Use of the Kelly Ball for Field Measurement Of Concrete Consistency

WILLIAM E. GRIEB and ROBERT A. MARR, JR.,
Highway Physical Research Engineers
Physical Research Branch, Bureau of Public Roads

The Kelly Ball test is a simple field method for determining the consistency of plastic concrete. It is made by measuring the penetration of a 30-pound metal "ball" into the surface of the concrete. This test can be made on the concrete in place and can be made easier and faster than the slump test. The results of tests reported in this article show good correlation between the slump test and the Kelly ball penetration test.

● THE ASTM standard slump test[1] has been used for many years as a measure of the consistency of fresh concrete in the laboratory and on the job. As a laboratory procedure it is reasonably satisfactory. In the field, especially on paving work, it has several disadvantages and the most serious of these is the time required to make the test. Others are the necessity for careful selection of samples and the close attention to details of the technique required to obtain reasonably accurate results.

Realizing the disadvantages of the slump test as a field control method Professor J. W. Kelly, of the Department of Civil Engineering of the University of California, developed a penetration device that is rugged and portable. This test was recently made an ASTM Tentative Standard (C 360-55 T).

Professors Kelly and Polivka of the University of California give the following account of the development of this test in an article published recently (5):

"The test was developed in the Engineering Materials Laboratory of the University of California at Berkeley as an outgrowth of an attempt to devise a simple test for workability of concrete. Workability is an elusive property, and early trials with various balls showed little correlation with the more elaborate tests in laboratory use. However, it was observed that static ball penetration correlated rather well with slump and it became apparent that the penetration test measured some property similar to slump, a property which had been termed 'consistency' but which is now called merely 'slump' in ASTM C 143. It is the significant property which is measurable in the field for practical purposes.

A 6-inch ball was considered to be the smallest that would integrate the resistance to penetration over several pieces of aggregate, and a 30-pound weight was found to be the lightest that would penetrate reproducibly the stiffest mixes of plastic concrete. This combination of area (or displaced volume) and force has been found applicable even to harsh concrete containing 2½-inch aggregate and having a nominal slump when wet-screened of 1½ inches. The apparatus has also been used on mass concrete containing 0 to 6-inch crushed aggregate by making the penetration test only on areas which had been found by probing to be free from the larger pieces of aggregate. A 20-pound weight on a 6-inch ball has sometimes been used for lightweight concrete.

Penetration tests have been developed independently in other countries. A static test used in Spain employs a weight on a spherical tip and having a flared edge so that the plunger will not sink too deep into wet concrete. The German Committee on reinforced concrete has adopted an impact test suitable for stiff mixes or mixes of low cement content; it consists in dropping a 33-pound plunger having a 4-inch hemispherical tip 8 inches onto the surface. In England, the Wigmore consistometer employs a metal ball set on the surface of a concrete sample which is vibrated on a table.

The static ball test was introduced to field use by E. L. Howard, Testing Engineer, Pacific Coast Aggregates, Inc., San Francisco. His experience with the variety of mixes used in ready-mixed concrete was so successful that it encouraged the authors

[1] Standard Method of Test for Slump of Portland-Cement Concrete, ASTM designation: C 143-52.

to report the test to ASTM Committee C-9 at its San Francisco meeting in 1949. Howard has continued to contribute to its field development, and is convinced that it will eventually replace the slump test.

Many other organizations have adopted the ball test, and hundreds of balls are in use throughout the country. The California Division of Highways has adopted it as a standard for field use on pavement construction. At least two other state highway departments, North Carolina and Colorado, are using it extensively. The Waterways Experiment Station, Concrete Division, U.S. Army Corps of Engineers, has adopted it as an alternative standard."

Kelly Ball Apparatus

The apparatus is popularly known as the "Kelly ball." It is made by machining into a hemisphere, one end of a solid right cylinder 6 inches in diameter and 4⅝ inches in height. It is fitted with a graduated vertical rod ½ inch in diameter which serves as a measuring scale and a handle. The vertical portion of the rod is graduated in ½-inch units with each inch numbered. The ball is guided by a stirrup or frame which also serves as a reference line in the measurement of the penetration of the ball into the plastic concrete. The zero on the graduated handle coincides with the top of the frame when the apparatus rests on a level rigid surface. The weight of the ball and handle is 30 pounds. The sketch of the original apparatus is shown in Figure 1.

