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CPAS

مركز الدراسات التخطيطية والمعمارية
"أ.د عبد الباقى إبراهيم وشركاه"
بيت خبرة فى الهندسة الاستشارية

Training Course in

Testing & Quality Control of Concrete

Prepared & Instructed by
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PART I

TESTS OF FRESH CONCRETE

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1-Slump Test

1- Objective

This test is made for the determination of the consistency of concrete mixes of low, medium and high workability having maximum aggregate size not exceeding 40mm. The test can be carried out in both field and the laboratory.

2- Summary of the test method

A sample of freshly mixed concrete is placed and compacted by rodding in a mould shaped as semi-cone. The mould is raised and the concrete allowed to subside. The distance between the original and displaced position of the center of the top surface of the concrete measured and reported as the slump of the concrete.

3- Apparatus:

1- *mould.* Metal frustum of a cone Fig. 1

- internal dimensions mm

Bottom diameter	200 + 3 - 1.6
Top diameter	100 + 3 - 1.6
Height	300 + 5 - 1.6
Thickness	≮ 1.6

- smooth internal surface
- foot pieces & handles

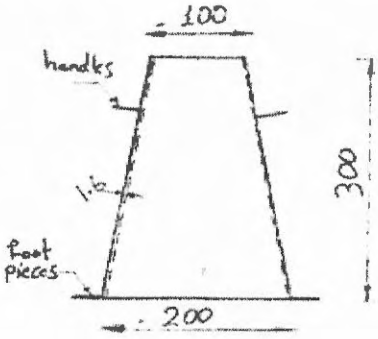

Fig. 1

2- *Tamping rod.* round straight steel rod of 16mm diameter, 600mm length and rounded at one end.

4- *Sampling.* 15 kg of fresh concrete.

5- procedure

- The internal surface of the mould should be cleaned.
- Place the mould on a smooth, horizontal, rigid and non-absorbant surface at place free from vibration and shock.

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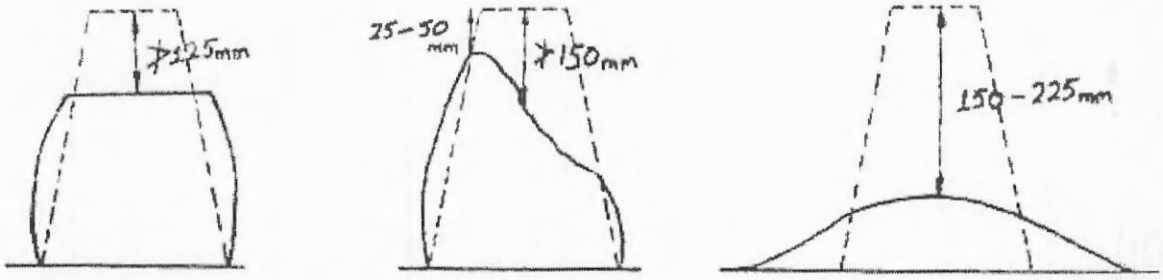
- Hold the mould firmly in place while it is being filled.
- Immediately fill the mould in three layers, each approximately one third the volume of the mould.
- Rod each layer 25 strokes of the tamping rod.
- Uniformly distribute the strokes over the cross section of each layer.
- Rod the bottom layer throughout its depth without stricking the bottom of the mould.
- Rod the second layer and the top layer each throughout its depth, so that the strokes just penetrate into the underlaying layer.
- After the top layer has been tamped the mould should be filled and the concrete struck off and finished level with a trowel.
- The mould shall be removed immediately from the concrete by raising it slowly and carefully in vertical direction.
- The slump should be measured immediately by determining the difference between the height of the mould and that of the centerpoint of the specimen.

6- Report:-

- date of test;
- identification of sample;
- true or collapse or shear slump;
- time after addition of mixing water.



true slump shear slump collapse

Three main types of slump

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Table 1. Relation between slump and consistency of concrete

slump (mm)	consistency
0 - 20	dry
10 - 40	stiff
30 - 120	plastic
100 - 200	wet
180 - 220	sloppy

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2- Method of compacting factor

1- Objective

This test is carried out on concrete mixes of low, medium to high workability having a maximum nominal size not exceeding 40mm. The test can be carried out in both feild and the laboratory.

2- Apparatus

- Compacting factor apparatus (Fig. 2).
- Sampling tray 1.2m x 1.2m x 50mm deep made from minimum 1.6mm thick non-corrodible metal.
- Square mouthed shovel.
- Tamping rod, steel, 16mm diameter, 600mm long with both ends hemispherical.
- Scales or balance, 25 kg capacity, 10 gm accuracy.
- Compacting bar or vibrating table.
- Two steel floats.

