An Evaluation of the Bulk Specific Gravity for Granular Materials

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Accurate determination of bulk specific gravity of aggregates is of paramount importance for successful design of bituminous paving mixtures as well as portland cement concrete. The complicating element in specific gravity determination is the achievement of saturated surface-dry conditions. The various modifications suggested by several investigators either offer little improvement or are too elaborate to be of practical value in the field or common laboratory. In this study, the bulk specific gravities of crushed aggregates and cylindrical rock cores from six limestone quarries, one slag, one crushed trap rock, and one synthetic aggregate (Synopal) were determined by five methods. The methods are standard ASTM, geometrical measurement, mercury displacement, and two chemical indicator methods proposed by the authors. The results by the standard ASTM methods, in terms of reasonableness and repeatability, are compared and evaluated in relation to results by the other four methods. The procedures of the proposed chemical indicator methods (cobalt chloride and fluorescein sodium salt) are described. The repeatability and reproducibility of the cobalt chloride indicator method are presented.

•BULK SPECIFIC GRAVITY is the ratio of the weight in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. The bulk specific gravity of an aggregate, as defined by the ASTM, equals the oven-dry weight of the aggregate (A) divided by the sum of the aggregate volume (Vs), the volume of the permeable voids (Vp), and the volume of the impermeable voids (Vi) times the unit weight of water (γw):

$$\text{bulk specific gravity} = \frac{A}{(Vs + Vp + Vi)\ \gamma w}$$

or

$$= \frac{A}{B - C}$$

where B is the saturated surface-dry weight (in grams) of the material in air and C is the weight (in grams) of saturated material in water. Those voids that cannot be filled with water after a 24-hour soaking are referred to as impermeable voids. Voids that can be filled with water after a 24-hour soaking period are referred to as permeable.

Percent voids is widely used as one of the criteria for the design of bituminous paving mixtures. The exact determination of bulk specific gravity of the various constituents of the paving mixture is necessary to calculate the voids properties accurately.

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Bulk specific gravity is also used in design calculations of concrete mixtures. The specific gravity of aggregates must be known to enable the designer to compute the amounts of the various ingredients in the mixture. Because almost all batching is now done on a weight basis, the importance of correctness of its value is readily apparent.

Experience has shown that, for some materials, the results of bulk specific gravity are very difficult to reproduce. This is mainly caused by the personal element involved in judging the point at which the wet aggregate has dried out sufficiently to reach the "saturated surface-dry condition," which is theoretically the point at which all the surface moisture has gone from the particles but with the permeable pores remaining completely filled.

ASTM Standard Methods C 127 and C 128 outline means for determining absorption and bulk specific gravity of aggregates. These standards call for immersion of material in water for 24 hours, followed by drying until the surface-dry state is attained. Coarse aggregates are rolled in an absorbent cloth until all visible films of water are gone.

Fine aggregates are spread on a pan and exposed to a gentle current of warm air until a free-flowing condition is reached. The aggregate is then lightly tamped into a conical mold. If the cone stands when the mold is removed, the fine aggregate is assumed to carry moisture on its surface, and it is dried further. When the cone just begins to slump after removal of the cone, it is assumed to be in a saturated surface-dry state. In addition to variation caused by individual judgment, the fact that large particles tend to dry more quickly than small particles may lead to overdrying of the larger particles, unless the precaution is taken of recognizing and handling these particles separately. These variations become significant in the case of aggregates having a rough and porous surface.

For natural, well-graded fine aggregates, the saturated surface-dry condition is usually reproducible. The end point is more erratic for crushed fine aggregates because the angularity of the particles does not permit a definite slump condition as do the rounded surfaces of natural sands. Besides this, the higher percentage of material passing the No. 100 sieve also poses a problem in achieving slump condition.

Various attempts have been made in the past to pinpoint the saturated surface-dry condition of the aggregates to improve the reproducibility of the bulk specific gravity test results. These include Howard's glass jar method (1, 2), Martin's wet and dry bulb temperature method (3), Saxer's absorption time curve procedure (4), and Hughes and Bahramian's saturated air-drying method (5). However, the various modifications either offer little improvement or are too elaborate to be of practical value in the field or average laboratory.

Bulk specific gravity has also been determined by simple mensuration; for example, by use of a micrometer or a dial gage to determine the volume of regular shape samples. When the sample is irregular or particulate it has been determined by mercury displacement under a given pressure, provided the mercury does not wet the surfaces of the sample. Both methods have been included in this study to assess the comparative values of bulk specific gravity as obtained from ASTM standard methods. Rock cores from the same block samples have been used for both these methods to eliminate errors caused by sample variation.