Modification of the Kelly Ball

The Kelly ball equipment used by the Bureau of Public Roads differs from the original in the following details:

1. To prevent the reference frame from tilting, the bearing area of each foot of the frame (originally specified as 1½ square inches) was increased by the addition of semicircular bearing plates of 5-inch diameter (area approximately 9¾ square inches). The clear distance between the feet was maintained at 9 inches as originally specified (see Figure 2). This change is included in the ASTM Tentative Method C 360-55T.
2. To facilitate reading the depth of penetration of the ball, a vertically movable pinch clamp was fastened to the graduated handle. This is clamped at the top of the handle before making the test and is lowered to make contact with the top of the frame after the ball has penetrated the surface of the concrete. The apparatus is then removed from the concrete and the penetration reading is made reading the position of the clamp on the rod. This makes the test procedure more convenient for the operator and avoids any possible delay in the concreting operation.

Use of the Kelly Ball

Plastic concrete can be tested with the Kelly ball after placement in the forms and prior to any manipulation or in suitable containers such as tubs, pans, wheelbarrows, or buggies.

In making the test, the surface of the concrete is smoothed and leveled quickly by the use of a small wooden float or screed. The surface is worked as little as possible to avoid formation of a mortar layer. During the test, the adjacent concrete should not be vibrated, jarred, or agitated.

The ball is held vertically by the handle in very light contact with the leveled concrete surface and with the zero on the rod coincident with the top of the frame. The handle is then released and the depth of penetration of the ball into the concrete is estimated on the graduated rod to the nearest 0.1 inch. (see Figure 3). A minimum of three readings should be taken from a batch or location. No correction is made for any slight settlement of the feet of the frame. The test requires less than ½ minute to perform, which allows the operator sufficient time to work where the concrete is being discharged from the mixer without delaying the placing and finishing operations.

Experience has indicated that the minimum depth of concrete tested should be 6 inches for a maximum size of coarse aggregate of 2 inches or less. When larger coarse aggregate is used, the minimum depth should be three times the nominal max-