Detail	dimension (mm)
- upper hopper	
top internal diam.	260 ± 2
bottom internal diam.	130 ± 2
internal height	280 ± 2
- lower hopper	
top internal diam.	240 ± 2
bottom internal diam.	130 ± 2
internal height	240 ± 2
- cylinder	
internal diam.	150 ± 1
internal height	285 ± 1
radius bet. wall & base	20

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distance between :

bottom of upper hopper and bottom of lower hopper = 200 ± 5mm
bottom of lower hopper and top of cylinder = 200 ± 5mm

3- procedure

- Insure that the internal surfaces of the hoppers and cylinder are smooth, clean and damp.
- Place the frame in a place free from vibration or shock, the axes of the hoppers and cylinder all lying on the same vertical line.
- Close the two trap doors and place the two floats on the cylinder to cover its top.
- Place the sample of concrete gently in the upper hopper.
- Open the upper trap door so that the concrete falls into the lower hopper.
- Immediately after the concrete has come to rest, remove the floats from the top of the cylinder, open the trap door of the lower hopper and allow the concrete to fall into the cylinder.
- Cut off the excess of concrete remaining above the level of the top of the cylinder by the two floats.
- Wipe clean the outside of the cylinder.
- Weight the partially compacted concrete in the cylinder and record its mass to the nearest 10 gm, this mass being measured within 150 second of commencing the test.
- Empty the partially compacted concrete from the cylinder and refill it with concrete from the same sample in such a way to remove as much entrapped air as possible and to produce full compaction of concrete with neither excessive segregation nor laitance, (compacting bar or vibrator).

calculate:

compacting factor = mp / mf

where mp = mass of partially compacted concrete kg.
mf = mass of fully compacted concrete kg.

4- Report

- the value of the compacting factor.
- consistency of concrete mix.
- time and date of test

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Table 2. Relation between slump, degree of workability and compacting factor

slump (mm)	degree of workability	compacting factor
0 - 25	very low	0.78
25 - 50	low	0.85
50 - 100	medium	0.92
100 - 175	high	0.95

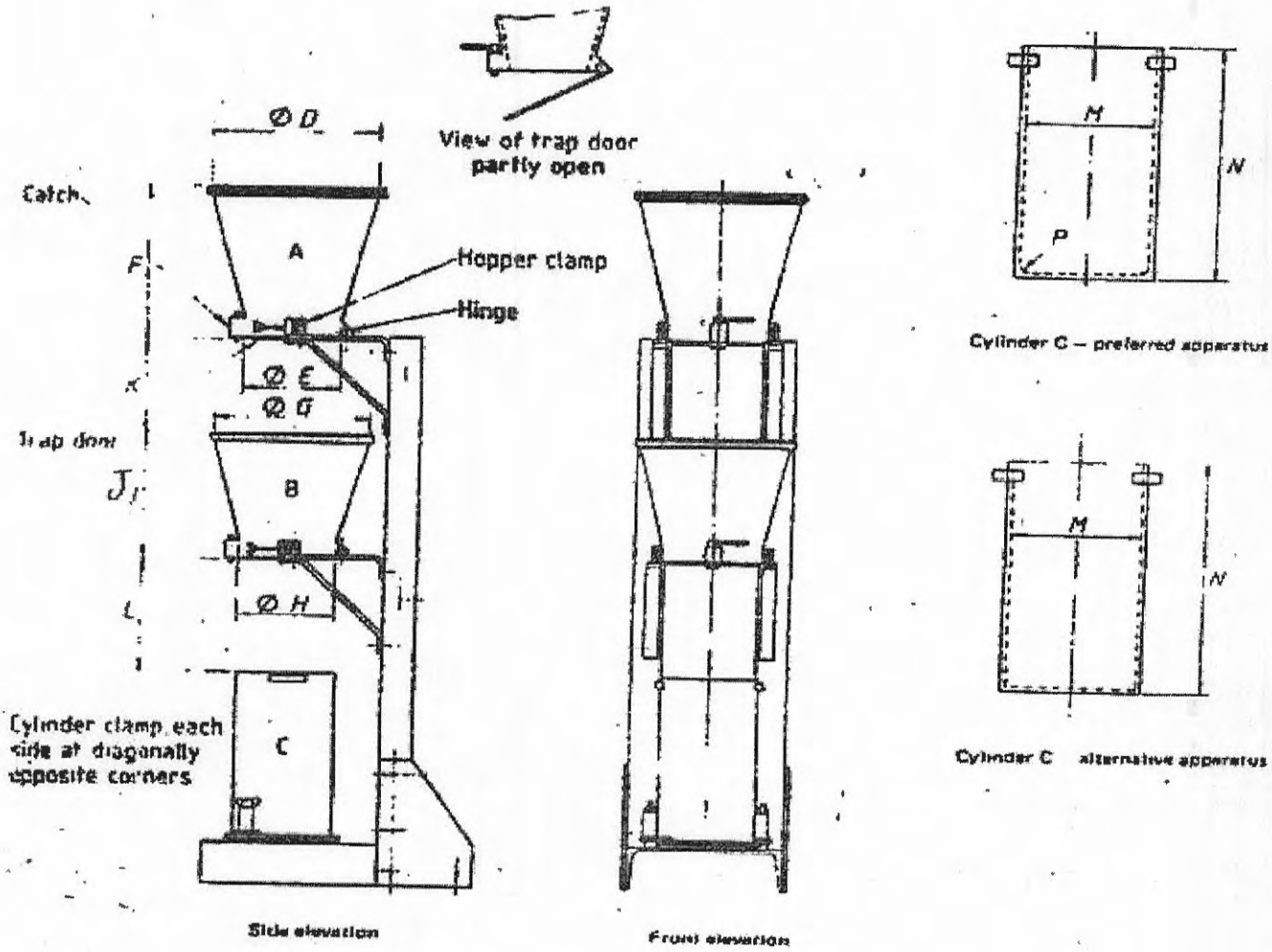

Fig. 2 compacting factor apparatus

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3- Method for determination of flow

