CONTENTS

Chapter 4

Fresh concrete

Although fresh concrete is only of transient interest, we should note that the strength of concrete of given mix proportions is very seriously affected by the degree of its compaction. It is vital, therefore, that the consistency of the mix be such that the concrete can be transported, placed, compacted, and finished sufficiently easily and without segregation. This chapter is therefore devoted to the properties of fresh concrete which will contribute to such an objective.

Before considering fresh concrete, we should observe that the first three chapters discussed only two of the three essential ingredients of concrete: cement and aggregate. The third essential ingredient is water, and this will be considered below.

It may be appropriate to add, at this stage, that many, if not most, concrete mixes contain also admixtures: these are the topic of Chapter 5.

Quality of mixing water

The vital influence of the quantity of water in the mix on the strength of the resulting concrete will be considered in Chapter 6. Apart from that, traditionally, those studying concrete have shown little interest in water in the mix. Admittedly, water is necessary to make the mix adequately workable and it is, of course, necessary, to hydrate the cement or, as was later established, only some of the cement. Consequently, relatively little effort was devoted to the study of the quality of water.

However, water is not just a liquid used to make concrete: it is involved in the whole life of concrete, for good or for evil. Most actions on concrete in service, other than loading, involve water, either pure or carrying salts or solids. The important influences of water, in addition to those on workability and strength, are those on: setting, hydration, bleeding, drying shrinkage, creep, ingress of salts, explosive failure of concrete with a very low water-cement ratio, autogenous healing, staining of the surface, chemical attack of concrete, corrosion of reinforcement, freezing and thawing, carbonation, alkali-silica reaction, thermal properties, electrical resistivity, cavitation and erosion, and quality of drinking water passed through concrete pipes or mortar-lined pipes. This is a pretty exhaustive list.

As some of the influences are for good, and others for bad, one could say that water and concrete are in a love-hate relationship; this indeed is the title of a

Neville, A, M 2016, 'Fresh Concrete', in *Properties of Concrete* (5th ed). Essex, England: Pearson Education Ltd, pp. 183–244.

chapter in my book *Neville on Concrete: an examination of issues in concrete practice*.[4.122] Another chapter in that book is titled "Water: Cinderella Ingredient of Concrete".

For these reasons, the suitability of water for mixing and curing purposes should be considered. Clear distinction must be made between the quality of mixing water and the attack on hardened concrete by aggressive waters. Indeed, some waters which adversely affect hardened concrete may be harmless or even beneficial when used in mixing.[4.15] The quality of curing water is considered on p. 324.

Mixing water should not contain undesirable organic substances or inorganic constituents in excessive proportions. However, quantitative limits of harmful constituents are not known reliably and also, because unnecessary restrictions could be economically damaging. Some limits are specified in BS EN 1008 : 2002.

In many project specifications, the quality of water is covered by a clause saying that water should be fit for drinking. Such water very rarely contains dissolved inorganic solids in excess of 2000 parts per million (ppm), and as a rule less than 1000 ppm. For a water/cement ratio of 0.5, the latter content corresponds to a quantity of solids representing 0.05 per cent of the mass of cement, and any effect of the common solids would be small.

While the use of potable water as mixing water is generally satisfactory, there are some exceptions; for instance, in some arid areas, local drinking water is saline and may contain an excessive amount of chlorides. Also, some natural mineral waters contain undesirable amounts of alkali carbonates and bicarbonates which could contribute to the alkali–silica reaction.

Conversely, some waters not fit for drinking may often be used satisfactorily in making concrete. As a rule, water with pH of 6.0 to 8.0,[4.33] or possibly even 9.0, which does not taste brackish is suitable for use, but dark colour or bad smell do not necessarily mean that deleterious substances are present.[4.16] A simple way of determining the suitability of such water is to compare the setting time of cement and the strength of mortar cubes using the water in question with the corresponding results obtained using known 'good' water or distilled water; there is no appreciable difference between the behaviour of distilled and ordinary drinking water. A tolerance of about 10 per cent is usually permitted to allow for chance variations in strength;[4.15] BS EN 1008-2002 also specifies 10 per cent. Such tests are recommended when water for which no service record is available contains dissolved solids in excess of 2000 ppm or, in the case of alkali carbonate or bicarbonate, in excess of 1000 ppm. When unusual solids are present a test is also advisable. Limits on chlorides, sulfates and alkali are given in BS EN 1008 : 2002 and ASTM C 1602-06.