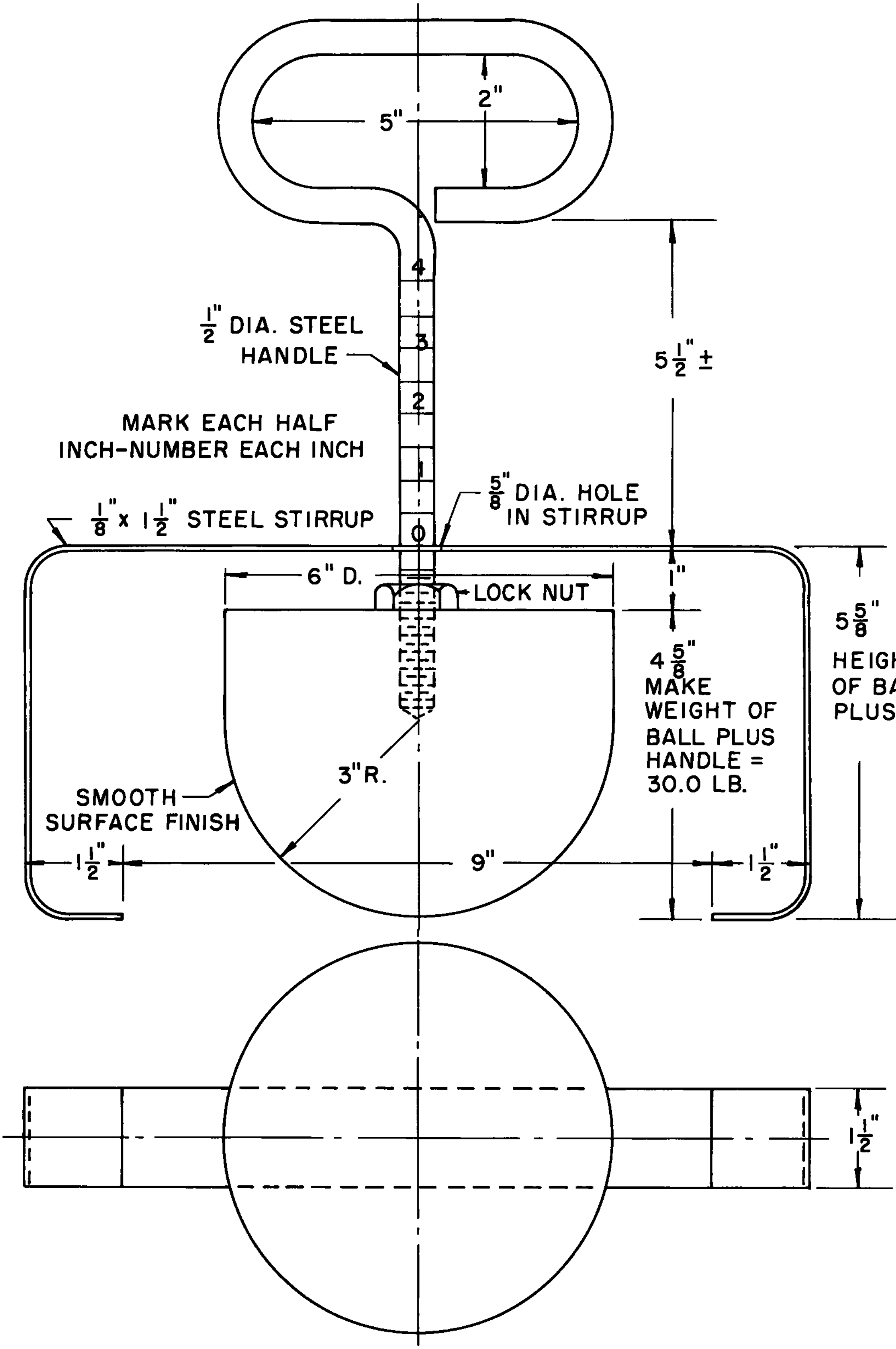

Figure 1. Ball-penetration apparatus for consistency of concrete.

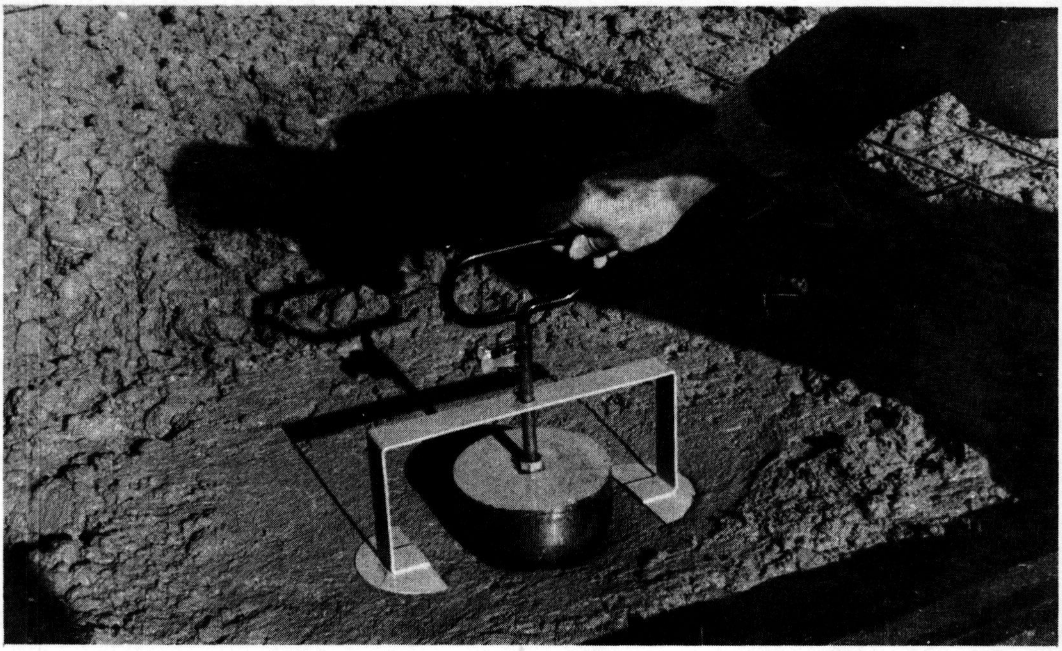

Figure 2. Kelly ball penetration test as used in the field.

imum size of coarse aggregate. When testing concrete placed inside forms, as in piers, walls, etc., a minimum horizontal distance of 9 inches from the face of the form to the point tested should be maintained to avoid boundary effects. For concrete discharged on the subgrade in pavement work, no test should be made nearer than 9 inches to the form edge of the leveled surface of the concrete. For a second test in the same batch of concrete the foot of the stirrup should be at least 6 inches from the point where the foot rested in the first test.

