United States Patent [19]

Nasser

[11] **3,863,494**

[45] **Feb. 4, 1975**

[54] **DEVICE FOR MEASURING THE WORKABILITY AND COMPACTION OF FRESH CONCRETE**

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[22] Filed: **Oct. 25, 1973**

[21] Appl. No.: **409,595**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 151,351, June 9, 1971, abandoned.

[30] **Foreign Application Priority Data**

Aug. 14, 1973 France 73.29769

[52] **U.S. Cl.** **73/54**

[51] **Int. Cl.** **G01n 11/00,** G01n 33/38

[58] **Field of Search** 73/54, 425, 425.2, 32

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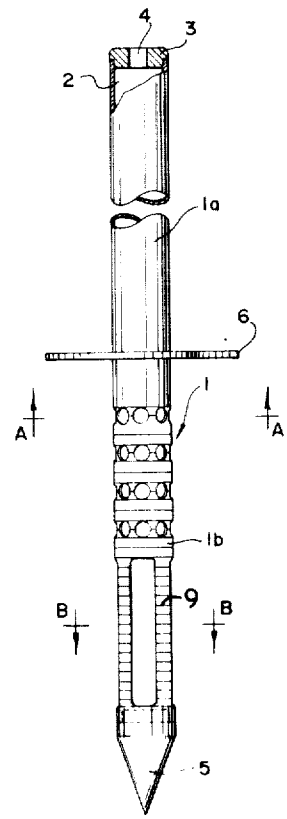
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[57] **ABSTRACT**

A device for use in determining the workability of a freshly prepared concrete mix which comprises a tube including a central bore, a plate fixedly attached to and extending substantially transversely of said tube for limiting the depth to which said tube may be inserted into said mix, at least one aperture in the shape of a slot extending longitudinally of said tube from a closed end thereof remote from said plate through which said mix may enter said bore on insertion of said device into said mix and index means associated with said tube for determining the residual height to which the mix is present in the bore of said tube on withdrawal from said mix as well as a method of determining the workability of a freshly prepared concrete mix using said device.

11 Claims, 10 Drawing Figures



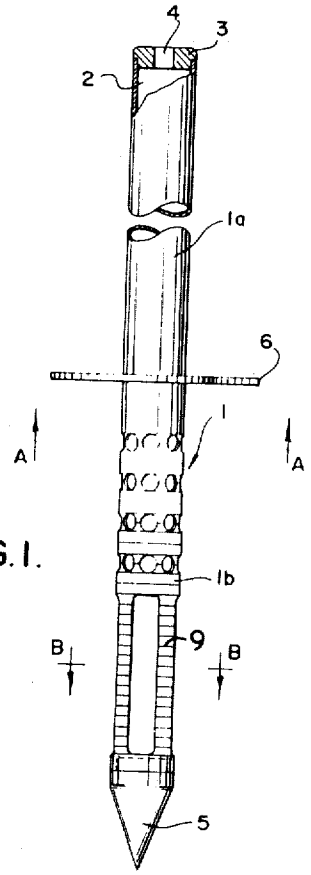


FIG. 1.

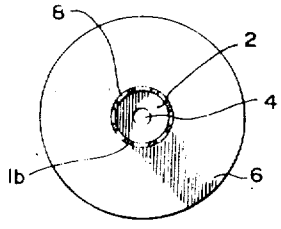


FIG. 2.

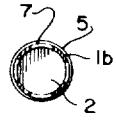


FIG. 3.

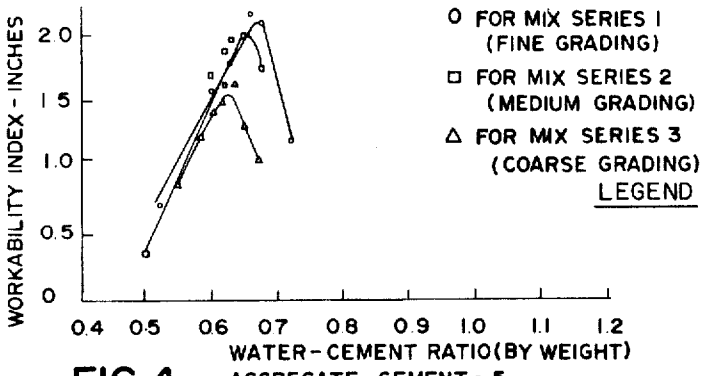


FIG. 4 AGGREGATE - CEMENT = 5

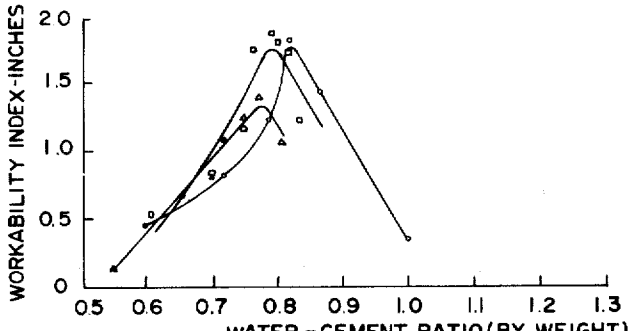


FIG. 5. AGGREGATE - CEMENT RATIO = 7

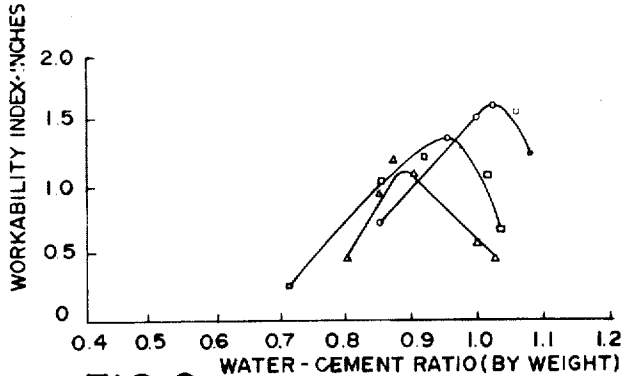


FIG. 6. AGGREGATE - CEMENT RATIO = 9

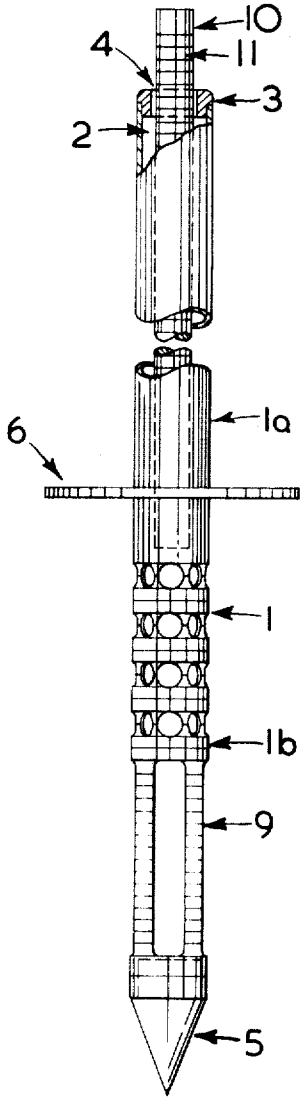


FIG. 7.