Because it is undesirable to introduce large quantities of clay and silt into the concrete, mixing water with a high content of suspended solids should be allowed to stand in a settling basin before use; a turbidity limit of 2000 ppm has been suggested.[4.7] However, water used to wash out truck mixers is satisfactory as mixing water, provided of course that it was satisfactory to begin with. ASTM C 94-94-09a and BS EN 1008-2002 give the requirements for the use of wash water. Clearly, cements and admixtures different from those originally used should not be involved. The use of wash water is an important topic, but is outside the scope of this book.

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Natural waters that are slightly acid are harmless, but water containing humic or other organic acids may adversely affect the hardening of concrete; such water, as well as highly alkaline water, should be tested. The effects of different ions vary, as shown by Steinour.[4.15]

It may be interesting to note that the presence of algae in mixing water results in air entrainment with a consequent loss of strength.[4.13] According to the appendix to BS 3148 : 1980, green or brown slime-forming algae should be regarded with suspicion, and water containing them should be tested.

Brackish water contains chlorides and sulfates. When chloride does not exceed 500 ppm, or SO_3 does not exceed 1000 ppm, the water is harmless, but water with even higher salt contents has been used satisfactorily.[4.35] The appendix to BS 3148 : 1980 recommends limits on chloride and on SO_3 as above, and also recommends that alkali carbonates and bicarbonates should not exceed 1000 ppm. Somewhat less severe limitations are recommended in American literature.[4.33]

Sea water has a total salinity of about 3.5 per cent (78 per cent of the dissolved solids being NaCl and 15 per cent $MgCl_2$ and $MgSO_4$) (cf. p. 517), and produces a slightly higher early strength but a lower long-term strength; the loss of strength is usually no more than 15 per cent[4.25] and can therefore often be tolerated. Some tests suggest that sea water slightly accelerates the setting time of cement, others[4.27] show a substantial reduction in the initial setting time but not necessarily in the final set. Generally, the effects on setting are unimportant if water is acceptable from strength considerations. BS EN 1008-2002 specifies a tolerance of 25 minutes in the initial setting time and a maximum final setting time of 12 hours.

Water containing large quantities of chlorides (e.g. sea water) tends to cause persistent dampness and surface efflorescence. Such water should, therefore, not be used where appearance of unreinforced concrete is of importance, or where a plaster finish is to be applied.[4.9] Much more importantly, the presence of chlorides in concrete containing embedded steel can lead to its corrosion; the limits on the total chloride ion content in concrete are considered on p. 566.

In this connection, but also with respect to all impurities in water, it is important to remember that water discharged into the mixer is not the only source of mix water: aggregate usually contains surface moisture (see p. 132). This water can represent a substantial proportion of the total mixing water. It is, therefore, important that the water brought in by the aggregate is also free from harmful material.

Tests on mixes with a range of waters suitable for use in concrete showed no effect on the structure of the hydrated cement paste.[4.103]

The preceding discussion was concerned with structural concrete, usually reinforced or prestressed. Under particular circumstances, for instance in the construction of unreinforced concrete bulkheads in a mine, highly contaminated water can be used. Al-Manaseer *et al.*[4.102] showed that water containing very high percentages of salts of sodium, potassium, calcium and magnesium used in making concrete containing Portland cement blended with fly ash did not adversely affect the strength of concrete. However, no information on long-term behaviour is available. Biologically treated domestic waste water has also been investigated for use as mixing water,[4.40] but much more information about the variability of such water, health hazards and long-term behaviour is required.

On page 183 reference was made to a possible effect of cement in the interior surface of a pipe on water destined for human consumption. As long as water moves through a concrete pipe (or a mortar-lined conduit) at speed, no significant chemical reaction with cement occurs. However, when water is near-stagnant, as during the night in domestic water conduits, leaching of cement may occur. This may raise the pH of the water and increase the content of $CaCO_3$, referred to as carbonate alkalinity or water hardness. The increase in $CaCO_3$ is induced by carbon dioxide dissolved in the water and a reaction with calcium hydroxide by water may also increase the content of aluminium, calcium, sodium, and potassium and of corrosion inhibitors in the mix.[4.122]

Curing water should generally satisfy the requirements for mixing water, but it should be free from substances that attack hardened concrete. Also, flowing pure water dissolves $Ca(OH)_2$ and causes surface erosion. Curing very young concrete with seawater may lead to an attack on reinforcement.

