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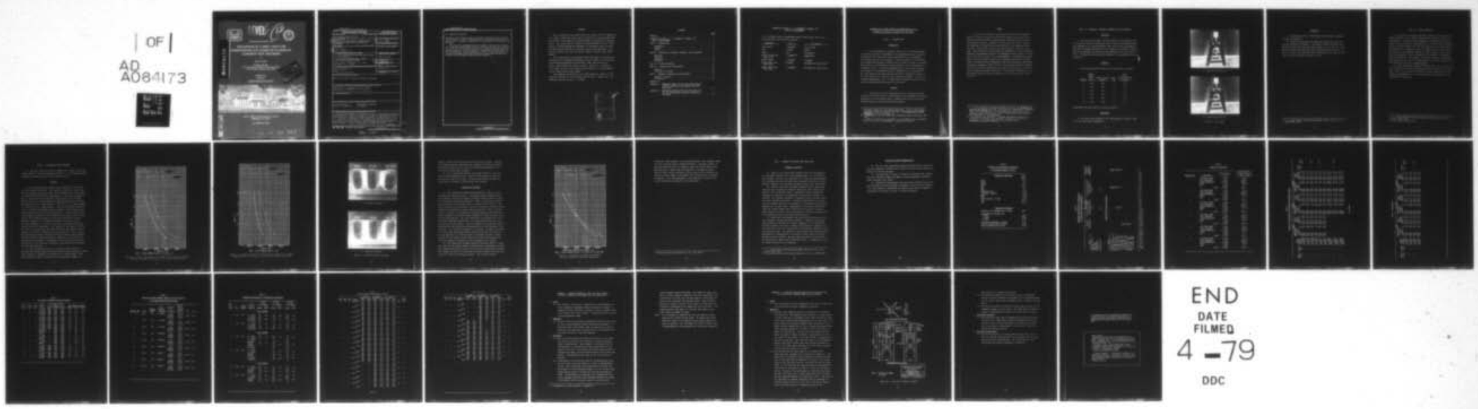

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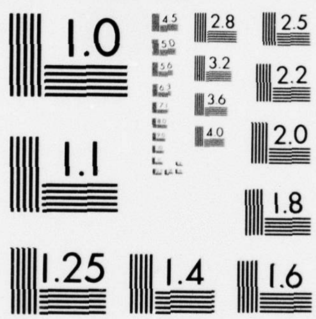

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MISCELLANEOUS PAPER C-78-17

EVALUATION OF A DROP TABLE FOR CONSOLIDATING 6-IN.-DIAMETER CYLINDRICAL CONCRETE TEST SPECIMENS

by

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December 1978

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under CWIS No. 31138

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Miscellaneous Paper C-78-17	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF A DROP TABLE FOR CONSOLIDATING 6-IN.-DIAMETER CYLINDRICAL CONCRETE TEST SPECIMENS		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Steven A. Ragan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Concrete Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS No. 31138
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE December 1978 13. NUMBER OF PAGES 33
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 38 p.		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(14) WES-MP-C-78-17

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Concrete cylinders
Concrete test specimens
Consolidation (Concrete)
Drop tables

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

A drop-table apparatus was evaluated by the U. S. Army Engineer Waterways Experiment Station (WES) to determine if it should be standardized and used for consolidating 6-in.-diameter cylindrical specimens of fresh concrete by the U. S. Army Corps of Engineers. Test specimens were fabricated from six concrete mixtures of three different slumps using both the drop-table method and the rodding and vibration methods, currently authorized by CRD-C 10-78 (ASTM C 192-76). Density and compressive strength tests were (Continued)

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20. ABSTRACT (Continued).

conducted on the specimens after they had been continuously moist cured for selected periods of time. Standard deviations were calculated from the test data in order to compare the uniformity of consolidation of each fabrication procedure.

The drop table consolidated the 6-in.-diameter concrete test specimens in a relatively uniform manner; however, the density and compressive strength test values were consistently lower than those obtained from the rodded and vibrated specimens. If it were decided to standardize procedures which produce drop-table test results comparable to those of current procedures, additional investigative work using alternative mold-filling techniques and varying height and number of drops would be required.

PREFACE

This investigation was authorized by the Office, Chief of Engineers, U. S. Army, in ENG Form 4417-R, dated 1 August 1977, covering CWIS Work Unit 31138, "Investigation of Testing Methods and Apparatus," paragraph 15b(1). The study relates to Mission Problem Statement 3-155-1, "Evaluation of Testing Methods and Equipment in Developing Design Criteria and Construction Evaluation of Concrete and Concrete Materials." The Technical Monitor for this work was Mr. James A. Rhodes, HQDA, DAEN-CWE-DC.

The investigation was conducted during 1977-1978 at the Structures Laboratory (SL), Engineering Mechanics Division (EMD), U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Messrs. Bryant Mather and John M. Scanlon. Messrs. K. L. Saucier, S. A. Ragan, and W. B. Lee actively participated in the investigation, and Mr. Ragan prepared this report.

The Commander and Director of the WES during the conduct of this study and preparation of this report was COL John L. Cannon, CE. The Technical Director was Mr. F. R. Brown.

CONTENTS

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

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

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.59327631	kilograms per cubic metre

EVALUATION OF A DROP TABLE FOR CONSOLIDATING 6-IN.-DIAMETER CYLINDRICAL CONCRETE TEST SPECIMENS

PART I: INTRODUCTION

Background

1. In the ASTM Book of Standards there are two standard methods for making concrete test specimens in the laboratory and in the field (C192 and C31).* There are also two procedures for consolidating cylindrical concrete test specimens. The two methods of consolidation are rodding and vibration; vibration may be either internal or external. The results of each method can vary according to the individual performing the test. A drop-table apparatus has recently been suggested as a method of consolidating concrete compression test specimens.** Mr. Lane reported that more uniform results are obtained by the use of the drop table due to reduction in the operator variable. If this is a general phenomenon, the U. S. Army Corps of Engineers would be interested in standardizing and using the drop table.

Purpose

2. The purpose of this investigation was to evaluate the effectiveness of the drop table for consolidating 6-in.†-diameter cylindrical specimens of fresh concrete, and to compare these results with those obtained using the currently authorized methods.

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* American Society for Testing and Materials, "Concrete and Mineral Aggregates; Manual of Concrete Testing," 1977 Annual Book of ASTM Standards, 1977, Philadelphia, Pa.

** Communication with Mr. Ralph Lane, Tennessee Valley Authority, July 1977.

† A table of factors for converting U. S. customary units of measurement to SI units of measurement is presented on page 3.

Scope

3. Six concrete mixtures, proportioned to give three different values of slump by varying the water-cement ratio (w/c), were used as control mixtures from which specimens were fabricated using the three consolidation methods: rodding, vibration, and drop table. Density and compressive strength tests were conducted on the specimens after they were continuously cured for selected periods of time in a moist room. Each mixture was air-entrained and contained a 1-1/2-in. nominal maximum size aggregate and had a fine aggregate content equal to 37 percent of the solid volume of the total aggregate. Specimens were fabricated from each mixture using both the drop-table procedures as specified in a proposed method (Appendix A) and the conventional fabrication procedures presented in CRD-C 10-78.* The resulting data were grouped according to specimen fabrication technique for the purpose of calculating and comparing standard deviations. The standard deviations of the drop-table specimens were also compared to the criteria given in ACI 214-77.**

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* U. S. Army Engineer Waterways Experiment Station, CE, Handbook for Concrete and Cement, Aug 1949 (with quarterly supplements), Vicksburg, Miss. This test method is also published as American Society for Testing and Materials Method C 192-76, "Making and Curing Concrete Test Specimens in the Laboratory."

** American Concrete Institute, "Standard Recommended Practice for Evaluation of Strength Tests Results of Concrete," ACI 214-77, ACI Manual of Concrete Practice, 1977, Detroit, Mich.

PART II: MATERIALS, MIXTURES, APPARATUS, AND PROCEDURES

Materials

4. Type I portland cement (RC-778), natural fine aggregate (CL-2 S-2), and a solution of neutralized vinsol resin air-entraining admixture (AEA-946), all from Mississippi, were used in the investigation. Physical and chemical properties of the cement are presented in Table 1. The coarse aggregate was limestone from Alabama (CL-2 6-1(2) and CRD G-40). The physical properties and gradings of the aggregates are given in Table 2.

