

IOWA STATE HIGHWAY COMMISSION
MATERIALS DEPARTMENT
SPECIAL INVESTIGATIONS SECTION

FINAL REPORT OF R-259

A STUDY OF

Methods to Increase
Durability of Reactive
("D" Cracking)
Coarse Aggregate in
Portland Cement Concrete

AUGUST 15, 1973

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Research Project R-259
Final Report

METHODS TO INCREASE DURABILITY
OF
REACTIVE ("D" CRACKING) COARSE AGGREGATE
IN
PORTLAND CEMENT CONCRETE

August 15, 1973

Ames Laboratory

By

Ronald D. Less

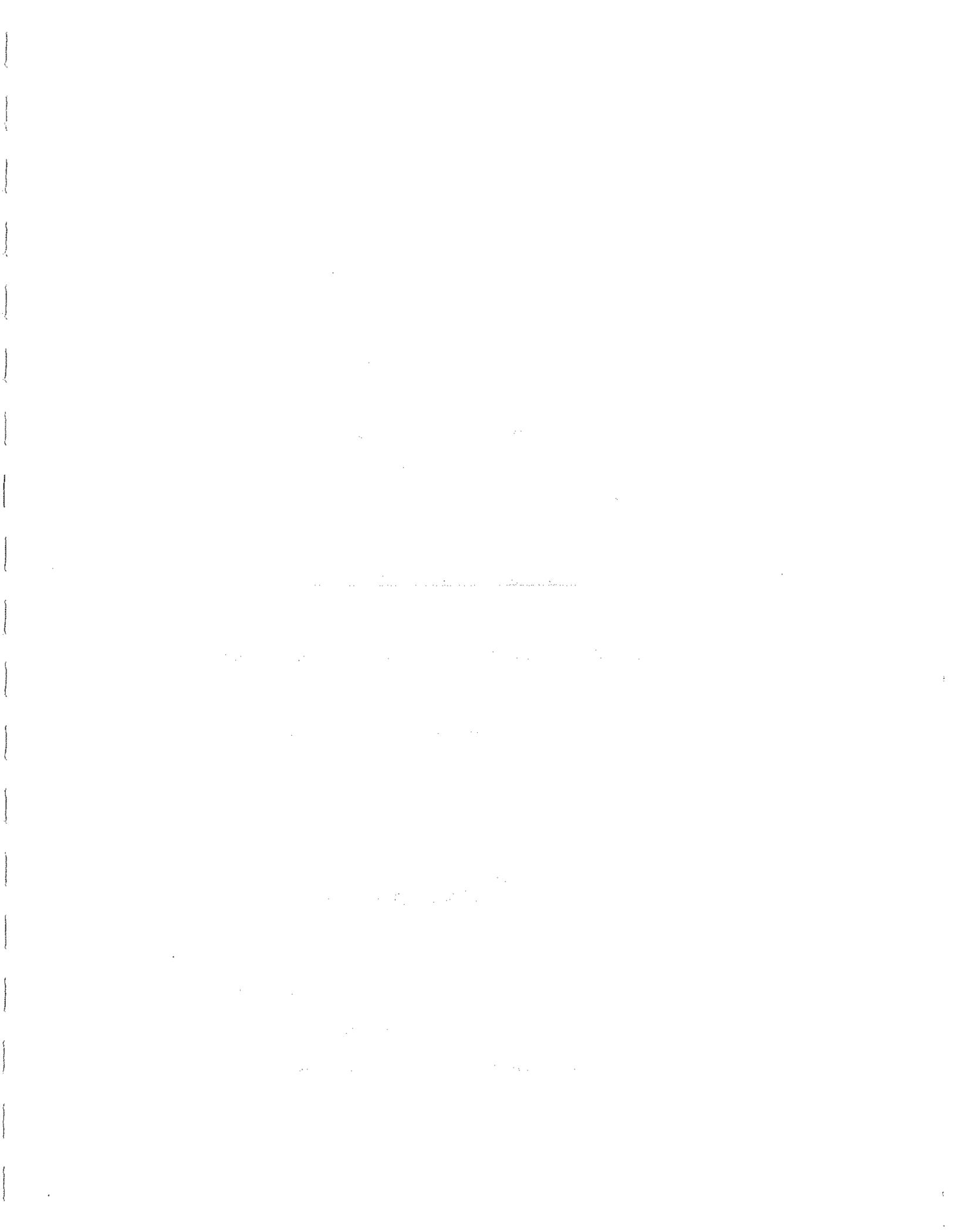
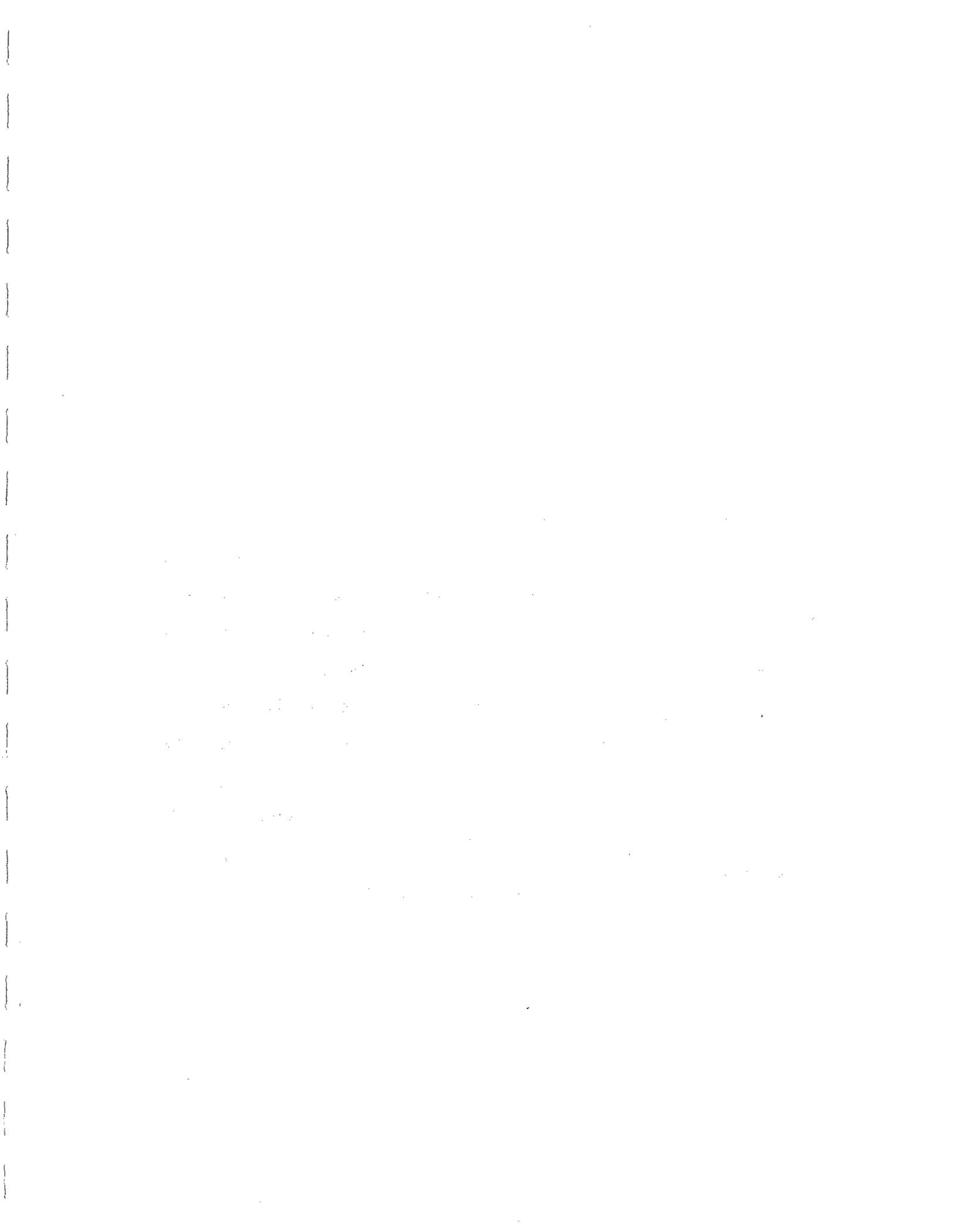