A new chemical indicator method has been tried in this study. Its adoption is suggested for determining the saturated surface-dry condition of both coarse and fine aggregates. This seems very practical and eliminates most of the personal judgment involved in standard ASTM tests.

OBJECTIVES

The purposes of this investigation are (a) to evaluate the reasonableness and repeatability of the standard ASTM methods for bulk specific gravity, as compared with other alternative methods; (b) to develop new, simple methods to determine the bulk specific gravity or the saturated surface-dry condition for granular materials more reliably; and (c) to evaluate these new methods as compared to the ASTM methods.

TABLE 1

LIMESTONE AGGREGATES STUDIED

Number	County	Quarry	Beds or Ledges	Geological Formation
1	Adair	Menlo	3-6-Argentine	Missourian series, Pennsylvanian system
2	Blackhawk	Pints	Rapid	Cedar Valley formation, Devonian system
3	Hardin	Alden	—	Gilmore City formation, Mississippian age
4	Scott	Linwood	Davenport	Devonian system
5	Story	Cook	—	St. Louis formation, Mississippian series
6	Washington	Keota	Beds 14 through 22	Osage series, Mississippian age

MATERIALS

Crushed Aggregates

Six limestone aggregates that were obtained from various areas in Iowa and that range from most absorptive to least absorptive in character have been included in the study for both coarse and fine aggregates. Mercury-intrusion porosity (21-0.05 μ pore radius range) varied from 0.90 percent in Linwood limestone to 17.44 percent in Cook limestone, with varying pore characteristics and surface texture. Besides these, one trap-rock aggregate and one blast-furnace slag were included to provide variation in water absorption, pore characteristics, and specific gravity. Subsequently, at a later stage, Synopal (a synthetic aggregate manufactured in Denmark) was also included because it is supposed to have uniform structure and other characteristics and it could be used in the comparative study on bulk specific gravity. The details of limestone aggregates studied are given in Table 1. For coarse aggregates, the fraction passing the $\frac{3}{8}$-in. sieve and retained on the No. 4 sieve was used so as to have uniformity in results. For fine aggregates, the fraction passing the No. 4 sieve and retained on the No. 100 sieve was used (Table 2).

Rock Cores

Rock cores $\frac{1}{2}$ in. in diameter were drilled from blocks obtained from the respective limestone quarries to be used for determination of bulk specific gravity. They do not necessarily represent the beds from which the aggregates were procured but have been used to ensure material homogeneity and to assess the relative values of ASTM bulk specific gravity in comparison with that obtained from other methods. For uniformity, the rock cores were drilled at right angles to the natural bedding planes. For geometrical measurements, the ends of the rock cores were trimmed so as to have a true cylinder for accurate measurement of volume.

TABLE 2

GRADATION OF FINE AGGREGATES

Sieve No.	Percent Passing					
	Menlo	Pints	Alden	Linwood	Cook	Keota
4	100	100	100	100	100	100
8	20	67	53	60	70	86
30	1	20	15	12	25	40
50	0.6	8.9	7.4	4.9	10.8	10.0
100	0.3	0.5	0.4	0.4	1.1	0.3

Chemical Indicators

For the new methods to determine saturated surface-dry condition, four chemical indicators were tried: (a) cobalt chloride, (b) fluorescein disodium salt, (c) cupric chloride, and (d) copper sulfate. Of these, only the first two gave encouraging results and have been included in this study.

METHODS FOR DETERMINING BULK SPECIFIC GRAVITY

Rock Cores

ASTM Method—ASTM Standard Method C 127 was adopted for ½-in. diameter rock cores to determine bulk specific gravity. The rock cores could be rolled uniformly on absorbent cloth to achieve a saturated surface-dry condition as defined by ASTM.

Geometrical Mensuration Method—In the geometrical mensuration method each rock core was weighed to 0.0001 gram and its dimensions were measured with a caliper up to 0.01 cm. Average diameter and length were calculated after measuring at three or four places. Duplicate determinations were made for each rock type. Bulk specific gravity was calculated as weight divided by measured volume.

Mercury Displacement Method—A mercury porosimeter, as used in determination of mercury-intrusion porosity and pore-size distribution of aggregates, was used to determine the bulk volume of the rock core at 5 psi. The theory and operation of the apparatus are described elsewhere (6, 7). The authors have devised a simpler apparatus, using a modified 250-ml burette connected to a sample chamber at one end and a mercury reservoir at the other end, to measure bulk specific gravity of aggregates by the mercury displacement method, but it will not be discussed here.

