9.2 Crushing Strength of Concrete

9.2.1 Introduction

Crushing tests are universally used for determining the strength of concrete and the standard test measures the crushing strength at an age of 28 days after mixing. Because of the time delay in obtaining the test results for concrete crushing strength, it is often very difficult or expensive to take remedial action if the test results are unsatisfactory. It is, therefore, essential to continuously control all aspects of concrete production so that the concrete very rarely fails in crushing strength tests.

Crushing strength tests may be carried out on either cylinders or cubes made in standard moulds, cured under standard conditions and crushed in a standard manner. Any variations in the methods of manufacture, curing or testing may affect the final results and all these aspects require careful control.

9.2.2 Scope

The results of this test may be used as the basis of concrete proportioning, mixing and placing operations; determination of compliance with specification, control for evaluating effectiveness of admixtures and similar uses. There are only minor differences in test methods between cubes and cylinders and they are, therefore, considered together.

9.2.3 Testing machine

Crushing machines may vary from small hand-operated models to large power-driven universal test machines. In the large majority of machines, the load is applied by a hydraulic jack and the load is measured by a pressure gauge calibrated directly in units of force.

Even a small crushing machine is likely to be one of the most expensive pieces of equipment in the laboratory and it should be maintained strictly in accordance with the manufacturer's instruction. In general, it should be installed in a dry place and should be kept clean at all times. The hydraulic reservoir or pump should be frequently topped up with the correct grade of hydraulic oil, (the use of ordinary motor oil may quickly ruin the machine). The maximum load on the gauge should never be exceeded and the machine should not be left under load for a prolonged time. Any oil leaks should be quickly reported and appropriate repairs carried out. A well maintained machine should last many years.

The accuracy of new crushing machines will vary somewhat with the type of machine, a smaller machine may be expected to give less accurate results than a high-quality universal test machine. If machines are used frequently at loads close to their design capacity, their accuracy will suffer and it is a wise precaution to only use machines at loads up to 75 percent of their design capacity.

With age the calibration of a machine may vary and all machines should periodically be re-calibrated using a load cell or a number of standard test specimens, a proportion of which are tested on a fully-standardised machine. If a replacement load gauge is fitted to a machine, re-calibration must be carried out.

The steel platens on a crushing machine are designed to withstand very high stresses, they should, however, occasionally be checked for damage and the ball seating of the upper platen should be checked for cleanliness and freedom of movement.
9.2.4 Sample preparation

Samples for crushing strength tests should truly represent the concrete used in the works and must, therefore, be taken throughout the period when work is in progress. It will be clear that if all specimens are made from only one batch of concrete this may represent only a small fraction of the concrete used in the pour. If, however, one specimen is made from each of a number of different batches of concrete throughout the day the specimens will be more representative of the average concrete used in the pour.

Samples for testing should be taken at random times throughout the day and it is best for the mix to be batted before any indication is given that tests are to be made. It is very easy for a mixer operator to produce ‘a good mix’ especially for the tests; the purpose of quality control testing is, however, to determine the true strength of the typical material used in the works.

The samples for crushing strengths may be collected in a similar manner as for workability test (slump test). In fact, it is usual procedure to test part of the sample for workability and part for crushing strength.

The specimens should be prepared immediately after sampling.

9.2.5 Making test cubes and cylinders

Concrete cube or cylinder moulds are made of steel or cast iron and of sufficient strength to resist deformation, the inside faces and ends are machined to give smooth surfaces and tight fitting joints. The moulds are made in two halves which bolt together for ease of removing the samples and cleaning. Cylinder moulds are normally 150 mm in diameter and 300 mm high; cube moulds normally have 150mm sides. The moulds sit on heavy baseplates which are fastened to the moulds by clamps.

There should be no dirt or hardened mortar on the faces or the flanges of the moulds before assembly, otherwise the sections will not fit together closely. These faces must be thinly coated with mould oil to prevent leakage during filling, and a similar oil should be provided between the contact surfaces of the bottom of the mould and the base. The inside of the mould must also be oiled to prevent the concrete from sticking to it. The sections must be bolted tightly together and the mould held down firmly on the baseplate. Any excess oil should be removed by wiping with a soft cloth as this may be detrimental to the concrete.

The concrete should be placed in the mould using a scoop, taking care to ensure the concrete does not segregate. The concrete should be placed in layers, each layer being compacted before placing another layer. The purpose of the procedure is to achieve full compaction (i.e. maximum density); a drier mix may, therefore, need more compaction than a wet mix. The following procedures are considered the minimum requirements to ensure full compaction; dry mixes may require considerably more compaction than the minimum shown: -

Cubes: - Place concrete in three layers giving each layer at least 35 blows of a 25mm square blunt-ended tamping rod.