Density of fresh concrete

Density, also called unit mass or unit weight in air, can be determined experimentally by using ASTM standard C 138-09 or BS EN 12350-6 : 2009. Theoretically, density is the sum of masses of all the ingredients of a batch of concrete divided by the volume filled by the concrete.

Alternatively, knowing the density of fresh concrete, the yield per batch can be determined as the mass of all the ingredients in a batch divided by the density.

Definition of workability

A concrete which can be readily compacted is said to be workable, but to say merely that workability determines the ease of placement and the resistance to segregation is too loose a description of this vital property of concrete. Furthermore, the desired workability in any particular case would depend on the means of compaction available; likewise, a workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible, or heavily reinforced sections. For these reasons, workability should be defined as a physical property of concrete alone without reference to the circumstances of a particular type of construction.

To obtain such a definition it is necessary to consider what happens when concrete is being compacted. Whether compaction is achieved by ramming or by vibration, the process consists essentially of the elimination of entrapped air from the concrete until it has achieved as close a configuration as is possible for a given mix. Thus, the work done is used to overcome the friction between the individual particles in the concrete and also between the concrete and the surface of the mould or of the reinforcement. These two can be called internal friction and surface friction, respectively. In addition, some of the work done is used in vibrating the mould or in shock and, indeed, in vibrating those parts of the concrete which have already been fully consolidated. Thus the work done consists of a 'wasted' part and 'useful' work, the latter, as mentioned before, comprising work done to overcome the internal friction and the surface friction. Because only the internal friction is an intrinsic property of the mix, workability can be best defined as the amount of useful internal work necessary to produce full compaction. This definition was developed by Glanville *et al.*[4.1] who exhaustively examined the field of compaction and workability. The ASTM C 125-09a definition of workability is somewhat more qualitative: "property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity". The ACI definition of workability, given in ACI 116R-90,[4.46] is: "that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished".

Another term used to describe the state of fresh concrete is *consistency*. In ordinary English usage, this word refers to the firmness of form of a substance or to the ease with which it will flow. In the case of concrete, consistency is sometimes taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concretes, but concretes of the same consistency may vary in workability. The ACI definition of consistency is: "the relative mobility or ability of freshly mixed concrete or mortar to flow";[4.46] this is measured by slump.

Technical literature abounds with variations of the definitions of workability and consistency but they are all qualitative in nature and more reflections of a personal viewpoint rather than of scientific precision. The same applies to the plethora of terms such as: flowability, mobility, and pumpability. There is also a term 'stability' which refers to the cohesion of the mix, that is, its resistance to segregation. These terms do have specific meaning but only under a set of given circumstances; they can rarely be used as an objective and quantifiable description of a concrete mix.

A good review of the attempts to define the various terms is presented by Bartos,[4.56] among others.

The need for sufficient workability

Workability has so far been discussed merely as a property of fresh concrete: it is, however, also a vital property as far as the finished product is concerned because concrete must have a workability such that compaction to maximum density is possible with a reasonable amount of work or with the amount that we are prepared to put in under given conditions.

The need for compaction becomes apparent from a study of the relation between the degree of compaction and the resulting strength. It is convenient to express the former as a density ratio, i.e. a ratio of the actual density of the given concrete to the density of the same mix when fully compacted. Likewise, the ratio of the strength of the concrete is actually (partially) compacted to the strength of the same mix when fully compacted can be called the strength ratio. Then the relation between the strength ratio and the density ratio is of the form shown in Fig. 4.1. The presence of voids in concrete greatly reduces its strength: 5 per cent of voids can lower strength by as much as 30 per cent, and even 2 per cent voids can result in a drop of strength of more than 10 per cent.[4.1] This, of course, is in agreement with Féret's expression relating strength to the sum of the volumes of water and air in the hardened cement paste (see p. 271).