Mixtures

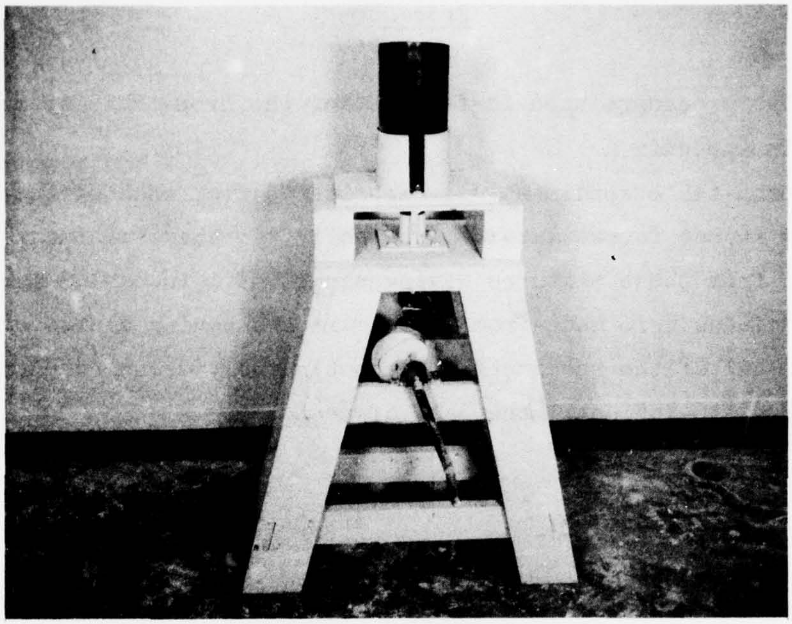
5. The concrete mixtures used in this study were as follows:

Mixture	Water-Cement Ratio by wt	Cement Content lb/yd^3	Slump in.	Air Content Pressure Method percent
1	0.40	517	1	4.6
2	0.43	517	3	6.2
3	0.46	517	5	5.5
4	0.50	414	1	5.6
5	0.50	445	3	5.8
6	0.50	476	5	6.2

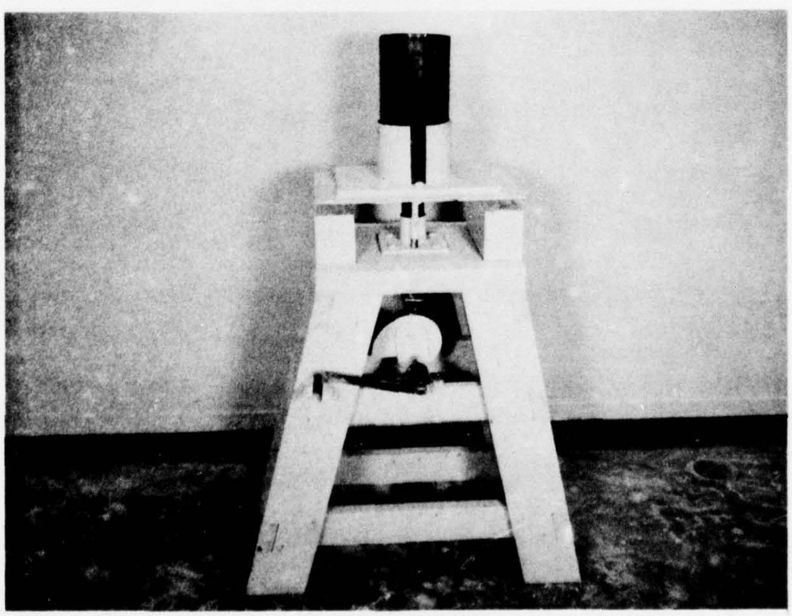
Proportions for each mixture are given in Table 3.

Apparatus

6. The drop table studied in the investigation is shown in Figure 1 and described in Appendix B.



a. Lowered table position



b. Raised table position

Figure 1. Drop table

Procedure

7. The procedure used in fabricating the drop-table specimens is given in Appendix A.

8. Drop-table specimens were fabricated from each of the six concrete mixtures investigated. Internally vibrated specimens were fabricated from these mixtures having slumps of 1 in. and 3 in., while rodded specimens were made from those mixtures having slumps of 3 in. and 5 in. All of the specimens were continuously moist cured as specified by CRD-C 10-78* until the date of test.

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* U. S. Army Engineer Waterways Experiment Station, CE, op. cit., Method CRD-C 10-78.

PART III: TESTS CONDUCTED

9. One hundred and eight drop-table specimens, 54 internally vibrated specimens, and 72 rodded specimens were fabricated during the investigation. Bulk density and compressive strength tests were conducted on the specimens at curing ages of 7, 28, and 90 days according to CRD-C 23-76* and CRD-C 14-73.** The theoretical air-free density of each mixture was calculated in order to compute the air content from the density of the hardened concrete for each specimen. Each round of tests was composed of three individual tests performed on specimens from the same batch. Two rounds of tests were conducted on specimens fabricated from 1-in and 5-in. slump mixtures, and three rounds of tests were conducted on the 3-in. slump mixtures.

10. Nine additional specimens were fabricated, three by each fabrication method, in order to investigate density changes within a specimen. Each of the cylinders was sawed into three specimens of equal length, approximately 4 in., and density tests were conducted on the specimens at 28 days age.

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* U. S. Army Engineer Waterways Experiment Station, CE, op. cit., Method CRD-C 23-76.

