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Committee C09 on Concrete and Concrete Aggregates
Subcommittee C09.45 on Roller-Compacted Concrete

Research Report: C09-1043

Ruggedness Study for ASTM C1170/1170M - Test Method for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table

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1. Introduction:

Ruggedness Study 901 was conducted to analyze the effects of seven factors on the precision of C1170/C1170M - Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table. The study was also conducted to establish a temporary precision statement for the standard.

48 tests were conducted in accordance with C1170/C1170M with replicate tests conducted on 24 different RCC mixtures. The seven factors evaluated were: 1 surcharge mass, 2 elapsed time from mixing to testing, 3 mix proportioning, 4 cementitious materials, 5 aggregate angularity, 6 nominal maximum aggregate size, and 7 absence or presence of air entrainment. Some information on single-operator precision was obtained.

The lab program was conducted in conjunction with testing to evaluate the ruggedness of two other standards (C1435/C1435M and a new draft standard for measuring air content and density using the C231 apparatus and the C1435/C1435M compaction hammer) the results of which are reported in in separate research reports.

2. Test Method:

The Test Method used for this ILS is C1170/C1170M. To obtain a copy of C1170/C1170M, go to ASTM's website, www.astm.org, or contact ASTM Customer Service by phone at 610-832-9585 (8:30 a.m. - 4:30 p.m. Eastern U.S. Standard Time, Monday through Friday) or by email at service@astm.org.

3. Participating Laboratory:

The following laboratory participated in this ruggedness study:

Fall Line Testing & Inspection, LLC 460 East 76th Avenue
Building 4, Unit C
Denver, Colorado 80229, USA
www.falllinetesting.com

4. Description of Samples:

Materials used for this study were the ingredients typically used for making RCC mixtures. Material quality was specified according to the standards annotated in the table below. Material data sheets for all materials (except water and cement) are included in Annex A.

Water was obtained from the city's potable water supply. No data is provided.

Cement (42 kg (92.6 lb.) sacks of Holcim Portland Type I, II) was obtained from a local home improvement store.

The air-entraining agent (AEA) was specified to be "1) synthetic detergents having a chemical description of alkyl-aryl sulfonates and sulfates (e.g., sodium dodecylbenzenesulfonate) or 2) wood derived acid salts (e.g. Vinsol resin) having a chemical description of alkali or alkanolamine salt of a mixture of tricyclic acids, phenolics, and terpenes.". The AEA was specified based on discussion with Jim Hinds and Steve Tatro. Both Mr. Hinds and Mr. Tatro retired from employment with the United States Army Corps of Engineers. They stated that, while working for USACE, they were successful entraining air with either of these types of AEA in RCC mixed in a pugmill.

MATERIALS QUALITY TABLE

Material	Type or Class	Quality Standard
Portland Cement	Type I or II	ASTM C150
Fly Ash	Class F	ASTM C618
Fine Aggregate		ASTM C33
Coarse Aggregate		ASTM C33
Water		ASTM C94
Air-Entraining Agent (AEA)		ASTM C260

5. Interlaboratory Study Instructions

Laboratory participants were emailed the test program instructions. For a copy of the instructions, please see Annex A.

6. Description of Equipment/Apparatus[1]:

For information on the equipment/apparatus used by each laboratory, please see Annex A.

7. Data Report Forms:

A copy of the data report forms are provided in Annex A with completed forms in Annex B.

8. Statistical Data Summary:

A summary of the statistics calculated from the data returned by the participating laboratories is provided in Annex B and in 10. Analysis of Variance.

9. Precision and Bias Statement:

The practice described in ASTM 1067 and employed in this research is not intended to provide information on multi-laboratory precision, but it does provide some information on single-operator precision, which has been used to develop the following temporary repeatability statement.

xx.1.2.1 Consistency - The single-operator standard deviation has been found to be 3.7s[A] for mixtures with Vebe consistencies below 20s and 8.7s[A] for mixtures with Vebe consistencies above 20s. Therefore, results of two properly conducted tests by the same operator on the same material are not expected to differ from each other by more than 10s for mixtures with Vebe consistencies below 20s and 24s for mixtures with Vebe consistencies above 20s.

