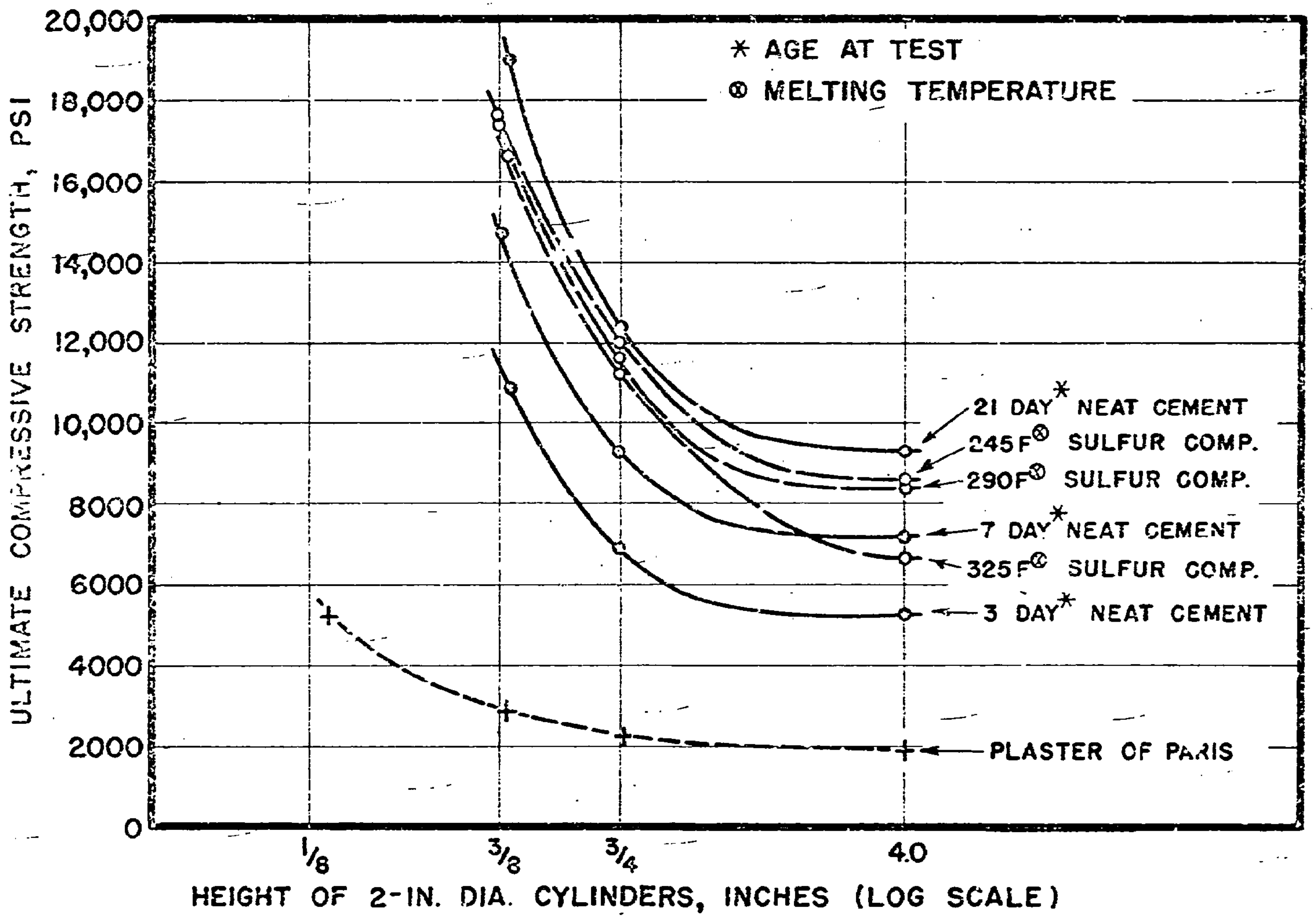


PLATE 5. COMPRESSIVE STRENGTH OF CAPPING MATERIALS