TABLE 1

CORRELATION OF KELLY BALL PENETRATION TEST AND SLUMP TEST FOR CONSISTENCY OF CONCRETE

Field Tests — Project No. 1

Kelly ball penetration		Slump
Individual	Average	
Inches	Inches	Inches
2.5-2.4	2.4	4.7
2.8	2.8	4.0
3.7	3.7	4.4
2.7	2.7	4.3
2.3-2.5	2.4	3.7
1.7-1.9-1.5	1.7	2.3
3.7-3.1	3.4	4.1
1.4-1.4-1.1	1.3	0.7
2.5-2.6-1.9	2.3	3.9
1.8-1.0	1.4	1.7
2.6-2.8	2.7	3.7
2.0	2.0	3.3
1.4-1.6	1.5	2.6
3.2-3.4	3.3	4.5
1.1-1.2-1.2	1.2	2.3
2.7-3.5-2.6	2.9	4.7
4.2-4.7-3.7	4.2	5.3
2.2-2.2-2.4	2.3	3.7
Average [a]	2.4	3.6

Coarse aggregate - Gravel, 2-inch maximum size.
Cement content = $6\frac{1}{2}$ sacks of cement per cubic yard.
Air content = 5 percent.

[a] Ratio of penetration to slump = 1 to 1.5.

Field Tests Using Kelly Ball

A limited number of tests were made on several paving projects to correlate Kelly ball penetration readings with the corresponding slumps. The concrete used on the first of these projects contained $6\frac{1}{2}$ sacks of cement per cubic yard, 2-inch maximum size gravel, and about 5 percent air. Batches were selected so that tests could be made without delaying the progress of the work and so that some adjustments could be made in the water content and consistency of the batches. The concrete was discharged on the subgrade in a pile 8 to 10 inches in height. A sample for the slump test was taken and thoroughly remixed in a pan. The Kelly ball penetration test was made on the concrete in place on the subgrade prior to any manipulation. The top surface of the concrete was leveled with a wood float, the apparatus set on that surface, and the penetration read. The water content of the concrete was varied in order to obtain a greater range in consistency. Usually 2 or 3 Kelly ball penetration readings were made for comparison with the reading of each slump. The test data taken over a two-day period are tabulated in Table 1 and are shown graphically in Figure 4 (A). The average penetration was 2.4 inches, the average slump was 3.6 inches, and the ratio of penetration to slump was 1 to 1.5.

