The Irish Concrete Society

Back to Basics Seminar, Monday 15th April 2002

Part 1: Concrete Workability and Slump
Part 2: Concrete Cubes
Part 3: Concrete Strength

by
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Part 1: Concrete Workability and Slump

Introduction

The term workability is all embracing, used to describe concrete in its fresh state. In fact, it has been 'defined' in many different ways but, in essence, it encapsulates various different properties of the concrete, which enable it to be transported, placed, compacted and finished as it was intended by the specifier/contractor. These properties include stability, pumpability, compactibility, finishability, etc. Depending on which part of the operation one is involved with, the term workability means different things to different people.

Its measurement, if that is uniquely possible, is equally problematic. The most common means, the **Slump** test, measures some characteristic of fresh concrete (probably its ability to support its own weight), but this may be quite removed from the aspects of relevance, as touched on above. Other laboratory tests that are available are seldom used in practice on site. These include the **Vebe** test (time in seconds to disperse concrete under vibration), the **Compacting Factor** test (ability to compact itself under a given amount of energy), the **Flow Table** test (how much it spreads when the table is dropped repeatedly) and the **Slump Flow** test (how much self-compacting concrete spreads).

There is an area of science which studies the flow of materials called **rheology**, and which can determine reliably the fundamental characteristics of many common fluids, including concrete. Concrete can be defined completely by two parameters, namely its **yield value** (the stress is required to get concrete to flow) and its **plastic viscosity** (how 'runny' it is when it does flow). Concrete can be reliably and repeatably characterised using these two parameters, to a high degree of accuracy, such that that any change to the concrete constituents can be diagnosed with some confidence. However, the machine which assesses these values, the **Two -Point Workability** apparatus, is expensive, cumbersome, operator sensitive and is not portable. Hence, it is used mostly in academic circles. Until a robust, cheap, reliable hand held rheological tool is available commercially, we are limited on site to using the slump test.

The Slump Test

The procedure for the slump test is outlined below. It is important that the exact conditions are carefully laid down and should be followed rigorously. Deviations from the procedure can affect the outcome, whence supposed **compliance** with the specification becomes meaningless. One needs to understand the limits on the **repeatability** and **tolerances** of the test, which is relatively crude - it is not an exact test. There are also limitations on its scope, being insensitive to very stiff or very fluid concrete.

The measured slump value is affected by many factors apart from the inadequacies of the test itself, not least the **constituents** of the concrete. Water and plasticiser content are particularly relevant, but also the condition of the aggregates, their grading (especially the fine fines), and the fineness of the cement. Slump also naturally reduces with **time**, so the timing of the test is important - delays in discharge can be especially influential. **Temperature** can also affect the outcome in that on warmer days the hydration and setting of the cement happens earlier and more evaporation of free water occurs, especially if continuously agitated in the drum when delayed.

These factors should be borne in mind when testing for slump - it is not an invariant property of the concrete - slump which is unsatisfactory at the time of test may not have been so at an earlier time. This is a moot point as it is the slump at time of discharge that matters so far as compliance is concerned.

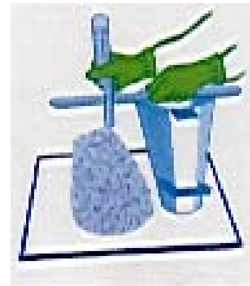
Sampling is another factor to be cognicent of as it can significantly affect the result - the sample should be representative of the batch and carried out to the standard (**BS 1881 Part 101 or BS EN 12350-1,** or an alternate method may be found in **BS 1881 Part 102 or BS EN 206-1, clause 5.4.1**).

In relation to **reporting**, the standard (**BS1881 Part 102** or **BS EN 12350-2**) specifies clearly what information is mandatory and yet the procedure is rarely followed and so, strictly, does not comply. What is required is listed elsewhere in the documentation provided.

Finally, an appreciation of the limitations of the test is particularly important in two regards. Firstly, it should be noted that two different concretes which give identical slump values may behave quite differently in practice when pumping, compacting, finishing, etc. Secondly, if a slump does change from batch to batch, the test will give no indication as to why the workability has changed (and by how much the constituents have changed) only that they appear to give different values within the tolerances of the test values.

