State of Nevada
Department of Highways
Materials and Testing Division

METHOD FOR DETERMINATION OF COMPRESSIVE STRENGTH OF CEMENT TREATED BASE AND CEMENT TREATED SUBGRADE (LABORATORY METHOD)

SCOPE

This method describes the procedure for determining compressive strength as an index of the effectiveness of cement treatment in imparting desirable properties to base and subgrade materials with emphasis on the cement content, optimum moisture and grading analysis.

A. APPARATUS

1. Drying and preheating oven thermostatically controlled to 230° ± 10° F. (110° ± 6° C.).
2. Drying and preheating oven thermostatically controlled to 140° ± 5° F. (60° ± 5° C.).
3. Water tank, 6 in. deep for use in submerging test specimens.
4. Balance with capacity of 5,000 g., accurate to 1 g.
5. Balance with capacity of 500 g., accurate to 0.1 g.
6. Sample splitter, riffle type, 3/4 in. (19.05 mm) openings.
7. Sieves, U.S. Standard sizes, 1 (25.40 mm), 3/4 (19.05 mm), 1/2 (12.70 mm), 3/8 (9.53 mm) in., No. 4 (4.75 mm) square openings.
8. Pans, 10 in. (254 mm) diameter x 2 in. (50.8 mm) deep.
9. Pans, 6 in. (152.40 mm) diameter x 1-1/2 in. (38.10 mm) deep.
10. Metal scoop, No. 3.
11. Funnel weigh scoop and tare weight.
12. Testing machine, 50,000 lb. (222.4 kN) capacity.
13. 250 ml. graduated cylinder or other suitable water metering device.

14. Mechanical mixing machine.

15. Mixing bowl and concrete cylinder cans.

16. Large mixing spoon.

17. Two 6 x 6 in. (152.4 x 152.4 mm) glass plates for each specimen.

18. Compaction accessories, hand method (Figure I).

19. One compression machine consisting of a 20 ton (177.92 kN) capacity hydraulic jack fitted with a spherically seated head and mounted in a 30 in. (762 mm) frame.

20. Measuring gauge and stand (Figure II).

B. TEST RECORD FORM

Use work card, Laboratory Record of Cement Treatment, for recording test data.

C. PREPARATION OF SAMPLE

1. Both proper preparation and accurate quartering of test samples, in addition to use of proper testing procedure, are necessary in order to obtain accurate test results and good test reproducibility. See Test Method Nev. T203 for description of proper methods to use for initial sample preparation and quartering.

2. Samples submitted for cement treatment tests are divided into the following five catagories:

   a. Bin samples or windrow samples.

   b. Stockpile samples.

   c. Pit or quarry samples.

   d. In-place material consisting of existing surfacing and/or base.

   e. Field compacted control samples.

3. The following methods shall be used for preparation of test samples:

   a. Bin samples or windrow samples are not subjected to any further processing prior to mixing with cement. Therefore, sample preparation of these samples shall consist only of separation on the coarse aggregate sieves. Since the aggregate is to be later proportioned for mixing, it will be necessary to split each sample into the following fractions:

Passing 1 inch (25.40 mm)	Retained 3/4 inch (19.05 mm)
Passing 3/4 inch (19.05 mm)	Retained 1/2 inch (12.70 mm)
Passing 1/2 inch (12.70 mm)	Retained 3/8 inch (9.53 mm)
Passing 3/8 inch (9.53 mm)	Retained No. 4 (4.75 mm)
Passing No. 4 (4.75 mm)	

Quartering the samples for separation into smaller fractions shall be accomplished by the methods described under Test Method Nev. T203. Do not obtain required amounts by scooping or pouring from containers.

b. Stockpile samples shall be treated in the same manner as bin samples provided there is to be no further processing in the field prior to addition of cement. However, if further field processing is planned, treat as described below for pit or quarry samples.

c. Pit or quarry samples are processed in various manners. Normally, instructions will be furnished by the sampler as to whether crushing is to be employed. If crushing is to be employed, the material shall be scalped on the sieve designated as the maximum size, and the oversize crushed to pass that maximum size sieve in such a manner that when blended back with its natural component, it will conform to the grading requirements for the project. Coatings shall be removed from coated coarse aggregates, and soil lumps shall be reduced to passing No. 4 (4.75 mm) sieve size. This is necessary in order that all fines be included in test specimens for determination of amount of cement required for desired compressive strength.