The concrete on the second project had the same cement content and the same max-

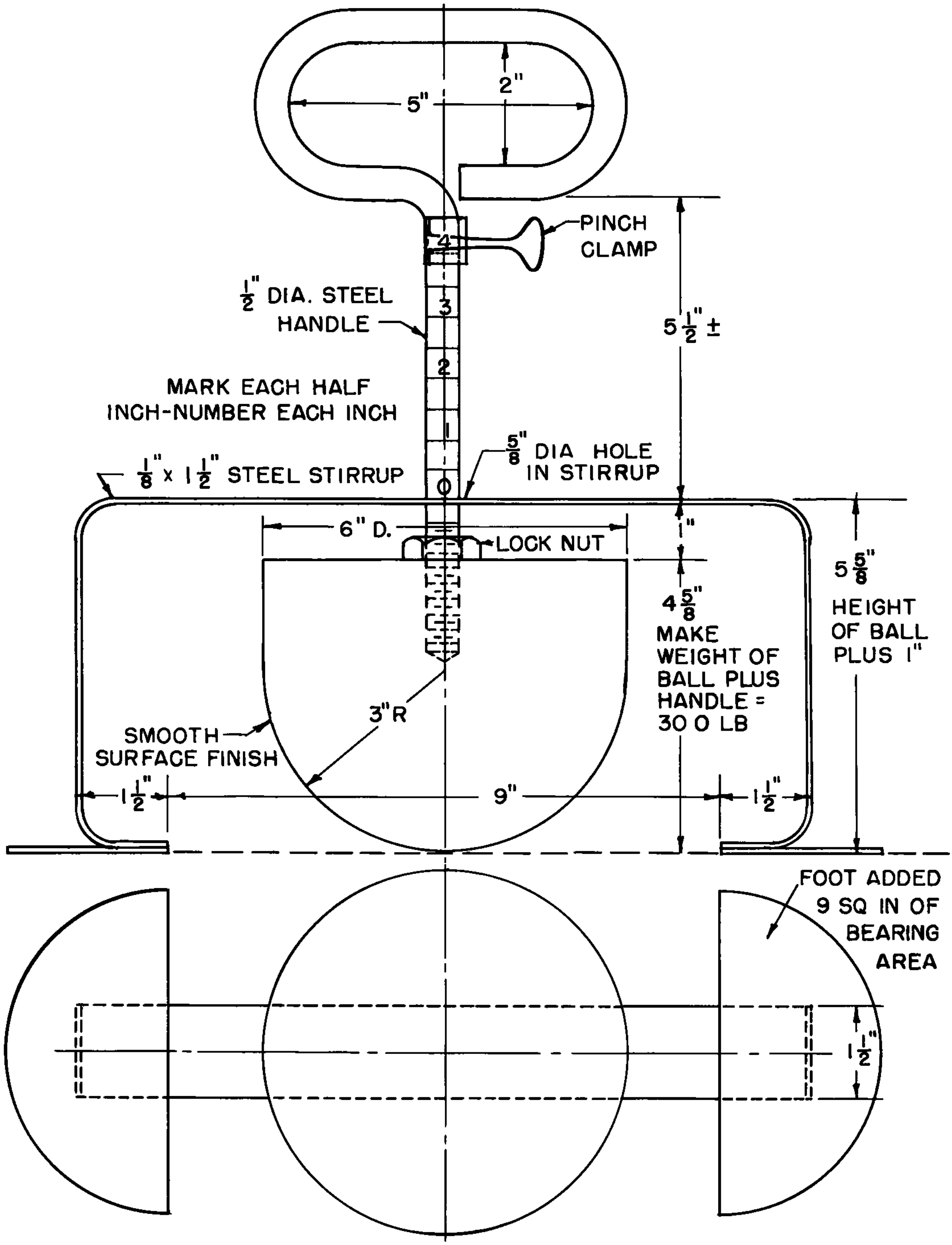

Figure 3. Ball-penetration apparatus for consistency of concrete Bureau of Public Roads modification.

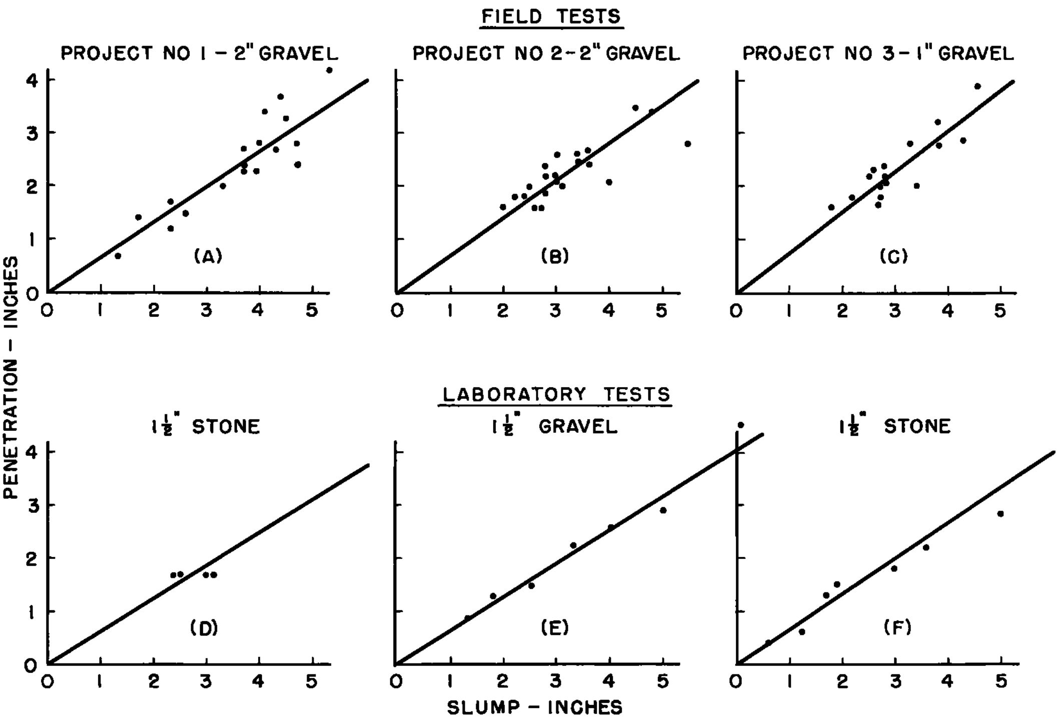

Figure 4. Correlation of Kelly ball penetration test and slump test.

imum size coarse aggregate as that on the first project. The aggregates were from a different source and the concrete was mixed in a ready-mix truck. The test data taken over a 7-day period are tabulated in Table 2 and are shown graphically in Figure 4 (B). For this job the average penetration was 2.3 and the average slump was 3.2 inches. The ratio of penetration to slump was 1 to 1.4.

