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# THE SLUMP FLOW TEST FOR HIGH-WORKABILITY CONCRETE

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**ABSTRACT**

Despite their inherent limitations, single-point workability tests continue to be used for the specification and quality control of concrete. The development of stable, high-workability mixes with a collapsed slump has led to the use of the flow test, more popular in Europe, and the slump flow test, used extensively in Asia. Results are given from a laboratory programme in which these two tests, and slump, were used on a range of concrete mixes. A good correlation between the flow and slump flow values was obtained. It is argued that the tests are therefore of equal value in assessing concrete properties, and hence the simpler and more convenient slump flow test is to be preferred. *© 1998 Elsevier Science Ltd*

## Introduction

The term workability can be used as a general description of the nature of fresh concrete, whose more specific properties include fluidity, mobility, and compactability. It is well established that fresh concrete closely approximates to the Bingham model, i.e., the relationship between the applied shear stress and the resulting rate of strain is near-linear and has a positive intercept on the shear stress axis (1,2). Two parameters are therefore required to describe this behaviour, i.e., the yield stress (the intercept), and the plastic viscosity (the gradient of the line). The "workability" tests included in many standards (e.g., slump, compacting factor) each measure a single but different value, none of which is a fundamental property; it has been shown that such tests are in effect measures of apparent viscosity at an arbitrary shear rate, which is a characteristic of the particular test (3). They have therefore been criticized as being at best limited, or, more often, misleading. Nevertheless, such tests are cheap and convenient and are commonly used both to "describe" the workability in specifications, and for quality control during concrete production and supply. It follows that it is important for the user to recognize the limitations of such tests, and to use the appropriate test for a given situation.

The slump test (4,5) is the most widely used of the single-point tests, but, as with most other such tests, its use is limited to a range of workabilities that is less than that used in construction practice. For example, mixes with zero slump for use in precast construction can be differentiated with the compacting factor test (6). At the other end of the workability

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spectrum, the use of superplasticizers has lead to the use of flowing concrete for ease of placement, and, in combination with cement replacement materials, to more recent developments such as self-compacting concrete (7,8). These mixes all have a “collapsed” slump for which, according to the British Standard (4), the slump test is invalid. To distinguish between mixes of this type, the flow test (also known as the flow table test) is commonly used in the UK (9) and other countries. This is somewhat more complex and time consuming than the slump test, and was severely criticized by Dimond and Bloomer (10) even before its inclusion in British Standards. Their criticisms included:

- the test is operator sensitive, potentially more so than the slump test;
- when the spread exceeds 510 mm, a recommended minimum for flowing concrete (11), the concrete thickness is about the same as a 20-mm aggregate particle, and the test cannot therefore be a satisfactory measure of the bulk concrete properties;
- there is a high degree of correlation between the initial spread before jolting and the final spread after jolting, and thus no extra information is gained by the jolting;
- although the likelihood of segregation can be assesssed by subjective visual judgement during and after the test, this can be equally well judged by tipping the concrete onto the floor.

Some of these criticisms were refuted by Mor and Ravina (12) when proposing the test for more widespread use.

An alternative test for high-workability mixes has been incorporated in Japanese standards (13). This is called the slump flow test, and is simply the measurement of the diameter of the concrete after it has collapased in a conventional slump test. This is much more convenient to carry out than the flow table test, and has the further advantage that when testing a concrete whose workablility is such that it is difficult to determine in advance if the slump will collapse, the value of either the slump or slump flow (or even both) as appropriate can be recorded.

Because it is a Japanese standard, it is not surprising that it is widely used in that area of world. To gain wider acceptance in other areas, comparisons with other tests, particularly the flow test, are required. This paper reports the results obtained from using the slump, slump flow, and flow tests on a range of concretes, most of which could be described as high-performance and high-workability. Many of the results reported were obtained by taking the opportunity to test mixes whose primary purpose was the examination of other properties, e.g., self-compacting concrete.

## Test Methods

The slump, slump flow, and flow tests were carried out according to the relevant standards (4,9,13). For the purpose of making comparisons, the values of both slump and slump flow were recorded on each mix, even though only one would strictly be applicable, i.e., the slump for true slump behaviour, or the slump flow if the concrete has collapsed. The flow test was also carried out on all mixes, and the spread diameter was measured both before and after jolting; these have been called the initial and final flow respectively. All spread diameters, for both the slump flow and flow test, were the average of two measurements at right angles to each other, and were recorded to the nearest 5 mm.