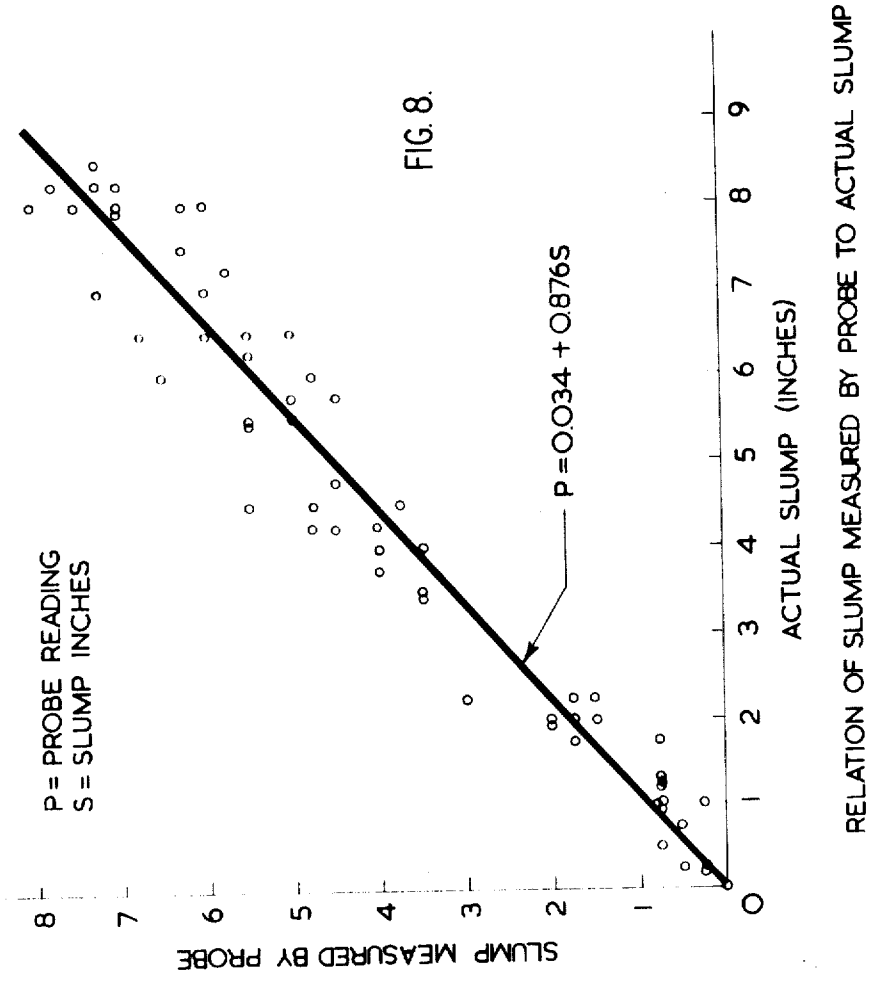


FIG. 8.

RELATION OF SLUMP MEASURED BY PROBE TO ACTUAL SLUMP

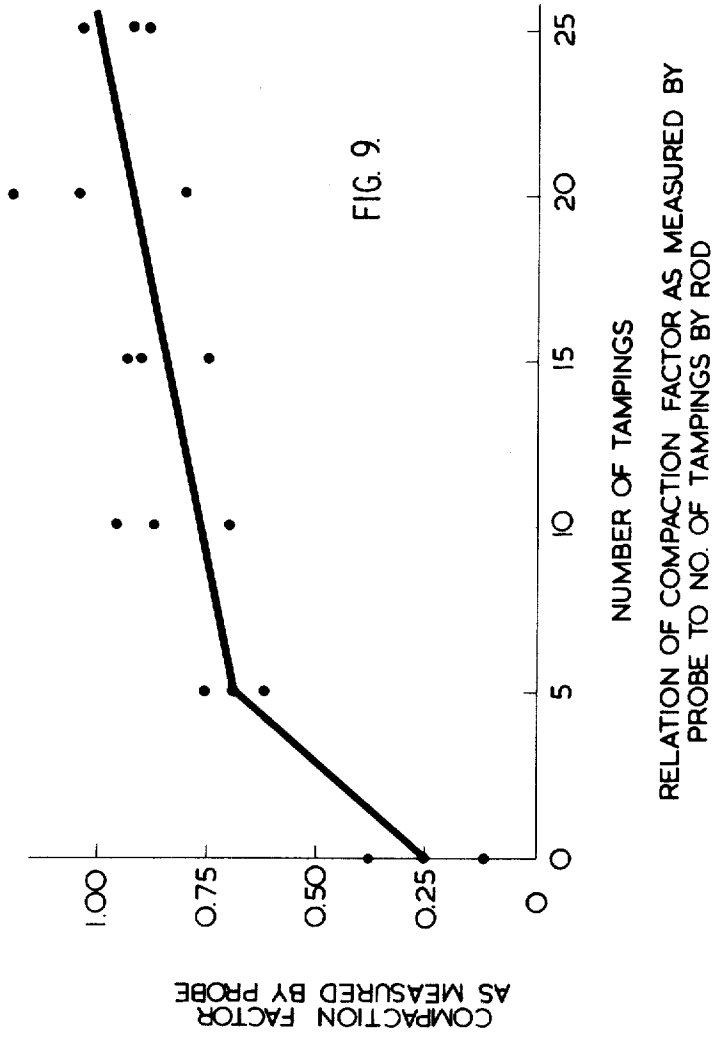
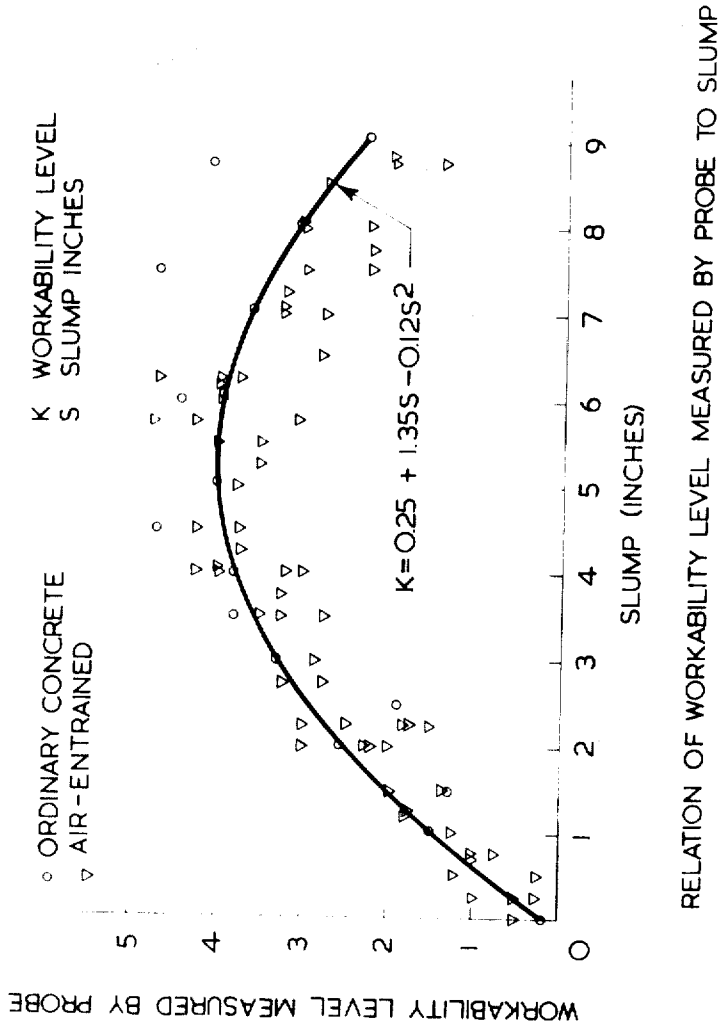