The concrete in the third project was similar to that in the second project, but the maximum size of coarse aggregate was 1 inch instead of 2 inches. The test data were taken over a 6-day period and are tabulated in Table 3 and are illustrated in Figure 4 (C). The average penetration and average slump for this job were 2.3 and 3.0 inches respectively. The penetration-slump ratio was 1 to 1.3.

The data in Tables 1, 2, and 3, and Figure 4 (field tests) show a reasonable correlation between Kelly ball penetration and slump readings for a range in slump of 1 to 5½ inches. The average Kelly ball reading multiplied by 1.4 would provide a fair estimate of the corresponding slump for the range indicated, and materials used. These limited data indicate that for a maximum size of coarse aggregate of 1 inch this ratio might be reduced to 1.3.

Laboratory Tests

Slump tests and Kelly ball penetration

TABLE 2

CORRELATION OF KELLY BALL PENETRATION TEST AND SLUMP TEST FOR CONSISTENCY OF CONCRETE

Field Tests — Project No. 2

Kelly ball penetration		Slump
Individual	Average	
Inches	Inches	Inches
1 6	1 6	2 7
2 1	2 1	4.0
2 0-1.8	1 9	2 8
2 2-2 0	2 1	3.0
3.1-2 0	2 6	3.0
1.7-2 2	2 0	3 1
2 3-1.3	1 8	2.5
2.1-2 8	2.4	2.8
2.8-2.5	2 6	3 4
1.6-1 7	1.6	2.6
2.2-2.2	2 2	2.8
3.6-3.4	3.5	4 5
1.6-1.6	1.6	2.0
2.0-1.6	1.8	2.2
2.2-2 2	2 2	3.0
2 4-2.6	2 5	3.4
2.6-2.1	2 4	3 6
2.8-2 9	2.8	5.5
3.5-3 3	3 4	4.8
1.6-2.1	1.8	2 4
2 5-2.9	2.7	3.6
Average [a]	2.3	3.2

Course aggregate - Gravel, 2-inch maximum size.
Cement content = 6½ sacks per cubic yard.
Air content = 5 percent.

[a]Ratio of penetration to slump = 1 to 1.4.

readings were also made on concrete mixed in the laboratory and placed in steel forms for the fabrication of slabs for structural tests containing approximately 33 cubic feet of concrete. The water content was the same for all batches.

TABLE 3

CORRELATION OF KELLY BALL PENETRATION TEST AND SLUMP TEST FOR CONSISTENCY OF CONCRETE

Field Tests — Project No 3

Kelly ball penetration: Individual	Kelly ball penetration: Average	Slump
Inches	Inches	Inches
3.4-3.0	3.2	3.8
2.3-2.5	2.4	2.8
2.4-2.2	2.3	2.6
2.3-2.2	2.2	2.5
3.0-2.6	2.8	3.8
2.0-1.7	1.8	2.7
1.6	1.6	1.8
2.8-2.9-3.1	2.9	4.3
1.9-2.4-1.8	2.0	2.7
1.8-1.9-1.8	1.8	2.2
2.1-2.2-2.0	2.1	2.8
3.8-4.0	3.9	4.6
1.6-1.5	1.6	1.8
2.1-2.4	2.2	2.8
2.8-2.8	2.8	3.3
1.8-1.6	1.7	2.7
2.0-1.9-2.2	2.0	3.4
Average[a]	2.3	3.0

Coarse aggregate - Gravel, 1-inch maximum size.
Cement content - 6¼ sacks per cubic yard.
Air content, 5 percent.

[a] Ratio of penetration to slump = 1 to 1.3.

The concrete was non-air-entrained and contained 6 sacks of cement per cubic yard with crushed stone coarse aggregate of 1½-inch maximum size. The results of these tests are shown in Table 4 and in Figure 4 (D). This figure does not have much significance due to the limited number of tests. For these tests the average slump was 1.6 times the Kelly ball reading.