Crushed Aggregates

ASTM Methods—ASTM Standard Methods C 127 and C 128 were followed for determination of bulk specific gravity of coarse and fine aggregates respectively, except that Chapman flasks were used for fine aggregates. The bulk specific gravity (Gb) was calculated as follows:

$$Gb = \frac{A}{V - 200}$$

where A = weight in grams of oven-dry sample in air, and
V = combined volume in millimeters of saturated surface-dry sample and water.

Mercury Displacement Method—The procedure used is the same as described for rock cores except that crushed aggregates were used instead in the sample chamber.

Chemical Indicator Methods—With the salt cobalt chloride there is a color change from the red hexahydrate through the violet monohydrate to the blue anhydrous salt; that is, anhydrous $CoCl_2$ is blue whereas $CoCl_2 \cdot 6H_2O$ is red. Use is made of this property of the indicator to pinpoint the saturated surface-dry condition. A 5 percent solution of cobalt chloride is prepared and the aggregate (coarse or fine) is immersed in this solution. After 24 hours of immersion, the aggregates are removed from the solution and spread on a table with a white top or in any wide white enameled tray. The aggregate may or may not acquire a pink tint, but as soon as drying proceeds and its surface is dry, it attains a distinct bluish color. This is assumed to be the saturated surface-dry condition. The remaining procedure is the same as indicated in ASTM Standard Methods C 127 and C 128. The detailed procedure is described in the Appendix.

In the other chemical indicator method, a solution (0.5 percent) of fluorescein sodium salt is prepared and the aggregate (coarse or fine) is immersed in this solution for 24 hours. When the aggregate is taken out of the solution, it acquires a distinct light yellow color. As the aggregate is spread on a white porcelain surface and is subjected to drying, the color of the aggregate changes from light yellow to distinct orange, thus achieving the saturated surface-dry condition. The remaining procedure is the same as in ASTM Standard Methods C 127 and C 128. The detailed procedure is described in the Appendix.

TABLE 3

BULK SPECIFIC GRAVITY OF ROCK CORES

Core	Bulk Specific Gravity by		
	ASTM Method	Geometrical Mensuration Method	Mercury Displacement Method
1-Menlo	2.637	2.728	2.710
2-Pints	2.271	2.337	2.312
3-Alden	2.510	2.586	2.527
4-Linwood	2.636	2.734	2.694
5-Cook	2.565	2.634	2.622
6-Keota	2.489	2.592	2.549

RESULTS AND DISCUSSION OF INVESTIGATIONS

Rock Cores

The bulk specific gravity of rock cores was determined by ASTM Standard Method C 127, the geometrical mensuration method, and the mercury displacement method. Results are given in Table 3. It is evident from the data that the ASTM standard test gives a minimum value whereas the geometrical mensuration method gives a maximum value of bulk specific gravity. The values obtained by three methods have excellent correlations with each other, which indicates that consistent results have been obtained by using rock cores.

Plots are made of values obtained by the ASTM standard test and those obtained by geometrical mensuration in Figure 1. The correlation coefficient is 0.9969, which is significant at the 1 percent level. The equation of the regression line is

$$Y = -0.0735 + 1.0625X$$

where X = bulk specific gravity by the ASTM method, and
Y = bulk specific gravity by geometrical mensuration.

Bulk specific gravity by geometrical mensuration is greater than that by the ASTM method. Differences range from 0.07 for light aggregate to 0.09 for heavy aggregate. A possible reason for this almost constant difference is the moist surface of the rock cores even after being rolled in absorbent cloth. Because of this, the saturated surface-dry weight observed is high, resulting in reduced bulk specific gravity. However, bulk specific gravity by geometrical measurements may give slightly higher results because of a slight undulation irregularity that is neglected in the measurement of dimensions. However, it seems that the moist surface plays a predominant role in causing this significant difference.

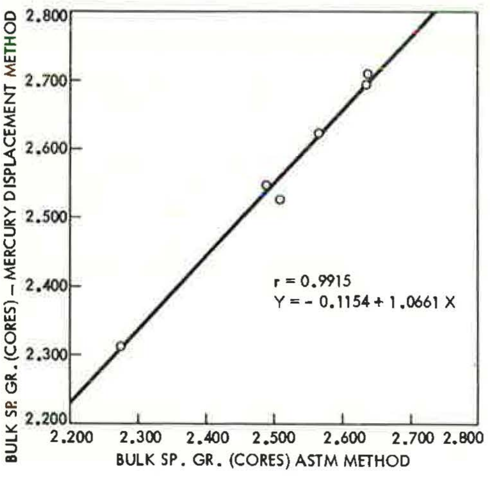

Figure 1. Bulk specific gravity of cores, ASTM method versus geometric mensuration method.