In conclusion, the Slump test is a simple test that is robust and cheap but its limitations are severe. At best, it gives a warning that concrete may have been significantly overdosed with water, thereby alerting the contractor that the strength may be lower and the durability characteristics may be disimproved. In consequence, the batch of concrete does not comply with the specification, no matter how inadequate the test may be and, hence, the concrete should be rejected.

Procedure
To BS 1881 : Part 102 or BS EN12350-2



1 Empty the sampling buckets onto the mixing tray
Scrape each bucket clean

2 Thoroughly remix the sample shovelling into a heap
Turn the heap over to form another
Do this three times

3 Flatten the final heap by repeatedly digging-in the shovel vertically
Lift the shovel clear each time
If the **alternative method** of sampling has been used, divide this heap into two and test each part

4 Ensure the slump cone is clean and camp
Place the metal plate on a solid level base away from vibration or other disturbance
Place the cone on the plate and stand on the foot-pieces

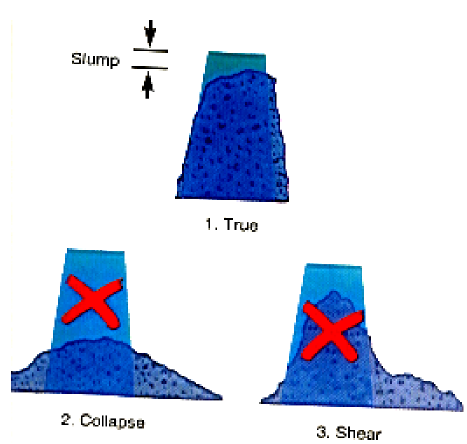
5 Fill the cone in **three** equal depth layers
Use the standard slump rod
Rod **each layer 25 times**
Spread the blows evenly over the area
Make sure the rod penetrates the layer below
Heap the concrete above the top of the cone before rodding the third layer

6 Top up if necessary
Use the rod with a sawing and rolling motion to strike the concrete level with the top of the cone

7 Carefully clean off spillage from side and baseplate

8 Carefully lift the cone straight up and clear, to a count of **between 5 and 10 seconds**
Complete steps 5 to 8 within 150 seconds

9 Lay the rod across the upturned slump cone
Measure the distance between the underside of the rod and the highest point of the concrete – the true slump
Record this distance to the nearest 5mm if using BS 1881: Part 102 or 10mm if using the BS EN 12350-2
In all cases record the kind of slump
Check the type of slump
If the slump isn't true, take a new sample and repeat the test
If the second slump isn't true, get advice
Complete the ***Sampling and testing certificates***



Three types of Slump

Part 2: Concrete Cubes

by Dr. Roger P. West, Trinity College Dublin

Introduction

When water is added to cement, a chemical reaction takes place, usually termed **hydration**, and a hardened paste is formed. If aggregate (coarse and fine) are added, the resulting concrete is usually stronger than the paste and the strength depends to a large extent on the original **water to cement ratio**. If too much water is added to the mix (or less cement), there is not enough cement to use up all of the water and, inevitably, water filled voids are left in the concrete. These become **air voids** as the concrete dries and the strength is lower as a consequence of too much water (or less cement) being added.

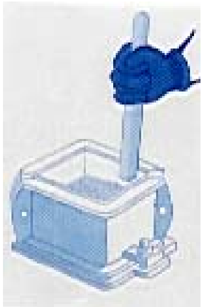
As a natural part of the mixing process, air is also trapped in the concrete, most of which can be removed by compacting the concrete. If the **compaction** is not thorough, then, again, the concrete will be weaker and less dense.

It is also notable that the cement hydration, like many chemical reactions, occurs faster if the **temperature** is higher. Hence, the strength develops quicker with time if it experiences a sustained higher temperature.