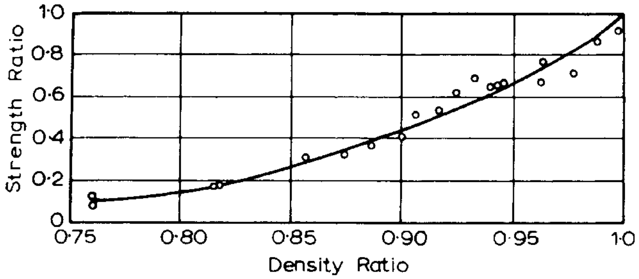

Fig. 4.1 Relation between strength ratio and density ratio.[4.1] (Crown copyright)

Voids in concrete are in fact either bubbles of entrapped air or spaces left after excess water has been removed. The volume of the latter depends primarily on the water/cement ratio of the mix; to a lesser extent, there may be spaces arising from water trapped underneath large particles of aggregate or underneath reinforcement. The air bubbles, which represent 'accidental' air, i.e. voids within an originally loose granular material, are governed by the grading of the finest particles in the mix and are more easily expelled from a wetter mix than from a dry one. It follows, therefore, that for any given method of compaction there may be an optimum water content of the mix at which the sum of the volumes of air bubbles and water space will be a minimum. At this optimum water content, the highest density ratio of the concrete would be obtained. It can be seen, however, that the optimum water content may vary for different methods of compaction.

Factors affecting workability

The main factor is the water *content* of the mix, expressed in kilograms (or litres) of water per cubic metre of concrete: it is convenient, though approximate, to assume that, for a given type and grading of aggregate and workability of concrete, the water content is independent of the aggregate/cement ratio or of the cement content of the mix. On the basis of this assumption, the mix proportions of concretes of different richness can be estimated, and Table 4.1 gives typical values of water content for different slumps and maximum sizes of aggregate. These values are applicable to non-air-entrained concrete only. When air is entrained, the water content can be reduced in accordance with the data of Fig. 4.2.[4.2] This is indicative only, because the effect of entrained air on workability depends on the mix proportions, as described in detail on p. 562.

If the water content and the other mix proportions are fixed, workability is governed by the maximum size of aggregate, its grading, shape and texture. The influence of these factors was discussed in Chapter 3. However, the grading and the water/cement ratio have to be considered together, as a grading producing the most workable concrete for one particular value of water/cement ratio may not be the best for another value of the ratio. In particular, the higher the water/cement ratio the finer the grading required for the highest workability. In actual fact, for a given value of water/cement ratio, there is one value of the coarse/fine aggregate ratio (using given materials) that gives the highest workability.[4.1]

Table 4.1 Approximate Water Content for Different Slumps and Maximum Sizes of Aggregate (partially based on the approach of the National Aggregates Association in the United States)

Maximum size of aggregate		*Water content of concrete*											
		25–50 mm (1–2 in.) slump				*75–100 mm (3–4 in.) slump*				*150–175 mm (6–7 in.) slump*			
mm	*in.*	*Rounded aggregate*		*Angular aggregate*		*Rounded aggregate*		*Angular aggregate*		*Rounded aggregate*		*Angular aggregate*	
		kg/m³	*lb/yd³*	*kg/m³*	*lb/yd³*	*kg/m³*	*lb/yd³*	*kg/m³*	*lb/yd³*	*kg/m³*	*lb/yd³*	*kg/m³*	*lb/yd³*
9.5	$\frac{3}{8}$	185	310	210	350	200	340	225	380	220	375	250	420
12.7	$\frac{1}{2}$	175	295	200	335	195	325	215	365	210	355	235	395
19.0	$\frac{3}{4}$	165	280	190	320	185	310	205	345	200	340	220	375
25.4	1	155	265	175	295	175	295	200	325	195	325	210	355
38.1	$1\frac{1}{2}$	150	255	165	280	165	280	185	310	185	310	200	340
50.8	2	140	240	160	270	160	270	180	305	170	290	185	315
76.2	3	135	230	155	260	155	260	170	285	165	280	180	305