Laboratory tests were made on concrete mixes using both gravel and crushed stone coarse aggregates of 1½-inch maximum size and having variable slumps. The concrete was non-air-entrained and contained 6 sacks of cement per cubic yard. The water content was varied to produce slumps ranging from 1 to 6 inches. The results of these tests are tabulated in Table 5 and are shown graphically in Figure 4 (E) for the gravel concrete and Figure 4 (F) for the crushed stone concrete. The ratio of the average Kelly ball penetration to slump was 1 to 1.6 for crushed stone and 1 to 1.5 for gravel. These tests show approximately the same relation between the slump and Kelly ball readings as were shown for the field tests where similar materials were used.

TABLE 4

CORRELATION OF KELLY BALL PENETRATION TEST AND SLUMP TEST FOR CONSISTENCY OF CONCRETE

Laboratory Tests - Fixed Water Content

	Kelly ball penetration	Slump
	Inches	Inches
	1.7	-
	2.2	-
	1.7	2.5
	2.0	-
	1.7	2.4
	1.7	-
	1.4	-
	1.5	-
	1.7	3.1
	1.5	-
	1.7	3.0
Average[a]	1.7	2.8

Coarse aggregate - Crushed Stone, 1½-inch maximum size.
Cement content = 6 sacks per cubic yard.
Non-air-entrained concrete.

[a] Ratio of penetration to slump = 1 to 1.6

TABLE 5

CORRELATION OF KELLY BALL PENETRATION TEST AND SLUMP TEST FOR CONSISTENCY OF CONCRETE

Laboratory Tests — Varying Water Content

	Mix 1 - Stone C.A.		Mix 2 - Gravel C.A.	
	Kelly ball penetration	Slump	Kelly ball penetration	Slump
	Inches	Inches	Inches	Inches
	0.4	0.6	0.9	1.3
	0.6	1.2	1.3	1.8
	1.3	1.7	1.5	2.5
	1.5	1.9	2.3	3.3
	1.8	3.0	2.6	4.0
	2.2	3.6	2.9	5.0
	2.8	5.0	3.8	5.6
			4.5	6.5
Average[a]	1.5	2.4	2.5	3.8

Each value for slump is average of two tests and each value for Kelly ball is average of six tests.
Maximum size coarse aggregate 1½ inches.
Cement content = 6 sacks per cubic yard.
Non-air-entrained concrete.

[a] Ratio of penetration to slump for gravel = 1 to 1.6.
Ratio of penetration to slump for stone = 1 to 1.5.

The results of field and laboratory tests discussed in this article are in reasonably good agreement with those obtained by other investigators. In an extensive series of tests conducted by the Concrete Division, Waterways Experiment Station of the U.S. Army Corps of Engineers at Jackson, Mississippi, the average ratio of slump to penetration of 1.8 was reported as compared to 1.5 and 1.6 obtained in this study. Walker and Bloem[2] in an unpublished report give the average ratio of slump to penetration of 1.66 for over 250 tests.

Advantages of the Kelly Ball Test

On any particular project using specific materials, a limited number of tests will correlate the Kelly ball readings with the corresponding slump tests sufficiently to permit using the Kelly ball for the control of the consistency of the concrete when a slump range has been specified.

The following comments are made on the Kelly ball test as a replacement for the slump test for measuring the consistency and uniformity of concrete in the field:

1. The concrete may be tested in place, therefore the selection or preparation of a sample is eliminated.

2. Three or more Kelly ball tests can be made at a selected location in less time and with less effort than is required for one slump test. Due to the speed with which