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METHODS TO INCREASE DURABILITY OF REACTIVE ("D" CRACKING) COARSE AGGREGATE IN PORTLAND CEMENT CONCRETE

1.0 Introduction

The coarse aggregates used for Portland Cement concrete in southwest Iowa have exhibited a poor serviceability. This early failure is attributed to a characteristic commonly referred as "D" cracking. "D" line cracking is a discolored area of concrete caused by many fine, parallel hairline cracks. "D" line cracking is primarily caused by the movement of water in and through coarse aggregate with a unique pore structure. The presence of the water in the aggregates at the time of freezing causes the "D" cracking to occur and early failure.

By making the pore structure less permeable to moisture, it is thought the durability factor of the concrete should increase. By drying the aggregate before mixing and then mixing with the cement, the particles of cement should enter the outer pore structure, and upon hydration make the pore structure less permeable to moisture.

2.0 Purpose

The purpose of this project, R-259, is to determine a feasible way of coating coarse aggregate prior to and during the mixing operation in order to increase the durability of the freeze and thaw beams.

3.0 Materials

The Type I cement used in this project was a blend of seven different cements tested under Lab No. AC2-95.

The fine aggregate from Hallett's pit at Ames (Sp. G. 2.67) complied with the standard specification 4110. This sand has been used as a standard for the ASTM C-291 durability work.

The coarse aggregates are limestone samples from the Argentine Limestone formations (Menlo Quarry) and the Winterset Limestone formations (Crescent Quarry). These samples, assigned Lab No. AAC2-19,20,524, and 539, used an AASHO 57 gradation.

The only admixture used was Ad Aire ACA9-24 for air entrainment. This Ad Aire is a vinsol resin produced by Carter Waters of Kansas City, Missouri.

4.0 Laboratory Procedure

Three different mixing procedures were used for both the Menlo and Crescent stone. Each of these mixing procedures was also incorporated in two different mix proportions, B-3 and C-3, as shown in the Standard Specifications.

The coarse aggregate for the standard mixing procedure (1) was soaked for a minimum of 20 hours prior to being spread out and dried to a surface dry condition before mixing. The coarse aggregate for the comparative test specimens (mixing procedure 2 and 3) was oven dried at 225°F. for a minimum of 20 hours and then allowed to come to room temperature before mixing. Proportioning allowances for predetermined absorption of the coarse aggregate were made.

The fine aggregate was air dried and assumed to have an absorption of 0.5%.

4.1 Mixing And Molding Procedure

Mixing Procedure 1:

The mixing procedure for the standard specimens was:

- 1) Weigh and add the fine aggregate
- 2) Weigh and add the cement

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This ensures transparency and allows for easy verification of the data.