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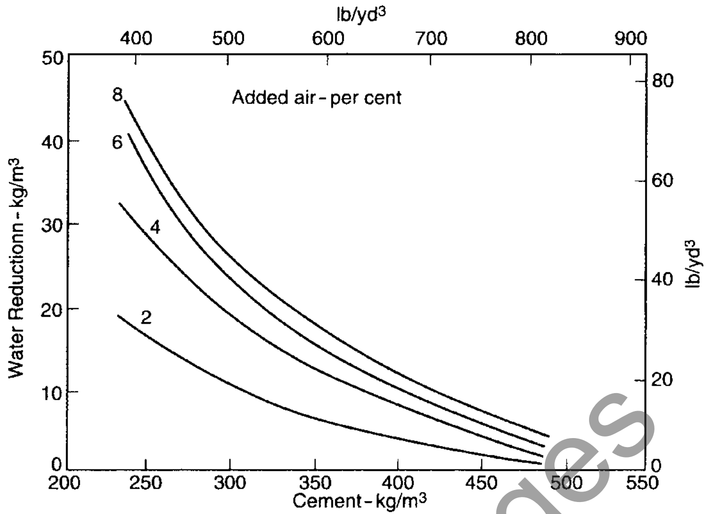

Fig. 4.2 Reduction in mixing water requirement due to addition of air by air entrainment[4.2]

Conversely, for a given workability, there is one value of the coarse/fine aggregate ratio which needs the lowest water content. The influence of these factors was discussed in Chapter 3.

It should be remembered, however, that, although, when discussing gradings of aggregate required for a satisfactory workability, proportions by mass were laid down, these apply only to aggregate of a constant specific gravity. In actual fact, workability is governed by the volumetric proportions of particles of different sizes, so that when aggregates of varying specific gravity are used (e.g. in the case of some lightweight aggregates or mixtures of ordinary and lightweight aggregates) the mix proportions should be assessed on the basis of absolute volume of each size fraction. This applies also in the case of air-entrained concrete because the entrained air behaves like weightless fine particles. An example of a calculation on absolute volume basis is given on p. 747. The influence of the properties of aggregate on workability decreases with an increase in the richness of the mix, and possibly disappears altogether when the aggregate/cement ratio is as low as $2\frac{1}{2}$ or 2.

In practice, predicting the influence of mix proportions on workability requires care since, of the three factors, water/cement ratio, aggregate/cement ratio and water content, only two are independent. For instance, if the aggregate/cement ratio is reduced, but the water/cement ratio is kept constant, the water content increases, and consequently the workability also increases. If, on the other hand, the water content is kept constant when the aggregate/cement ratio is reduced, then the water/cement ratio decreases but workability is not seriously affected.

The last qualification is necessary because of some secondary effects: a lower aggregate/cement ratio means a higher total surface area of solids (aggregate and cement) so that the same amount of water results in a somewhat decreased workability. This could be offset by the use of a slightly coarser grading of aggregate. There are also other minor factors such as fineness of cement, but the influence of this is still controversial.

Measurement of workability

Unfortunately, there is no acceptable test which will measure directly the workability as given by any of the definitions on p. 187. Numerous attempts have been made, however, to correlate workability with some easily determinable physical measurement, but none of these is fully satisfactory although they may provide useful information within a range of variation in workability.

Slump test

This is a test used extensively in site work all over the world. The slump test does not measure the workability of concrete, although ACI 116R-90[4.46] describes it as a measure of consistency, but the test is very useful in detecting variations in the uniformity of a mix of given nominal proportions.

The slump test is prescribed by ASTM C 143-10 and BS 1881 : 103 : 1993. The mould for the slump test is a frustum of a cone, 300 mm (12 in.) high. It is placed on a smooth surface with the smaller opening at the top, and filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm ($\frac{5}{8}$ in.) diameter steel rod, rounded at the end, and the top surface is struck off by means of a sawing and rolling motion of the tamping rod. The mould must be firmly held against its base during the entire operation; this is facilitated by handles or foot-rests brazed to the mould.

Immediately after filling, the cone is slowly lifted, and the unsupported concrete will now slump – hence the name of the test. The decrease in the height of the slumped concrete is called *slump*, and is measured to the nearest 5 mm ($\frac{1}{4}$ in.). The decrease is measured to the highest point according to BS EN 12350-2 : 2009, but to the "displaced original center" according to ASTM C 143-10. In order to reduce the influence on slump of the variation in the surface friction, the inside of the mould and its base should be moistened at the beginning of every test, and prior to lifting of the mould the area immediately around the base of the cone should be cleaned of concrete which may have dropped accidentally.