** Ibid., Method CRD-C 14-73.

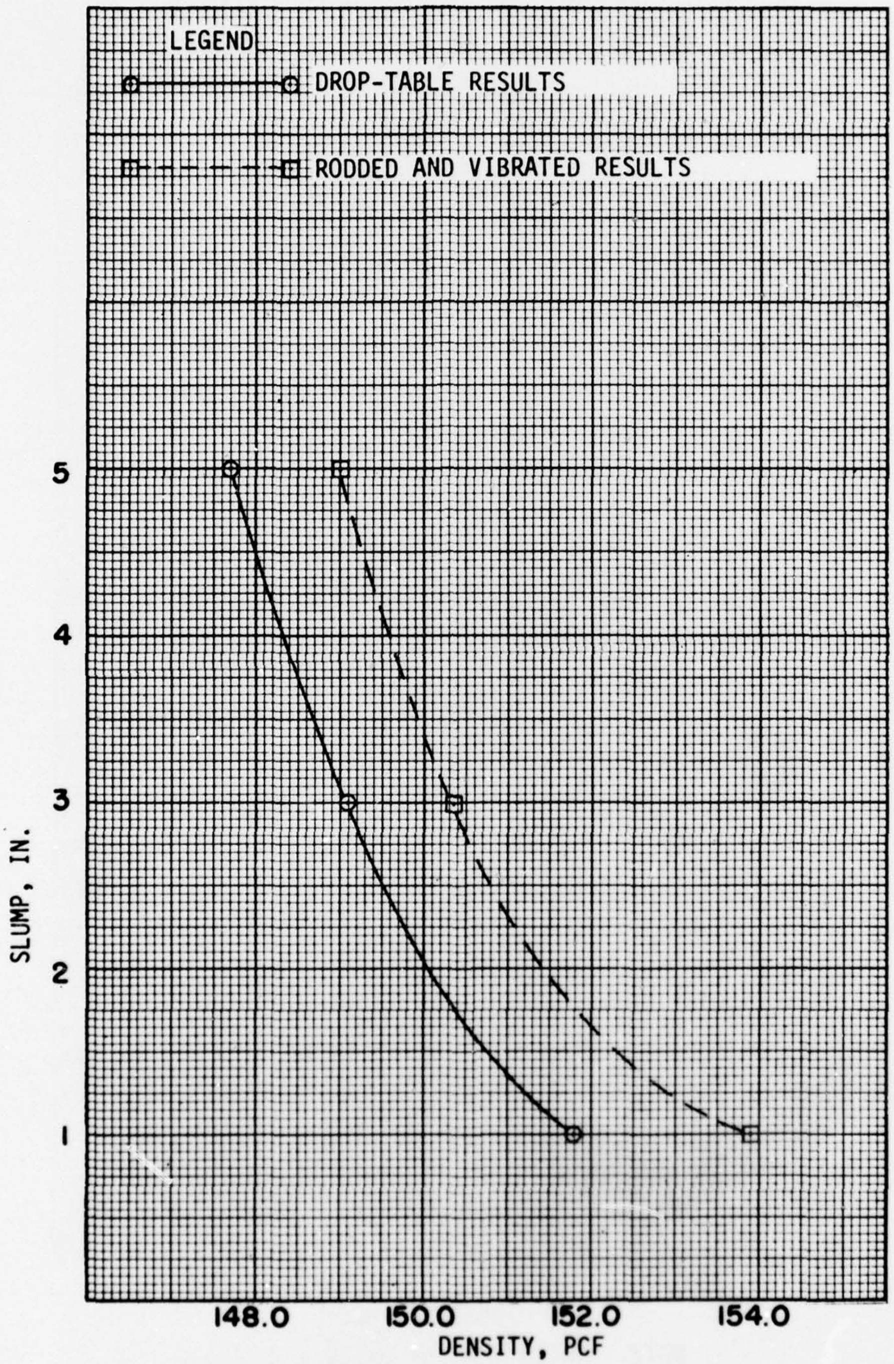
PART IV : DISCUSSION OF TEST RESULTS

11. The test results are shown in Tables 4-8. Table 4 gives the average values $\bar{X}$ and the standard deviations σ of the densities and compressive strengths within a given round of tests.

Density

12. The average density values tend to establish a trend over the entire range of mixtures. The drop-table values for a given mixture are somewhat lower than those values determined for either rodded or vibrated specimens from the same mixture, as is shown in Figures 2 and 3. The points plotted represent values obtained by averaging Table 4 values for a given mixture and fabrication method at all ages. The range in values is approximately 1 lb/ft^3 for 5-in. slump mixtures to 2 lb/ft^3 for 1-in. slump mixtures. The lower drop-table densities of the consolidated specimens may have resulted in part from the procedure followed in filling the specimen molds. A large amount of the air entrapped initially in each specimen was not removed after consolidation, even though the number of drops was sufficient to achieve adequate compaction at the specimen surface as prescribed by the procedure (Appendix A). Figure 4 shows typical hardened drop-table, rodded, and vibrated specimens. The larger size and number of surface air voids in the drop-table specimens illustrate the apparent lack of complete consolidation obtained using this procedure. Table 5 shows that hardened drop-table specimens generally contained more entrapped air than rodded or vibrated specimens, regardless of the mixture or specimen age investigated. Consequently, lower density values should be expected for the drop-table specimens, especially those fabricated from low-slump mixtures.

13. The standard deviations of the density values (Table 4) indicate that no appreciable variation existed within any group of drop-table specimens, regardless of specimen age or mixture number. The data presented in Table 6 indicate that no appreciable changes in



NOTE: ACTUAL CEMENT FACTOR = 517 LB/CU YD

Figure 2. Density comparisons of drop-table and rodded and vibrated hardened specimens for mixtures with the same cement factor

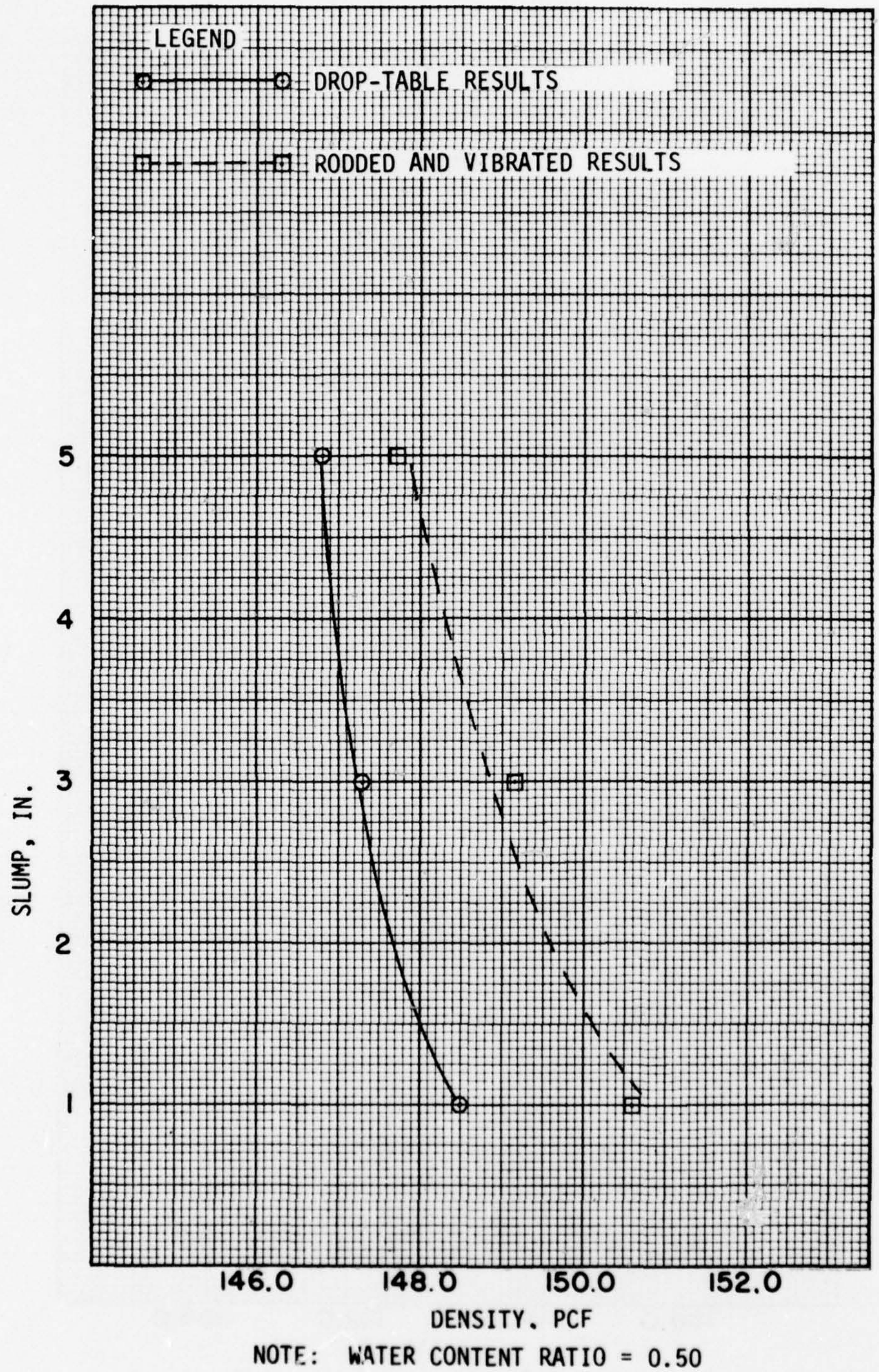
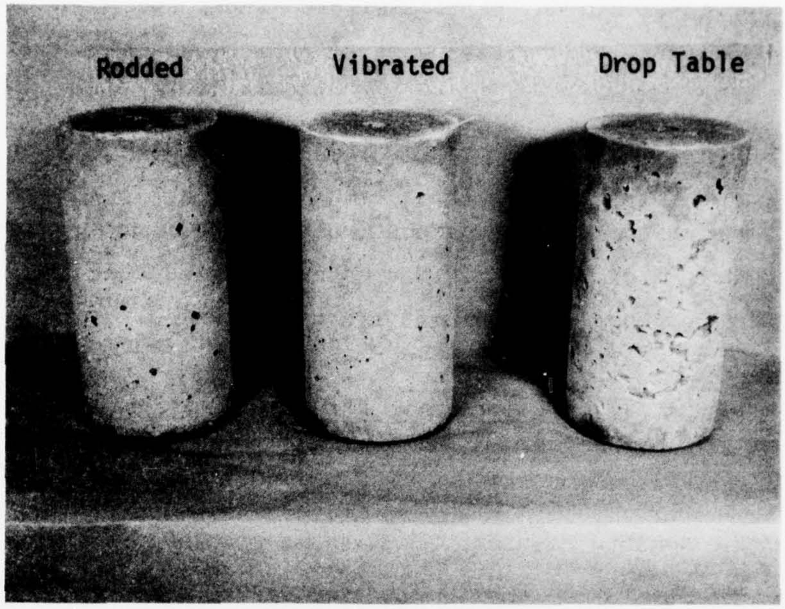
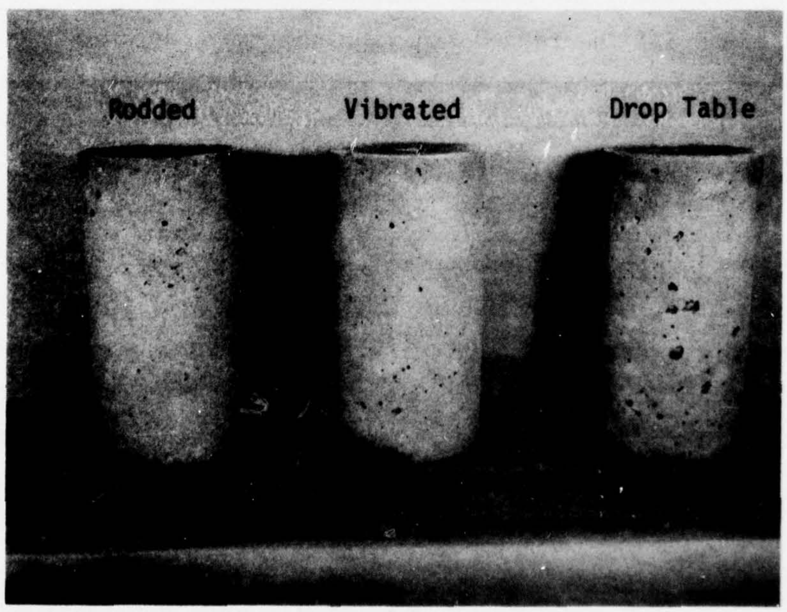