COMPACTION FACTOR AS MEASURED BY PROBE
1.00
0.75
0.50
0.25
0
0
5
10
15
20
25
NUMBER OF TAMPINGS
RELATION OF COMPACTION FACTOR AS MEASURED BY PROBE TO NO. OF TAMPINGS BY ROD

FIG. 9.



RELATION OF WORKABILITY LEVEL MEASURED BY PROBE TO SLUMP

FIG. 10

DEVICE FOR MEASURING THE WORKABILITY AND COMPACTION OF FRESH CONCRETE

This application is a continuation-in-part of Ser. No. 151,351 filed June 9, 1971 and now abandoned.

The present invention relates to the determination of the workability of a freshly prepared concrete mix. In particular, the present invention relates to a device for use in measuring the workability of concrete mixes as well as the method of effecting such measurement using such device.

Workability is one of the physical properties of concrete which affects extensively the strength and durability as well as the cost of labour and appearance of the finished product. The term workability has been used repeatedly in concrete technology and literature with an implied expection that its meaning is well understood. However, when pressed for a definition it is difficult to say exactly what it does means. Concrete is said to be workable when it is easily placed and compacted homogeneously, i.e., without segregation. Unworkable concrete needs more work or effort to be compacted in place and further it is probable that some defects will be visible in the finished products, such as honeycombs or pockets. The term workability may be defined as a property of fresh concrete which is indicated by the amount of useful internal work required to fully compact the concrete with no segregation of the finished product. There are numerous factors which effect workability and include the amount of water in the concrete mix, the amount of cement and its properties, the aggregate grading (size distribution), the nature of the aggregate particles (shapes, surface texture, porosity, etc.), the temperature of the concrete mix, and the humidity of the environment. Much research has been conducted to determine the effects of these variables on workability.

There has been a great number of devices developed to measure some property which can be related to workability since it is difficult to develop a test for workability itself. The more important ones are as follows: slump tests, flow tests, penetration tests, drop tests, mixer tests, deforming tests and compaction tests. Most of the tests have not found much use although some of them have been adopted in one or more countries. In particular, the most widely used methods at the present time are the slump test and the compaction test. Such tests are summarized in Powers, T. C., "Studies of Workability of Concrete," ACI Journal Proceedings, volume 28, No. 6, Feb. 1932, pp 419 to 530 and Kelly, J. W., and Polivka, Miles, "Ball Test for Field Control of Concrete Consistency", ACI Journal, Proceedings, Vol. 51, No. 9, May 1955, pp 881–888.

Although it was originally developed as a measure of workability, the slump test has long since been abandoned as such by most authorities and is now regarded merely as a practical control test for maintaining a certain degree of uniformity in concrete and for preventing the use of excessive water in mixes. There are two reasons why the slump test is not considered as a measure of workability. First of all, there is no obvious relation between the test and workability as defined heretofore. Secondly, the same values of the test results may represent mixes of different observed workabilities. This is easily shown by changing the water contact of a lean mix to obtain a slump equal to that of a rich mix, but actually the workability is far from being the same. Yet another disadvantage of the slump test is that when it is applied to precisely similar mixes, the results may exhibit a wide range of variation due to the procedure itself, and due to personal factors inherent in the method of performance of the test. Generally, there are three distinct types of slumps which have been observed by investigators. The first type may be termed the true slump and consists of a general uniform subsidence. The second type, the shear slump, occurs when one half of the cone shears off along an inclined plane, whilst the other half behaves as a true slump. The third type occurs when the concrete cone collapses. The true and collapsed slump has had no difficulty in measurement, the former is found in the case of dry or rich mixes, while the latter occurs only with lean and stoney mixes. The normal mix tends to combine the forms of either true and shear or the collapsed slumps depending upon its degree of wetness. In the shear slump there are at least two possible values of the slump, namely the minimum subsidence and the maximum subsidence and in general the measurement of the slumps of this type is quite arbitrary and is taken at the center. Further, most specifications recommend that the test should be repeated if shear slump persists. Dry mixes of stiff consistency have zero slumps and thus no distinction of workability can be made over a small range of such mixes. Rich mixes behave satisfactorily, their slump being of the true type and sensitive to variations of the factors that effect workability. Lean mixes tend to have shear slump as mixing water is increased. In spite of these limitations, the slump test serves a useful purpose as a control of the water content of a mix. However, the reliability is least with lean mixes for which the importance of control is greatest. Thus the slump test measures the consistency of a particular mix only, its measurement cannot be correlated between different mixes and the measurements are in no way uniquely related to the workability and compaction of the fresh concrete and on the whole the test is cumbersome and sensitive to personal effects.

The compacting factor test is based on the concept of providing the concrete mix with a certain amount of useful work and measuring its degree of compaction and in particular involves determining the relative density of concrete in a mold after the concrete has dropped from a standard height into the mold. The relative density is expressed as the ratio of observed weight of the filled mold to the weight calculated from the composition of the mixture without air voids. Unlike the slump test, variations in the workability of dry concrete are easily reflected in the compacting factor test, i.e., the test is more sensitive at the low workability end of the scale. However, the compacting factor test fails to show the effect of segregation in the concrete.