In the second section, the author outlines the various methods used to collect and analyze the data. This includes both primary and secondary data collection techniques. The primary data was gathered through direct observation and interviews with key personnel. Secondary data was obtained from internal company reports and industry publications.

The third section details the statistical analysis performed on the collected data. Various statistical tests were used to determine the significance of the findings. The results indicate a strong positive correlation between the variables being studied. This suggests that the factors being examined have a significant impact on the outcome.

Finally, the document concludes with a series of recommendations based on the research findings. These recommendations are designed to help the organization improve its performance and address the issues identified during the study. The author also notes that further research is needed to explore other aspects of the problem.

- 3) Mix for one minute
- 4) Weigh and add the coarse aggregate
- 5) Mix for one minute
- 6) Mix for three minutes while adding the air entraining agent in approximately one half of the required water and then adding water to yield a slump of $2-1/2 \pm 1/2$ inches. The air was adjusted to yield $6 \pm 1\%$. All tests were conducted after step seven was completed.
- 7) The mix was allowed to stand for 15 minutes and was then mixed for three minutes before checking slump and air and making the specimens.

Mixing Procedure 2:

The first mixing procedure for the dry coarse aggregate was:

- 1) Weigh and add the dry coarse aggregate
- 2) Weigh and add cement
- 3) Mix for one minute
- 4) Mix for four minutes while adding mixing water with air entraining agent and then adding the proportioned sand.
- 5) The mix was allowed to stand for 15 minutes and was then mixed for three minutes before checking slump and air and making the specimens.

Mixing Procedure 3:

The second mixing procedure for the dry coarse aggregate was:

- 1) Weigh and add the mixing water with the proper amount air entraining agent
- 2) Weigh and add the cement
- 3) Mix for one minute
- 4) Weigh and add dry coarse aggregate
- 5) Mix for one minute
- 6) Weigh and add the fine aggregate
- 7) Mix for three minutes
- 8) Allow the mix to rest for 15 minutes and then remix for three minutes before checking slump and air and making the specimens.

Molding Procedure:

- 1) Determine and record low pressure air test
- 2) Determine and record slump test
- 3) Mold three 4"x4"x18" Conrad freeze thaw durability specimens by the standard procedure (consolidated in two layers.)
- 4) Mold four 6"x12" horizontal compression specimens by the standard procedure (consolidated in two layers.)

4.2 Curing Methods

The curing of concrete compression specimens was:

- 1) Cover with polyethylene film for 20 to 24 hrs.
- 2) Store in moist room (ASTMC-511) for 25 days.
- 3) Soak in water tank for 48 hours.

The curing of the durability specimens was:

- 1) Cover with polyethylene film for 20 to 24 hrs.
- 2) Store in moist room 89 days (ASTMC-511).
- 3) Soak in 40°F. water bath one day.

4.3 Testing Procedure

Testing for compressive strength will be at 28 days.

Testing for durability was in accordance with ASTM C-666 Procedure B except that:

- 1) The beams were 18" long.
- 2) The beams were not weighed.

5.0 Interpretation of Results

The durability factors, compressive strengths, and growth in percent are tabulated in Table II. The durability test (freezing in air and thawing in water ASTM C-666 Procedure B) was continued for 300 cycles, or until the dynamic modulus was reduced to 60% of the original dynamic modulus, whichever occurred first.

Figure No. I and II are comparisons of the durability factors for the three mixing procedures. The Crescent stone showed a decrease in durability factor from the standard mix (1) for both mixing procedure 2 and 3 and mixes, B-3 and C-3. The Menlo stone exhibited the same decrease in durability factor for C-3 mix. The B-3 mix did show a slight increase in durability factor when compared with mixing procedure 1 (D.F. = 78) to mixing procedure 2 (D.F. = 80).

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is essential for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the need for consistent data collection procedures and the use of advanced analytical techniques to derive meaningful insights from the data.

3. The third part of the document focuses on the role of technology in data management and analysis. It discusses how modern software solutions can streamline data collection, storage, and analysis processes, thereby improving efficiency and accuracy.

4. The fourth part of the document addresses the challenges associated with data management, such as data quality, security, and privacy. It provides strategies to mitigate these risks and ensure that the data remains reliable and secure throughout its lifecycle.

5. The fifth part of the document discusses the importance of data governance and the role of various stakeholders in ensuring that data is used ethically and in compliance with relevant regulations and standards.

6. The sixth part of the document provides a detailed overview of the data lifecycle, from data collection and storage to data analysis and reporting. It emphasizes the need for a clear and consistent data lifecycle framework to support the organization's data management goals.

7. The seventh part of the document discusses the role of data in decision-making and the importance of providing timely and accurate data to support strategic planning and operational decision-making.

8. The eighth part of the document provides a summary of the key findings and recommendations of the study. It highlights the need for a comprehensive data management strategy that addresses all aspects of data collection, storage, analysis, and governance.

9. The ninth part of the document provides a list of references and sources used in the study. It includes books, articles, and other publications that provide additional information on the topics discussed in the document.

10. The tenth part of the document provides a list of appendices and supplementary materials. These materials include detailed data collection forms, analysis scripts, and other documents that provide additional information on the study's methodology and findings.

The comparisons of the compressive strengths are shown on Figures 3 and 4. For both the Menlo and Crescent stone, the compressive strength (P.S.I.) increased above the standard (1) for mixing procedures 2 and 3. This increase would indicate the cement has entered the pores of the coarse aggregate and has caused much better matrix-aggregate bond. Also mixing procedure 3 with the cement, water and air entraining agent mixed together before mixing with the coarse aggregate showed increased strengths over mixing procedure 2 with the coarse aggregate and cement mixed together before adding water.