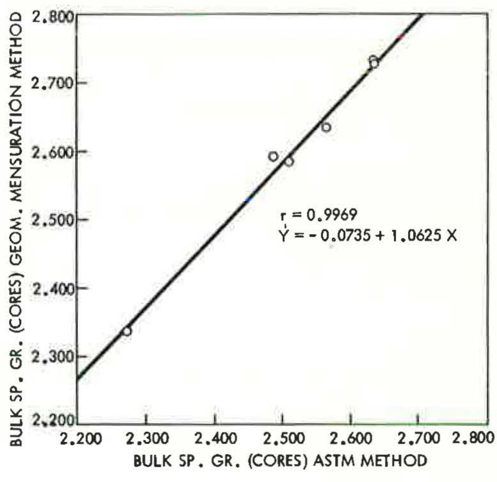

Figure 2. Bulk specific gravity of cores, ASTM method versus mercury displacement method.

The correlation coefficient for values obtained by the ASTM standard method and those by the mercury displacement method is 0.9915 (Fig. 2), which is significant at the 1 percent level. The equation for the regression line is

$$Y = -0.1154 + 1.0661X$$

where X = bulk specific gravity by the ASTM method, and
Y = bulk specific gravity by the mercury displacement method.

Specific gravity obtained by the mercury displacement method is higher than that of the ASTM standard method. The difference ranges from 0.04 for light aggregate to 0.06 for heavy aggregate. Again, a possible reason is the moistness over the surface in the ASTM standard test.

From the results of these three methods, it thus appears that ASTM standard tests C 127 and C 128 may underestimate the bulk specific gravity as they take into account absorption as well as adsorption of the particles. This is indicated by the moistness that can be seen visually. This discrepancy had been pointed out by Shergold (8), who recommended that the aggregate should be exposed to the atmosphere for at least 10 minutes before being weighed after the aggregate has been wiped dry with absorbent cloth. However, this 10-minute time period cannot be adopted in all circumstances because of the varying air temperature and humidity conditions, but it does indicate the required improvement of the test.

Hughes and Bahramian (5) also obtained results showing that water absorption values obtained from the ASTM method were significantly higher than those obtained by their saturated air method. This further supports the underestimation of bulk specific gravity by standard test.

TABLE 4

BULK SPECIFIC GRAVITY OF COARSE AGGREGATES BY VARIOUS METHODS

Aggregate[a]	ASTM Method	$CoCl_2$ Method	FSS Method	Mercury Displacement Method
Cook				
1-S-B	2.567	2.601	2.615	2.560
1-L-A	2.613	—	—	2.556
1-L-B	2.603	—	—	2.526
Pints				
2-A	2.348	—	—	2.321
2-B	2.333	2.356	2.337	2.364
Alden				
3-S-B	2.475	2.537	2.487	2.496
3-L-A	2.517	—	—	2.546
3-L-B	2.508	—	—	2.555
Linwood				
4-A	2.613	—	—	2.644
4-B	2.582	2.620	2.631	2.658
Cook				
5-S-B	2.397	2.445	2.437	2.480
5-L-A	2.426	—	—	2.447
5-L-B	2.408	—	—	2.481
Keota				
6-A	2.326	—	—	2.322
6-B	2.263	2.270	2.250	2.257
Slag				
A	2.668	—	—	—
B	2.656	2.639	2.654	—
Trap				
A	2.822	—	—	—
B	2.857	2.900	2.903	—
Synopal				
B	2.149	2.180	—	—

[a]A = passing 1 in. sieve and retained on 3/8 in. sieve. B = passing 3/8 in. sieve and retained on No. 4 sieve.

COARSE AGGREGATES

Bulk specific gravity of coarse aggregates was determined by four methods: ASTM Standard Method C 127, chemical indicator method using cobalt chloride, chemical indicator method using fluorescein sodium salt, and mercury displacement method. Average results based on duplicate determinations are given in Table 4.