If instead of slumping evenly all round as in a true slump (Fig. 4.3), one half of the cone slides down an inclined plane, a shear slump is said to have taken place, and the test should be repeated. If shear slump persists, as may be the case with harsh mixes, this is an indication of lack of cohesion in the mix.

Mixes of stiff consistency have a zero slump, so that, in the rather dry range, no variation can be detected between mixes of different workability. Rich mixes behave satisfactorily, their slump being sensitive to variations in workability. However, in a lean mix with a tendency to harshness, a true slump can easily change to the shear type, or even to collapse (Fig. 4.3), and widely different values of slump can be obtained in different samples from the same mix.

The approximate magnitude of slump for different workabilities (in a modified form of Bartos' proposals[4.56]) is given in Table 4.2. Table 4.3 gives the proposed European classification of BS EN 206-1 : 2000. One reason for the difference

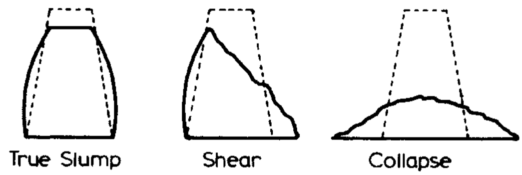

Fig. 4.3 Slump: true, shear, and collapse

Table 4.2 Description of Workability and Magnitude of Slump

Description of workability	*Slump*	
	mm	*in.*
No slump	0	0
Very low	5–10	$\frac{1}{4}$–$\frac{1}{2}$
Low	15–30	$\frac{3}{4}$–$1\frac{1}{4}$
Medium	35–75	$1\frac{1}{2}$–3
High	80–155	$3\frac{1}{4}$–6
Very high	160 to collapse	$6\frac{1}{4}$ to collapse

Table 4.3 Classification of Workability and Magnitude of Slump According to BS EN 206-1 : 2000

Classification of workability	*Slump mm*
S1	10–40
S2	50–90
S3	100–150
S4	⩾160

between the two tables is that the European approach is to measure slump to the nearest 10 mm. It should be remembered, however, that with different aggregates, especially a different content of fine aggregate, the same slump can be recorded for different workabilities, as indeed the slump bears no unique relation to the workability as defined earlier. Moreover, slump does not measure the ease of compaction of concrete and, as slump occurs under the self-weight of the test concrete only, it does not reflect behaviour under dynamic conditions such as vibration, finishing, pumping or moving through a tremie. Rather, slump reflects the 'yield' of concrete.[4.110]

Despite these limitations, the slump test is very useful on the site as a check on the batch-to-batch or hour-to-hour variation in the materials being fed into the mixer. An increase in slump may mean, for instance, that the moisture content of aggregate has unexpectedly increased; another cause would be a change in the grading of the aggregate, such as a deficiency of sand. Too high or too low a slump gives immediate warning and enables the mixer operator to remedy the situation. This application of the slump test, as well as its simplicity, is responsible for its widespread use.

A mini-slump test was developed for the purpose of assessing the influence of various water-reducing admixtures and superplasticizers on neat cement paste.[4.105] The test may be useful for that specific purpose, but it is important to remember that the workability of concrete is affected also by factors other than the flow properties of the constituent cement paste.

Compacting factor test

There is no generally accepted method of directly measuring the amount of work necessary to achieve full compaction, which is a definition of workability.[4.1] Probably the best test yet available uses the inverse approach: the degree of compaction achieved by a standard amount of work is determined. The work applied includes perforce the work done against the surface friction but this is reduced to a minimum, although probably the actual friction varies with the workability of the mix.

The degree of compaction, called the *compacting factor*, is measured by the density ratio, i.e. the ratio of the density actually achieved in the test to the density of the same concrete fully compacted.

The test, known as the compacting factor test, is described in BS 1881-103 : 1993 and in ACI 211.3-75 (Revised 1987) (Reapproved 1992),[4.70] and is appropriate for concrete with a maximum size of aggregate up to 40 mm (or $1\frac{1}{2}$ in.). The apparatus consists essentially of two hoppers, each in the shape of a frustum of a cone, and one cylinder, the three being above one another. The hoppers have hinged doors at the bottom, as shown in Fig. 4.4. All inside surfaces are polished to reduce friction.