xx.1.2.2 Density - The single-operator standard deviation has been found to be 8.0 kg/m^3 [0.5 lb/ft^3][A] for mixtures with Vebe consistencies below 20s, 11.2 kg/m^3 [0.7 lb/ft^3][A] for mixtures with Vebe consistencies over the range from 20s to 30s, and 14.4 kg/m^3 [0.9 lb/ft^3][A] for mixtures with Vebe consistencies above 30s. Therefore, results of two properly conducted tests by the same operator on the same material are not expected to differ from each other by more than 20.8 kg/m^3 [1.3 lb/ft^3] for mixtures with Vebe consistencies below 20s, 32.0 kg/m^3 [2.0 lb/ft^3] for mixtures with Vebe consistencies over the range from 20s to 30s, and 41.6 kg/m^3 [2.6 lb/ft^3] for mixtures with Vebe consistencies above 30s.

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[1] The equipment listed was used to develop a precision statement for C1170-14. This listing is not an endorsement or certification by ASTM International.

[A] These numbers represent, respectively, the [1s] and [d2s] limits as described in ASTM Practice C670, for Preparing Precision Statements for Test Methods for Construction Materials.

xx.2. *Bias* – The test method has no bias because the values determined can be defined only in terms of the test method.

10. Analysis of Variance:

The practice described in ASTM 1067-12 and employed in this research evaluates the effects of seven factors (A through G) on the results of a test. It only estimates the main effects of the factors and does not detect the effects of interactions among factors. C1170/C1170M yields two results: 1) the Vebe consistency in seconds and 2) the density of the concrete.

The analysis results in a number for each factor evaluated. This number, termed the "F statistic", is designated F_f, for f = A through G. If F_f is greater than 5.32, the factor f (A through G) has a statistically significant effect. If F_f is shown to be NS it has a value of less than or equal to 5.32 and has no statistically significant effect.

The results of the ANOVA are shown in the tables and further discussed below.

C1170 Consistency

Summary of F Values for All Laboratories, All Materials, and All Factors

Material	Average Consistency	Surcharge Mass	Elapsed Time	Proportioning	Cementitious Materials	Coarse Aggregate Shape	NMSA	Air Entrainment
	Seconds	F_A	F_B	F_C	F_D	F_E	F_F	F_G
A	19	NS	NS	NS	NS	NS	NS	35.20
B	31	NS	NS	19.83	NS	NS	NS	NS
C	47	NS	NS	NS	NS	NS	NS	NS

C1170 Density

Table 17 Summary of F Values for All Laboratories, All Materials, and All Factors

Material	Average Density	Surcharge Mass	Elapsed Time	Proportioning	Cementitious Materials	Coarse Aggregate Shape	NMSA	Air Entrainment
	pcf	F_A	F_B	F_C	F_D	F_E	F_F	F_G
A	149.5	8.39	NS	130.39	NS	285.02	159.29	509.16
B	150.5	NS	NS	6.60	NS	95.33	28.22	158.03
C	148.6	51.29	15.28	86.73	17.84	208.95	68.29	18.74

<u>F_A – Apparatus Mass</u>

Procedure A requires a 50 lb surcharge and Procedure B a 27.5 lb surcharge.

The apparatus mass had no significant effect on the precision of the consistency test for any of the three materials. A previously unpublished study by the US Bureau of Reclamation (USBOR) showed apparatus mass to have a significant effect for mixtures with Vebe consistencies below 20s and for mixtures above 30s. The study showed that for mixtures with Vebe consistencies over the range from 20s to 30s there was very little difference in the Vebe consistency test results when tested with either surcharge mass. The study was reported in a memorandum to C09.45 Chairman Wayne Adaska on November 21, 2003 from C09.45 Task Group Leader Tim Dolen of the USBOR. Additional analysis is recommended to verify the effect of mix consistency on the variation in C1170 consistency test results.

Apparatus mass had a slightly significant effect on the variation of density results of mixtures with Vebe consistencies below 20s and for mixtures with Vebe consistencies above 30s the effect was significant. For mixtures with Vebe consistencies over the range from 20s to 30s the effect was insignificant.