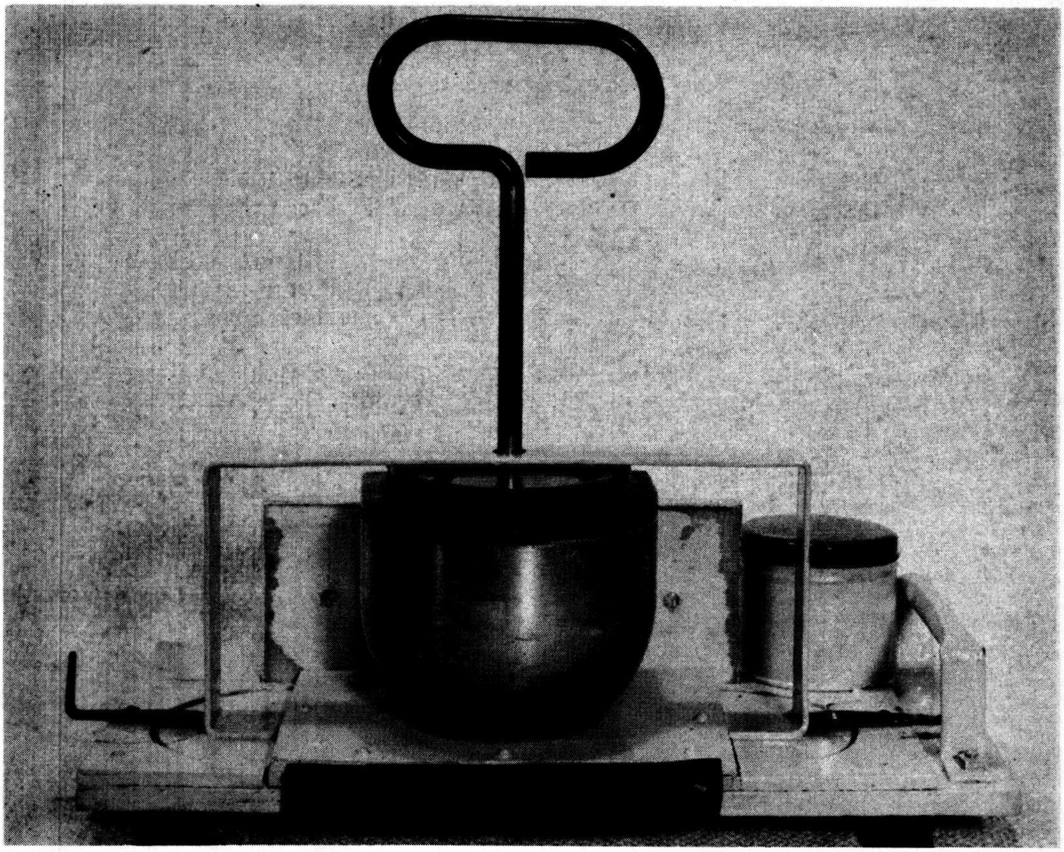

Figure 5. Field carrying kit for Kelly ball apparatus.

the test can be made, the operator can work where the concrete is being discharged from the mixer without delaying paving or finishing operations.

3. Making the consistency test easier and faster, should encourage more frequent testing and should be helpful in the control of the uniformity of the concrete.

4. The apparatus can be maintained in usable condition between tests by merely wiping with an oily rag.

---

[2] Director of Engineering and Assistant Director of Engineering, respectively, National Sand and Gravel Association and National Ready Mixed Concrete Association.

5. The slump test is not practical for use in testing concrete with a maximum size of coarse aggregate over 2 inches. The Kelly ball penetration test may be used on concrete containing larger aggregate if a sufficient volume is available to provide adequate depth.

Field Kit

For ease in transporting, the ball with wood float and a base plate can be readily assembled into a compact field kit as shown in Figure 5. The wooden float is used to level the concrete at the area to be tested. A tin "rag can" provides a place to keep oily cloth or waste to wipe the ball clean after each test. The ball should not be placed too near the side forms or the edge of a pile of concrete in order to meet this requirement, the operator must often place one foot into wet concrete to set the ball in place. The carrying base plate is designed as a foot board to support the weight of the operator on the plastic concrete.

The apparatus may built in any machine shop. However, it has been adopted as a tentative standard by the American Society for Testing Materials and may be offered for sale by the leading instrument companies.

References

1. Kelly, J.W. and Haavik, Norman E., "A Simple Field Test for Consistency of Concrete," ASTM Bulletin No. 163, January 1950, pp. 70-74.

2. Howard, E.L. and Leavitt, George, "Kelly Ball vs Slump Cone-Comparative Tests of Samples Taken at Travis Air Base," ACI Journal, December 1951, Proc. V. 48, pp. 353-356.

3. Howard, E.L., "Is the Slump Cone on Its Way Out?" Western Construction, V. 28, No. 7, July 1953, pp. 81-82.

4. Haynes, Ben. F., "Using the Kelly Ball to Test Concrete," Western Construction, V. 29, No. 6, June 1954, pp. 77-78.

5. Kelly, J.W. and Polivka, Milo, "Ball Tests for Field Control of Concrete Consistency," ACI Journal, May 1955, V. 26, No. 9, pp. 381-388.