From Table II, the comparison of growth of the test beams can be made. The Menlo stone showed an increase in growth from mixing procedure 1 through 3 for both the B-3 and C-3 mix. The Crescent stone reached the 60% of original frequency before the 300 cycles were complete. However, the same general trend can be realized when the number of cycles are considered.

7.0 Summary

In Conclusion:

- 1) The durability results of mixing procedures 2 and 3 did not indicate a feasible way of coating the coarse aggregate prior to or during the mixing operation.
- 2) Mixing procedures 2 and 3 did improve compressive strength, but due to construction problems and the decrease in durability mentioned above, both procedures can not be utilized.

TABLE I

Absolute Volume and Batch Weights

| <u>Material</u> | Mix Number | | | |
|------------------|--------------------|-----------------------------|--------------------|-----------------------------|
| | B-3 | | C-3 | |
| | Absolute Volume | Weights 1 cu. yd. | Absolute Volume | Weights 1 cu. yd. |
| Cement | .090539 | 479 | .114172 | 604 |
| Water | .152017 | 256 | .153840 | 259 |
| Air | .060000 | ** | .060000 | ** |
| Fine Aggregate | .313850 | 1412 | .301895 | 1358 |
| Coarse Aggregate | .383594 | Menlo 1719 Crescent 1707 | .370093 | Menlo 1659 Crescent 1647 |

** Air agent at 1 fluid ounce per sack of cement.

| Year | 1910 | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Population | 100 | 105 | 110 | 115 | 120 | 125 | 130 | 135 | 140 | 145 | 150 | 155 | 160 | 165 | 170 | 175 | 180 | 185 | 190 | 195 | 200 | 205 | 210 | 215 | 220 | 225 | 230 | 235 | 240 | 245 | 250 | 255 | 260 | 265 | 270 | 275 | 280 | 285 | 290 | 295 | 300 | 305 | 310 | 315 | 320 | 325 | 330 | 335 | 340 | 345 | 350 | 355 | 360 | 365 | 370 | 375 | 380 | 385 | 390 | 395 | 400 | 405 | 410 | 415 | 420 | 425 | 430 | 435 | 440 | 445 | 450 | 455 | 460 | 465 | 470 | 475 | 480 | 485 | 490 | 495 | 500 | 505 | 510 | 515 | 520 | 525 | 530 | 535 | 540 | 545 | 550 | 555 | 560 | 565 | 570 | 575 | 580 | 585 | 590 | 595 | 600 | 605 | 610 | 615 | 620 | 625 | 630 | 635 | 640 | 645 | 650 | 655 | 660 | 665 | 670 | 675 | 680 | 685 | 690 | 695 | 700 | 705 | 710 | 715 | 720 | 725 | 730 | 735 | 740 | 745 | 750 | 755 | 760 | 765 | 770 | 775 | 780 | 785 | 790 | 795 | 800 | 805 | 810 | 815 | 820 | 825 | 830 | 835 | 840 | 845 | 850 | 855 | 860 | 865 | 870 | 875 | 880 | 885 | 890 | 895 | 900 | 905 | 910 | 915 | 920 | 925 | 930 | 935 | 940 | 945 | 950 | 955 | 960 | 965 | 970 | 975 | 980 | 985 | 990 | 995 | 1000 |
| Area | 100 | 105 | 110 | 115 | 120 | 125 | 130 | 135 | 140 | 145 | 150 | 155 | 160 | 165 | 170 | 175 | 180 | 185 | 190 | 195 | 200 | 205 | 210 | 215 | 220 | 225 | 230 | 235 | 240 | 245 | 250 | 255 | 260 | 265 | 270 | 275 | 280 | 285 | 290 | 295 | 300 | 305 | 310 | 315 | 320 | 325 | 330 | 335 | 340 | 345 | 350 | 355 | 360 | 365 | 370 | 375 | 380 | 385 | 390 | 395 | 400 | 405 | 410 | 415 | 420 | 425 | 430 | 435 | 440 | 445 | 450 | 455 | 460 | 465 | 470 | 475 | 480 | 485 | 490 | 495 | 500 | 505 | 510 | 515 | 520 | 525 | 530 | 535 | 540 | 545 | 550 | 555 | 560 | 565 | 570 | 575 | 580 | 585 | 590 | 595 | 600 | 605 | 610 | 615 | 620 | 625 | 630 | 635 | 640 | 645 | 650 | 655 | 660 | 665 | 670 | 675 | 680 | 685 | 690 | 695 | 700 | 705 | 710 | 715 | 720 | 725 | 730 | 735 | 740 | 745 | 750 | 755 | 760 | 765 | 770 | 775 | 780 | 785 | 790 | 795 | 800 | 805 | 810 | 815 | 820 | 825 | 830 | 835 | 840 | 845 | 850 | 855 | 860 | 865 | 870 | 875 | 880 | 885 | 890 | 895 | 900 | 905 | 910 | 915 | 920 | 925 | 930 | 935 | 940 | 945 | 950 | 955 | 960 | 965 | 970 | 975 | 980 | 985 | 990 | 995 | 1000 |