C1170 currently requires Procedure B be used for mixtures with Vebe consistencies below 20s and Procedure A be used for mixtures with Vebe consistencies above 30s. For mixtures with Vebe consistencies over the range from 20s to 30s, C1170 allows the use either of the two procedures. No change is recommended.

Future studies to obtain precision data for C1170 should be designed to report the precision of three separate materials as defined within this ruggedness study.

F_B – Elapsed Time

The elapsed time between mix discharge and testing was an insignificant factor in the variation of consistency test results for any of the three materials and an insignificant factor in variation of density test results for Materials A and B. It was a slightly significant factor in the variation of density test results for Material C. This factor was chosen because it is anticipated that a future effort to study test precision will benefit from having at least 30 minutes to perform the tests needed to generate the data for the analysis. Concrete specifications generally require testing be completed no later than 15 minutes after sampling, but for RCC this study indicates the allotted time for testing may be expanded to 30 minutes.

Future consideration may be given to allowing 30 minutes from the time of sampling to complete C1170 testing; however, that was not the intent when we chose elapsed time as one of the 11 factors and the typical 15 minute time allotted from testing to sampling has not been reported to the subcommittee as posing any problems.

F_C – Proportioning

The mix was proportioned to be lean (300 lb of cementitious material per cubic yard) or rich (450 lb of cementitious material per cubic yard). (Note that these proportions were chosen to ensure that there would be enough paste in the mixes to form a mortar ring around the surcharge. These proportions should not be viewed as typical proportions for RCC mixtures.) Proportioning had a slightly significant effected on the variation of consistency test results of Material B, but had an insignificant effect for Materials A and C. Proportioning had a significant effect on the variation of density test results for Materials A and C and a slightly significant effect on the variation of density test results for Material B.

It is recommended that any lab program designed to further study precision of C1170 density test results be designed to report density test value precision of a lean mix separate from that of a rich mix.

F_D – Cementitious Material (CM)

The original lab program called for some mixes to include only Portland cement for the cementitious material (CM) and some to have only Class F fly ash as the CM. This would allow an analysis of the effect of CM on the variation in the results. Since compressive strength was to be tested, the lab program was modified to have some cement in all of the mixes. The CM was a ratio of either 25:75 cement to fly ash (by weight) or 75:25. Varying the ratio of cement to fly ash had an insignificant effect on the variation of consistency test results for all three materials and an insignificant effect on the density of Materials A and B. It only had a slightly significant effect on the variation of density test results for Material C.

Since the ratio of cement to fly ash appears not to be a significant factor, further studies may use 100% Class F fly ash for the cementitious component. This will allow one relatively large mix to be proportioned and moisture adjusted over a relatively long period of time with no variability in consistency or density that would otherwise be caused by cement hydration.

F_E – Coarse Aggregate Shape

The coarse aggregate shape (rounded or angular) had no significant effect on the variation of consistency test results of any of the materials, but did have a significant effect on the variation of density results for all of the materials tested.

When studying precision of density tests made according to C1170, reporting the density value precision of the angular aggregate separate from that of the rounded aggregate may be prudent.

F_F – Nominal Maximum Size Aggregate

Changing the NMSA had no significant effect on the variation of consistency test results of any of the materials, but did have a significant effect on the variation of density results for all of the materials tested.

When studying precision of density test made according to C1170/C1170M, studying precision values for various NMSA should be considered.

F_G – Air Entrainment

Air entrainment was included as a factor because it is needed in the evaluation of the proposed test standard for measuring air content and density; it was not a factor that was deemed necessary to study the precision of C1170/C1170M. The presence of air entraining agent (AEA) had a significant effect on the variation in both consistency and density results of Material A and of the density results of Materials B and C.

It is recommended that any lab program designed to further study precision of consistency and density of specimens made per C1170/C1170M be designed to report precision of A/E mixtures separate from that of non-A/E mixtures or only report precision of non-A/E mixtures since this is the more common type of RCC mixture.

Annex A: Laboratory Instructions and Worksheets

For
ASTM Subcommittee C09.45 Ruggedness Study for
Ruggedness and Precision of

ASTM C1170/1170M-08 - Test Method for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table

Contents of Annex A