1- Objective

This part specifies the method for determination of the flow of concrete of high to very high workability.The method applies to plain and air-entrined concrete, having a flow diameter of 500mm to 650mm, made with lightweight, normal weight or heavy aggregates having a nominal maximum size of 20mm or less. It does not apply to aerated concrete or no fines concrete.

2- Apparatus

1- *Flow table*, consisting of a flat plat, on which concrete can be placed, hinged to a rigid base on to which it can fall from a fixed height. The essential dimensions of the flow table and a suitable form of construction are shown in Fig. 3.
The flow table top shall be constructed from a flat metal plate of minimum thickness 1.5mm , not readily attacked by cement past or liable to rust. The top shall have a plan area of 700mm x 700mm and a flatness of within 1.5mm. The center of the table shall be scribed with a cross, the lines of which run parallel to and out to the edges of the plate, and with a central circule 200mm in diameter. The under surface of the plate shall be reinforced in order to prevent distortion of the flate surface. The front of the flow table top shall be provided with a lifting handle as shown in Fig. 3. The total mass of the flow table top shall be 16 ± 1 kg. The flow table shall be hinged to the base frame using externally mounted hinges in such a way that no aggregate can become trapped easily between the hinges or hinged surfaces. An upper stop similar to that shown in Fig. 3 shall be provided on each side of the table so that the lower front edge of the table can only be lifted 40 ± 1mm.

2- *Mould* made of metal not readily attacked by cement past or liable to rust and of minimum thickness 1.5mm. The mould shall be in the form of a hollow frustum of a cone having the following internal diameters:

diameter of base: 200 ± 2mm
diameter of top : 130 ± 2mm
height : 200 ± 2mm

The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mould shall be provided with two metal foot pieces at the

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bottom and two handles above them (see Fig. 4).

3- *Tamping bar*, made of suitable hard wood and having a 40mm x 40mm square section of minimum length 200mm. Further 120mm to 150mm should be turned to circular section to form a handle to the bar (see Fig. 5).

4- *Scoop*, about 100mm wide.

5- *Sampling tray*, 1.2m x 1.2m x 50mm deep, made from non-corrodible metal of minimum thickness 1.5mm.

6- *Square mouthed shovel*

7- *Rule*, of minimum length 700mm and having 5mm subdivision along its entire length.

3- Preparing the sample for test

Empty the sample from the container on to the sampling tray. insure that no more than light covering of slurry is lift adhering to the container.
Thoroughly mix the sample by using the shovel to turn the concrete over from the outside of the tray towards the center, working progressively once round all four sides of the tray.

4- Procedure

- Place the flow table on a flate, horizontal and solid surface free from external vibration or shock.
- Ensure that the hinged top of the table can be lifted to the correct limit of its travel and is then free to fall to the lower stop.
- Check that the table is so supported that, when the top of the table falls to the lower stop, there is minimal tendency for the top to bounce.
- The table and the mould shall be clean and damp.
- Place the mould centerally on the table top and hold it in position by standing on the two foot pieces.
- Fill the mould with concrete in two equal layers using the scoop, tamping each layer lightly 10 tampes with the wooden tamping bar.
- Strike off the concrete flush with upper edge of the mould and clean the free area of the table top of any excess concrete.
- at 30 seconds after striking of the concrete, slowly raise the mould vertically by

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the hands over a period of 3s to 6s.

- Slowly raise the table top by the handle till it reaches the upper stop in such a manner that the table top does not impact hard againest the upper stop.
- Allow the table top to fall freely to the lower stop.
- Repeat this cycle to give a total of 15 drops, each cycle taking not less than 3s nor mare than 5s, in this way the concrete spreads across the table top.
- Measure with the rule the total diameter of the concrete spread in two directions, parallel to the table edges.
- Calculate the arithmetic mean of both diameters as the measurement of flow in millimeters.

5- Expression of results

Record the mean of the two flow diameters in millimeters to the nearest 5mm.

6- Report

- time, date and place of test
- degree of workability of tested concrete, high or very high.
- the mean value of the flow diameter.