TABLE NO. II

Durability Factor, Compressive Strengths, and Growths

| Quarry | Mixing Procedure | Mix | Durability Factor | Compressive Strength (PSI) | Growth at Cycles (In.) * |
|----------|------------------|-----|-------------------|----------------------------|--------------------------|
| Menlo | 1 | B-3 | 78 | 3780 | .051 300 |
| | | C-3 | 70 | 4530 | .047 300 |
| | | B-3 | 80 | 4230 | .054 300 |
| | 2 | C-3 | 63 | 4900 | .089 300 |
| | | B-3 | 56 | 4305 | .085 282 |
| | | C-3 | 44 | 4910 | .098 220 |
| | 3 | B-3 | 66 | 4025 | .114 300 |
| | | C-3 | 59 | 4590 | .153 295 |
| | | B-3 | 39 | 4290 | .098 196 |
| Crescent | 1 | C-3 | 52 | 4900 | .140 261 |
| | | B-3 | 58 | 4490 | .132 290 |
| | | C-3 | 40 | 5280 | .125 198 |
| | 2 | B-3 | 39 | 4290 | .098 196 |
| | | C-3 | 52 | 4900 | .140 261 |
| | | B-3 | 58 | 4490 | .132 290 |
| 3 | B-3 | 58 | 4490 | .132 290 | |
| | C-3 | 40 | 5280 | .125 198 | |
| | B-3 | 39 | 4290 | .098 196 | |

* Growth was measured at 300 cycles or 60% of original frequency, whichever occurred first.

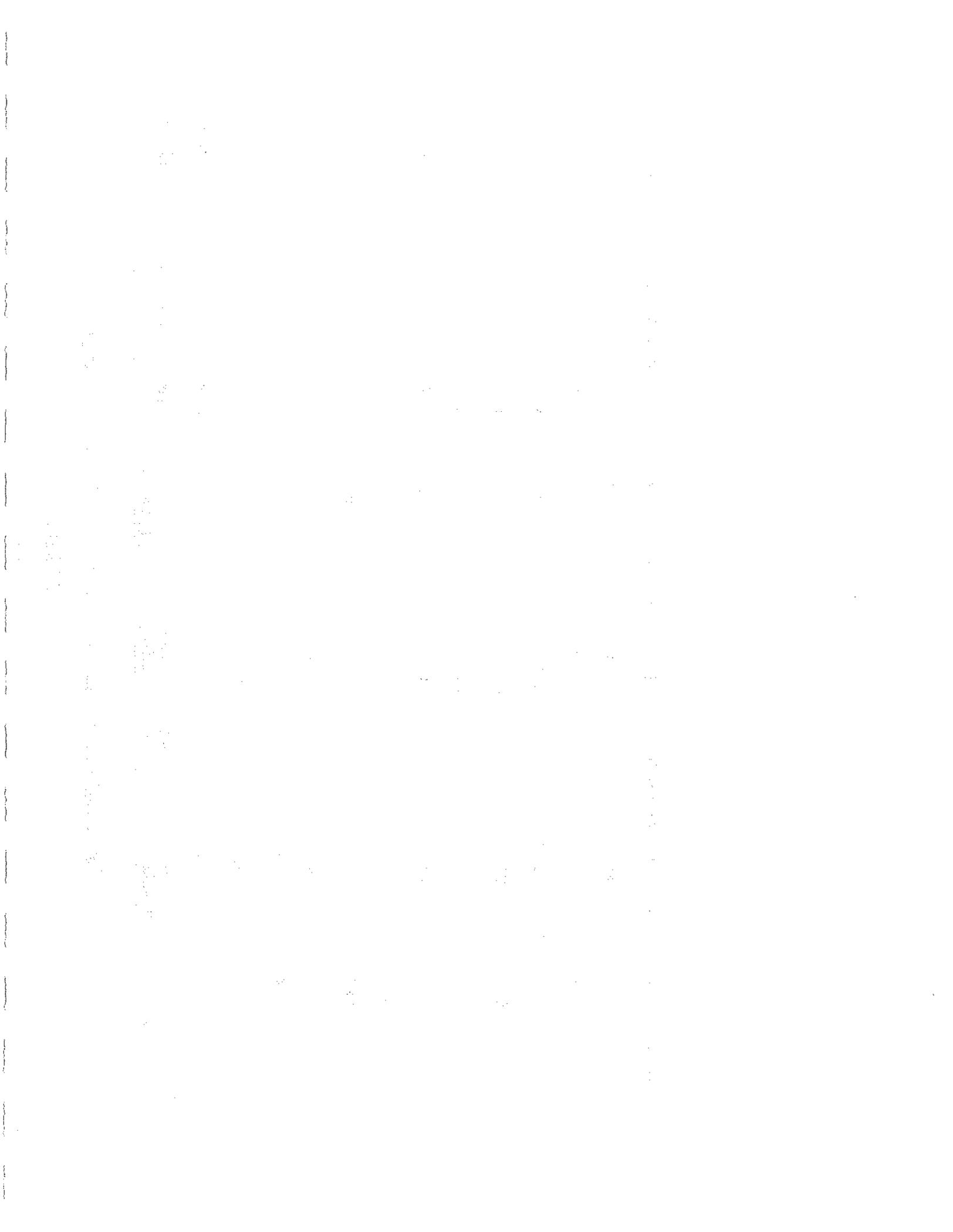
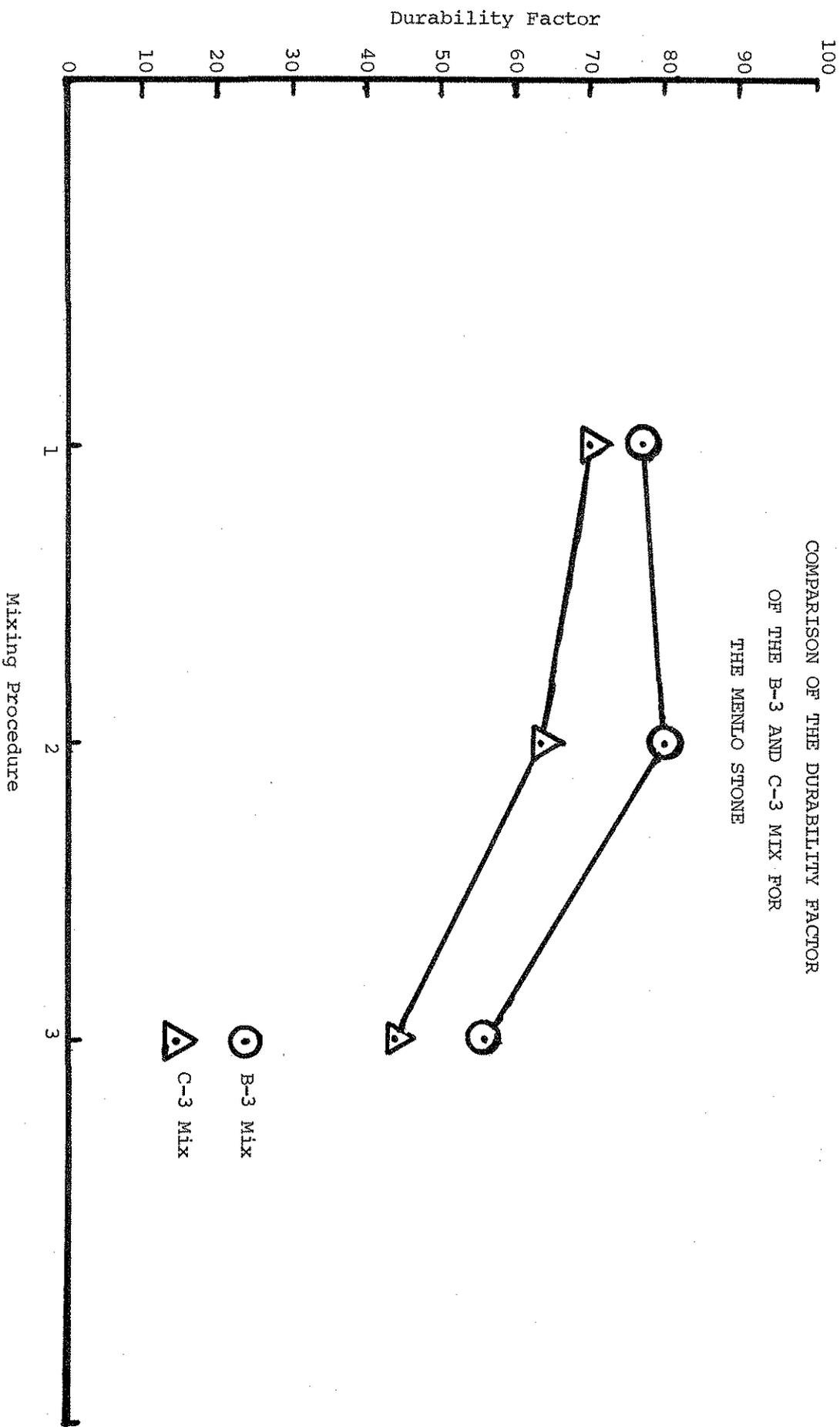