Figure 3. Density comparisons of drop-table and rodded and vibrated hardened specimens for mixtures with the same water-cement ratio



a. Extreme variation



b. Typical variation

Figure 4. Hardened concrete specimens

density occurred within any particular drop-table specimen. However, the average drop-table densities were slightly lower than the average rodded and vibrated values, due to the additional entrapped air in each group of drop-table specimens.

14. For a particular mixture, the overall density of the drop-table specimen appeared to be a function of the number of drops and perhaps the height of the drop. No tests were conducted during the investigation, however, to substantiate this premise.

Compressive Strength

15. The compressive strength data presented in Table 1 tend to complement the density results. Drop-table specimen strength values were generally lower than rodded or vibrated specimen values for each of the concrete mixtures investigated. Figure 5 graphically supports this conclusion for specimens tested in compression at 28 days. The points from which the drop-table curve was constructed represent values obtained by averaging the 28-day values presented in Table 4 for mixtures 1, 2, and 5. The rodded and vibrated specimen curve represents values computed by averaging 28-day vibrated and rodded specimen values for the same mixtures. The voids created by the entrapped air in the drop-table specimens appeared to be the contributing factors in lower compressive strength values. The air contents at various ages (Table 5) predicted the lower drop-table specimen densities and subsequent lower strengths. The relation of change in air content to change in strength of the test specimens consolidated using the drop table was found to be approximately a 9 percent decrease in strength for each 1 percent increase in air content, rather than the more generally encountered 5 percent change in strength per percent change in air content.

16. The compressive strength standard deviations (Table 7) indicate that for the limited amount of data produced, reproducible results were achieved within each round of tests for each fabrication procedure. The standard deviations for drop-table specimens compare favorably with those for rodded and vibrated specimens. The overall standard

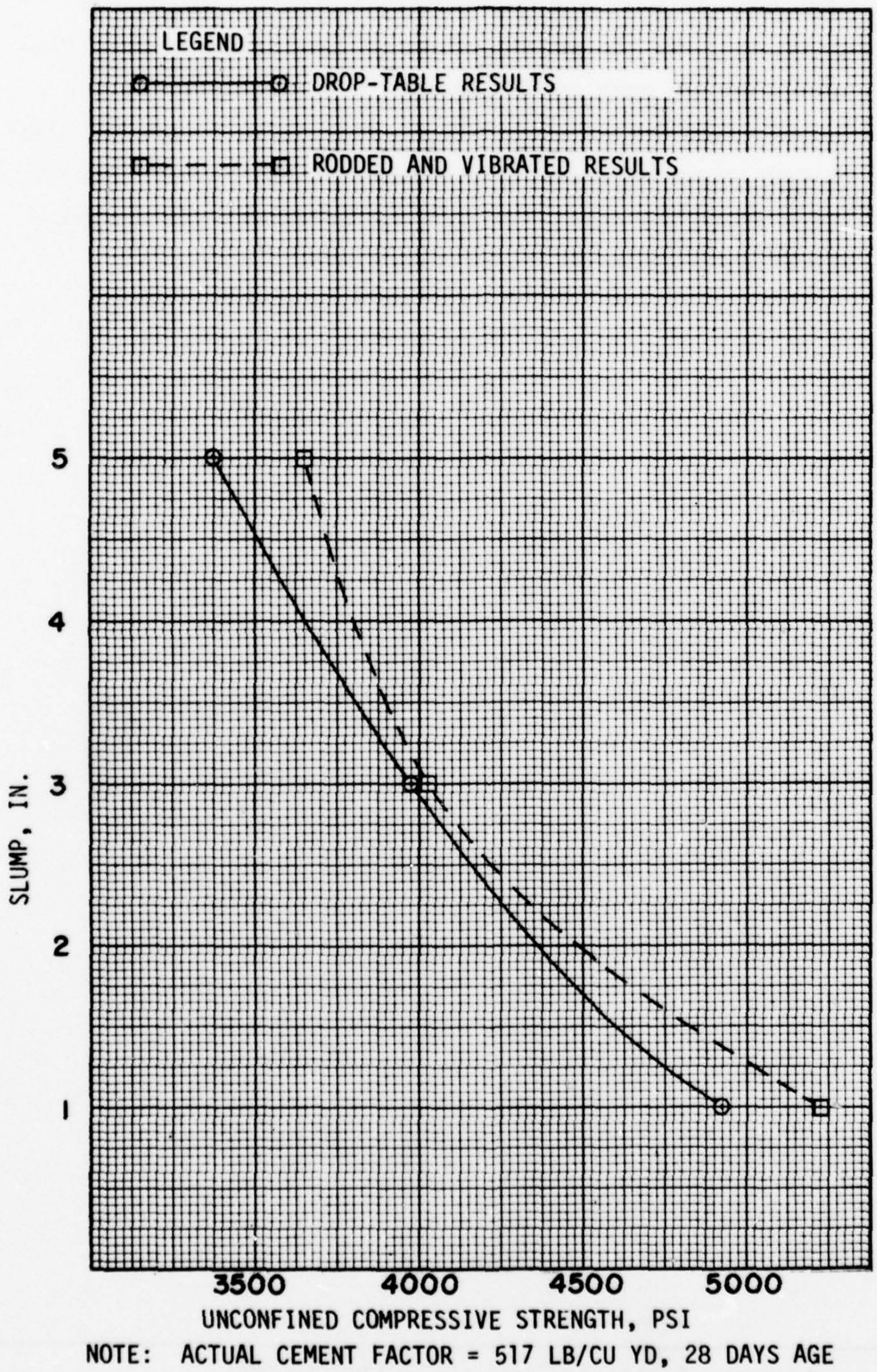


Figure 5. Drop-table and rodded and vibrated specimen compressive strength comparisons

deviations, shown adjacent to the group variations, are somewhat larger than the individual group standard deviations. Batching, mixing, or sampling variations were the probable causes for larger overall standard deviations, rather than discrepancies in testing procedures. Based on these overall deviations, fair to good field or general construction control might be attainable with the drop table.* However, the amount of test data available is not sufficient to yield a conclusive statistical evaluation of the drop table.