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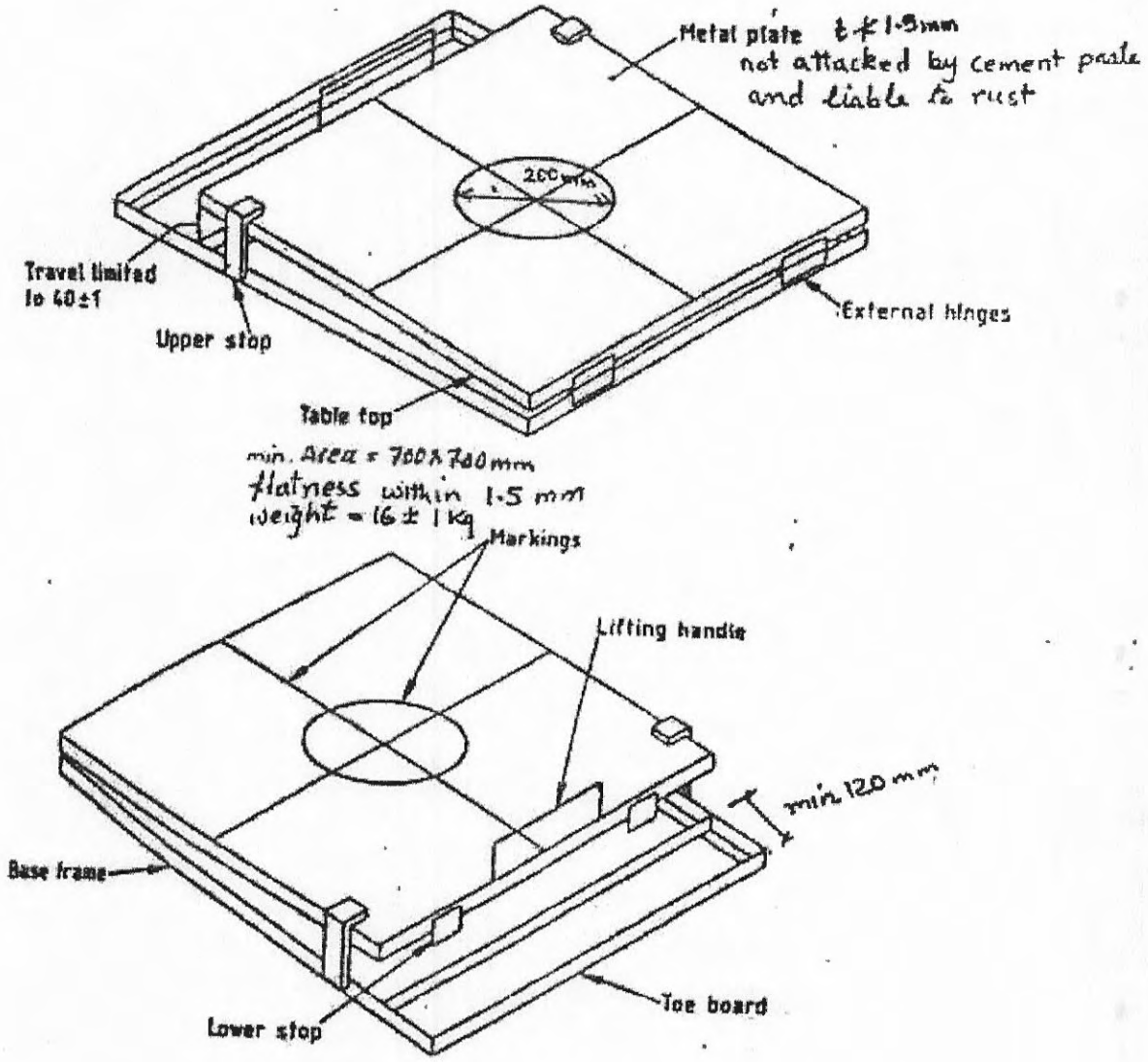

Fig.3 Flow table.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

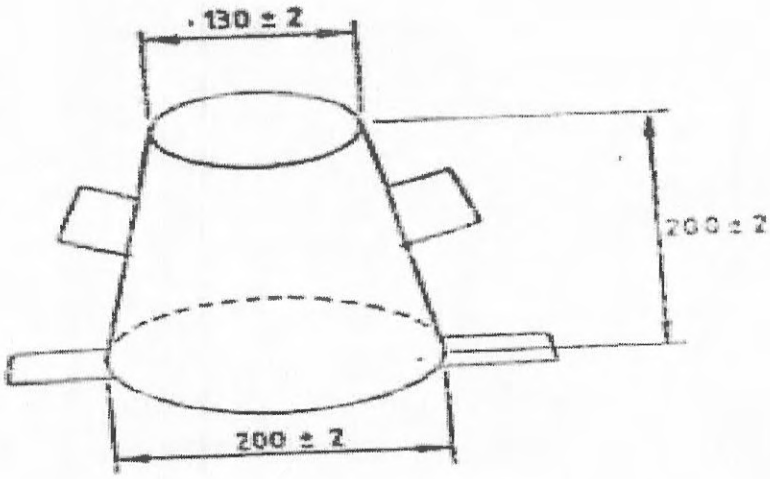

Fig.4 Concrete mould.