FIGURE I

COMPARISON OF THE DURABILITY FACTOR
OF THE B-3 AND C-3 MIX FOR
THE MENTLO STONE



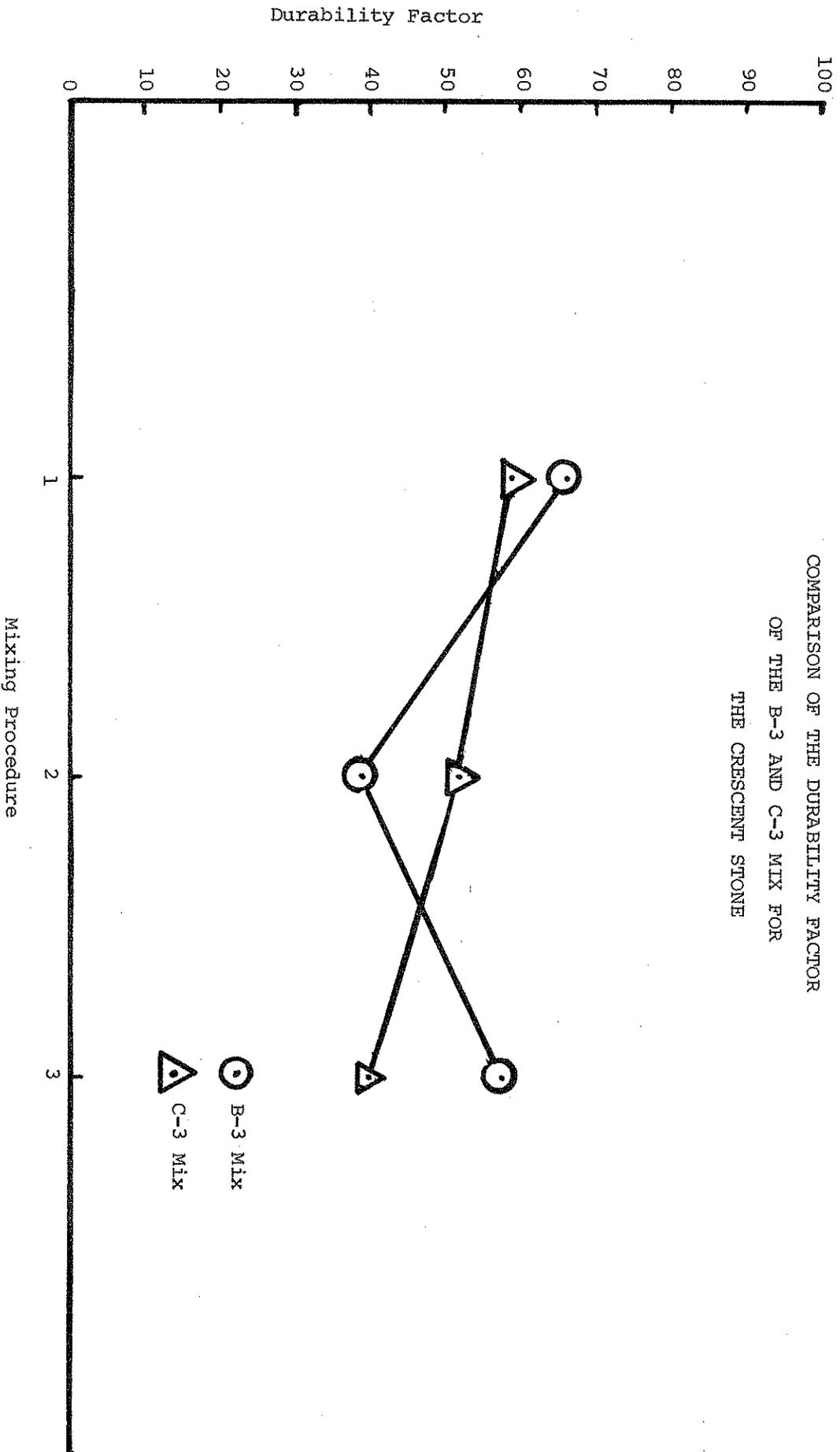
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FIGURE II