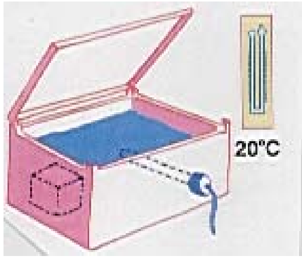
If concrete is not **cured** (kept moist), then the hydration process is incomplete and, despite a surplus of water at mixing, the absence of water (due to evaporation from the surface) stops the reaction from continuing and, again, inevitably, the strength does not reach its potential.

When concrete is poured, it is customary to make a number of small **cubes** by compacting them in a standard way in cube moulds, protect them overnight and put them immediately in a water tank on striking. The water in the tank is kept at a standard temperature until they are removed for testing at **7** or **28 days** after casting. If this process is conducted properly, the cube, when tested in a cube-crushing machine, gives a standard measure of the concrete strength, largely dependent on the concrete constituents. As such, it offers a measure of **quality control** of the concrete provided on site. However, it is not uncommon for concrete not to reach its desired strength and why this might be so is dealt with presently.

Cube Manufacture



Firstly, it is important to state, briefly, the procedure for making cubes. The equipment must be of the correct dimensions, within allowable tolerances, greased to allow easy release, a standard compaction bar (not a reinforcing bar!) should be used to tamp the concrete and the mould should be on a stable horizontal surface. The concrete should be compacted in three layers of a minimum of 35 tamps per layer (for a 150mm cube). The top surface should be smoothed off from the centre outwards using a trowel and a nail should not be used to label the cube! The cube should be protected from rain and frost overnight using wet hessian and a cover and, when stripped within 24 hours, should be placed in a tank at 20°C+/- 1°C, immersing the cube fully in the water to ensure full and continuous curing.



There are a number of items that must be stated in a report on the test to comply with the British or European Standard (**BS 1881 part 108 or BS EN 12390-2**), including where and when the cubes were made, size, cube ID and the name of the person making the cube. Other information is optional, such as the supplier, grade and workability and where the concrete was used in the structure.

Part 3: Concrete Strength

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Introduction

In order to ensure that concrete cubes are properly tested for their compressive strength under standards conditions, they should be carefully stored in a curing tank at 20^{o}C until testing. Cubes should be tested at the appropriate **age** while still **damp** on the surface in a properly **calibrated** testing machine and at a set **loading rate**. All of these conditions are important in ensuring comparable and consistent results.

The peak load applied to a single cube prior to 'failure' defines the stress at failure (stress is the force divided by the cross-sectional area) and a **pair of cubes** must be tested to give a 'result' for a cube. The difference between the individual cube tests must not exceed 15% of their mean (for example, if the strengths are 37 and 42 N/mm^2, their difference is 5 N/mm^2 and their mean is 39.5 N/mm^2 - therefore, 5/39.5 = 12.7% < 15%, so the results are valid).

There is also a rule, which is often written into a **specification** that the average of any cube must be greater than the specified grade (f_{cu}, or **characteristic strength**) + 3 N/mm^2 and no one individual result must be less than f_{cu} - 3 N/mm^2. To determine this, a running average of four results is often kept.

Variations in Cube Results

As part of the process of making concrete mixes that are, ostensibly, the same, there is a natural variation in the constituents and conditions. This means that, all other things being equal, if one tests a large number of cubes from different batches of similar concrete, one finds that the strength varies in a particular way, modeled by a normal probability distribution:

Hence, if one specifies, say, a **Grade** 35 concrete (that is, f_{cu} = 35N/mm^2 or 35MegaPascals (MPa) in more recent units to this country), then some cubes will have slightly lower strengths, some higher. To ensure, therefore, that only 1 cube in 20 will fall below the specified grade, one aims for a higher strength in the knowledge that the variation of the mix will cause at most 5% of the cubes to fall below this characteristic value. This new average value that is aimed for is known as the **target mean strength** and it is equal to the characteristic strength plus a reasonable **margin** to allow for this variation. This margin is determined as 1.64 times the standard deviation (a measure of the statistical spread of results) for 5% failures. If the variation is known from previous records, a reasonably low margin can be used; otherwise a conservative estimate must be used. Also, good quality control implies a low standard deviation and a lower margin can be used. Hence, the vast majority (> 95%) of the cubes should be safely above the grade value, but while one should be concerned if a single isolated cube just happens to fail, the overall trend is what is important.