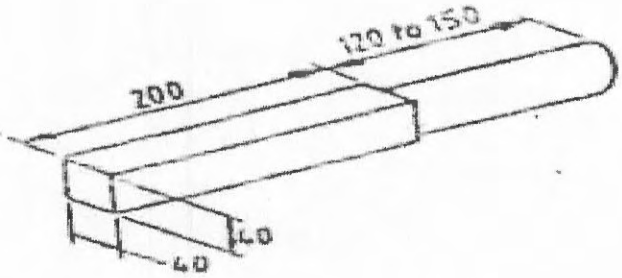

Fig.5 Tamping rod.

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4- Ball penetration Test (Kelly Ball)

1- Objective and apparatus

This is a simple field test consisting of the determination of the depth to which a 152mm (6 in.) diameter metal hemispher, weighing 13.6 Kg (30 lb), will sink under its own weight into fresh concrete. Sketch of the apparatus, devised by J. W. Kelly and known as the Kelly ball, is known in Fig. 6.

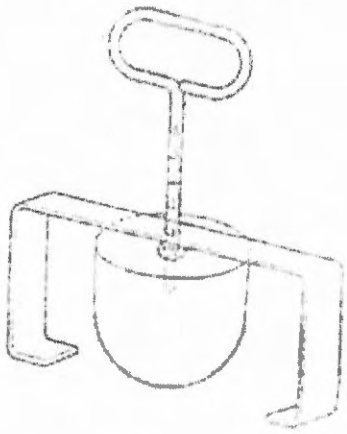

Fig. 6 Kelly ball

The use of this test is similar to that of the slump test, that is routine checking of consistence for control purposes. It is, however, worth considering the kelly ball test as an alternative to the slump test, over which it has some advantages. In practical, the ball test is simpler and quicker to perform and, what is more important, it can be applied to concrete in a wheelbar-row or actually in the form. In order to avoid the effect of a boundary the depth of the concrete being tested should be not less than 200mm (8 in.), and the least lateral dimension 460mm (18 in.). As would be expected, there is no simple correlation between penetration and slump, since neither test measures any basic property of concrete but only the response to specific conditions. On a site, when particular mix is used, the ball test is essentially used to measure variations in the mix, such as those due to a variation in the moisture content of the aggregate.

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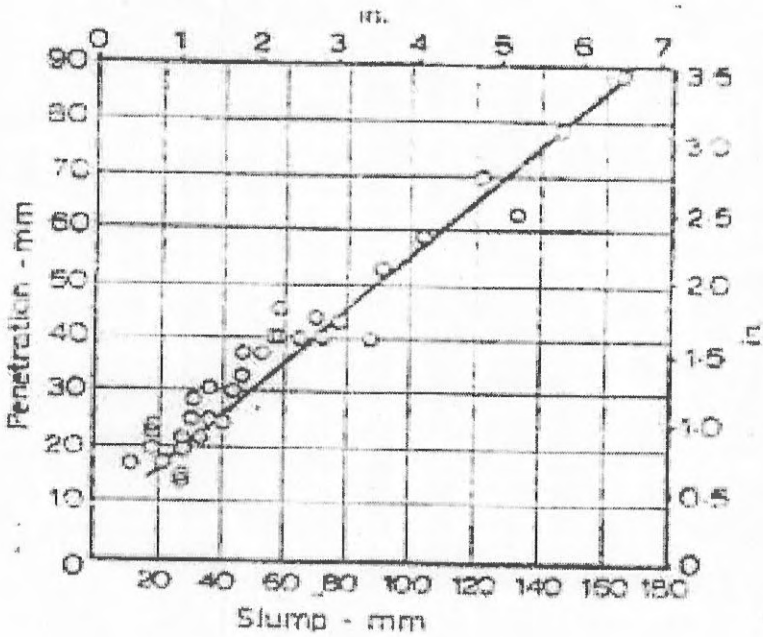

Fig. 7 Relation between Kelly ball and slump.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

5- Method for determination of air content of fresh concrete

1-Objective

This part describes a method for determination of air content of compacted fresh concrete, made with normal weight of relatively dense aggregate having a nominal maximum size of 40mm or less. The method is not applicable to aerated concrete, very stiff concrete which cannot be compacted by vibration alone nor a concrete made with lightweight aggregates or aggregates of high porosity.

2- General

In this method the operational principle consists of merging a known volume of air at a known pressure in a sealed air champer with the known volume of air in the concrete sample, the dial on the pressure gauge being calibrated in terms of percentage of air for the resultant pressure.

3- Apparatus

General. The apparatus, one form of which is shown diagrammatically in Fig. 8 consists of the following.

1- *Container*. A flanged cylindrical vessel of steel or hard metal, not readily attacked by cement past, having a nominal capacity of at least 5 liters and a ratio of diameter to height of not less than 0.75 or more than 1.25. The outer rem and the interior surfaces of the vessel shall be machined to a smooth finish. The container shall be watertight and in addition it and the cover assembly shall be suitable for an operating pressure of approximately 200 kN/m2.