Cylinders: - Place concrete in three layers, each approximately one-third the volume of the mould, giving each layer 25 strokes of a 16mm diameter round-ended tamping rod of 600mm length.
As an alternative to the above procedures vibration may be used to fully compact the specimen. This may be done either on a vibrating table or using an immersion vibrator.

On completion of compaction, excess concrete should be removed with a steel float and the surface floated off level with the top of the mould. It is preferably for the finished surface to be slightly proud of the mould especially if the mix is very wet. Care should be taken when floating off the top surface to ensure the surface is not devoid of fines or contains too much mortar, as far as possible the top surface should be of a similar consistency to the concrete in the mould.

The moulds should not be moved at all within the first four hours after casting and it is preferable to leave them undisturbed for 24 hours. The reference number of the specimen may be marked on the surface of the concrete once this has started to set.

9.2.6 Curing specimens

The conditions under which a specimen is cured can cause substantial variations in the final strength of the concrete. For example, a normal concrete cured entirely in air, will have a strength at 28 days about half that of the same mix cured in water. Similarly, a specimen cured in water at 13°C will have a strength at 7 days about 70% of that of the same mix cured in water at 46°C. Because of these variations, it is essential that all specimens are cured in a similar manner if strengths are to be compared.

Immediately after casting, the moulds should be covered with damp hessian (jute bags), the hessian should not be so wet as to allow water to fall on the surface of the specimen. It is a good practice to raise the hessian off the surface of the concrete by means of small pieces of wood. The moulds and hessian should then be covered with a sheet of polythene to prevent drying out. The polythene should completely enclose the moulds and be weighted down at the edges with bricks or stones. If polythene is not available, the hessian must be kept damp at all times. The moulds should not be exposed to direct sunlight.

After 24 ± ½ hours, the specimens should be uncovered and removed from the moulds. The concrete is still weak at this stage and should be handled carefully. To remove from the mould, loosen all the bolts and clamps, slide off the baseplate and then tap the mould gently to free the specimen. On removal from the mould, the specimen should be put straight into a tank of clean water. It will not normally be possible to control the water temperature other than by shielding from direct sunlight but it should be normally within the range 25 to 35°C. In the case of laboratory tests for trial mixes etc., the temperature should be maintained at 30± 1°C. The water should be changed at least once a month.

It should be noted that in the USA and Europe the standard curing temperature is 20°C. In Bangladesh it is not normally possible to attain this temperature without artificial cooling and a standard temperature of 30°C is used. This temperature difference has only a minor effect on 28-days strengths but results in a higher strength at 7 days. Care should, therefore, be taken when comparing test results with typical values given in reference books and papers.

9.2.7 Transporting specimens

In many cases it will be necessary to transport cubes and cylinders from the site to a central laboratory where they are to be crushed. Specimens must not be transported...
during the first 24 hours after casting and, if possible, reduce the risk of damage during transit.
Immediately prior to transport, the specimen should be removed from the curing tank and completely wrapped in hessian which should be at least two layers thick. The hessian and specimen should then be completely soaked with water and placed in a polythene bag which should be firmly sealed. A ticket containing details of the specimen should be placed in the bag.

As an alternative to a polythene bag, the specimen may be placed in an airtight tin. Occasionally, purpose-made curing cans may be available, these have a sponge lining which is thoroughly wetted prior to inserting the specimen, thus dispensing with the need for hessian. The whole purpose in transporting is to keep the specimen wet at all times and to prevent physical damage during the journey. If the specimens are to be transported by lorry or over rough roads, additional protection may be required. On reaching the laboratory, the specimens should be immediately placed in a tank of water to complete the period of curing.

9.2.8 Testing specimens

On completion of the required period of curing, the specimens are removed from the water, allowed to drain and surface-dried, using a soft cloth.

The weight of the saturated surface-dry specimen is then determined, weight a. The weight of the sample in water is then taken by use of wire basket suspended from a suitable balance and immersed in a tank of water, weight b.

Any burrs or edges on the sides of the specimen should then be removed using a carborundam block.

The sample may now be tested. In the case of cubes, the sample is placed in the crushing machine on its side so that the two faces in contact with the platens of the machine are faces which were in contact with the polished steel sides of the mould, they should, therefore, be perfectly plane and smooth. Cylinders must, however, be tested in an upright position and the upper surface has only been float-finished. If the cylinder was crushed with the upper surface directly in contact with the platen of the test machine, the test result would almost certainly give a low result as the upper surface will be in contact with the machine at a number of high spots and compact stress patterns will be developed. It is, therefore, standard procedure to cap specimens prior to test.