The present invention provides a device for measuring the workability of freshly prepared concrete which is not subject to the disadvantages of the aforesaid slump and compaction tests, and in particular, for a particular concrete mix, provides a measurement which is uniquely related to the workability of the freshly prepared concrete mix. Further, the present invention provides a device which is simple to manufacture at reasonable cost and does not need continual calibration and is extremely simple to use in both the field and laboratory with very little training. In particular, the device of the present invention takes advantage of the influence of cohesion and adhesion on the compaction and segregation of fresh concrete. A non-

homogeneous material such as a fresh concrete mix can hardly be fully compacted unless there is enough cohesion and adhesion existing between its particles to place it in a very dense state. Although the factors that influence compaction are not easily analyzed, yet it is known that water plays an important part in influencing the behavior of fine grain materials. When water is added to cement and aggregates the very fine particles absorb a film of water and cohesive and adhesive forces are set into play. Upon addition of more water, these films get thicker and permit the particles to slide over each other more easily. This process is often called lubrication and it helps the compaction of the full set of particles together. It should be noted that the thickness of a water film on a coarse particle is small in comparison with the particle diameter and hence its effects are negligible. If still more water is added both the cohesiveness and adhesiveness of the mix will start to decrease and segregation will follow. Therefore an optimum amount of mixing water for a given mix will produce a maximum compaction and minimum segregation. The device of the present invention is designed to measure a physical quantity which is related to the cohesiveness and adhesiveness of the mix and this same quantity is also related to the workability of the mix.

According to the present invention therefore, there is provided a device for use in determining the workability of a freshly prepared concrete mix which comprises a tube including a central bore, a plate fixedly attached to and extending substantially transversely of said tube for limiting the depth to which said tube may be inserted into said mix, at least one aperture in the shape of a slot extending longitudinally of said tube from a closed end thereof remote from said plate through which aperture said mix may enter said bore on insertion of said device into said mix, and index means associated with said tube for determining the residual height to which the mix is present in the bore of said tube on withdrawal from said mix.

The present invention also provides a method of determining the workability of a freshly prepared concrete mix which comprises inserting such a device set forth above into the freshly prepared concrete mix to a depth up to the plate, subsequently removing the device from the mix and ascertaining the residual height of the mix in the bore of the tube. The residual height of the mix in the bore of the tube, i.e., after removal of the device from the concrete mix provides a reading which is related to the workability of the concrete mix and thus is the workability index for that particular concrete mix.

In a preferred embodiment of the present invention, the tube includes a plurality of the slotted apertures, each extending from the end of the tube remote from the plate and in a typical embodiment, the tube includes four such slotted apertures disposed at 90° around the periphery of the tube.

While it is within the scope of the present invention for the slotted apertures to extend substantially completely longitudinally of the tube up to said plate, it is found that such slots substantially weaken the tube and detract from the performance of the device. In a preferred embodiment of the present invention therefore, the slotted apertures extend only partially along the tube and the tube includes between the ends of the slotted apertures and the plate at least one set of a plurality of small apertures disposed around the periphery of the tube through which apertures concrete mix may pass into and out of the bore on insertion of the device into the concrete mix. In a particular embodiment of the present invention, the tube includes a plurality of sets of small apertures longitudinally spaced along the tube. Suitably each ring of apertures consists of eight apertures disposed at 45°.

The device of the present invention is suitably provided with a handle means and preferably the handle means is provided by an extension of the tube beyond the plate, i.e., the plate is located intermediate the ends of the tube. Further, in order to facilitate insertion of the tube into the concrete, the end thereof remote from the plate is provided with a solid conical head portion.

The index means in the device in one specific embodiment constitutes markings spaced axially along the outside of the tube. Such index means allows the residual height of the mix in the tube to be read directly, which allows the workability and the compaction properties of the freshly prepared concrete mix to be calculated directly, and the slump and consistency of the mix are calculated indirectly based upon this residual height reading. In particular, slump, consistency, workability and compaction are interrelated properties of freshly prepared concrete that are influenced extensively by the water/cement ratio (w/c ratio), and when one of these properties is measured, the other properties can be determined therefrom to a certain degree. In particular, the relationship between the workability and slump of a freshly prepared concrete mix is given by the equation

$$K = 0.25 + 1.35\,S - 0.12\,S^2 \text{ where}$$

K = workability level

S = slump in inches.

In accordance with a preferred embodiment of the present invention, the index means comprises a rod locatable in the bore of the tube and arranged for axial movement along the bore, said rod being of sufficient length to extend from an open end of said tube and including an index associated therewith so that the extent to which the rod extends from the bore is readily determined, and thus also the height of the mix within the bore of the tube. The height of the freshly prepared concrete mix in the bore of the tube may be determined using such index means both before and after withdrawal of the tube from the freshly prepared concrete mix. The height of the mix in the bore of the tube whilst the tube is in the mix gives a direct determination of the slump and consistency of the mix according to the equation

$P = 0.034 + 0.876\,S$ where P is the reading on the rod, and S is the actual slump.

The residual height of the freshly prepared concrete mix in the tube after withdrawal from the concrete mix as previously mentioned gives a direct determination of the workability and compaction of the concrete mix.

The present invention also provides a method of determining the workability, consistency, slump and compaction of a freshly prepared concrete mix which comprises inserting a device into said mix, said device comprising a tube including a central bore, a member fixedly attached to and extending substantially transversely of said tube, a plurality of apertures each in the shape of a slot extending longitudinally of said tube

from a closed end thereof remote from said transverse member, partially along said tube including between the ends of said slotted aperture and said transverse member, at least one set of a plurality of small apertures disposed around the periphery of said tube, and index means associated with said tube, said device being inserted into said mix until said transverse member is seated on the stop of said mix, whereby said mix may enter the bore of the device, determining a first height of the mix in said tube by lowering a rod having an index associated therewith through a top open end of said tube, down said bore into contact with the surface of said mix in said bore, raising said rod, removing the device from the mix while allowing said mix in said bore to flow freely therefrom during said removal and ascertaining residual height of the mix in the bore of the tube by once more lowering the rod into contact with the surface of the mix in said bore.

The present invention will be further illustrated by way of the accompanying drawings, in which:

FIG. 1 is a side elevation, partially broken away of a device for determining the workability, consistency and compaction of freshly prepared concrete mixes according to a preferred embodiment of the present invention;

FIG. 2 is a section taken along the line A—A in FIG. 1;

FIG. 3 is a section taken along the line B—B in FIG. 1; and

FIGS. 4 to 6 are graphs of workability index against water cement ratio in a concrete mix as determined by the device of FIGS. 1 to 3.

FIG. 7 is a side elevation of the device similar to FIG. 1 with an index means according to another embodiment of the present invention.

FIG. 8 represents a graph of slump as measured by the device in inches in relation to the actual slump for a concrete mix as set forth in the original disclosure.

FIG. 9 represents a graph of the compaction factor as measured by the device in relation to the number of tampings for concrete mix as set forth in the original disclosure.

FIG. 10 represents a graph of workability level measured by the probe against slump in inches.