Bulk specific gravity values determined by the ASTM method have been plotted in Figure 3 against those obtained by the mercury displacement method for 15 coarse aggregates. Correlation is very good—value of the correlation coefficient is 0.9924, which is significant at the 1 percent level. The equation of the regression line is

$$Y = 0.1738 + 0.9358X$$

where X = bulk specific gravity by the ASTM method, and
Y = bulk specific gravity by the mercury displacement method.

As in cores, bulk specific gravity values obtained by mercury displacement are higher than those obtained by the ASTM method.

Values of bulk specific gravity obtained by using cobalt chloride (Table 3) as the indicator of saturated surface-dry condition

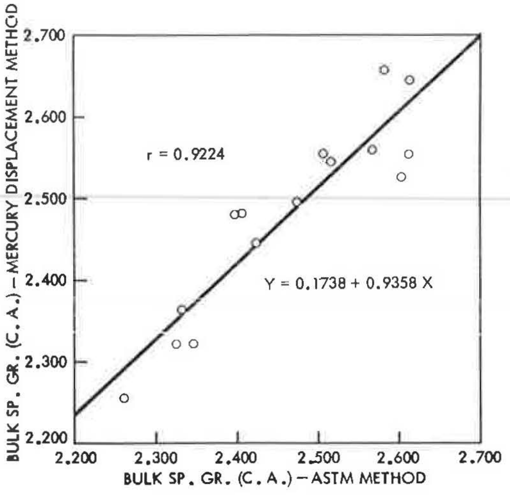

Figure 3. Bulk specific gravity of coarse aggregates, ASTM method versus mercury displacement method.

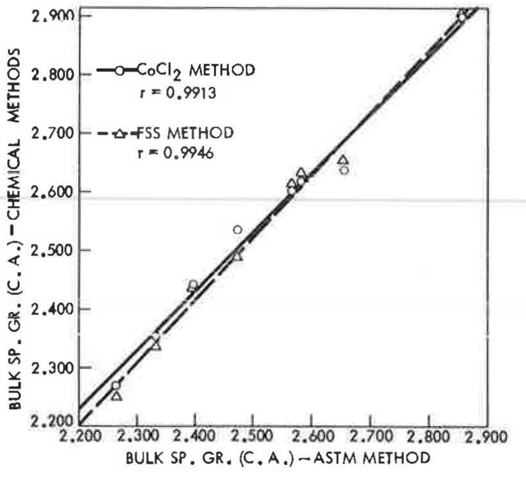

Figure 4. Bulk specific gravity of coarse aggregates, ASTM method versus chemical dye method.

are higher than those obtained by the ASTM method. The difference is about 0.03 for the entire range of aggregates. Linear correlation is excellent (Fig. 4)—the correlation coefficient is 0.9913, which is significant at the 1 percent level.

The striking constancy of difference in the entire range of light to heavy aggregates, except slag, seems to point out that the chemical method takes care of the adsorbed water on the surface of the aggregates, because only anhydrous $CoCl_2$ can have a blue color while $CoCl_2 \cdot 6H_2O$ is red. Because of the disappearance of adsorbed water, the weight of saturated surface-dry aggregate in air is less, which gives an increased value of bulk specific gravity. It seems that the chemical method gives realistic bulk specific gravity values. It is further supported when these values obtained from the $CoCl_2$ method are compared with those obtained by the mercury-displacement method (Fig. 5). Correlation is excellent—the value of the correlation coefficient is 0.9671, which is significant at the 1 percent level. The discrepancy in values of bulk specific gravity in the case of slag obtained by the ASTM and chemical methods can probably be attributed to the cellular nature of slags, which retain internal water not held by capillary forces.

As in the case of cobalt chloride, fluorescein sodium salt has also indicated the saturated surface-dry condition of the aggregates fairly well. The values of bulk specific gravity obtained by using this indicator are shown in Figure 4 against those obtained by the ASTM standard method. The correlation coefficient is 0.9946, which is significant at the 1 percent level. The values obtained from the fluorescein sodium salt (FSS) method also have excellent linear correlation with those obtained

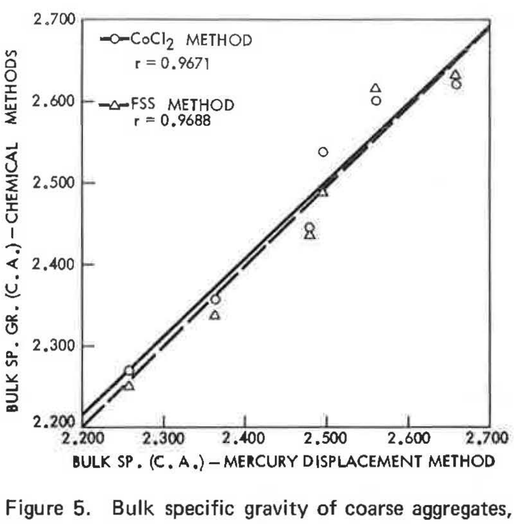

Figure 5. Bulk specific gravity of coarse aggregates, mercury displacement method versus chemical dye method.