* American Concrete Institute, op. cit., ACI 214-77.

PART V: SUMMARY OF RESULTS AND CONCLUSIONS

Summary of Results

17. Based on the limited data obtained from this investigation, the drop table appeared to be an acceptable means of consolidating 6-in.-diameter concrete test specimens in a relatively uniform manner. The individual group and overall mixture standard deviations of compressive strengths for drop-table specimens support this observation.

18. However, the lower drop-table specimen density values and resulting lower compressive strength values pose some problems with respect to use of the drop table. Individual specimen compressive strengths are important in determining the compressive strength of concrete. The required strength is stipulated by the designer, based on current standard procedures. A mixture proportioned to meet this required strength would not be acceptable if evaluated using specimens compacted by the drop table. Adjustments in the mixture proportions involving a water-cement ratio reduction and consequent increase in cement content and cost would be necessary to achieve acceptable mixture proportions based on the drop-table procedure.

19. Additional investigative work involving different mold filling techniques, varying drop-table heights, or number of drops might yield drop-table specimen test results comparable to the rodded and vibrated specimen test values. Studies involving power camshaft rotation could also prove to be beneficial in establishing consistent field and laboratory data. The question of which fabrication method produces specimens most representative of in place concrete might also be addressed in future studies. The drop table specified in CRD-C 6-74,* also described in ASTM C-124** from 1936 to 1974, is suggested for use if further work were to be conducted.

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* U. S. Army Engineer Waterways Experiment Station, CE, op. cit., Method CRD-C 6-74.

** American Society for Testing and Materials, op. cit., ASTM C-124.

Conclusions and Recommendations

20. The drop table generally achieved reproducible but lower density and compressive strength tests results than the values obtained for rodded and vibrated specimens.

21. The procedure followed in filling the specimen molds together with the stipulated height and number of drops apparently caused the lower drop-table test values.

22. Additional investigative work involving alternative mold filling techniques and varying height and number of drops would be required if it were decided to standardize procedures which produce comparable drop-table test results to those of current procedures.

Table 1

Chemical and Physical Properties

of Portland Cement, RC-778

Chemical Properties	Percent
SiO_2	23.3
Al_2O_3	3.4
Fe_2O_3	5.3
CaO	62.5
MgO	3.1
SO_3	1.6
Ignition loss	0.6
Insoluble residue	0.13
Na_2O	0.06
K_2O	0.55
Total alkali, as Na_2O	0.42
C_3S	43.1
C_2S	34.0
Physical Properties	
Fineness, air permeability, cm^2/g	3270
Compressive strength, psi	
3 days	1630
7 days	2200
28 days	4390
Autoclave expansion, percent	0.07
Initial setting time, hr/min	4:05
Final setting time, hr/min	6:05

Table 2

Gradings and Physical Properties

of Fine and Coarse Aggregates

Test	Size Range: Fine (CL-2 S-2)	Size Range: No. 4 to 3/4-in. (CL-2 G-1 (2))	Size Range: 3/4- to 1-1/2-in. (CRD G-40)	Combined Coarse Aggregate*
Bulk Specific Gravity, Saturated-Surface-Dry		2.71	2.74	
Absorption, %		0.4	0.5	
Sieve	**Cumulative Percent Passing**			
50 mm (2 in.)			100	100
38.1 mm (1-1/2 in.)			98	99
25.0 mm (1 in.)			42	71
19.0 mm (3/4 in.)		98	10	54
12.5 mm (1/2 in.)		74	3	38
9.5 mm (3/8 in.)		41	2	21
4.75 mm (No. 4)	97	4	2	1
2.36 mm (No. 8)	87			
1.18 mm (No. 16)	77			
600 µm (No. 30)	58			
300 µm (No. 50)	19			
150 µm (No. 100)	3			
75 µm (No. 200)				

* The two size ranges of coarse aggregates were combined in the following proportions: 50%, 3/4- to 1-1/2-in.; 50%, No. 4 to 3/4-in.

Table 3

Mixture Proportions

Mixture No.	Material	Solid Volume ft^3	Bulk Density Saturated-Surface-Dry, lb/yd^3
1	Portland cement	2.630	517.0
	Fine aggregate	7.241	1183.8
	Coarse aggregate	12.330	2096.6
	Water	3.314	206.8
	Air	1.485	--
	Total	27.000	4004.2
2	Portland cement	2.630	517.0
	Fine aggregate	7.150	1169.0
	Coarse aggregate	12.173	2069.9
	Water	3.562	222.3
	Air	1.485	--
	Total	27.000	3978.2
3	Portland cement	2.630	517.0
	Fine aggregate	7.057	1153.7
	Coarse aggregate	12.017	2043.4
	Water	3.811	237.8
	Air	1.485	--
	Total	27.000	3951.9
4	Portland cement	2.104	413.6
	Fine aggregate	7.436	1215.7
	Coarse aggregate	12.661	2152.9
	Water	3.314	206.8
	Air	1.485	--
	Total	27.000	3989.0
5	Portland cement	2.262	444.6
	Fine aggregate	7.282	1190.5
	Coarse aggregate	12.409	2110.0
	Water	3.562	222.3
	Air	1.485	--
	Total	27.000	3967.4
6	Portland cement	2.420	475.6
	Fine aggregate	7.135	1166.5
	Coarse aggregate	12.149	2065.8
	Water	3.811	237.8
	Air	1.485	--
	Total	27.000	3945.7

Table 4

Results of Compressive Strength and Density Tests

Mixture No.	Round No.	Type Consolidation	7-Day Compressive Strength psi $\bar{X}$	σ	7-Day Bulk Density lb/ft^3 $\bar{X}$	σ	28-Day Compressive Strength psi $\bar{X}$	σ	28-Day Bulk Density lb/ft^3 $\bar{X}$	σ	90-Day Compressive Strength psi $\bar{X}$	σ	90-Day Bulk Density lb/ft^3 $\bar{X}$	σ	Slump in.	W/C
1	1	D. Table	2880	80	152.6	3.0	4790	30	159.4	0.3	6150	330	148.6	3.3	1	0.40
		Vibrated	3060	50	151.3	2.6	5110	15	153.6	0.1	6290	375	156.5	0.8		
1	2	D. Table	3280	30	152.2	0.3	5080	85	153.1	0.2	6610	155	152.7	0.1		
		Vibrated	3310	125	153.9	0.0	5250	65	153.9	1.0	6540	50	154.2	0.3		
4	1	D. Table	1540	10	148.3	0.8	2960	5	148.9	0.2	4260	110	148.8	0.4	1	0.50
		Vibrated	1790	20	150.6	0.2	3310	85	150.9	0.7	4570	140	150.6	0.2		
4	2	D. Table	1570	5	148.6	0.2	2920	50	148.3	0.4	4240	55	148.0	0.7		
		Vibrated	1820	50	150.2	0.6	3190	150	150.5	0.2	4950	25	150.9	0.3		
2	1	D. Table	2330	30	148.5	0.4	4010	110	148.7	0.2	5450	90	149.1	0.1	3	0.43
		Rodded	2370	35	149.9	0.2	4070	95	150.1	0.3	5430	60	150.5	0.3		
2	2	D. Table	2330	30	148.7	0.4	3950	65	149.7	0.6	5260	75	149.7	0.2		
		Rodded	2350	45	149.9	0.2	3880	95	150.2	0.7	5090	120	150.6	0.4		
2	3	D. Table					3990	75	148.7	0.5	5390	125	149.2	0.6		
		Vibrated					4150	50	150.3	0.6	5480	100	150.9	0.5		
		Rodded					3980	135	150.6	0.5	5240	55	150.4	0.5		
5	1	D. Table					3260	40	147.5	0.4	4160	150	148.2	0.7	3	0.50
		Vibrated					3790	80	150.6	0.4	5190	85	151.0	0.1		
		Rodded					3390	65	148.6	0.5	5030	25	148.2	0.2		
5	2	D. Table					2890	30	146.6	0.2	4700	125	147.0	0.3		
		Vibrated					3280	80	149.4	0.3	4600	75	149.9	0.4		
		Rodded					2830	35	148.1	0.4	4300	65	147.5	0.3		