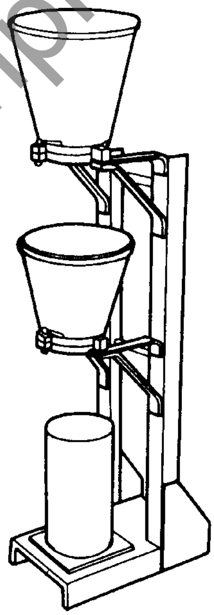

Fig. 4.4 Compacting factor apparatus

Table 4.4 Description of Workability and Compacting Factor[4.3]

Description of workability	*Compacting factor*	*Corresponding slump mm*
Very low	0.78	0–25
Low	0.85	25–50
Medium	0.92	50–100
High	0.95	100–175

The upper hopper is filled with concrete, this being placed gently so that at this stage no work is done on the concrete to produce compaction. The bottom door of the hopper is then released and the concrete falls into the lower hopper. This is smaller than the upper one and is, therefore, filled to overflowing, and thus always contains approximately the same amount of concrete in a standard state; this reduces the influence of the personal factor in filling the top hopper. The bottom door of the lower hopper is then released and the concrete falls into the cylinder. Excess concrete is cut by two floats slid across the top of the mould, and the net mass of concrete in the known volume of the cylinder is determined.

The density of the concrete in the cylinder is now calculated, and this density divided by the density of the fully compacted concrete is defined as the compacting factor. The latter density can be obtained by actually filling the cylinder with concrete in four layers, each tamped or vibrated, or alternatively calculated from the absolute volumes of the mix ingredients. The compacting factor can also be calculated from the reduction in volume that occurs when a defined volume of partially compacted concrete (by passing through the hoppers) is fully compacted.

The compacting factor apparatus shown in Fig. 4.4 is about 1.2 m (4 ft) high and its use is generally limited to pavement construction and precast concrete manufacture.

Table 4.4 lists values of the compacting factor for different workabilities.[4.3] Unlike the slump test, variations in the workability of dry concrete are reflected in a large change in the compacting factor, i.e. the test is more sensitive at the low workability end of the scale than at high workability. However, very dry mixes tend to stick in one or both hoppers and the material has to be eased gently by poking with a steel rod. Moreover, it seems that for concrete of very low workability the actual amount of work required for full compaction depends on the richness of the mix while the compacting factor does not: leaner mixes need more work than richer ones.[4.4] This means that the implied assumption that all mixes with the same compacting factor require the same amount of useful work is not always justified. Likewise, the assumption, mentioned earlier, that the wasted work represents a constant proportion of the total work done regardless of the properties of the mix is not quite correct. Nevertheless, the compacting factor test undoubtedly provides a good measure of workability.

ASTM flow test

This laboratory test gives an indication of the consistency of concrete and its proneness to segregation by measuring the spread of a pile of concrete on a table subjected to jolting. This test also gives a good assessment of consistency of stiff, rich, and rather cohesive mixes. The test was covered by ASTM C 124-39 (Reapproved 1966) which was withdrawn in 1974 because the test was little used, rather than because it was thought to be not appropriate.

Remoulding test

Use of a jolted table is made in another test, in which an assessment of workability is made on the basis of the effort involved in changing the shape of a sample of concrete. This is the remoulding test, developed by Powers.[4.5]

The apparatus is shown diagrammatically in Fig. 4.5. A standard slump cone is placed in a cylinder 305 mm (12 in.) in diameter and 203 mm (8 in.) high, the cylinder being mounted rigidly on a flow table, adjusted to give a 6.3 mm ($\frac{1}{4}$ in.) drop. Inside the main cylinder, there is an inner ring, 210 mm ($8\frac{1}{4}$ in.) in diameter and 127 mm (5 in.) high. The distance between the bottom of the inner ring and the bottom of the main cylinder can be set between 67 and 76 mm ($2\frac{5}{8}$ and 3 in.).