TABLE 5

BULK SPECIFIC GRAVITY OF FINE AGGREGATES

Aggregate	ASTM Method	$CoCl_2$ Method	FSS Method
Cook	2.551	2.553	2.535
Pints	2.284	2.288	2.295
Alden	2.498	2.480	2.492
Linwood	2.534	2.516	2.536
Cook	2.395	2.420	2.408
Keota	2.426	2.409	2.401

by mercury displacement. The linear correlation coefficient is 0.9688, which is significant at the 1 percent level. Comparison of the two chemical methods (Fig. 4) shows that the two indicators give practically identical results for an average weight aggregate.

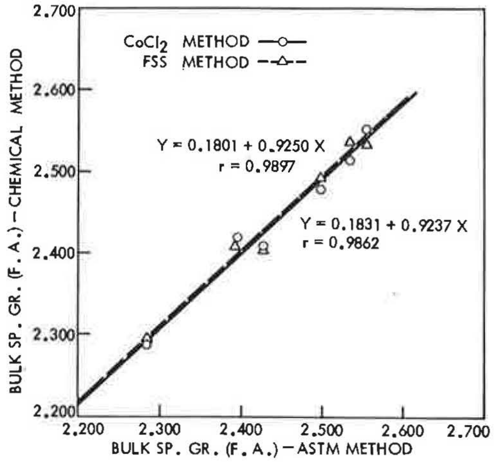

Figure 6. Bulk specific gravity of fine aggregates, ASTM method versus chemical dye method.

Fine Aggregates

Results of bulk specific gravity tests on fine aggregates (average value based on duplicate determinations) are given in Table 5. Figure 6 shows the linear correlations of ASTM bulk specific gravity with values obtained by using the two chemical methods.

With cobalt chloride, the correlation coefficient is 0.9862, which is significant at the 1 percent level, and the equation for the regression line is

$$Y = 0.1831 + 0.9237X$$

where X = bulk specific gravity by the ASTM method, and
Y = bulk specific gravity by the $CoCl_2$ method.

As in the case of coarse aggregates, values obtained by the $CoCl_2$ method are higher than those obtained by the ASTM method. The difference is about 0.01 for the entire range of aggregates and is smaller than the 0.03 observed in the case of coarse aggregates.

TABLE 6

DIFFERENCES BETWEEN DUPLICATE DETERMINATIONS OF BULK SPECIFIC GRAVITY OF COARSE AGGREGATES

Coarse Aggregate	ASTM Method	$CoCl_2$ Method	FSS Method
Menlo	0.022	0.005	0.008
Pints	0.001	0.005	0.003
Alden	0.005	0.006	0.004
Linwood	0.022	0.008	0.011
Cook	0.006	0.003	0.007
Keota	0.019	0.009	0.012
Trap	0.014	0.004	0.019
Slag	0.020	0.022	0.015
Average difference	0.014	0.008	0.010
Range	0.001 to 0.022	0.003 to 0.022	0.003 to 0.019
Average difference, excluding slag	0.012	0.006	0.009
Range, excluding slag	0.001 to 0.022	0.003 to 0.009	0.003 to 0.019

With fluorescein sodium salt, the correlation coefficient is 0.9897, which is significant at the 1 percent level. The equation for the regression line is

$$Y = 0.1801 + 0.9250X$$

where X = bulk specific gravity by the ASTM method, and
Y = bulk specific gravity by the FSS method.

The relationship is similar to that observed in the case of cobalt chloride.

Repeatability and Reproducibility

Coarse Aggregate—Table 6 gives the differences between duplicate determinations for each coarse aggregate for three methods, that is, the ASTM standard method and the two chemical methods. It is evident from Table 6 that probably both the ASTM method and the chemical methods are not suited for determination of bulk specific gravity of slag.

From the data in Table 6 obtained from limited study, it appears that both the $CoCl_2$ method and the FSS method give better duplicate results than the ASTM standard test. The $CoCl_2$ method in particular gives duplicate determinations that check within 0.01, compared with the 0.02 provided in the case of the ASTM standard test, and is recommended for further investigations to establish its repeatability and reproducibility.