Causes of Cube Failures

If a cube test does fail, it is usually a matter of concern because it may be indicative of a steady trend in low results, which could be serious, or it may be because one isolated cube test has failed for some other reason. So now, considering all of the foregoing, one can identify some of the main possible causes of a cube failure, which creates so much concern on site:

Statistical variation: Natural random variation suggests that it is possible, though not likely, to have a cube failure with normal concrete

Material causes: cement missing, extra water added, very stiff concrete

Improperly made cubes: lack of compaction, not protected overnight, improperly cured, incorrectly labeled, poor sampling, not greased, not properly assembled

Improperly tested cubes: machine not calibrated properly, cube not wet when tested, not aligned centrally in machine, not loaded on cast face, rate of loading wrong, tested at wrong age.

Often, if a cube result is surprisingly low, the cube is retained for inspection. By checking the **failure mode** of the cube, a concrete specialist can determine whether there is something irregular about the test and evidence may point to the possible cause of the failure.

So, if one is satisfied that the making, storing and testing of the cubes are not likely to be the cause of the failure, what other options are available to detect the source of the problem? While it is true that it is possible to find out the cement and water content of the hardened mix (within limits of accuracy), these tests are expensive and cumbersome. There are, in fact, a number of regularly used tests to ascertain the strength of the concrete in-situ, which is, after all, what is important. Coring is the most reliable but is partially non-destructive and expensive.

In establishing this by whatever means, it is important to realise that the cube has (one presumes at this stage) been exposed to perfect **compaction** and **curing** (at the right **temperature**). The concrete in the structure, on the other hand, is likely to have a lower strength that the specimen cubes because i) it is not uniform, ii) it has probably not had full compaction throughout iii) its temperature will vary over its first 28 days depending on the heat of hydration and the ambient temperature (amongst other things) and iv) it will almost certainly have been cured inadequately. Hence, the first things to do, if a test of the strength of the concrete in the structure is to be assessed, are to establish the uniformity of the concrete and test a sample from a typical area.

Two easily conducted, **non-destructive** tests to investigate uniformity are the **Pundit** and the **Schmidt Hammer** tests. The Pundit provides a measure of the density variation while the Schmidt Hammer indicates the variation in the surface strength properties. While it is often claimed that both will provide estimates of compressive strength, they can only do so with careful **calibration**, using the actual mix used in the case in question. Such calibration is seldom available when needed.

Most of the tests that claim to measure in-situ strength are **partially destructive** insofar as they break off a small piece of concrete from the surface. There are many such tests which pull-off (**Clam**, **Limpet**), break off (**Capo**, **Lok** or **Break-Off**), penetrate (**Windsor Probe**) or just plain drill out (**core** testing) a sample of the concrete near the surface. Many actually measure the tensile strength (that is, a pulling, not pushing/compression action) and, again, as such they need careful calibration against an equivalent compressive strength, if that is what is sought.

Core Testing

Some emphasis may be given to this here, as it is relatively reliable and can be compared (somewhat tenuously) with the original cube strength, if required. The extraction of a cylindrical core which ranges from 90-150mm in diameter (depending on the maximum aggregate size) is achieved using a core drilling device and one should try to obtain a length of specimen at least 1.5 times the diameter (its **aspect ratio**). The use of a **covermeter** can usually ensure that reinforcement is avoided, although if it is unavoidable, an allowance can be made for this in the calculation. The samples are cut at their ends and capped using high **alumina cement**, leaving the concrete with an ideal aspect ratio of about 1.2. A visual examination also allows an assessment of the degree of compaction and a factor accounts for this in the calculation of the compressive strength.

When tested in a compression machine the raw result of stress (again, the force required to fail the core divided by the cross-sectional area) can be converted into an **equivalent cube strength** (what a cube might have achieved given perfect compaction and curing) or a **potential strength** (the strength that could have been achieved in the structure given perfect compaction). A number of cores should be taken from selected locations to gain some confidence in the variability of the results.