d. Treat the in-place materials in the same manner as a pit or quarry sample if the material does not contain bitumen. In-place materials containing lumps of bituminous mix should have the lumps reduced in size to pass a 1-in. (25.4 mm) sieve and no sieve analysis is required. Quarter out required amounts for test specimens from this passing 1-in. (25.4 mm) sieve size portion.

e. Leave field compacted control samples in the tin liner with ends sealed for a 6-day curing period from date of field compaction, then remove from the liner and submerge in water for 1 day to complete the curing period.

4. Weigh representative samples of coarse and fine aggregates to 0.1 g. and heat to dryness at 230° F. (110° C.) to determine initial moisture in aggregate.

5. From the sieve analysis of the sample or samples, design the mix to conform to the specified grading limits by blending or adjusting if necessary. Designing to a smooth grading curve approximating the middle of a specified range is desirable but not always essential. General practice is to produce the best possible grading within the specification limits with the material

on hand, but any adjustment should be such that it can be duplicated under actual field conditions. All gradings shall be washed gradings.

Whenever a larger size than 1 in. (25.4 mm) maximum is specified, the percentage of material passing the No. 4 (4.75 mm) sieve is held constant and the percentage passing the 1-in. (25.4 mm) sieve is equated to 100 percent. The intermediate sizes between the 1-in. (25.4 mm) and No. 4 (4.75 mm) are proportioned in the same ratio as the original grading.

See Test Method NHD 930 for methods of adjusting gradings when the as-received grading is to be changed.

6. The following example illustrates a method for calculating weights of materials and moisture content for cement-treated bases and cement-treated subgrade test specimens. First, make an estimation of the dry weight per cu. ft. for one compacted test specimen.

Assume: 130 lb. per cu. ft. (2082.4 kg/m^3) for trial density, 0.8% moisture for the coarse, 1.2% moisture for the fines, a cement content of 2.0% by weight and 80 g. of water added for proper consistency. From attached table of weights (Figure III), select values opposite 130 lb. per cu. ft. (2082.4 kg/m^3) and arrange as follows:

Weight per Cu. Ft.	Grams of Cement and Aggregate	Grams of Cement
130 (2082.4 kg/m^3)	1716	34

Assume grading as follows:

Sieve Size	Percent Retained	Percent Passing
1" (25.40 mm)	0	100
3/4" (19.05 mm)	4	96
1/2" (12.70 mm)	11	85
3/8" (9.53 mm)	15	70
No. 4 (4.75 mm)	20	50
Minus No. 4 (4.75 mm)	50	

Then from the grading analysis determine the individual weights of aggregate for each sieve size and then the total weight of aggregate, cement and moisture needed for one 4" x 4" (101.6 x 101.6 mm) compacted specimen, as follows:

Dry Weight in grams		Moisture correction	Corrected weight in grams
Ret 3/4" (19.05 mm)	- .04 x 1682 = 67	.008 x 67 = 1	68
Ret 1/2" (12.70 mm)	- .11 x 1682 = 185	.008 x 185 = 2	187
Ret 3/8" (9.53 mm)	- .15 x 1682 = 252	.008 x 252 = 2	254
Ret #4 (4.75 mm)	- .20 x [illegible]2 = 337	.008 x 337 = 3	340
Pass #4 (4.75 mm)	- .50 x 1682 = 841	.012 x 841 = 10	851
Ceme	34	18	Total 1,734
Wate		80	

Total moisture in sample $\frac{18 + 80}{1716} = 5.6\%$

Total weight of sample = 1734 + 80 = 1814 g.

D. DETERMINING OPTIMUM MOISTURE

1. When combinations of various sized particles of mineral aggregate and a constant weight proportion of cement are mixed with different quantities of water and then compacted by identical methods, the use of one certain moisture content will usually result in a greater density (as indicated by the compacted dry weight of material for a given volume) than will be the case using any other moisture content for the particular material under consideration. The amount of water thus required for maximum compaction, expressed as percent of the dry weight of the material, is commonly referred to as the "optimum moisture content" for that combination of aggregates and cement.