Referring to the drawings, the device comprises a hollow tube 1 suitably made of brass and having a bore 2. The tube 1 has a cap 3 including an air outlet 4 at one end thereof and a solid cone 5 at the other end thereof to facilitate smooth insertion of the device into a freshly prepared concrete mix. Intermediate the ends of the tube 1 is a circular flotation disc 6 which is fixedly mounted transversely of the tube 1 and prevents the tube from sinking into the concrete mix, the disc 6 during testing of the concrete mix being seated on the top of the mix. The disc 6 divides the tube 1 into a handle portion 1*a* and a testing portion 1*b*. The testing portion 1*b* of the tube 1 includes slotted apertures 7 extending longitudinally along the tube 1 which allow the concrete mix to enter the bore 2 including the concrete paste and coarse particles in the mix. The testing portion 1*b* of the tube 1 also includes longitudinally spaced rings of small apertures 8 which also allow concrete mix to enter the bore 2 of the tube 1 and also allow the level of the concrete mix to be determined when it is above the level of the slotted apertures 7. Further the presence of such rings of apertures 8 render the device particularly useful with wet and lean 16 concrete mixes. The testing portion 1*b* of the tube 1 also includes index 9 for use in determining the residual height of the mix in the device after it has been withdrawn from the concrete mix.

In a particular embodiment of the present invention the overall length of the tube 1 is 13.343 inches having a three-fourths inch external diameter and a five-eighths inch internal diameter. The handle portion 1*a* is 7-¼ inches long and the testing portion 1*b* including the cone 5 is 6-1/6 inches long. the slotted apertures 7 are four in number at 90° each being rectangular, 2 inches long, and five-sixteenths inch wide, which will allow the paste and coarse particles up to one-fourth inch in size of the concrete mix to enter the bore 2. The apertures 8 are in four rows of eight apertures each having a diameter of seven thirty-seconds inch and spaced at 45°. The index 9 is 4 inches long and is divided in increments of one-eighth inch and is engraved on the tube 1. The floater disc 6 is 2 ½ inches in diameter and three thirty-seconds inch thick. A typical weight of such device is about 12 ounces.

In operation, the device is inserted into the freshly prepared concrete mix up to the disc 6. The concrete mix may be located where desired and the device of the present invention is useful both in the laboratory and in the field and as such may be inserted in a standard compression cylinder or in an ordinary bucket or wheelbarrow or in the structural members of a building such as slabs, beams, columns and walls before setting thereof. The mix passes into the bore 2 and after a suitable period of time of the order of 15 seconds to 5 minutes, the device is removed from the mix and the residual height of the mix in the bore 2 is determined by means of the index 9. It is found that the reading is generally independent of time of residence of the device in the concrete mix over a wide range of mix proportions. The reading is related directly to the workability, consistency and compaction of the concrete mix and is thus the workability index. The reading may also be used to check the compaction of the concrete after it is placed and to predict the expected strength of the hardened concrete if sufficient tests have been accumulated upon such a mix.

The ability of the device of the present invention to assess the workability of a fresh concrete mix will be illustrated by way of the following examples in which the main factors of workability, i.e., water content cement content and aggregate grading were varied. The device used was of the precise dimensions as set forth heretofore.

Preparation of the test specimen

The cement used was Type III High Early Strength Portland Cement.

Two kinds of fine aggregates and three kinds of coarse ones were used, the fine aggregates were designated torpedo sand (S_5) and plaster sand (S_7) while the coarse aggregates were cA_2, cA_3 and cA_4 depending upon their grading. Tables 1 and 2 show the results of the sieve analysis effected according to CSA standard *A*23.2.2, and ASTM standard Designation C136–63.

TABLE 1

RESULTS OF SIEVE ANALYSIS OF COARSE AGGREGATES

Sieve No.	Cumulative Percentage Passing								
				CA_5 (CA_2:CA_3 = 1:0.45)		CA_6 (CA_2:CA_4 = 1:0.35)		CA_7 (CA_3:CA_4 = 1:0.78)	
	CA_2	CA_3	CA_4	Design*	Test	Design*	Test*	Design*	Test
1	95.90	100	100	97	98	97	99	100	100
¾	83.70	93.2	100	86.5	87	88	90	96	97
⅜	16.2	25.2	93.5	19	20	36	36	55	54
4	8.30	4.5	36.0	7	8	16	17	18	22
S	4.60	3.1	13.10	4	4	7	8	7	8
Defined Grading				COARSE		MEDIUM		FINE	

* Obtained by calculation

TABLE 2

RESULTS OF SIEVE ANALYSIS OF FINE AGGREGATES

Sieve No.	Cumulative Percentage Passing			
	S_5	S_6 (S_5:S_7 = 1:0.5)		S_7
		Design*	Test	
⅜	100	100	100	100
4	89.3	91.8	92.1	96.7
8	77.0	81.4	81.2	90.4
16	60.8	66.5	66.4	78.0
30	41.4	45.7	45.6	54.5
50	18.00	19.2	19.5	21.5
100	3.50	4.00	4.00	4.9
F.M.	3.10	2.91	2.91	2.54
Define Grading	COARSE	MEDIUM		FINE

* Obtained by calculation

Table 1 shows three combinations of coarse aggregates defined as coarse, medium and fine respectively. CA_5 and CA_7 were approximated to the extreme values specified by CSA and ASTM while CA_6 was their average The gradings were first calculated, and then checked by test.

As shown in Table 2, S_5 was defined as coarse grading, while S_7 was defined as fine grading. S_6 was defined as medium grading. All aggregates were kept in room-dry condition, and stored in separate closed wooden bins. The weather changes had insignificant effect on the test results since the aggregates were stored in a laboratory.

Three series of concrete mixes 1, 2 and 3 were prepared, the proportions in each of the mix series 1, 2 and 3 respectively being shown in Tables 3*a*, *b* and *c*, 4*a*, *b* and *c*, and 5*a*, *b* and *c*.