(Continued)

Table 4 (Concluded)

Mixture No.	Round No.	Type Consolidation	7-Day Compressive Strength psi $\bar{X}$	7-Day Compressive Strength psi σ	7-Day Bulk Density lb/ft^3 $\bar{X}$	7-Day Bulk Density lb/ft^3 σ	28-Day Compressive Strength psi $\bar{X}$	28-Day Compressive Strength psi σ	28-Day Bulk Density lb/ft^3 $\bar{X}$	28-Day Bulk Density lb/ft^3 σ	90-Day Compressive Strength psi $\bar{X}$	90-Day Compressive Strength psi σ	90-Day Bulk Density lb/ft^3 $\bar{X}$	90-Day Bulk Density lb/ft^3 σ	Slump in.	W/C
3	1	D. Table	2040	25	146.6	0.6	3530	15	146.6	0.6	4820	120	152.4	1.2	5	0.46
		Rodded	2150	65	147.8	0.9	3670	55	147.8	0.9	4770	230	152.7	0.4		
3	2	D. Table	1850	65	146.7	0.4	3260	100	147.0	0.5	4730	75	147.1	0.2		
		Rodded	1940	50	148.3	0.2	3570	100	148.3	0.3	5000	155	148.9	0.2		
6	1	D. Table	1700	30	146.8	0.8	3290	75	146.2	0.5	4500	45	147.0	0.2	5	0.50
		Rodded	1790	75	147.6	0.3	3390	105	148.0	0.1	4880	125	148.2	0.5		
	2	D. Table	1660	15	147.0	0.5	3230	85	146.8	0.6	4330	230	147.1	0.4		
		Rodded	1780	65	147.4	0.5	3220	120	147.8	0.3	4600	15	147.4	0.3		

Table 5

Air Content of Hardened Concrete Specimens

Mixture No.	Round No.	Slump in.	Type Consoli- dation	Compressive Strength psi, $\overline{X}$			Air Content, percent		
				7 Days	28 Days	90 Days	7 Days	28 Days	90 Days
1	1	1	D. Table	2880	4790	6150	2.8	--	5.3
			Vibrated	3060	5110	6290	3.6	2.1	0.3
1	2	1	D. Table	3280	5080	6610	3.0	2.4	2.7
			Vibrated	3310	5250	6540	1.9	1.9	1.7
4	1	1	D. Table	1540	2960	4260	5.1	4.7	4.8
			Vibrated	1790	3310	4570	3.6	3.5	3.6
4	2	1	D. Table	1570	2920	4240	4.9	5.1	5.3
			Vibrated	1820	3190	4950	3.9	3.7	3.5
2	1	3	D. Table	2330	4010	5450	4.7	4.6	4.4
			Vibrated	3370	4070	5430	3.8	3.7	3.5
2	2	3	D. Table	2330	3950	5260	4.6	4.0	4.0
			Vibrated	2370	3880	5090	3.8	3.7	3.5
2	3	3	D. Table	--	3990	5390	--	4.6	4.3
			Vibrated	--	4150	5480	--	3.6	3.2
			Rodded	--	3980	5240	--	3.4	3.5
5	1	3	D. Table	--	3260	4700	--	5.1	4.7
			Vibrated	--	3790	5190	--	3.2	2.9
			Rodded	--	3390	5030	--	4.4	4.7
5	2	3	D. Table	--	2890	4160	--	5.7	5.5
			Vibrated	--	3280	4600	--	3.9	3.6
			Rodded	--	2830	4300	--	4.8	5.1
3	1	5	D. Table	2040	3530	4820	5.4	--	1.6
			Rodded	2150	3670	4770	4.6	--	1.4
3	2	5	D. Table	1850	3260	4730	5.3	5.1	5.0
			Rodded	1940	3570	5000	4.3	4.3	3.9
6	1	5	D. Table	1700	3290	4500	5.0	5.4	4.9
			Rodded	1790	3390	4880	4.5	4.3	4.1
6	2	5	D. Table	1660	3230	4330	4.9	5.0	4.9
			Rodded	1780	3220	4600	4.7	4.4	4.7

Table 6

Results of Bulk Density Tests on 6-in.-Diam by 4-in.-High Cylindrical Sections

Mixture No.	W/C	Cement lb/yd^3	Type Consoli-idation	Location of Section	28-Day Bulk Density lb/ft^3	$\overline{X}$	σ
2	0.43	517	D. Table	Top	149.4		
				Middle	149.5	149.6	0.3
				Bottom	150.0		
2	0.43	517	D. Table	Top	--		
				Middle	148.4	148.9	0.7
				Bottom	149.4		
2	0.43	517	D. Table	Top	148.8		
				Middle	149.3	149.5	0.8
				Bottom	150.4		
2	0.43	517	Vibrated	Top	153.4		
				Middle	153.6	153.5	0.1
				Bottom	153.6		
2	0.43	517	Vibrated	Top	152.2		
				Middle	153.3	153.1	0.8
				Bottom	153.8		
2	0.43	517	Vibrated	Top	153.0		
				Middle	153.1	153.2	0.2
				Bottom	153.4		
2	0.43	517	Rodded	Top	150.4		
				Middle	151.1	151.4	1.1
				Bottom	152.6		
2	0.43	517	Rodded	Top	150.3		
				Middle	151.7	151.3	0.8
				Bottom	151.8		
2	0.43	517	Rodded	Top	150.1		
				Middle	150.4	150.7	0.8
				Bottom	151.6		

Table 7

Standard Deviations of Compressive Strengths

Mixture No.	W/C	Cement lb/yd^3	Type Consolidation	7 Days σ, psi Group	7 Days σ, psi Overall	28 Days σ, psi Group	28 Days σ, psi Overall	90 Days σ, psi Group	90 Days σ, psi Overall
				1-in. Slump					
1	0.40	517	D. table	80	222	30	169	330	342
			D. table	30		85		155	
			Vibrated	50	163	15	87	375	276
			Vibrated	125		65		50	
4	0.50	414	D. table	10	16	5	39	110	79
			D. table	5		50		55	
			Vibrated	20	38	85	127	140	225
			Vibrated	50		150		25	
				3-in. Slump					
2	0.43	517	D. table	30	27	110	78	90	120
			D. table	30		65		75	
			D. table			75		125	
			Rodded	35	37	95		60	
			Rodded	45		95	135	120	181
			Rodded			135		55	
			Vibrated			50		100	
5	0.50	445	D. table			40	202	150	321
			D. table			30		125	
			Rodded			65	309	25	401
			Rodded			35		65	
			Vibrated			80	290	85	333
			Vibrated			80		75	
				5-in. Slump					
3	0.46	517	D. table	25	113	15	161	120	102
			D. table	65		100		75	
			Rodded	65	119	55	91	230	216
			Rodded	50		100		155	
6	0.50	476	D. table	30	31	75	78	45	175
			D. table	15		85		230	
			Rodded	75	63	105	135	125	177
			Rodded	65		120		15	