2. If no previous data on the soil or aggregates in question is available, a trial initial moisture content may be estimated from the appearance of the soil or from its sieve analysis. Usually, tests are started with a moisture content below the expected optimum. As a rule, an initial moisture of 3 to 7 percent, depending upon the type of material, will give a good starting point.

3. An estimation is made of the weight of dry material required to fabricate the 4 x 4 in. (101.6 x 101.6 mm) test specimen. This estimate is based upon the type of material to be used for the test. For simplicity, the several different types of materials may be classified according to their densities or compacted dry weights per cubic foot, which normally ranges as follows:

Volcanic tuff	70 to 100 lb. per cu. ft. 1121.2 to 1601.8 kg/m^3
Fine Sand	110 to 120 lb. per cu. ft. 1762.0 to 1922.2 kg/m^3
Silty sand or sandy soil	120 to 128 lb. per cu. ft. 1922.2 to 2050.3 kg/m^3
Clayey silt or fine grained soil	125 to 135 lb. per cu. ft. 2002.3 to 2162.4 kg/m^3
Decomposed granite	128 to 132 lb. per cu. ft. 2050.3 to 2114.4 kg/m^3
Coarse to fine or well-graded material	130 to 145 lb. per cu. ft. 2082.4 to 2322.6 kg/m^3

This classification is given merely as a guide for the operator in selecting proper weights to begin the tests. However, some materials may produce densities higher or lower than those shown.

4. The following formula may be used for determining the total combined weights of aggregate and cement that are required for the fabrication of 4 x 4 in. (101.6 x 101.6 mm) test specimens of various weights per cubic foot (kg/m^3):

$$W_g = \frac{WfH}{.303}$$

Where:

W_g = Dry weight in grams of 4 x 4 in. (101.6 x 101.6 mm) compacted test specimen.

Wf = Dry weight in lb. per cu. ft. (Kg/m^3) of compacted test specimen.

H = Height of test specimen in inches.

.303 = Constant used to convert weight in grams to weight in lb. per cu. ft. for a 4-in. (101.6 mm) diam. specimen having a height H.

Example:

Assume a weight of 107 lb. per cu. ft. (1713.9 kg/m^3) for a trial density and a cement content of 2 percent.

Substituting in above formula,

$$Wg = \frac{107 \times 4}{.303} \; \frac{(1713.9\ kg/m^3 \times 101.6\ mm)}{123.328} = 1412\ g.\ \text{of cement and aggregate}$$

$$\frac{1412}{100 + 2} \times 100 = 1384\ g.\ \text{of aggregate}$$

1412 - 1384 = 28 g. of cement.

5. In order to simplify the procedure for calculating the amount of aggregate and cement to be used in fabricating one 4 x 4 in. (101.6 x 101.6 mm) test specimen, a table is furnished (Figure III), for reference. This table gives dry weights of materials in grams required to produce one 4 x 4 in. (101.6 x 101.6 mm) test specimen with cement content varying from 2 percent to 8 percent by weight, and densities varying from 107 to 150 lb. per cu. ft. (1713.9 to 2402.7 kg/m^3). If quantities of materials are needed to make specimens with a density lower than 107 (1713.9 Kg/m^3) or higher than 150 lb. per cu. ft. (2402.7 kg/m^3) the above formula must be used.

6. For the trial or pilot specimen, add water to the mixture in small increments up to a point where visual inspection and hand squeezing of small amounts of the mixture indicate sufficient water to provide good cohesion between the cement and aggregates. For this trial mix, attempt to produce a specimen of 4.000 ± .200 in. (101.6 mm ± 5.08 mm) in height where 8 to 10 g. of water is squeezed out when the specimen is compressed with the specified static load. After the trial specimen is made, it may be necessary to make adjustments both of the amount of material needed to fabricate one specimen 4 in. (101.6 mm) high and of the proper amount of water needed to get 8 to 10 g. squeezed out.

7. In determining the optimum moisture, fabricate three test specimens with different moisture contents. For most materials the moisture increment is about 1 percent, but for absorptive materials the moisture increment may be increased to 2 percent. The ideal situation is reached when one of the specimens is at the point of saturation, another is slightly above the point of saturation (8 to 10 g. of water exuded under the static load), and the third specimen is slightly below the saturation point.