TABLE 3a

DESIGN OF MIX SERIES I — FINE GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms.				
			Water	Cement	Coarse Aggregate CA_7		Fine Aggregate
					CA_3	CA_4	S_7
E_1	"5"	0.52	8,518	16,380	20,450	15,950	45,500
E_2		0.60	9,828	16,380	20,450	15,950	45,500
E_3		0.63	10,319	16,380	20,450	15,950	45,500
E_4		0.66	10,811	16,380	20,450	15,950	45,500
E_5		0.675	11,057	16,380	20,450	15,950	45,500
E_6		0.72	11,794	16,380	20,450	15,950	45,500

TABLE 3b

DESIGN OF MIX SERIES I — FINE GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms.				
			Water	Cement	Coarse Aggregate CA_7		Fine Aggregate S_7
					CA_3	CA_4	
D_1	"7"	0.60	7,375	12,291	21,483	16,757	47,800
D_2		0.66	8,112	12,291	21,483	16,757	47,800
D_3		0.72	8,850	12,291	21,483	16,757	47,800
D_4		0.78	9,587	12,291	21,483	16,757	47,800
D_5		0.82	10,079	12,291	21,483	16,757	47,800
D_6		0.868	10,669	12,291	21,483	16,757	47,800
D_7		1.00	12,291	12,291	21,483	16,757	47,800

TABLE 3c

DESIGN OF MIX SERIES — FINE GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregate CA_7 CA_3	CA_4	Fine Aggregate S_7
F_1	"9"	0.85	8,510	10,012	22,500	17,550	50,062
F_2		0.90	9,011	10,012	22,500	17,550	50,062
F_3		0.95	9,511	10,012	22,500	17,500	50,062
F_4		1.00	10,012	10,012	22,500	17,550	50,062
F_5		1.03	10,312	10,012	22,500	17,550	50,062
F_6		1.06	10,613	10,012	22,500	17,550	50,062
F_7		1.08	10,813	10,012	22,500	17,550	50,062

TABLE 4a

DESIGN OF MIX SERIES 2 — MEDIUM GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregate CA_6 CA_2	CA_4	Fine Aggregate S_6 S_5	S_7
A_1	"5"	0.50	8,190	16,380	26,963	9,437	30,333	15,167
A_2		0.55	9,009	16,380	26,963	9,437	30,333	15,167
A_3		0.60	9,828	16,380	26,963	9,437	30,333	15,167
A_4		0.62	10,165	16,380	26,963	9,437	30,333	15,167
A_5		0.625	10,238	16,380	26,963	9,437	30,333	15,167
A_6		0.63	10,319	16,380	26,963	9,437	30,333	15,167
A_7		0.65	10,647	16,380	26,963	9,437	30,333	15,167
A_8		0.68	11,138	16,380	26,963	9,437	30,333	15,167

TABLE 4b

DESIGN OF MIX SERIES 2 — MEDIUM GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregates CA_6 CA_2	CA_4	Fine Aggregates S_6 S_5	S_7
B_1	"7"	0.62	7,603	12,263	28,266	9,894	31,800	15,900
B_2		0.70	8,584	12,263	28,266	9,894	31,800	15,900
B_3		0.75	9,197	12,263	28,266	9,894	31,800	15,900
B_4		0.765	9,381	12,263	28,266	9,894	31,800	15,900
B_5		0.80	9,810	12,263	28,266	9,894	31,800	15,900
B_6		0.805	9,872	12,263	28,266	9,894	31,800	15,900
B_7		0.82	10,056	12,263	28,266	9,894	31,800	15,900
B_8		0.835	10,241	12,263	28,266	9,894	31,800	15,900

TABLE 4c

DESIGN OF MIX SERIES 2 — MEDIUM GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregate CA_6 CA_2	CA_4	Fine Aggregates S_6 S_5	S_7
C_1	"9"	0.72	7,236	10,050	29,778	10,422	33,500	16,750
C_2		0.85	8,543	10,050	29,778	10,422	33,500	16,750
C_3		0.92	9,246	10,050	29,778	10,422	33,500	16,750
C_4		0.95	9,548	10,050	29,778	10,422	33,500	16,750
C_5		1.00	10,050	10,050	29,778	10,422	33,500	16,750
C_6		1.03	10,352	10,050	29,778	10,422	33,500	16,750

TABLE 5a

DESIGN OF MIX SERIES 3 — COARSE GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregate CA_5 CA_2	CA_3	Fine Aggregate S_5
G_1	"5"	0.55	9,009	16,380	25,100	11,300	45,500
G_2		0.57	9,337	16,380	25,100	11,300	45,500
G_3		0.585	9,582	16,380	25,100	11,300	45,500
G_4		0.61	9,992	16,380	25,100	11,300	45,500
G_5		0.625	10,238	16,380	25,100	11,300	45,500
G_6		0.63	10,319	16,380	25,100	11,300	45,500
G_7		0.65	10,647	16,380	25,100	11,300	45,500
G_8		0.67	10,975	16,380	25,100	11,300	45,500

TABLE 5b

DESIGN OF MIX SERIES 3 — COARSE GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregate CA_5 CA_2	CA_3	Fine Aggregate S_5
H_1	"7"	0.55	6,760	12,291	26,370	11,870	47,800
H_2		0.60	7,375	12,291	26,370	11,870	47,800
H_3		0.70	8,604	12,291	26,370	11,870	47,800
H_4		0.725	8,911	12,291	26,370	11,870	47,800
H_5		0.75	9,218	12,291	26,370	11,870	47,800
H_6		0.775	9,526	12,291	26,370	11,870	47,800
H_7		0.80	9,833	12,291	26,370	11,870	47,800

TABLE 5c

DESIGN OF MIX SERIES 3 — COARSE GRADING

Mix Design No.	Aggregate Cement Ratio	Water Cement Ratio	Weight in gms. Water	Cement	Coarse Aggregate CA_5 CA_2	CA_3	Fine Aggregate S_7
I_1	"9"	0.80	7,840	9,800	27,035	12,165	49,000
I_2		0.85	8,330	9,800	27,035	12,165	49,000
I_3		0.875	8,575	9,800	27,035	12,165	49,000
I_4		0.90	8,820	9,800	27,035	12,165	49,000
I_5		0.95	9,310	9,800	27,035	12,165	49,000
I_6		1.00	9,800	9,800	27,035	12,165	49,000
I_7		1.02	9,996	9,800	27,035	12,165	49,000

In the design of these mix series the following important factors that effect workability were considered:

1. The proportions of fine and coarse aggregates were kept constant within each grading.

2. Three aggregate/cement ratios of 5, 7 and 9 were used, which represent rich, average and lean mixes respectively.

3. The water-cement ratio was varied for each aggregate/cement ratio. An average of 6 to 8 mixes were used in each case depending upon the richness and the grading of the group being investigated.

4. Table 6 shows the gradings that were used for mix series 1, 2 and 3 and were defined as fine, medium and coarse respectively.

TABLE 6

GRADING OF COMBINED COARSE AND FINE AGGREGATES

Sieve No.	Cumulative Percentage Passing COARSE $CA_5:S_5 = 1:1.25$	MEDIUM $CA_6:S_6 = 1:1.25$	FINE $CA_7:S_7 = 1:1.25$
1	98	99	100
¾	94	95	100
⅜	64	72	80
4	53	58	62
8	44	48	53
16	31	37	45
30	24	26	31
50	10	11	14
100	2	3	4
F.M.	4.80	4.51	4.11
Remarks	Used in Mix series 3	Used in Mix series 2	Used in Mix series 1

The fine grading for mix series 1 was obtained by combining the fine and coarse aggregates of fine grading as defined heretofore. The other combinations were obtained in a similar procedure.