COMPARISON OF THE DURABILITY FACTOR
OF THE B-3 AND C-3 MIX FOR
THE CRESCENT STONE



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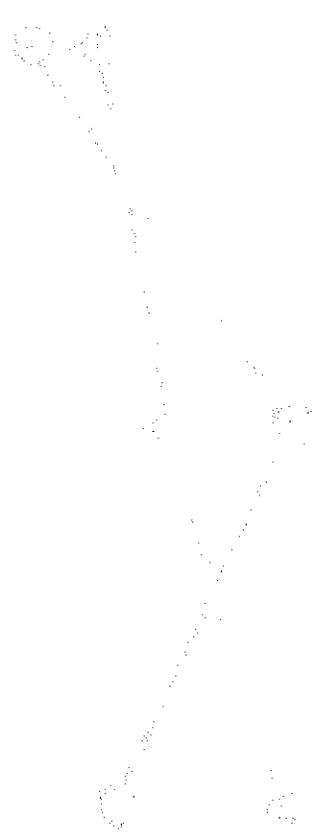
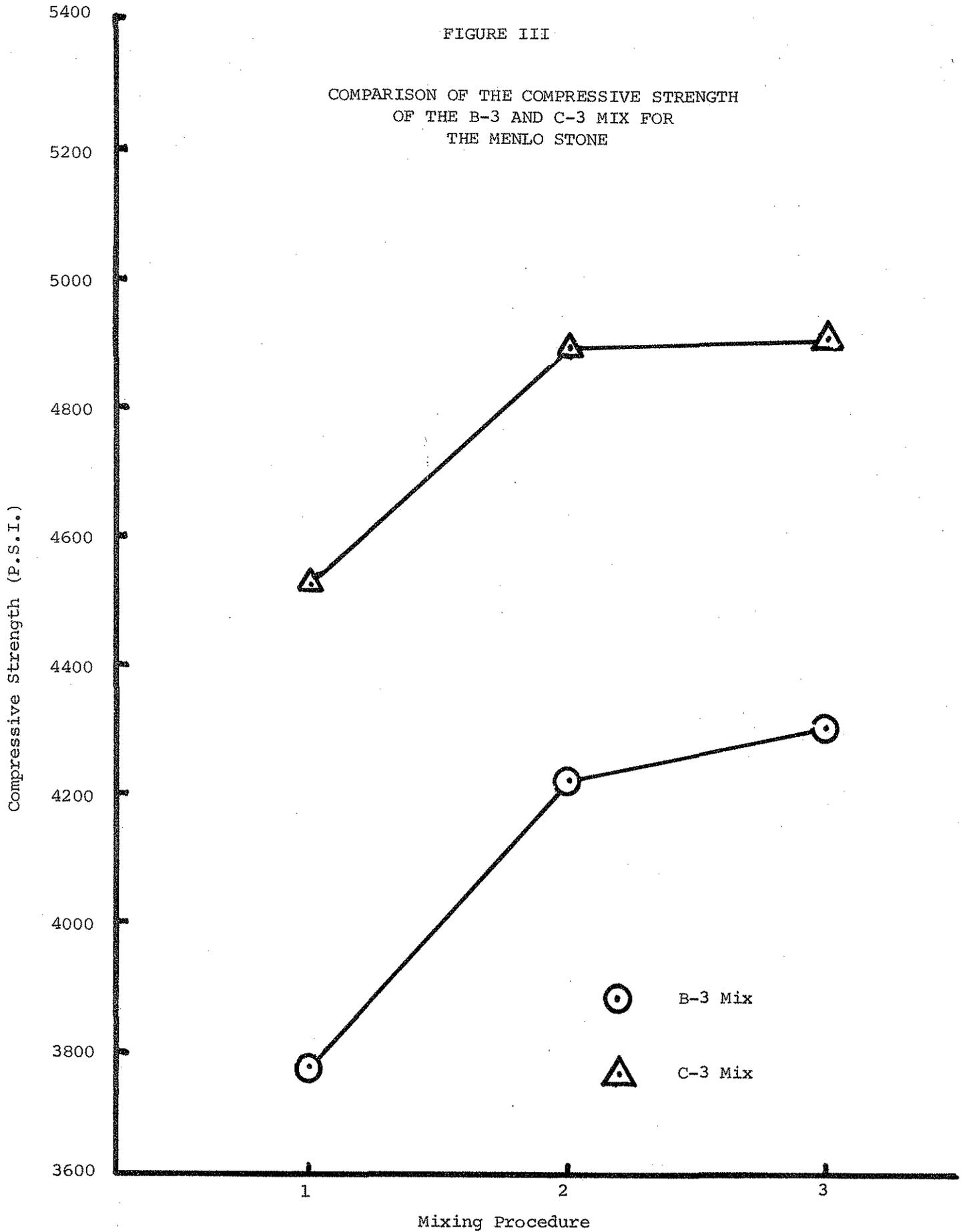