8. The specimens fabricated to determine the optimum moisture are cured and tested for compressive strength.

9. Highest density is usually attained in cement treated base and cement treated subgrade test specimens if a small amount of water is exuded from the specimen when subjected to a static load. From the data obtained in the fabrication of the three specimens, calculate the amount of moisture required to produce maximum density. This amount of moisture expressed as percent of the dry weight of material is knows as the optimum moisture.

10. Using the data obtained from the fabrication of the optimum moisture speciments, fabricate additional specimens, increasing the cement content 0.5% per specimen until an amount of 4.5% cement is obtained. The moisture content is held constant at or as near the predetermined optimum moisture as possible.

11. These additional specimens are for compressive strength determinations and are for the purpose of determining the necessary amount of cement to provide a specified or desired strength under optimum moisture conditions.

12. Fabricate any additional test specimens necessary for special tests such as wetting and drying, or freezing and thawing, in the same manner.

13. Mix the individual test specimens in the following manner:

    a. Mix together the proper proportion of aggregates and cement prior to adding water. After the dry ingredients are thoroughly mixed, add the required amount of water and continue mixing until all of the aggregates are coated.

    b. Any mechanical mixer which will produce a homogeneous mix may be used, or the composite materials may be mixed by spoon and mixing bowl method.

    c. After mixing, place the aggregate-cement-water mixture in a can and cover with a tight fitting lid for a period of 30 min. before compaction in the individual test specimens.

E. COMPACTION OF THE TEST SPECIMENS

1. Method A - Hand Compaction

    a. Place tin liner in Figure I on 1/2 of the split mold. Place the other half of the split mold on top and fasten securely with the four bolts.

While the mold is still in a horizontal position, insert plunger into the bottom of the mold. With pin fasten the plunger at a desired height, keeping in mind that the lower holes should be used when compacting granular materials and the higher holes when compacting plastic materials. Stand the mold upright and place extension collar on top.

b. Place approximtely one-half of the weighed sample in the mold with a scoop or large spoon. If the material contains rock particles larger than 1/4-inch (6.35 mm), rod 20 to 30 times with a 3/8 inch (9.525 mm) bullet-nosed rod during this operation in order to prevent the formation of rock pockets at the bottom or sides of the specimen. Tamp the first layer of material 50 blows with the small end of the 6 lb. hand tamper. Physical exertion in tamping should be only sufficient to move the tamper in approximately a 4 inch (101.6 mm) travel. Guide the tamper over the entire surface of the specimen. The actual compactive effort should be provided only by the weight of the tamper, using the hand as a guide. Avoid having a smoothly compacted surface at this stage because it will result in a compaction plane in the specimen when the next layer is tamped, and this would prevent the two layers from being bonded together.

c. Place the remaining portion of the sample in the mold (rodded, if sample contains coarse aggregate), and tamp, using 100 blows with the small end of the hand tamper. Level off the top of the compacted specimen by tamping lightly with the large end of the tamper in order to provide a smooth surface on an even plane at right angles to the axis of the mold. Remove the extension collar, insert the follower and place the assembly in the compression machine. Pull the plunger pin and gradually apply a total load of 15,000 lb. (66.7 kN) in 1 min. Hold the total load of 15,000 lb. (66.7 kN) for 1 min. before releasing.

d. Place the mold in the vise, take out the plungers, open the mold, remove the specimen with its tin jacket and weigh.

Determine the height with the measuring gauge, by seating the circular measuring guide firmly on top of the cylinder. Care must be taken to seat the dial indicator tip properly in the center of the measuring guide.

e. From the determined amount of moisture in the specimen, the equivalent compacted dry weight in lb. per cubic foot (kg/m^3) can be obtained by use of the following formula.

$$D = \frac{30.3\ Ww}{(100 + M)H} \qquad \frac{(123.33\ Ww)}{(\ (100+M)H)}$$

Where:

D = Dry density of the test specimen in lb. per cubic foot (kg/m^3)

W_w = Wet weight of the test specimen in grams after compaction.

M = Percent moisture of the sample

H = Height of test specimen in inches

30.3 = Constant used to convert weight in grams to lb. per cu. ft. (kg/m^3) for a 4 inch (101.6 mm) diameter specimen having the height measured in inches.

f. If the specimen is to be tested for compressive strength only, the identification number can be marked on the side of the specimen with an indelible pen. However, if the specimen is to be tested for "wetting and drying" or "freezing and thawing" there is danger of losing such identification due to sloughing; therefore, it is advisable to attach a small numbered brass or copper washer to the top of the specimen by means of a brass screw.