Capping may be done by a number of methods but the two most commonly used are neat cement and capping compounds. Using neat cement the cylinder is capped shortly after casting. During casting, the wet concrete should be left about 3mm. below the top of the mould. After at least 4 hours when the concrete has initially set, the mould is topped up with a neat cement paste. The cement paste should have been allowed to stand for some time prior to use, to allow some of the initial shrinkage to take place; it should not, however, have started to harden. To obtain a perfectly smooth surface the cement paste is finished off level with the top of the mould using a flat piece of glass which is slid across the top surface. It is sometime useful to apply a thin layer of graphite grease to the glass to aid sliding, some practice may be required before a perfectly smooth surface can be achieved. The specimen is then cured as usual.

Using capping compound, the cylinder is capped immediately prior to testing. The capping compound may be pure sulphur or preferably a mixture of sulphur and milled fired clay (brick dust). The compound is heated in a metal pot until molten, when a portion is removed with a ladle, and poured onto a polished steel plate. The cylinder
is then gently lowered onto the compound and rotated to ensure the face is completely
covered. A special jig is normally used for this purpose, this ensures the cylinder is kept absolutely vertical during the capping operation. Once cool, the compound is immediately ready for use. After testing, compound may be recovered by re-heating.

The capped cylinder is placed in the crushing machine. Specimens should be tested in a saturated surface-dry condition.

The steel platens of the crushing machine are brought together until they just touch the upper and lower surfaces of the specimen. The specimen should be central on the platens and the upper platen should be free to rotate so that any small differences in alignment between the upper and lower surfaces of the specimen may be accounted for.

The crushing machine should be fitted with a guard to contain the specimen on fracture.

The load is then applied to the specimen at a constant rate to give an increase in stress on the specimen of 0.2 to 0.4 N/mm²/sec. On automatic machines the rate of loading may be shown by a load pacer, but on manual machines, pacing should be done using a stopwatch. It is a good practice to overlay the dial with a clear plastic sheet with times corresponding to each dial gauge reading shown. Note that, as the sample begins to fail the actual speed of the platens must be increased to maintain the same rate of application of load.

The rate of loading has a significant effect on the test result in that, too quick a rate will give a high result and too slow a rate will give low results, it is, therefore, important to maintain the correct rate.

The specimen is considered to have failed when the load begins to decrease, even though the operator is still attempting to maintain the rate of loading. Prior to this condition, small decreases in the load may take place and after a short time the load again increases, this re-orientation of the specimen close to failure may be disregarded. The maximum load attained during the test should be recorded. Some of the satisfactory and unsatisfactory of failures are shown in Figure 9.2.1 and Figure 9.2.2.

9.2.9 Calculation

It is usual to test cubes and cylinders on a daily basis and the test results for a day’s work may be recorded on a sheet such as Form 9.2.1.

The volume of the specimen is give by:

\[ V_c = (\text{weight}_a - \text{weight}_b) \text{ ml} \]

Where, weight \(a\), is weight of SSD specimen in air (grams) and weight \(b\), is weight of SSD specimen in water (grams).

The density of the concrete is give by:

\[ \text{Density} = \frac{\text{Weight}}{\text{Volume}} = \frac{a}{c} \text{ gm / ml} \]

\[ = \frac{a}{c} \times 1000 \text{ kg / cu.m} \]
The stress on the specimen is given by:

\[ \text{Stress} = \frac{\text{Maximum test load}}{\text{Cross-sectional area of specimen}} \]

In the case of a cube, the cross-sectional area = \(L^2\).

In the case of a cylinder, the cross-sectional area = \(\pi \frac{D^2}{4}\),

Where \(L\) is length of side of a cube, \(D\) is diameter of a cylinder.

The final results of a batch of cubes may be given on a form as shown in Form 9.2.2.

**9.2.10 Reporting of results**

The crushing strength of the concrete should be reported to the nearest N/mm\(^2\) and the density of the hardened concrete should be reported to the nearest kg/cu.m.

The test report should include at least the following information:

a) Name of testing agency
b) Client
c) Contractor's name
d) Contract name
e) Date and time specimens made
f) Age of specimen at test

g) Method of compacting specimens
h) Sample identification number
i) Conditions of curing and storage
j) Supplier of concrete
k) Date concrete delivered to site
l) Location of concrete in structure
m) Slump of concrete
n) Maximum load at failure
o) Density of specimen
p) Appearance of concrete
q) Description of failure
r) Name of sampler
s) Name of tester
t) Any other information
NOTE. All four exposed faces are cracked approximately equally, generally with little damage to faces in contact with the platens.