To compare the reproducibility of the standard ASTM method and the proposed $CoCl_2$ method of bulk specific gravity determination, experiments were conducted on 6 materials involving three experienced operators. Duplicate determinations were made on all materials by all operators and with both methods. The results are given in Table 7. Average values based on the duplicate determinations have been calculated. Between operators, the maximum difference observed in value of bulk specific gravity by the $CoCl_2$ method is 0.006, whereas for the ASTM method it is 0.026 (Table 7). Average variation between operators is 0.005 in the case of the $CoCl_2$ method and 0.019 for the ASTM standard test. In all cases, bulk specific gravity by the ASTM method is less than that by the $CoCl_2$ method The difference is greater, in the case of absorptive aggregates (2-B and 3-S-B).

Fine Aggregate—Table 8 gives the differences between duplicate determinations for each fine aggregate for the ASTM standard method and the two chemical methods. The data given in Table 8 also indicate the better performance of chemical methods, which

TABLE 7

RESULTS OF REPRODUCIBILITY STUDIES FOR COARSE AGGREGATES, VALUES OF BULK SPECIFIC GRAVITY

Aggregate	Operator L	Operator D	Operator K	Maximum Variation Between Operators
1-S-B				
$CoCl_2$	2.615, 2.600 > 2.608	2.608, 2.599 > 2.604	2.605, 2.598 > 2.602	0.006
ASTM	2.576, 2.577 > 2.577	2.598, 2.588 > 2.589	2.590, 2.592 > 2.590	0.013
2-B				
$CoCl_2$	2.404, 2.417 > 2.411	2.402, 2.415 > 2.409	2.401, 2.414 > 2.408	0.003
ASTM	2.318, 2.317 > 2.318	2.334, 2.339 > 2.337	2.335, 2.331 > 2.333	0.019
3-S-B				
$CoCl_2$	2.529, 2.522 > 2.526	2.530, 2.524 > 2.527	2.518, 2.523 > 2.521	0.006
ASTM	2.446, 2.452 > 2.449	2.475, 2.474 > 2.475	2.472, 2.475 > 2.474	0.026
5-S-B				
$CoCl_2$	2.554, 2.550 > 2.552	2.560, 2.552 > 2.556	Not done	0.004
ASTM	—	—	—	—

TABLE 8

DIFFERENCES BETWEEN DUPLICATE DETERMINATIONS OF BULK SPECIFIC GRAVITY OF FINE AGGREGATES

Fine Aggregate	Difference		
	ASTM Method	$CoCl_2$ Method	FSS Method
Menlo	0.014	0.007	0.002
Pints	0.000	0.008	0.001
Alden	0.004	0.009	0.002
Linwood	0.007	0.014	0.013
Cook	0.008	0.005	0.006
Keota	0.021	0.004	0.008
Average difference	0.009	0.008	0.005
Range	0.000 to 0.021	0.004 to 0.014	0.001 to 0.013

TABLE 9

RESULTS OF REPRODUCIBILITY STUDIES FOR FINE AGGREGATES, VALUES OF BULK SPECIFIC GRAVITY

Aggregate	Operator L	Operator D	Operator K	Maximum Variation Between Operators
1-S-C				
$CoCl_2$	2.574, 2.573 > 2.574	2.637, 2.634 > 2.636	2.552, 2.551 > 2.552	0.084
ASTM	2.571, 2.561 > 2.566	2.569, 2.568 > 2.569	2.560, 2.557 > 2.559	0.010
3-S-C				
$CoCl_2$	2.466, 2.464 > 2.465	2.522, 2.519 > 2.521	2.510, 2.507 > 2.509	0.056
ASTM	2.481, 2.486 > 2.484	2.553, 2.542 > 2.548	2.491, 2.486 > 2.489	0.064

may give duplicate determinations checking within 0.01. Because $CoCl_2$ is very inexpensive in comparison with fluorescein sodium salt, the former is preferred.

Between operators, the maximum difference observed in value of bulk specific gravity by the $CoCl_2$ method is 0.084, whereas for the ASTM method it is 0.064 (Table 9). It seems that overdrying occurred in some of the tests, resulting in higher bulk specific gravity.