F. CURING TEST SPECIMENS

1. Store or seal all test specimens in such a manner after compaction that no moisture is lost from the specimens during the curing period. This can be accomplished by curing specimens in a moist cabinet, by covering specimens with set burlap, or by placing lids on each end of the tin sleeve and sealing with adhesive tape.

2. Cure all test specimens for 6 days. Then remove the tin sleeves and use an indelible pen to write proper identification on the side of the specimens.

3. Next, submerge the specimens in water for 1 day. This concludes the 7-day curing period, and the specimens are ready to be tested for compressive strength.

G. TESTING FOR COMPRESSIVE STRENGTH

1. Remove test specimens from the soaking tank and dry the surfaces of the specimen with a cloth.

2. For each specimen, grease two 6 x 6 inch (152.4 x 152.4 mm) glass plates on one side using ordinary lubricating oil. Arrange the glass plates in a double row on a table and place the surface dried test specimens in a row between the two rows of greased plates.

3. Mix enough plaster of paris with water to form a thick paste sufficient in quantity to cap approximately six specimens, top and bottom.

4. Place an amount of paste equivalent to a large tablespoonful on top of each of the test specimens and on each of the glass plates in the row nearest the operator.

5. Place the outer row of glass plates that have no paste on them on the top surface of the specimens containing the plaster paste. Force the plates down until the paste covers the entire surface of the specimens. Then place the specimens with top plates in place on the row of plates that have paste on them, and press the specimens down until the paste cover the entire area of the bottom of the specimens. Adjust the specimens while plaster is still soft so that top and bottom plates are as nearly as possible at right angles to the vertical axis of test specimen.

6. Allow specimens to stand for a period of 30 to 40 min. to permit hardening of the plaster. Remove the glass plates by tapping the edges lightly with a piece of soft wood. If difficulty is experienced in removing the plates, apply warm water and continue tapping lightly.

7. The specimens are now ready to be placed in the testing machine for compressive strength tests.

   a. If a mechanical testing machine is used, the travel of the head shall be at the rate of 0.05 in. (1.27 mm) per min.

   b. If a hydraulic testing machine is used, apply the load at the rate of between 20 and 50 lb. per square inch (137.90 kPa and 344.74 kPa) per second. Ideal rate of loading on a 4-in. (101.6 mm) diam. specimen for the hydraulic testing machine is 2,200 lb. (9.8 kN) total load in 5 sec.

8. Apply the load until ultimate fracture of the test cylinder occurs. An initial fracture will usually occur at approximately 80 percent of the load required for ultimate fracture.

9. Report the test results as compressive strength in pounds per square inch which equals the total compression load divided by the end area of the test cylinder. In the standard 4-in. (101.6 mm) test cylinder the end area is 12.57 sq. in. (8109.7 mm^2). An optional method is to multiply the total compression load by .080 (.000123 mm) in lieu of dividing total load by 12.57 (8109.7).

REPORTING OF RESULTS

Report the test results on test report. Include grading used, compressive strength, and recommended moisture and cement contents.

