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

Research Report RR # C09-1031

Interlaboratory Study to Establish Precision Statements for ASTM C1040, Standard Test Methods for In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods

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ROUND ROBIN TESTING – ASTM C 1040
ASTM TASK GROUP C09.45.XX

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Narrative of Testing Program:

All testing was conducted at Salado Creek Watershed, Site 15; a NRCS floodwater retarding dam under construction in San Antonio, Texas. The tests were conducted on the morning of March 23, 2004.

The purpose of the testing was to establish precision values for nuclear gages operating in the direct transmission mode when testing unhardened concrete according to test method C1040. Troxler, CPN, and Humbolt were all invited to participate in the testing. Only Troxler was able to participate.

The testing program included five Troxler gages. All gages had been calibrated per the manufacturer's recommendation. Each gage and the assigned operator represented a "lab" for purposes of the testing program.

The test sites were located on the roller compacted concrete (RCC) auxiliary spillway of Site 15. Six test sites were prepared in RCC of the same mix design. The sites were located 30 feet apart to prevent interference between gages operating simultaneously. The RCC was placed and compacted immediately prior to conducting the tests. At each test site a hole was formed in the RCC using the guide plate and hole forming device described in the test standard. A stainless steel sleeve was inserted in each hole to prevent damage to the material that may have occurred from the repeated insertion and extraction of the nuclear gage probe.

The procedure for testing was for each laboratory (gage plus operator) to take a wet density measurement at a test site, and then rotate the gage 90 degrees around the axis of the hole and take another wet density measurement at that site. This procedure was repeated for the remaining five test sites until two density readings had been taken by each laboratory at all six sites. All gages then repeated the testing two more times for a total of three rotations through all six sites. All measurements were made with the probe extended to a depth of eight inches from the surface. All measurements were made with the nuclear gage operating in the one-minute testing mode.

Test data was recorded in the field on standard worksheets developed for the round robin testing. The test data is located in Appendix 1 of this report.

Narrative of Statistical Analysis:

A statistical analysis was conducted for the purpose of determining the repeatability and reproducibility of the test method. The data was analyzed in accordance with the standard practice described in ASTM E 691-99, Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method. The statistical analysis is located in Appendix 2 of this report.

Each nuclear gage with operator constituted one laboratory. Two measurements were made at each test location with the second measurement made with the gage oriented 90 degrees from the gage orientation of the first measurement. Each measurement was identified by the test site location number and the degree of gage orientation. For example, the first measurement made at test site 1 is identified as 1 – 0° and the second measurement made at the test site 1 is identified as 1 – 90°. The density of the materials varied between locations and between gage orientations at each location, therefore, each location and gage orientation was treated as a different material in the statistical analysis. Hence, the materials have the following designations: Material 1 – 0°, Material 1 – 90°, Material 2 – 0°, Material 2 – 90°, etc. Treating each location and gage orientation as a different material provided an analysis of the precision of the test method only, factoring out any variation in the materials.

The test results were organized in rows and columns with each column containing the data obtained from all laboratories for one material, and each row containing the data from one laboratory for all materials (see page A2-2). Arranging the data in this manner resulted in a matrix with sets of three test values made by each of the five laboratories on each of the 12 different materials or a total of 60 sets of data with three test results per data set. The matrix was studied to identify suspect data that may have resulted from an error in testing. The test values in four sets of data were omitted from the analysis due to the suspicion that the values resulted from tests that were not made in strict accordance with the test standard. The sets of values that were omitted each contained one test result that differed from the other two test results by a magnitude of at least 3 pounds per cubic foot (lb/ft^3). One of the sets of data contained a value that was 7 lb/ft^3 lower than the next value in the set. In determining to omit the data from these four sets of data, consideration was given to the relatively small variation within the other 56 sets of data. The 56 sets of data that were retained for further analysis will henceforth be identified as the "corrected data".

Intermediate statistics were computed for each material. The intermediate statistical values that were computed for each material are:

- AVG x – the cell averages (i.e. the average of the three test values obtained by each of the laboratories);
- s – the standard deviation of the three test values obtained by each of the laboratories;
- A – the average of the cell averages (i.e. AVG x / p where p = the number of laboratories);

- d – the cell deviation (i.e. AVG x – A)
- Sx – the standard deviation of the cell averages.

Precision statistics were computed for each material. The precision statistical values that were computed for each material are:

- S_r – the repeatability standard deviation;
- S_R – the reproducibility standard deviation;
- h – the between-laboratory consistency statistic
- k – the within-laboratory consistency statistic

The h and k values were arranged in tables (see page A2 – 9) and bar graphs were prepared of the data in the tables. The bar graphs were plotted in two ways for both the h and k values. The two ways the bar graphs were plotted were: materials grouped by laboratory (see pages A2 -10 and A2 -11) and laboratories grouped by materials (see pages A2 -12 and A2 -13). These graphs were investigated for data consistency according to section 17 of ASTM E 691-99. No clerical, sampling, or procedural errors were disclosed from this investigation. It was determined that all of the corrected data would be retained for final analysis.

The computed statistical values of A, Sx, Sr, S_R for each of the 12 materials were summarized in the following table (table is also included with values defined on page A2 – 14). The 95 percent repeatability limit (r (pcf)) and reproducibility limit (R (pcf)) were determined by multiplying S_r and S_R by 2.8 respectively.

MATERIAL	A	Sx	S_r	S_R	r (pcf)	R (pcf)	CV_r	CV_R	r (%)	R (%)
1 - 0°	141.9267	1.0084	0.5106	1.0912	1.4	3.1	0.3597	0.7688	1.0	2.2
2 - 0°	148.1000	0.6438	0.6653	0.8424	1.9	2.4	0.4492	0.5688	1.3	1.6
3 - 0°	147.8083	0.9500	0.4726	1.0254	1.3	2.9	0.3197	0.6937	0.9	1.9
4 - 0°	151.4533	0.7050	0.4017	0.7775	1.1	2.2	0.2652	0.5134	0.7	1.4
5 - 0°	151.6533	1.3545	0.3606	1.3862	1.0	3.9	0.2377	0.9140	0.7	2.6
6 - 0°	151.0333	0.7968	0.4992	0.8949	1.4	2.5	0.3305	0.5925	0.9	1.7
1 - 90°	139.6133	0.8342	0.4987	0.9283	1.4	2.6	0.3572	0.6649	1.0	1.9
2 - 90°	149.6417	0.8478	0.6305	0.9919	1.8	2.8	0.4213	0.6628	1.2	1.8
3 - 90°	150.6917	0.9016	0.5972	1.0250	1.7	2.9	0.3963	0.6802	1.1	1.9
4 - 90°	151.5800	0.5133	0.5483	1.2397	1.5	3.5	0.3617	0.8179	1.0	2.3
5 - 90°	153.0533	1.2197	0.3235	1.2479	0.9	3.5	0.2114	0.8154	0.6	2.3
6 - 90°	151.1567	0.5676	0.5750	0.7367	1.6	2.1	0.3804	0.4873	1.1	1.4
AVERAGE =			0.5	1.0	$\boxed{1.4}$	$\boxed{2.8}$	0.3	0.7	$\boxed{1.0}$	$\boxed{1.9}$
STANDARD DEVIATION =			0.1	0.2	0.3	0.6	0.1	0.1	0.2	0.4

The repeatability and reproducibility based on the coefficient of variation was also computed and shown in the table, however, there doesn't appear to be any strong dependency of standard deviation on the level of density values obtained by the nuclear gage. Therefore, the average value of standard deviation makes a good basis for the precision statement.