Table 8

Individual Compressive Strength and Density Test Results

Mixture No.	Round No.	Slump in.	Type Consolidation	7 Days Compressive Strength psi	7 Days Bulk Density lb/ft^3	28 Days Compressive Strength psi	28 Days Bulk Density lb/ft^3	90 Days Compressive Strength psi	90 Days Bulk Density lb/ft^3	W/C	Air Content Percent
1	1	1	Drop table	2920	150.7	4820	159.2	6320	149.7	0.40	4.6
				2790	156.0	4790	159.1	5770	144.9		
				2940	151.0	4760	159.6	6360	151.2		
			Average	2880	152.6	4790	159.4	6150	148.6		
1	1	1	Vibrated	3000	153.2	5100	153.6	6430	157.2	0.40	4.6
				3090	152.3	5130	153.6	6570	156.7		
				3080	148.4	5110	153.7	5860	155.6		
			Average	3060	151.3	5110	153.6	6290	156.5		
1	2	1	Drop table	3310	152.5	4980	153.2	6690	152.6	0.40	4.1
				3260	151.9	5140	153.1	6710	152.7		
				3260	152.3	5120	152.9	6430	152.8		
			Average	3280	152.2	5080	153.1	6610	152.7		
1	2	1	Vibrated	3300	153.9	5290	152.9	6550	153.9	0.40	4.1
				3440	153.9	5180	153.9	6480	154.2		
				3190	153.9	5290	154.9	6580	154.4		
			Average	3310	153.9	5250	153.9	6540	154.2		
4	1	1	Drop table	1550	148.4	2960	149.1	4150	149.2	0.50	6.2
				1540	149.0	2950	148.8	4250	148.7		
				1530	147.5	2960	148.7	4370	148.4		
			Average	1540	148.3	2960	148.9	4260	148.8		
4	1	1	Vibrated	1770	150.8	3210	151.1	4710	150.7	0.50	6.2
				1810	150.5	3360	150.2	4430	150.6		
				1800	150.6	3360	151.5	4570	150.4		
			Average	1790	150.6	3310	150.9	4570	150.6		
4	2	1	Drop table	1560	148.4	2950	148.7	4210	147.2	0.50	6.2
				1570	148.5	2950	148.3	4200	148.4		
				1570	148.8	2860	147.9	4300	148.5		
			Average	1570	148.6	2920	148.3	4240	148.0		
4	2	1	Vibrated	1790	150.8	3200	150.3	4960	151.2	0.50	6.2
				1790	149.8	3340	150.6	4960	150.8		
				1880	149.9	3040	150.6	4920	150.6		
			Average	1820	150.2	3190	150.5	4950	150.9		
2	1	3	Drop table	2310	148.5	3960	148.8	5540	149.0	0.43	5.5
				2310	148.1	4130	148.9	5360	149.1		
				2360	148.9	3930	148.5	5460	149.2		
			Average	2330	148.5	4010	148.7	5450	149.1		
2	1	3	Rodded	2340	149.8	3960	150.3	5390	150.2	0.43	5.5
				2410	149.8	4130	150.2	5410	150.5		
				2360	150.1	4110	149.8	5500	150.7		
			Average	2370	149.9	4070	150.1	5430	150.5		
2	2	3	Drop table	2320	149.0	3890	150.4	5180	149.8	0.43	5.2
				2360	148.8	3930	149.3	5320	149.8		
				2300	148.2	4020	149.3	5290	149.5		
			Average	2330	148.7	3950	149.7	5260	149.7		
2	2	3	Rodded	2380	149.8	3980	150.8	4960	150.1	0.43	5.2
				2300	150.2	3880	150.5	5200	150.8		
				2370	149.8	3790	149.4	5100	150.9		
			Average	2350	149.9	3880	150.2	5090	150.6		
2	3	3	Drop table	--	--	3960	149.1	5320	148.9	0.43	5.6
				--	--	3930	148.7	5320	148.9		
				--	--	4070	148.2	5540	149.9		
			Average			3990	148.7	5390	149.2		
2	3	3	Vibrated	--	--	4210	150.8	5540	151.2	0.43	5.6
				--	--	4110	149.6	5370	150.3		
				--	--	4140	150.4	5540	151.2		
			Average			4150	150.3	5480	150.9		
2	3	3	Rodded	--	--	4070	150.2	5290	151.0	0.43	5.6
				--	--	3820	150.4	5250	150.2		
				--	--	4040	151.2	5180	150.0		
			Average			3980	150.6	5240	150.4		
5	1	3	Drop table	--	--	3270	147.9	4610	147.5	0.50	5.8
				--	--	3290	147.2	4640	148.8		
				--	--	3210	147.3	4840	148.2		
			Average			3260	147.5	4700	148.2		
5	1	3	Vibrated	--	--	3870	150.2	5140	151.1	0.50	5.8
				--	--	3710	150.9	5290	151.0		
				--	--	3800	150.8	5140	150.9		
			Average			3790	150.6	5190	151.0		

(Continued)

Table 8 (Concluded)

Mixture No.	Round No.	Slump in.	Type Consolidation	7 Days Compressive Strength psi	7 Days Bulk Density lb/ft^3	28 Days Compressive Strength psi	28 Days Bulk Density lb/ft^3	90 Days Compressive Strength psi	90 Days Bulk Density lb/ft^3	W/C	Air Content Percent
5	1	3	Rodded	--	--	3390	148.1	5000	148.1	0.50	5.8
				--	--	3450	149.0	5040	148.4		
				--	--	3320	148.8	5050	148.1		
			Average			3390	148.6	5030	148.2		
5	2	3	Drop table	--	--	2910	146.8	4320	147.3	0.50	6.2
				--	--	2910	146.4	4130	147.0		
				--	--	2860	146.6	4020	146.7		
			Average			2890	146.6	4160	147.0		
5	2	3	Vibrated	--	--	3370	149.6	4570	149.7	0.50	6.2
				--	--	3210	149.5	4680	149.6		
				--	--	3260	149.1	4540	150.4		
			Average			3280	149.4	4600	149.9		
5	2	3	Rodded	--	--	2840	147.6	4230	147.7	0.50	6.2
				--	--	2790	148.4	4320	147.7		
				--	--	2860	148.3	4360	147.2		
			Average			2830	148.1	4300	147.5		
3	1	5	Drop table	2010	146.5	3520	--	4890	151.2	0.46	6.0
				2060	147.2	3550	--	4680	153.5		
				2050	146.1	3520	--	4890	152.4		
			Average	2040	146.6	3530	--	4820	152.4		
3	1	5	Rodded	2010	148.3	3680	--	4890	152.5	0.46	6.0
				2220	148.4	3610	--	4500	152.4		
				2110	146.8	3720	--	4910	153.1		
			Average	2150	147.8	3670	--	4770	152.7		
3	2	5	Drop table	1840	146.5	3230	147.4	4680	147.1	0.46	6.2
				1920	147.2	3180	147.1	4700	147.3		
				1790	146.5	3370	146.5	4820	147.0		
			Average	1850	146.7	3260	147.0	4730	147.1		
3	2	5	Rodded	2000	148.2	3590	148.1	4820	149.0	0.46	6.2
				1900	148.1	3660	148.6	5060	148.7		
				1930	148.5	3460	148.1	5110	148.9		
			Average	1940	148.3	3570	148.3	5000	148.9		
6	1	5	Drop table	1670	146.5	3210	145.9	4460	146.9	0.50	6.2
				1700	147.7	3290	146.0	4500	147.3		
				1730	146.3	3360	146.8	4550	146.9		
			Average	1700	146.8	3290	146.2	4500	147.0		
6	1	5	Rodded	1710	147.8	3300	148.0	4750	148.2	0.50	6.2
				1820	147.2	3500	148.1	4890	147.8		
				1850	147.7	3360	147.9	5000	148.7		
			Average	1790	147.6	3390	148.0	4880	148.2		
6	2	5	Drop table	1640	147.1	3160	146.8	4070	147.5	0.50	6.2
				1670	147.4	3320	147.3	4430	146.9		
				1670	146.5	3200	146.2	4500	146.8		
			Average	1660	147.0	3230	146.8	4330	147.1		
6	2	5	Rodded	1840	147.8	3320	148.0	4610	147.1	0.50	6.2
				1790	146.9	3090	147.5	4590	147.5		
				1710	147.4	3250	148.0	--	147.6		
			Average	1780	147.4	3220	147.8	4600	147.4		

APPENDIX A: TENTATIVE METHOD OF TEST FOR CONSOLIDATING CONCRETE COMPRESSION SPECIMENS USING THE DROP TABLE

1. <u>Scope</u>

1.1 This method of test covers a procedure for consolidating concrete compression specimens using a drop table to impart a compactive effort sufficient to produce uniform cylinders without excessive loss of air content. It may be used for concrete of any measureable slump.

2. <u>Apparatus</u>

2.1 The drop table shall conform to ASTM Specification,* Drop Table for Use in Consolidating Concrete Compression Specimens. A relatively flat, firm surface shall be provided as a base on which the drop table may be placed, and in a convenient location near the point of concrete sampling.