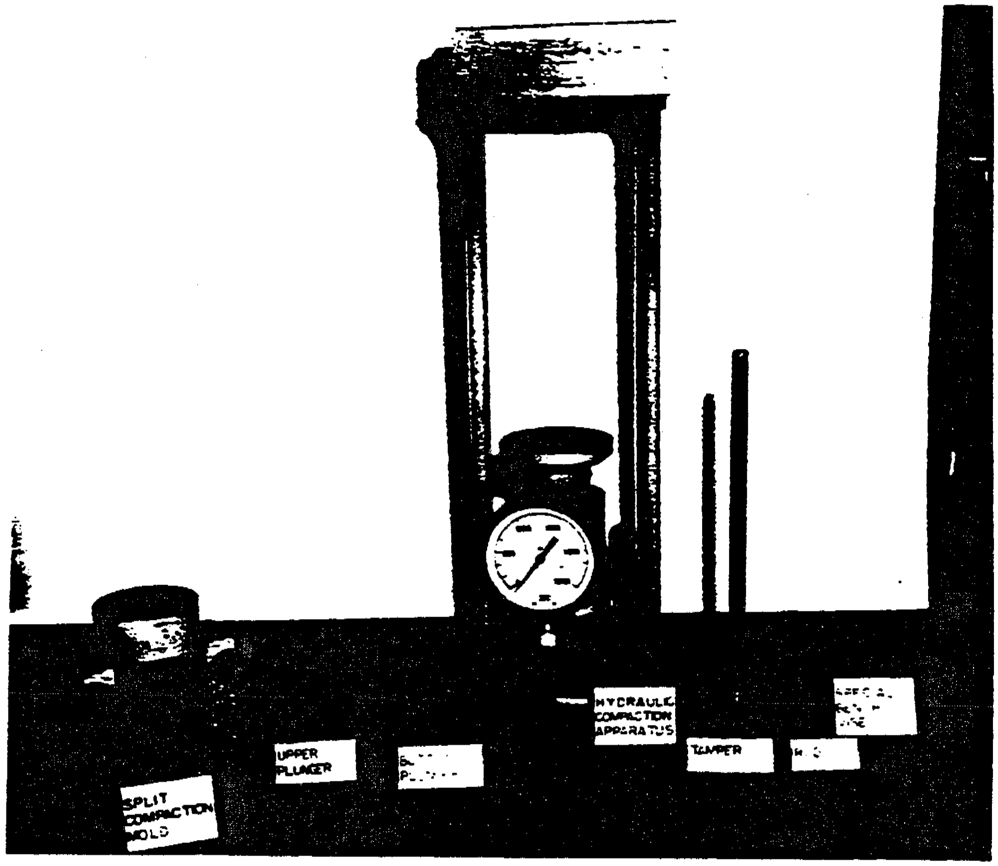
SPLIT COMPACTION MOLD
UPPER PLUNGER
HYDRAULIC COMPACTION APPARATUS
TAMPER

FIGURE 1

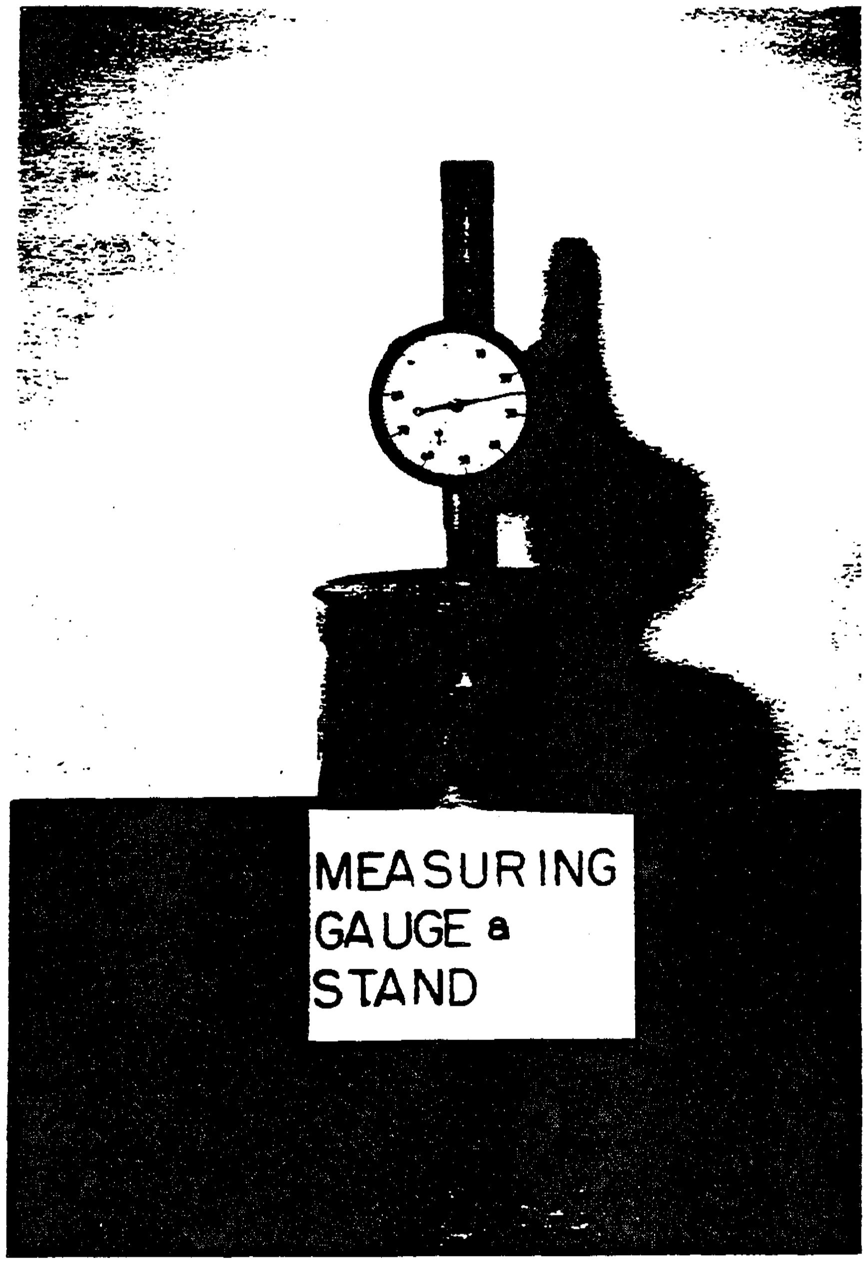

FIGURE 2

FIGURE III

Table of Weights for Use in Fabricating 4-in. (101.6 mm) Diameter x 4-in. (101.6 mm) High Test Specimens of Various Weights Per cu. ft. (mm^3)

Wt. lbs. cu. ft.	Total grams cement + agg.	Kg/m^3	Grams Cement 2 percent	3 percent	4 percent	5 percent	6 percent	7 percent	8 percent
107	1,412	1713.9	28	41	54	67	80	92	105
108	1,426	1729.9	28	42	55	68	81	93	106
109	1,439	1746.0	28	42	55	69	82	94	107
110	1,452	1762.0	29	42	56	69	82	95	108
111	1,465	1778.0	29	43	56	70	83	96	109
112	1,478	1794.0	29	43	57	70	84	97	109
113	1,492	1810.0	29	44	57	71	85	98	110
114	1,505	1826.1	30	44	58	72	85	99	111
115	1,518	1842.1	30	44	58	72	86	99	112
116	1,531	1858.1	30	45	59	73	87	100	113
117	1,544	1874.1	30	45	59	74	87	101	114
118	1,558	1890.1	31	45	60	74	88	102	115
119	1,571	1906.1	31	46	60	75	89	103	116
120	1,584	1922.2	31	46	61	75	90	104	117
121	1,597	1938.2	31	47	61	76	90	105	118