SUMMARY AND CONCLUSIONS

The following conclusions can be drawn from this study, wherein a new method has been proposed:

1. Investigations have shown that the ASTM standard tests underestimate the bulk specific gravity of aggregates because these tests measure adsorption as well as absorption of particles. Results obtained in determination of bulk specific gravity by other methods, such as the mercury displacement method, the geometrical mensuration method, and the chemical methods appear to confirm this statement.
2. Experiments on rock cores indicate that the mercury displacement method gives realistic values in between those obtained from the ASTM standard method and the geometrical mensuration method. Further investigations are needed to establish a properly specified pressure at which the measurements of volume displaced by mercury should be taken for consistent results with all aggregates.
3. Chemical methods eliminate the human element to a great extent in observing the saturated surface-dry condition of the aggregates because color change is quite apparent.

4. Chemical methods achieve the elimination of the moistness over the aggregates and thus tend to give realistic values of bulk specific gravity. Attainment of saturated surface-dry condition in the case of fine aggregates by the chemical method is not affected by the interlocking of the particles.

5. Results of chemical methods agree well with those obtained from the mercury displacement method.

6. The cobalt chloride method in general appears to be the preferable of the two chemical methods investigated, considering the data in this study and the relative cost. However, fluorescein sodium salt is better suited when dealing with dark-colored aggregates.

7. Data in this limited study seem to indicate that most duplicate determinations check within 0.01 in the case of the chemical method compared with the 0.02 specified in the ASTM standard test, although extensive tests should be made in various laboratories to establish the reproducibility and limitations of this method.

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REFERENCES

1. Howard, E. L. Discussion, Proc. Am. Concrete Inst., Vol. 54, 1958, p. 1215.
2. Pearson, J. C. A Simple Titration Method for Determining the Absorption of Fine Aggregate. Rock Products, Vol. 32, 1929, p. 64.
3. Martin, J. R. Two Years of Highway Research at Oklahoma A. and M. Proc. AAPT, Vol. 19, 1950, pp. 41-54.
4. Saxer, E. L. A Direct Method of Determining Absorption and Specific Gravity of Aggregates. Rock Products, Vol. 87, 1956, pp. 77-79.
5. Hughes, B. P., and Bahramian, B. An Accurate Laboratory Test for Determining the Absorption of Aggregates. Materials Research and Standards, 1967, pp. 18-23.
6. Lee, D. Y. The Relationships Between Physical and Chemical Properties of Aggregates and Their Asphalt Absorption. Proc. AAPT, Vol. 38, pp. 242-275, 1969.
7. Hiltrop, C. L., and Lemish, J. Relationship of Pore-Size Distribution and Other Rock Properties to the Serviceability of Some Carbonate Aggregates. HRB Bull. 239, 1960, pp. 1-23.
8. Shergold, F. A. Test for the Apparent Specific Gravity and Absorption of Coarse Aggregates. Jour. Appl. Chem., Vol. 3, Pt. 3, 1953, pp. 110-117.

Appendix

DETERMINATION OF BULK SPECIFIC GRAVITY OF AGGREGATES BY CHEMICAL INDICATOR METHODS

Cobalt Chloride Method

The procedure is the same as for the ASTM Standard Methods C 127 and C 128 except for the following points:

1. The sample is immersed in a 5 percent solution of cobalt chloride instead of plain water for 24 hours.

2. The sample is removed from the solution and put on a table, which should have a white top, or it can be put in a wide, white enameled tray. The aggregate may not appear to be colored, but the visible water films on the aggregate will be pinkish in color.

3. The sample is spread out to have a layer of individual particles exposed to a gently moving current of warm air. It is stirred frequently to secure uniform drying. Some of the solution sticking to the porcelain will appear to be pink.

4. As drying proceeds, the aggregate attains a bluish color. The aggregate should be turned over frequently by gentle hand action. If there is still some moisture on the surface of the aggregate, the bluish color on the porcelain will change back to pink. Keep turning the sample, while exposing it to warm air, until all the aggregate is bluish in color and the bluish spots on the white porcelain no longer turn pink. This is assumed to be the saturated surface-dry condition.

5. The saturated surface-dry coarse aggregate is immediately weighed in air and water as outlined in ASTM Method C 127, while the fine aggregate is introduced into the Chapman's flask, which has been filled with water to the 200 ml mark.

Fluorescein Sodium Salt Method

The procedure is essentially the same as the cobalt chloride method. In this case a 0.5 percent solution of fluorescein sodium salt is used. The sample is dried in the same manner as in the cobalt chloride test. The sample acquires a yellowish color when taken from the solution after 24 hours of immersion. On drying, an orange color appears on the aggregates; the porcelain also changes to a distinct orange. This is assumed to be the saturated surface-dry condition, and the sample is further treated according to the ASTM C 127 and C 128 test procedures.