3. <u>Procedure</u>

3.1 With the specimen mold positioned in the center of the table top, place the concrete in the molds in one filling using a scoop or small shovel. Each scoopful or shovelful shall be representative of the batch and evenly distributed as it is placed in the mold. The operator shall heap the mold before compaction is begun so that the mold remains filled after compaction. Overfilling by more than 1/4 in. (5 mm) shall be avoided.

3.2 Consolidation of the concrete shall be accomplished by turning the crank of the drop table at a speed of approximately 30 rpm. Each revolution of the crank raises the table top and allows it to drop through a height of 1 in. (25 mm), thus compacting the plastic concrete and removing entrapped air voids. Consolidation is considered to be adequate when the coarse aggregate particles just disappear beneath the surface of the mortar and the concrete ceases to settle and the

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* In preparation, draft presented in Appendix B.

surface appears smooth and glossy. The number of drops necessary to achieve adequate compaction will vary depending on the consistency of the mix, but the same number of drops shall be given to all cylinders from any given batch. Most concrete mixes will require from five to ten drops to attain full consolidation, depending on mix composition and consistency. Low slump concrete, less than 1 in. (25 mm), may require up to three times the number of drops.

Note: It is necessary to establish by trial the number of drops required for a given mix and slump. Too many drops of the table will result in a reduction in air content and an increase in density. Too few drops will lead to surface voids or honeycombing of the specimens and a reduction in density.

APPENDIX B: TENTATIVE SPECIFICATION FOR DROP TABLE FOR USE IN CONSOLIDATING CONCRETE COMPRESSION SPECIMENS

1. Scope

   1.1 This specification covers requirements for the drop table used in consolidating concrete compression specimens.

2. Apparatus

   2.1 The drop table apparatus shall be constructed in accordance with Figure B1. The apparatus shall consist of a rigid wooden or steel frame and a rectangular steel table top with a cylindrical steel shaft welded perpendicular to the table top. The entire table top and shaft assembly shall be mounted to the frame in such a manner that it can be raised and dropped vertically through a height of 1 ±0.020 in. (25.40 ±0.50 mm) by means of a rotated cam. The top and bottom surfaces of the table top shall be plane, horizontal, and parallel with the top surface of the frame so that full contact is maintained at the end of each drop. The table top shall be of intermediate grade, cold-rolled, carbon steel with an edge thickness of 0.25 in. (6.5 mm); and the weight of the top shall be symmetrical around the center of the shaft.

   2.2 The cam and vertical shaft shall be of medium carbon machinery steel, hardened where indicated in Figure B1. The shaft shall be straight, and the difference between the diameter of the shaft and the diameter of the bore of the frame shall be not less than 0.002 in. (0.05 mm) and not more than 0.003 in. (0.10 mm) for new tables and shall be maintained at from 0.002 in. (0.05 mm) to 0.010 in. (0.025 mm) for tables in use. The end of the shaft shall not fall upon the cam at the end of the drop, but it shall make contact with the cam not less than 120 degrees from the point of drop. The face of the cam shall be a smooth, spiraled curve of uniformly increasing radius from 1.5 to 4 in. (40 to 100 mm) in 360 degrees; and there shall be no appreciable jar as the

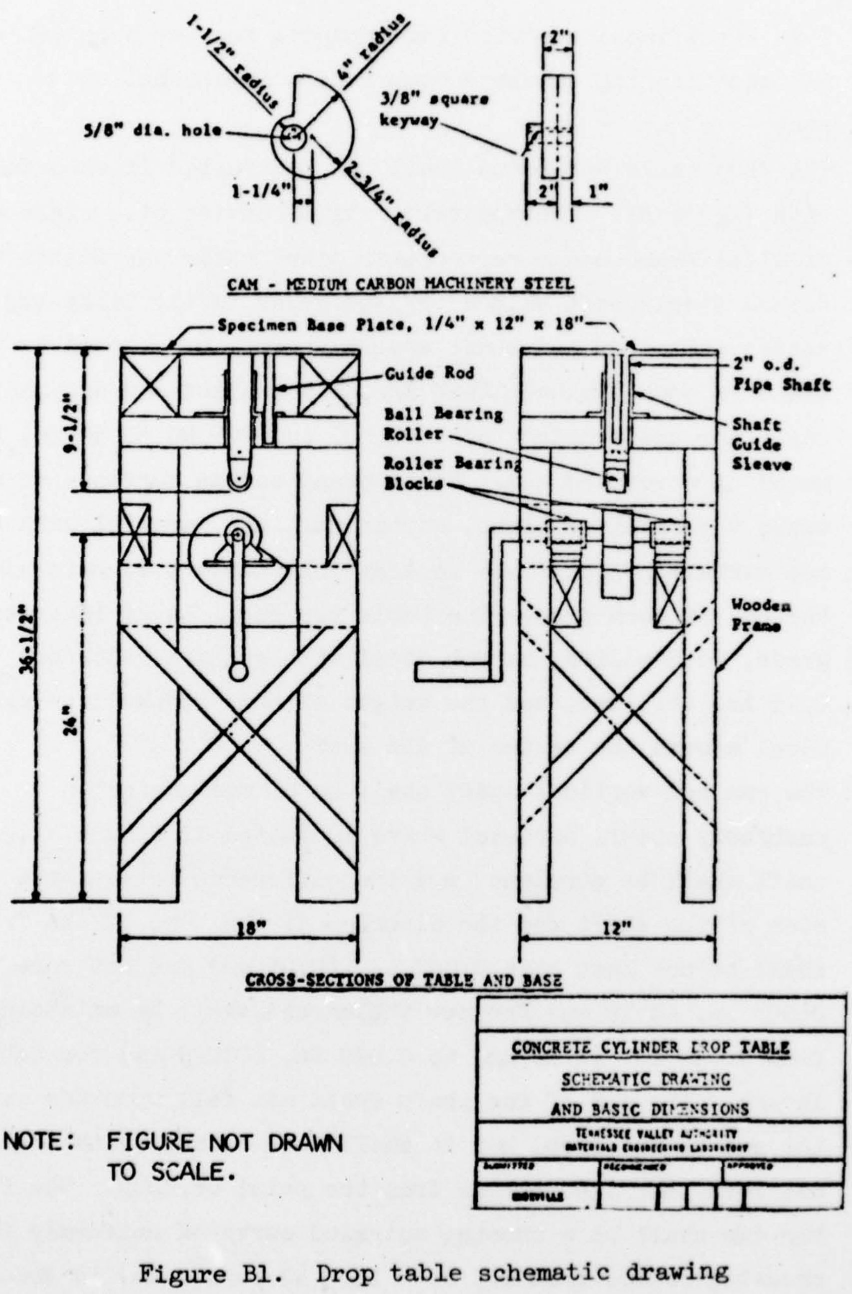

Figure B1. Drop table schematic drawing

shaft comes into contact with the cam.

2.3 The supporting frame of the drop table shall be adequately braced to prevent deflection or movement of the supporting legs, and the entire frame shall be equipped with a suitable leveling device.

2.4 The drop table shall be driven by a hand crank connected to the camshaft by means of a set screw. The crank shall be turned at a speed of approximately 30 rpm or one drop every 2 seconds.

3. Drop-table mounting

3.1 The drop-table frame shall be equipped with leveling screws at the base of the frame legs by which the apparatus may be adjusted so that the table top shall be level along two transverse directions at right angles to each other, in both the raised and lowered positions.

4. Drop-table lubrication

4.1 The vertical shaft of the table shall be kept clean, and it shall be lightly lubricated with a heavy mineral oil or light cup grease, such as petrolatum. Oil on the cam face will lessen wear and promote smoothness of operation.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Ragan, Steven A
Evaluation of a drop table for consolidating 6-in.-diameter cylindrical concrete test specimens / by Steven A. Ragan. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
18, [15] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; C-78-17)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under CWIS No. 31138.
Includes bibliographical footnotes.

1. Concrete cylinders. 2. Concrete test specimens. 3. Consolidation (Concrete). 4. Drop tables. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; C-78-17.
TA7.W34m no.C-78-17