122	1,610	1954.2	32	47	62	77	91	105	119
123	1,623	1970.2	32	47	62	77	92	106	120
124	1,637	1986.2	32	48	63	78	93	107	121
125	1,650	2002.3	32	48	64	79	93	108	122
126	1,663	2018.3	33	49	64	79	94	109	123
127	1,676	2034.3	33	49	65	80	95	110	124
128	1,690	2050.3	33	49	65	81	96	111	125
129	1,703	2066.3	33	50	66	81	96	111	126
130	1,716	2082.4	34	50	66	82	97	112	127
131	1,729	2098.4	34	50	67	82	98	113	128
132	1,742	2114.4	34	51	67	83	99	114	129
133	1,756	2130.4	35	51	68	84	99	115	130
134	1,769	2146.4	35	52	68	84	100	116	131
135	1,782	2162.4	35	52	69	85	101	117	132
136	1,795	2178.5	35	52	69	86	102	118	133
137	1,808	2194.5	36	53	70	86	102	118	134
138	1,822	2210.5	36	53	70	87	103	119	135
139	1,835	2226.5	36	53	71	87	104	120	136
140	1,848	2242.5	36	54	71	88	105	121	137
141	1,861	2258.6	37	54	72	89	105	122	138
142	1,874	2274.6	37	55	72	89	106	123	139
143	1,888	2290.6	37	55	73	90	107	124	140
144	1,901	2306.6	37	55	73	91	108	124	141
145	1,914	2322.6	38	56	74	91	108	125	142
146	1,927	2338.6	38	56	74	92	109	126	143
147	1,940	2354.7	38	57	75	92	110	127	144