All mixes were mixed in a Pan-type mixer. The ingredients were first weighed separately in a balance sensitive to 1 gram, then placed in the mixer, and mixed dry for 2 minutes. Water was then added slowly while the mixer was rotating, and mixing was continued for an additional 1 ½ to 2 minutes, depending on the wetness and richness of the mix. The device was wetted before testing.

A standard 6 × 12 inch cardboard cylinder was filled with concrete through a hopper in three layers and jolted 25 jolts by a mechanical compacting table. The device was then pushed slowly and vertically down in the concrete until its floater disc rested on the top surface of the specimen. The device was kept in the concrete for 1 minute, then removed carefully and slowly in the same manner, and the height of the material retained in the bore was read and recorded. The results obtained are shown in Tables 7, 8, and 9 and in FIGS. **4, 5** and **6.**

TABLE 7

RESULTS OF WORKABILITY AND SLUMP TESTS OF MIX SERIES 1

Mix Design No.	E_1	E_2	E_3	E_4	E_5	E_6		Aggregate Cement Ratio
Water-Cement Ratio	0.52	0.60	0.63	0.66	0.675	0.72		
Average Workability Index (in)	0.70	1.54	1.79	2.125	2.08	1.20		5
Average Slump (in)	0.70	4.10	5.50	7.80	8.06	9.30		
Mix Design No.	D_1	D_2	D_3	D_4	D_5	D_6	D_7	Aggregate Cement Ratio
Water-Cement Ratio	0.60	0.66	0.72	0.78	0.82	0.868	1.00	
Average Workability Index (in)	0.45	0.67	0.83	1.25	1.83	1.45	0.375	7
Average Slump (in)	0.25	1.06	1.33	3.50	5.00	8.13	10.25	
Mix Design No.	F_1	F_2	F_3	F_4	F_5	F_6	F_7	Aggregate Cement Ratio
Water-Cement Ratio	0.85	0.90	0.95	1.00	1.03	1.06	1.08	
Average Workability Index (in)	0.75	1.00	1.375	1.54	1.625	1.54	1.275	9
Average Slump (in)	0.41	0.88	1.83	4.13	5.50	7.38	8.33	

TABLE 8

RESULTS OF WORKABILITY AND SLUMP TESTS OF MIX SERIES 2

Mix Design No.	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	Aggregate Cement Ratio
Water-Cement Ratio	0.50	0.55	0.60	0.62	0.625	0.63	0.65	.68	
Average Workability Index (in)	0.33	0.81	1.625	1.58	1.88	1.96	2.00	1.75	5
Average Slump (in)	0.13	0.63	2.50	4.25	4.63	4.88	6.50	8.63	
Mix Design No.	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	Aggregate Cement Ratio
Water-Cement Ratio	0.62	0.70	0.75	0.765	0.80	0.805	0.82	0.835	
Average Workability Index	0.54	0.83	1.15	1.71	1.85	1.83	1.75	1.25	7
Average Slump (in)	0.50	0.80	1.75	3.83	6.00	6.75	8.05	9.50	
Mix Design No.	C_1	C_2	C_3	C_4	C_5	C_6	—	—	Aggregate Cement Ratio
Water-Cement Ratio	0.72	0.85	0.92	0.95	1.00	1.03			
Average Workability Index	0.30	1.05	1.25	1.375	1.08	0.70			9
Average Slump (in)	0.30	1.38	3.25	5.50	7.25	9.25			

TABLE 9

RESULTS OF WORKABILITY AND SLUMP TESTS OF MIX SERIES 3

Mix Design No.	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8	Aggregate Cement Ratio
Water-Cement Ratio	0.55	0.57	0.585	0.61	0.625	0.63	0.65	0.67	
Average Workability Index (in)	0.83	1.12	1.20	1.40	1.50	1.6	1.32	1.05	5
Average Slump (in)	1.42	2.26	3.00	4.50	5.25	5.67	7.15	8.00	
Mix Design No.	H_1	H_2	H_3	H_4	H_5	H_6	H_7	—	Aggregate Cement Ratio

TABLE 9 – Continued

RESULTS OF WORKABILITY AND SLUMP TESTS OF MIX SERIES 3

Mix Design No.	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8	Aggregate Cement Ratio
Water-cement Ratio	0.55	0.60	0.70	0.725	0.75	0.775	0.80	—	
Average Workability Index (in)	0.12	0.28	0.82	1.10	1.23	1.38	1.07	—	7
Average Slump (in)	0.08	0.25	1.30	2.00	4.00	5.25	7.00		
Mix Design No.	I_1	I_2	I_3	I_4	I_5	I_6	I_7	—	Aggregate Cement Ratio
Water-Cement Ratio	0.80	0.85	0.875	0.90	0.95	1.00	1.02	—	
Average Workability Index (in)	0.50	1.00	1.20	1.125	0.90	0.625	0.50	—	9
Average Slump (in)	1.00	2.50	3.25	4.00	6.00	7.50	8.50		

It is clear from tables **7, 8** and **9** that for a mix with a fixed aggregate/cement ratio the slump varies with water-cement ratio, i.e., the wetter the concrete the higher its slump value. However, the curves and the tables show that workability increases with the water-cement ratio up to a certain point then it starts to decrease indicating a possible onset of segregation. Thus, for any given method of compaction there is an optimum water content of the mix at which the sum of the volumes of air bubbles and water space is a minimum. At this optimum water content the highest density ratio of the concrete is obtained. It is believed that the loss of workability for very wet mixes is mainly due to segregation as mentioned heretofore and also due to decrease of cohesion and adhesion of the materials. It will be further seen that the highest workability reading corresponds to the mix with the lowest aggregate/cement ratio for the same grading. Thus workability of a mix is seriously affected by the amount of fine particles that passes sieve No. 50. These fine particles consist of the cement particles and a portion of the sand in the mix. Both materials, when mixed with water, represent the main cohesive and adhesive elements in the mix.

It will be further seen that aggregate grading affects the workability of the concrete mix. For finer grading, more water is needed to wet the surface in order to obtain the same workability. The results show that for a fixed aggregate/cement ratio the optimum workability within any mix means less water when the grading is coarser. Thus for example in FIG. **5** the coarse grading has its optimum workability at a water/cement ratio of about 0.77 while the fine grading has its optimum workability at a water/cement ratio of 0.82. The medium grading workability is roughly their average. It will be further noted that the fine gradings are less likely to lose their workability with higher water/cement ratios while the coarse grading started to segregate and lose workability at a relatively lower water/cement ratio. Thus it will be seen that workability does not always increase with an increase in water of the mix. After an optimum water content is reched workability starts to decrease with further addition of water. Undoubtedly, this addition of water makes the concrete easier to place and be compacted yet this induces some segregation and loss in cohesion and adhesion. From a theoretical point of view, when segregation occurs an additional amount of work should be applied to restore the concrete back to a homogeneous state and hence concrete suffers loss in workability due to the addition of water. It is known practice in the field to consider any concrete mix with a slump rating from 2 to 5 inches a workable and satisfactory one. Thus it will be seen that the device of the present invention provides a simple and easy test to assess the workability of concrete and in particular to evaluate both factors of compaction and segregation involved in the workability of concrete.