The slump cone is filled in the standard manner, removed, and a disc-shaped rider (weighing 1.9 kg (4.3 lb)) is placed on top of the concrete. The table is now jolted at the rate of one jolt per second until the bottom of the rider is 81 mm ($3\frac{3}{16}$ in.) above the base plate. At this stage, the shape of the concrete has changed from a frustum of a cone to a cylinder. The effort required to achieve this remoulding is expressed as the number of jolts required. For very dry mixes a considerable effort may be necessary.

The test is purely a laboratory one but is valuable because the remoulding effort appears to be closely related to workability.

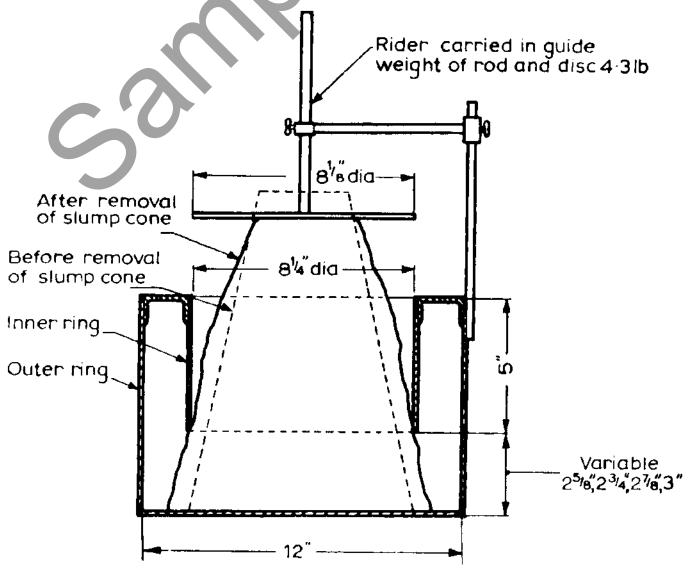

Fig. 4.5 Remoulding test apparatus

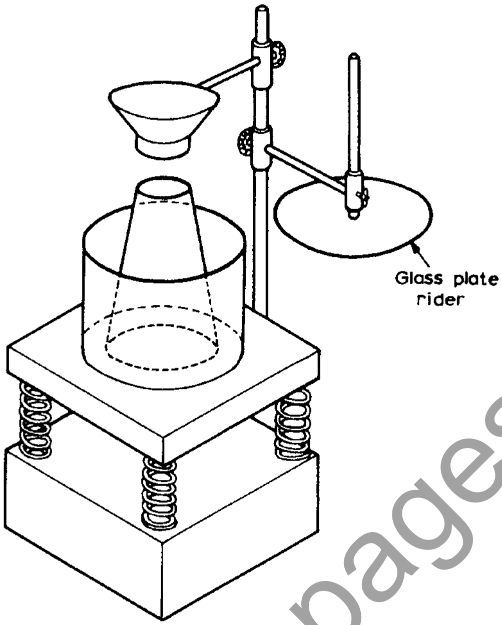

Fig. 4.6 Vebe apparatus

Vebe test

This is a development of the remoulding test in which the inner ring of Powers' apparatus is omitted and compaction is achieved by vibration instead of jolting. The apparatus is shown diagrammatically in Fig. 4.6. The name 'Vebe' is derived from the initials of V. Bährner of Sweden who developed the test. The test is covered by BS EN 12350-3 : 2009; it is referred to also in ACI 211.3-75 (Revised 1987).[4.70]

The remoulding is assumed to be complete when the glass plate rider is completely covered with concrete and all cavities in the surface of the concrete have disappeared. This is judged visually, and the difficulty of establishing the end point of the test may be a source of error. To overcome it, an automatically operated device for recording the movement of the plate against time may be fitted.

Compaction is achieved using a vibrating table with an eccentric mass rotating at 50 to 60 Hz and a maximum acceleration of $3g$ to $4g$. It is assumed that the input of energy required for compaction is a measure of workability of the mix, and this is expressed as the time in seconds, called *Vebe time*, required for the remoulding to be complete. Sometimes, a correction for the change in the volume of concrete from V_2 before, to V_1 after, vibration is applied, the time being multiplied by V_2/V_1. The test is appropriate for mixes with a Vebe time between 3 and 30 seconds.

Vebe is a good laboratory test, particularly from very dry mixes. This is in contrast to the compacting factor test where error may be introduced by the