2- *Cover assembly*. A flanged rigid cover of steel or other hard metal not readily attacked by cement past. the outer rem and lower surfaces of the flange as well as the interior surfaces shall be machined to a smooth finish. The cover shall have provision for being clamped to the container to make a pressure seal without entrapping air at the joint between flanges of the cover and the container.
The cover assembly shall be fitted with a pressure gauge calibrated to indicate air content from 0% to at least 8% and preferably 10%. Up to an air content of 6% the scale of the gauge shall be graduated with divisions every 0.1% air content.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

3- *calibration cylinder*. A hollow cylindrical measure of brass or other non-corrodible metal having a capacity of approximately 0.3 liter, which may be integral with the cover assembly.

4- *Transparent plate*. Rigid transparent plate, suitable for use as a closer for the container.

5- *Air pump*. A hand pressure pump such as a bicycle tyre pump with a lead facilitating connection to the non-return inlet valve on the cover assembly.

6- *Scoop*

7- *Compacting bar or vibrator*. Compacting bar made out of straight steel bar weighing 1.8 kg, 380mm long and having ramming face 25mm square, or a vibrating table suitable for compacting the concrete.

8- *Mallet*. A soft-faced mallet with a mass of approximately 250gm.

9- *syring*. A rubber syring, suitable for injecting water into the container either through valve A or valve B.

10- *Balance*. Balance capable of weighing up to 10 kg to an accuracy of $\pm$ 0.5 gm for use in calibrating the apparatus.

4- Calibration of the apparatus

a- *General*. The calibration test detailed below shall be made as frequently as necessary to check the accuracy of the graduations indicating air content on the dial of the pressure gauge. Recalibration of the apparatus is not required with changes in elevation at which it is used or with changes in atmospheric pressure.

b- Checking air content graduations on the pressure gauge.

- The capacity of the container is found by determining the mass of water. m2. required to fill it.
- Fill the container with water at ambient temprature and place the transparent plate over it to eleminate any convex meniscus.
- Smear a thin film of grease on the flange of the container to effect a water tight joint between the transparent plate and the top of the container.
- Wipe away surplus water and determine the mass of the container filled with

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

water by weighing on the balance.

- Screw the extention tubing (see Fig. 8) into the threaded hole beneath valva A on the underside of the cover assembly and clamp the cover assembly into place. care being taken to ensur that there is a good pressure seal between cover and container.
- Close the main air valve and open valves A and B.
- Add water through valve A until all trapped air has been expelled through valve B.
- Pump Air into the air champer until the pressure reaches the indicated initial pressure line.
- After allowing a few seconds for the compressed air to cool to ambient temprature, stabilize the hand on the pressure gauge at the initial pressure line by further pumping in or bleeding off air as necessary.During this process lightly tap the gauge and close valve B.
- Remove water from the apparatus to the calibration cylinder in just suffecient quantity to fill it full or up to a predetermined line marked on it, then determine the mass of water displaced, m3, by weighing on the balance. Control the flow of water either by opening valve A and using the main air valve to control flow, or by opening the main air valve and using valve A to control flow.
- Release the pressure in the container by opening valve B.
- The volume of air in the container is now equal to the volume of the displaced water; close all valves, pump air into the air champer until the pressure reaches the initial pressure line, and then open the main air valve.
- The air content indicated by the pressure gauge corresponds to the percentage of air, A1, determined to be in the container, where A1 = m3 / m2 x 100 %.
- If two or more determinations show the same variation from the correct air content, reset the hand on the pressure gauge to the correct air content and repeat the test until the gauge reading correspond to the calibrated air content within 0.1 % air content.

5- Procedure

- Fill the container with tested concrete in three equal layers each of height approximately one third the height of the container, tamping each layer 25 strokes using the tamping rod (compaction of tested concrete can be made using a vibrating table).
- Wipe the flanges of the container and of the cover assembly thoroughly clean.
- Clamp the cover assembly in place, care being taken to ensure that there is a good pressure seal between the cover and the container.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

- Close the main air valve and open valve A and valve B.
- Using A rubber syring, inject water through either valve A or valve B until water emerges from the other valve. Lightly tap the apparatus with a mullet until all entrapped air is expelled from this same valve. Close the air bleeder valve on the air champer and pump air into the air champer until the hand on the pressure gauge is on the initial pressure line.
- After allowing a few seconds for the compressed air to cool to ambient temprature stabilize the hand on the pressure gauge at the initial pressure line by further pumping in or bleeding off air as necessary. During this process lightly tap the gauge.
- Close both valve A and valve B and then open the main air valve. Tap the sides of the container sharply. Lightly tap the pressure gauge to stabilize it and then the reading of the pressure gauge is equal to the apparent percentage of air, A.
- Open valves A and B in order to release the pressure befor the cover assembly is removed.

6- Calculation and expression of results

Calculate the air content of the concrete in the container, Ac from the formula:

$$Ac = A1 - G$$

where

A1 is the apparent air content of the sample tested, to the nearest 0.1 %;
G is the aggregate correction factor to the nearest 0.1 %.

Express the air content to the nearest 0.1 %.