Figure 9.2.1 Satisfactory failures

NOTE. T = tensile crack

Figure 9.2.2 Some unsatisfactory failures
### BANGLADESH ROAD RESEARCH LABORATORY

#### CONCRETE CYLINDER / CUBE STRENGTHS

**Project:** Gorai River Bridge  

**Date cast:** 5/10/79 - 14/9/79  
**Date crushed:** 12/10/79  

**Name and Designation of Operator:**  

<table>
<thead>
<tr>
<th>Age</th>
<th>Cylinder / Cube No.</th>
<th>Height / Size, mm</th>
<th>Dia., mm</th>
<th>Weight in Air (a) kg</th>
<th>Weight in Water (b) kg</th>
<th>cm$^3$ (c=a-b)</th>
<th>Density (a/c) kg/m$^3$</th>
<th>Load in kN</th>
<th>Stress MN/m$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cubes</strong> 7 days</td>
<td>86</td>
<td>150</td>
<td></td>
<td>8161</td>
<td>4786</td>
<td>3375</td>
<td>2420</td>
<td>617</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>87</td>
<td>&quot;</td>
<td></td>
<td>8204</td>
<td>4838</td>
<td>3398</td>
<td>2440</td>
<td>644</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>88</td>
<td>&quot;</td>
<td></td>
<td>8166</td>
<td>4788</td>
<td>3376</td>
<td>2420</td>
<td>653</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>54</td>
<td>&quot;</td>
<td></td>
<td>8160</td>
<td>4787</td>
<td>3374</td>
<td>2420</td>
<td>633</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>&quot;</td>
<td></td>
<td>8212</td>
<td>4842</td>
<td>3370</td>
<td>2440</td>
<td>626</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>56</td>
<td>&quot;</td>
<td></td>
<td>8151</td>
<td>4775</td>
<td>3375</td>
<td>2410</td>
<td>635</td>
<td>28</td>
</tr>
<tr>
<td><strong>Cylinders</strong>  7 days</td>
<td>150</td>
<td>300</td>
<td>150</td>
<td>12723</td>
<td>7421</td>
<td>5302</td>
<td>2400</td>
<td>446</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>151</td>
<td>300</td>
<td>150</td>
<td>12714</td>
<td>7415</td>
<td>5299</td>
<td>2400</td>
<td>424</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>152</td>
<td>300</td>
<td>150</td>
<td>12742</td>
<td>7442</td>
<td>5300</td>
<td>2400</td>
<td>459</td>
<td>26</td>
</tr>
<tr>
<td>28 days</td>
<td>206</td>
<td>300</td>
<td>150</td>
<td>12776</td>
<td>7469</td>
<td>5307</td>
<td>2400</td>
<td>654</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>207</td>
<td>300</td>
<td>150</td>
<td>12748</td>
<td>7436</td>
<td>5312</td>
<td>2400</td>
<td>724</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>208</td>
<td>300</td>
<td>150</td>
<td>12736</td>
<td>7435</td>
<td>5301</td>
<td>2400</td>
<td>671</td>
<td>38</td>
</tr>
</tbody>
</table>

To nearest gram.  

Volume cube = 150$^3$/1000 = 3375 ml±20 say  

Volume cylinder = ($\pi$150$^2$ x 300) / (4 x 1000) = 5301 ml±20 say
# BANGLADESH ROAD RESEARCH LABORATORY

## CONCRETE CYLINDER CUBE TEST RESULTS

**Project:** Goral River Bridge  
**Location:**  
**Class of concrete:** 20 MN/m²  
**Date cast:** 10/6/79  
**Aggregate cement ratio:** 6.5  
**Cement content:** 300 kg/m³  
**Water cement ratio:** 0.5  
**Aggregate content:** 1,550 kg/m³  
**Slump:** 20 mm to 30 mm  
**Sand content:** 400 kg/m³  
**Water content:** 160 kg/m³  
**Quality of concrete placed:** 40 cu.m  
**7 Day Test Results - Crushing Date:** 10/12/79  

<table>
<thead>
<tr>
<th>Cube No.</th>
<th>Weight</th>
<th>Density</th>
<th>Slump</th>
<th>Load</th>
<th>Strength</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>8161</td>
<td>2420</td>
<td>20</td>
<td>617</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>87</td>
<td>8204</td>
<td>2440</td>
<td>25</td>
<td>644</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>8185</td>
<td>2420</td>
<td>15</td>
<td>653</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

**28 Day Test Results - Crushing Date:** 11/12/79

<table>
<thead>
<tr>
<th>Cube No.</th>
<th>Weight</th>
<th>Density</th>
<th>Slump</th>
<th>Load</th>
<th>Strength</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>89</td>
<td>8151</td>
<td>2410</td>
<td>20</td>
<td>633</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>8162</td>
<td>2400</td>
<td>10</td>
<td>655</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>8210</td>
<td>2420</td>
<td>30</td>
<td>810</td>
<td>36</td>
<td></td>
</tr>
</tbody>
</table>

**Curing Date**  
**Initial curing and transport:** 24 hours under damp sacking  
**Date placed in curing tank at:** 30°C, 10/6/79  
**Name and Designation of Tester**

---

MAY 2001  
Page 9.15