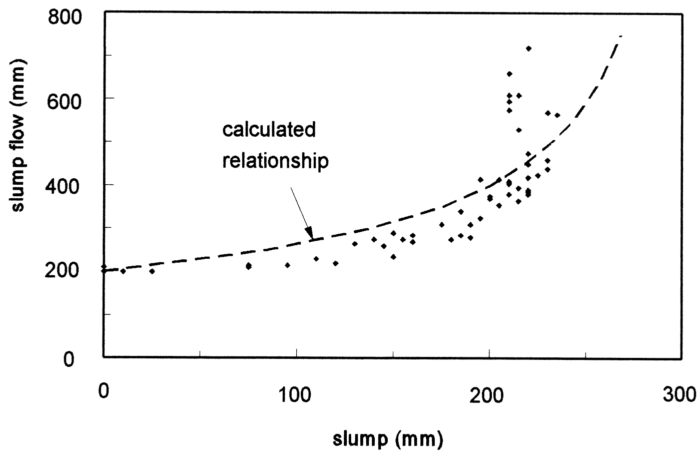


FIG. 1.
Slump vs. slump flow results.

The measurements reported were carried out by a number of operatives, including a research assistant, research students, and undergraduate project students.

## Mixes

The range of mixes tested all contained binder contents in excess of 400 kg/m$^3$, with workability varied by either water/binder ratio or superplasticizer content. More than half of the results were for plain Portland cement mixes, and the rest were for mixes that also contained either pulverized fuel ash, ground granulated blast furnace slag, or microsilica. The coarse aggregate in all cases was a 20-mm Thames Valley gravel. No variations in the relationships reported could be discerned with variation of materials or mix proportions, and therefore full details of the mixes need not be given.

## Results and Discussion

The results are given in the form of relationships between the measurements from the various tests. These are presented and discussed in turn.

The slump and slump flow values are plotted in Figure 1. The relationship is of the expected form, with little variation of slump flow for slumps up to about 180 mm, the approximate limit of true slump, and considerable change in slump flow for slumps in excess of 200 mm, i.e., in the collapsed slump range for which the slump test is considered to be invalid, and in which the measurement itself is more subject to operator interpretation. The slump flow for zero slump is, of course, 200 mm, because this is the diameter of the base of the concrete as the cone is lifted.

The calculated relationship superimposed on Figure 1 has been obtained assuming that the concrete remains in the shape of the frustum of a cone during the slumping, as shown in Figure 2. For constant concrete volume ($V$), the relationship between the slump ($s$) and base diameter ($D$, the slump flow) is given by:

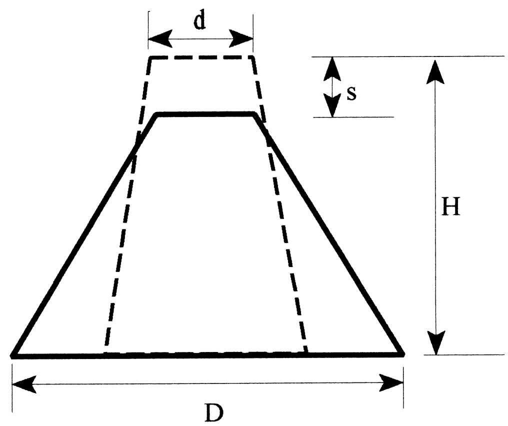


FIG. 2.
Assumed shape of concrete for calculation of slump vs. slump flow.

$$s = H - 12v(D - d)/\pi(D^3 - d^3)$$

where $d$ is the diameter of the top surface of the frustum, assumed constant at 100 mm, and $H$ is the initial height (i.e., 300 mm).

The departure of the results from the calculated relationship at lower slumps is due to the incorrect nature of this assumption; in practice, the sides bulge with little base spread when "true" slump behaviour occurs. With the high slumps, when the concrete has collapsed, the differences may be at least partially due to uncertainty in measuring the slump value; for example, one coarse aggregate particle resting on another will have large proportional effect on the measured value. This highlights the potential problems when drawing conclusions from collapsed slump values.