7- Report

- date, time and place of sampling and sample identity number;
- time and place of test;
- aggregate correction factor;
- measured air content of sample tested.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

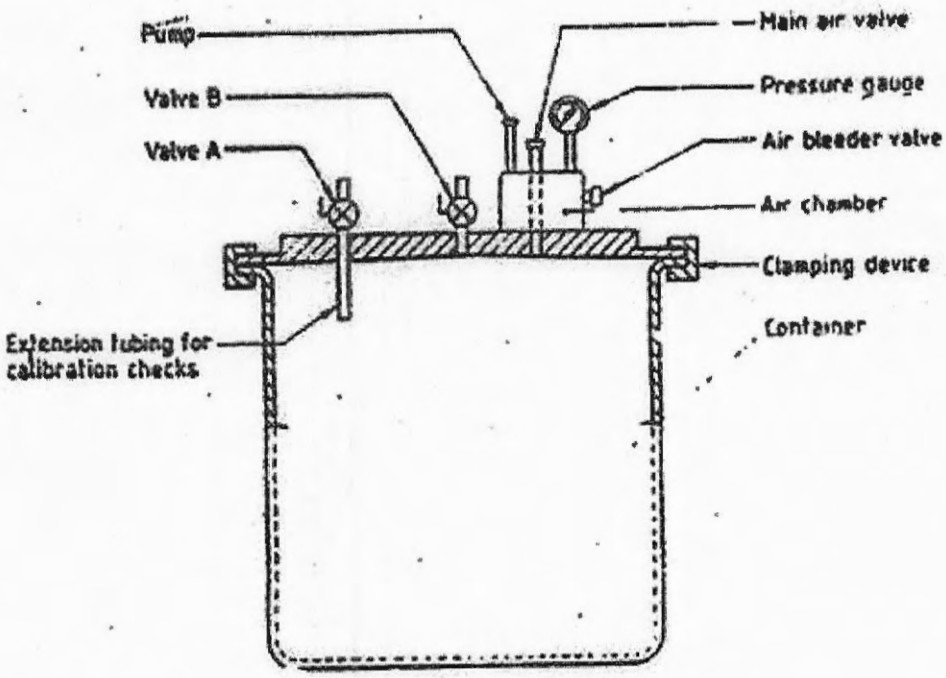

Fig.8 Apparatus of determination of air content in concrete mixes.

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مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

6- Method for preparing test cubes from fresh concrete

1- Objective

This part describes a method for making test cubes of nominal size 100mm and 150mm out of fresh concrete. The method applies to plain and air-entrained concrete made with lightweight, normal weight and heavy aggregates having a nominal maximum size not exceeding 20mm for 100mm cubes and 40mm for 150mm cubes.
This method does not apply to aerated concrete, very stiff concrete, which cannot be compacted by vibration alone, and no fines concrete.

2- Apparatus

1- *Mould*, the sides of the mould shall be of ferrous metal (perferably cast iron or cast steel). The mould shall include a removable steel base plate. All parts of the mould shall be robust enough to prevent distortion. Before assembly for use, the joints between the sides of the mould and between them and the base plate shall be thinly coated with oil or grease to prevent loss of water. The parts of the mould when assemled shall be positively located and rigidly held together in such a manner as to prevent leakage from the mould. The internal faces of the assembled mould shall be thinly coated with release agent to prevent adhegant of the concrete.
The sides of the mould shall be clearly marked with a reference number or code to enable each concrete specimen to be identified when it is demoulded and the mould to be correctely re-assembled.

2- *Scoop*, approximately 100mm wide.

3- *Compacting bar or vibrating table*, a compacting bar made out of a steel bar weighing 1.8 kg, 380mm long and having ramming face 25mm square or a vibrating table.

4- *Steel float*

5- *Sampling tray*, 1.2m x 1.2m x 50mm deep made from 1.6mm thick non-corrodible metal.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

6- *Square mouthed shovel*

7- *Plasterer`s float*

3- Preparing the sample

Empty the sample from the container on to the sampling tray. Ensure that no more than a light covering of slurry is left adhering to the container. Throughly mix the sample by shovelling it to form a cone on the sampling tray and turning this over with the shovel to form a new cone, the operation being carried out three times.

4- Procedure

- *Filling the mould.* Place the mould on a rigid horizontal surface or on the vibrating table and fill with concrete in such a way as to remove as much entrapped air as possible (without segnificantly reducing the amount of entrained air, if present) and to produce full compaction of the concrete with neither excessive segregation nor laitance. For this purpose, by means of the scoop, place the concrete in the mould in layers approximately 50mm deep and compact each layer by using either the compacting bar or the vibrator. After the top layer has been compacted, smooth it level with the top of the mould using the plasterer`s float, and wipe clean the outside of the mould.

- *Compacting with compacting bar.* When compacting each layer with the compacting bar, distribute the strokes of the compacting bar in a uniform manner over the cross section of the mould, and ensure that the compacting bar does not penetrate segnificantly any previous layer nor forcibly strike the bottom of the mould when compacting the first layer. The number of strokes per layer required to produce full compaction will depend upon the workability of the concrete but in no case shall the concrete be subjected to less than 35 strokes per layer for 150mm cubes or 25 strokes per layer for 100mm cubes, except in the case of high workability concrete. record the number of strokes.