FIGURE III

COMPARISON OF THE COMPRESSIVE STRENGTH
OF THE B-3 AND C-3 MIX FOR
THE MENLO STONE



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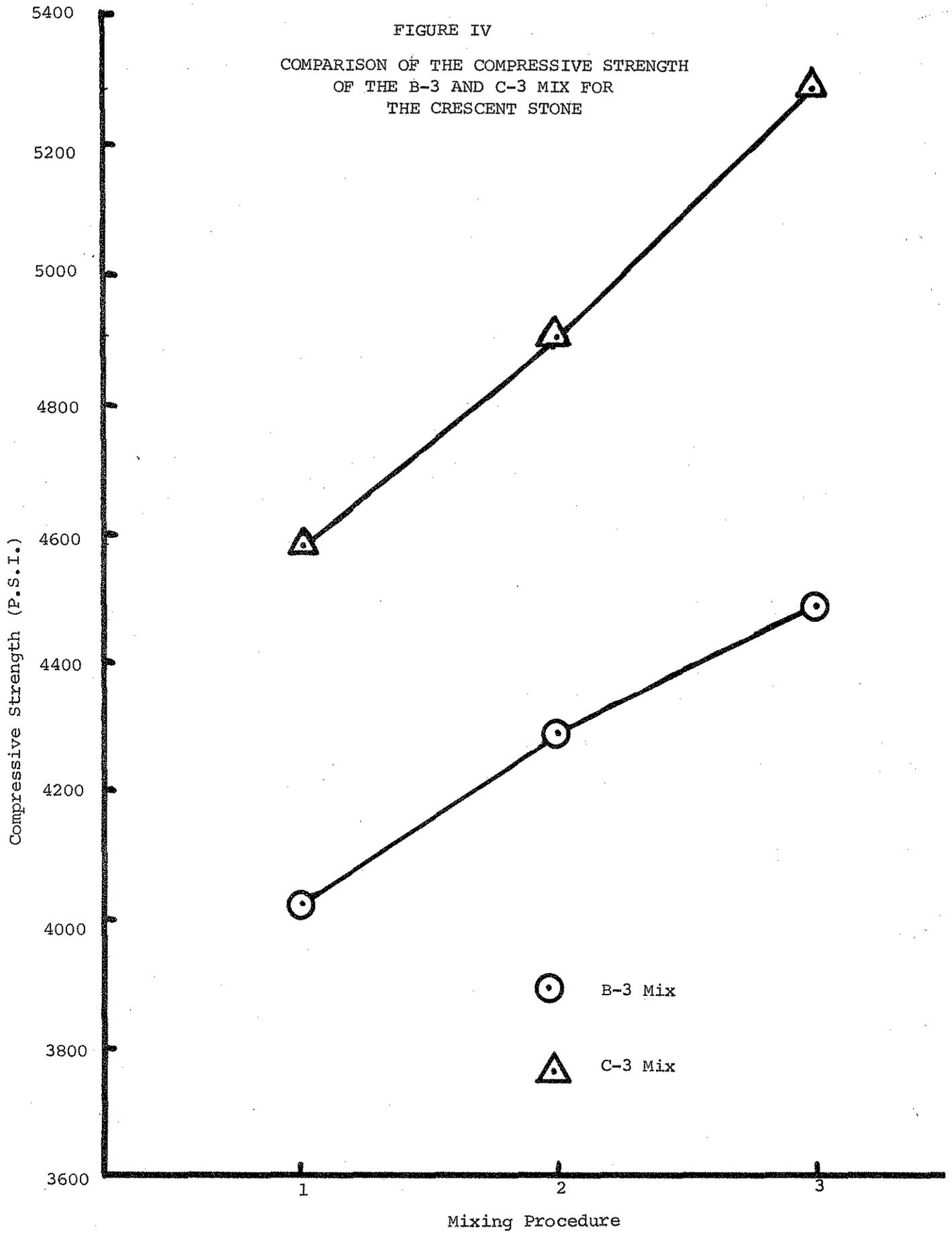
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15. The fifteenth part of the document is a list of names and addresses of the members of the committee.

FIGURE IV

COMPARISON OF THE COMPRESSIVE STRENGTH
OF THE B-3 AND C-3 MIX FOR
THE CRESCENT STONE



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