The flow table results (final spread) are plotted against slump in Figure 3, together with the mean lines of results obtained by other workers. The general pattern follows that previously

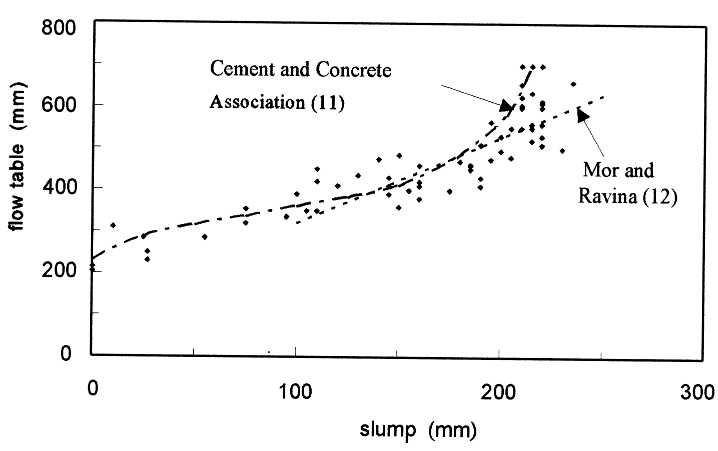


FIG. 3.
Slump vs. flow table (final) results.

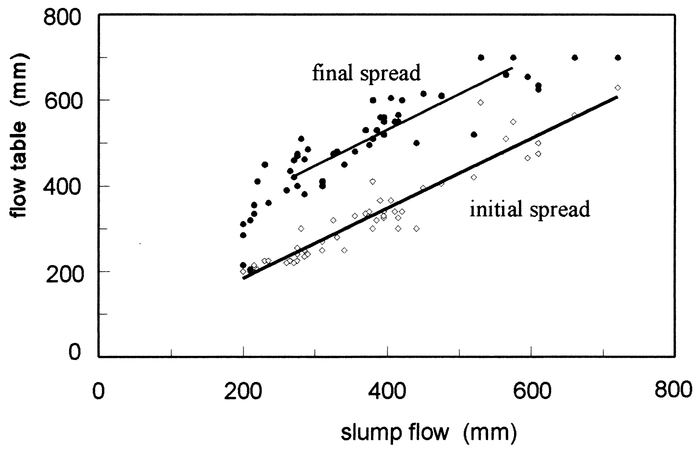


FIG. 4.
Slump flow vs. flow table (initial and final) results.

given by the Cement and Concrete Association (11), who reported results that were for concrete containing both rounded gravel and crushed rock coarse aggregate. The linear relationship obtained by Mor and Ravina (12) was for a more limited range of slumps or flow table values than the current tests. There is perhaps a trend for the results from the curent programme to give slightly lower flow table results for the same slump than the average of the others. This may be due to the relatively high binder contents producing a more cohesive concrete in which the jolts have reduced effect. However, the important point is that only a very broad relationship can be expected because the two are not measuring similar properties.

As far as the present analysis is concerned, the most important correlation is that between the slump flow and the flow table results. This is shown in Figure 4, with both initial and final flow table values plotted. The results start at an “origin” of 200 mm, which in both tests is the diameter of the base of the concrete as formed. The slump and initial flow table values show a linear correlation over the whole range, which is expected because these are identical measurements on a different volume of concrete. The correlation between slump flow and final slump is also good, considering the inherent operator dependence of the both tests and the fact that the results were obtained by a number of operators, some inexperienced. The relationship appears to be linear over a range of flow table values from 400 mm to 700 mm (the maximum value that can recorded before the concrete spills over the side of the table). A linear regression analysis gives the relationship

$$\text{flow table} = 0.73 \times \text{slump flow} + 240$$

in this range, with a correlation coefficient of 0.88. Further tests on individual mixes to determine, say, the sensitivity to admixture dosage would be required before the test could be used for quality control purposes in concrete production.

Visual observation during the tests showed that the likelihood of segregation could be equally well assessed with either test, supporting the view of Dimond and Bloomer (10).

## Concluding Remarks

The results show that the slump flow test gives as good an estimate of the fluidity as the flow table test, and that there is no advantage to be a gained by using the less convenient flow table test, at least for the range of high performance concretes with high binder contents tested. However, this an argument only for using the slump flow test as an alternative to the flow table test. It will have similar limitations to any other single-point test, but, if a single-point test is to be used, it seems logical to use the most convenient one, rather than a test that gives some false impression of representing the behaviour of concrete in construction practice.

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