In the device of FIG. **7**, a rod **10** is axially slidably located within the bore **2** of the tube **1** and passes through the outlet **4** in the cap **3**. The rod **10** includes an index **11** thereon.

In operation, the device is wetted with water and then shaken to remove the excess. The measuring rod **10** is raised and allowed to rest on a pedestal (not shown) located within the bore near the level of the disc **6**. The surface of the concrete mix is levelled and the device is inserted vertically downward until the disc **6** rests on the surface of the concrete. The device should not be rotated while it is either inserted or removed from the concrete mix. After 60 seconds, the rod **10** is lowered slowly in the bore **2** until it rests on the surface of the concrete mix that entered the bore **2** of the tube **1**, and the slump *S* is read directly on the index **11** of the rod **10**. The rod **10** is then raised and allowed to rest on the aforesaid pedestal and the device is removed vertically upwardly from the concrete mix until it is clear of the concrete mix, whence once again, the rod **10** is lowered slowly downwardly until it touches the surface of the concrete mix retained in the bore **2** of the tube **1**, and the workability level (*K*) is directly read on the index **11** of the rod **10**. The device is then washed with water and ready for further use.

The first reading *S* is the actual ordinary slump and consistency, while the second reading *K* is a measure of the workability and compaction. The greater the value *K*, the better will be the workability and compaction of the concrete mix. The device may be inserted in a compacted 6 × 12 inch cylinder, in buckets, wheelbarrows, readymix truck shutes, slabs, columns, beams and any other desired location where fresh concrete is placed, provided that there is a minimum of about 6 inches of concrete around the device and that the disc **6** rests freely on the surface of the concrete mix. When the device is used in buckets, wheelbarrows, and ready-mix truck shutes, tamping gives a more uniform result. When the device is used in a standard cylinder, it is desirable to tap the cylinder lightly about 20 times with a compacting rod to close the hole that was left in the concrete after removal of the device.

I claim:

1. A device for use in determining the workability, consistency, slump and compaction of a freshly prepared concrete mix which comprises a tube including a central bore, a member fixedly attached to and ex-

tending substantially transversely of said tube for limiting the depth to which said tube may be inserted into said mix, a plurality of apertures each in the shape of a slot extending from a closed end of the tube remote from the transverse member partially along said tube, including between the ends of said slotted apertures and said transverse member at least one set of a plurality of small apertures disposed around the periphery of said tube through which apertures said mix may enter said bore on insertion of said device into said mix, and index means associated with said tube for determining the residual height to which the mix is present in the bore of said tube on withdrawal of said device from said mix.

2. A device as claimed in claim **1** in which said tube includes four slotted apertures disposed at 90° around the periphery of said tube.

3. A device as claimed in claim **1** in which said tube includes a plurality of such sets of apertures, said sets being longitudinally spaced along the tube.

4. A device as claimed in claim **1** which includes handle means attached to said transverse member remote from said tube.

5. A device as claimed in claim **4** in which said transverse member is located intermediate the ends of the tube to provide said handle means.

6. A device as claimed in claim **1** in which the index means comprises marking on the outside periphery of the tube.

7. A device as claimed in claim **1** including a solid cone attached to the end of the tube remote from the transverse member to facilitate insertion of the device into the concrete mix.

8. A device for use in determining the workability, consistency, slump and compaction of a freshly prepared concrete mix which comprises a tube including a central bore, a member fixedly attached to and extending substantially transversely of said tube for limiting the depth to which said tube may be inserted into said mix, said tube including four slotted apertures disposed at 90° around the periphery of said tube, each of said apertures extending from the end of the tube remote from the transverse member only partially along said tube, said tube including between the ends of the slotted apertures and said transverse member four sets of a plurality of small apertures, each set being spaced longitudinally along said tube and being formed by a plurality of small apertures extending around the periphery of said tube through which apertures said mix may enter said bore on insertion of said device into said mix, and index means associated with said tube for determining the residual height to which the mix is present in the bore of the tube on withdrawal from said mix.

9. A method of determining the workability, consistency, slump and compaction of a freshly prepared concrete mix which comprises inserting a device into said mix, said device comprising a tube including a central bore, a member fixedly attached to and extending substantially transversely of said tube, a plurality of apertures each in the shape of a slot extending longitudinally of said tube from a closed end thereof remote from said transverse member, partially along said tube, including between the ends of said slotted apertures and said transverse member at least one set of a plurality of small apertures disposed around the periphery of said tube, and index means associated with said tube, said device being inserted into said mix until said transverse member is seated on top of said mix whereby said mix may enter the bore of said device removing the device from the mix while allowing said mix in said bore to flow freely therefrom during said removal and ascertaining the residual height of the mix in the bore of the tube by viewing the index means of said tube.

10. A device for use in determining the workability, consistency, slump and compaction of a freshly prepared concrete mix which comprises a tube including a central bore, a member fixedly attached to and extending substantially transversely of said tube for limiting the depth to which said tube may be inserted into said mix, a plurality of apertures each in the shape of a slot extending from a closed end of the tube remote from the transverse member partially along said tube, including between the ends of said slotted apertures and said transverse member at least one set of a plurality of small apertures disposed around the periphery of said tube, through which apertures said mix may enter said bore on insertion of said device into said mix, and index means associated with said tube comprising a rod locatable in said bore and arranged for axial movement along said bore, said rod being of sufficient length to extend through an open end of said tube, and including an index associated therewith whereby the height of the mix in the bore of said tube may be determined before and after withdrawal of the device from said mix.

11. A method of determining the workability, consistency, slump and compaction of a freshly prepared concrete mix which comprises inserting a device into said mix, said device comprising a tube including a central bore, a member fixedly attached to and extending substantially transversely of said tube, a plurality of apertures each in the shape of a slot extending longitudinally of said tube from a closed end thereof remote from said transverse member, partially along said tube, including, between the ends of said slotted apertures and said transverse member, at least one of a plurality of small apertures disposed around the periphery of said tube, and index means associated with said tube, said device being inserted into said mix until said transverse member is seated on the top of said mix, whereby said mix may enter the bore of the device, determining a first height of the mix in said tube by lowering a rod having an index associated therewith through a top open end of said tube, down said bore into contact with the surface of said mix in said bore, raising said rod, removing the device from the mix while allowing said mix in said bore to flow freely therefrom during said removal and ascertaining the residual height of the mix in the bore of the tube by once more lowering the rod into contact with the surface of the mix in said bore.

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