- *Compacting with vibrator.* When compacting each layer by means of vibrating table use applied vibration of the minimum duration necessary to acheive full compaction of the concrete. Over vibration may cause excessive segragation and laitance or loss of entrained air, if present. The required duration of vibration will depend abone the workability of the concrete and the effectivness of the vibrator and vibration shall cease as soon as the surface of the concrete becomes relatively smooth and has a glazed appearance. Record the duration of vibration.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

5- Report

- date, time and place of sampling and sample identity number;
- time and place of making cubes;
- number and nominal size of cubes;
- method of compaction (hand or vibration);
- identification number or codes of cubes.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

PART II

TESTS OF HARDNED CONCRETE

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

1- Method of normal curing of test specimens (20 °C method)

1- Objective

This part describes the method of normal curing of concrete specimens (cubes, beams or cylinders) at 20 °C for strength tests at ages of 1 day and over.

2- Apparatus

1- *Curing tank.* A curing tank constructed from any material which is of adequate strength and will resist corrosion. The internal dimensions of the tank shall be appropriate for the number and size of the specimens to accommodate, shall permit adequate circulation of water and shall be such that specimens can be easily removed. The tank shall contain clean morter which shall be replaced at least once a month. At any point in the tank where specimens are stored the temprature shall be 20 ± 2 °C.

3- Procedure

Immediately after making specimens store them in a place free from vibration and in conditions which will prevent loss of moisture. If it is necessary to move the specimens to the place of storage, move them in their moulds ensuring no loss of concrete.
Store the specimens either:
a- in an atmospher with a relative humidity of not less than 90% in a moist air curing room, or
b- under damp matting or any other suitable damp material warpped completely with polyethylene or other impervious sheeting.
Whichever method of moist and storage is used, maintain the temprature of the specimen at 20 °C if the specimens are to be tested at an age of 7 days or more, or at 20 ± 7 °C if the specimen are to be tested at an earlier age.
Demould specimens to be tested at 24 h just before testing.
Demould specimen to be tested at greater ages within the period 16 h to 28 h after the addition of water to the other constituents in the mix unless the concrete has not acheived suffeceint strength to enable specimens to be demoulded during this period. Mark each specimen clearly and indelibly with an identification number or code. Keep all specimens which are immediately transfered to the curing tank submerged and remove them just befor testing unless it is necessary to transport

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them to another location for testing. Immediately after removal from the moulds or from the curing tank, pack specimens to be transported in such a way as to prevent any segnificant change in moisture content. Store the transported specimens in the curing tank for not less than 24 h before the time of testing. This transfere of specimens may take place at any time between demoulding

4- Report

- identification number or codes of specimens;
- location of moist air curing;
- method of moist air curing;
- period of moist air curing.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

2- Method for determination of compressive strength of concrete cubes

1- Objective

This part describes the mathod for determining the compressive strength of concrete cubes.

2- Apparatus

- *Testing machine*. A compression testing machine of reasonable capacity, 1500 to 2000 KN.
- *Balance*. A balance of capacity 10 kg, 10 gm accuracy.

3- Test specimens

1- *Preraration*. Test specimens shall be concrete cubes made, cured and stored in accordance with specified standards and recommendations. Do not test cubes which have been made in badly assembled moulds or which are clearly misshapen. State the reasons in the test report. Remove any projecting fins unless auxiliary platens of the required dimensions are to be used; report any treatement to remove fins.

2- *Mass*. weigh each specimen, as-received or saturated.

3- *Dimensions*. Check the nominal dimensions and take measured dimensions of each specimen.

4- *Density*. Determine the density of each specimen.

4- Procedure

- *Preparation*. Immerse in water, for a minimum of 5 min, those cubes which have not cured in water or where the surfaces have been allow to dry. Remove the cubes from the curing water tank and test while they are still wet.

- *Placing the cubes in the testing machine*. Ensure that all testing machine bearing surfaces are wiped clean and that any extraneous material is removed from the

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

surfaces of the cube which will be in contact with the platens. Use no packing between the cube and platens, and the spacing blocks if used.
Carefully center the cube on the lower platen and ensure that the load will be applied to two opposit cast faces of the cube.

- *loading*. Without shock, apply and increase the load continuously at a nominal rate within the range 0.2 N/(mm2.s) to 0.4 N/(mm2.s) until no greater load can be sustained. On manually controlled machines as failure is approached the loading rate will decrease; at this stage operate the controls to maintain as far as possible the specified loading rate. Record the mximum load applied to the cube.

5- Types of failure

Record any unusual features in the type of failure. Refer to Fig. 9 for examples of satisfactory failure, and to Fig. 10 for examples of some unsatisfactory failures.

note. Unsatisfactory failures are usually caused by insuffecient attention to the detail of the various procedures that have to be followed to make and test the specimen. For example, unsatisfactory failure may be due to the cubes being badly made, the use of moulds that do not comply with the specification, or mis-placement of the cubes in the testing machine. It is also possible for a machine fault to be the cause of unsatisfactory failure.

6- Calculation and expression of results

Calculate the cross-sectional area of the cube face from the checked nominal dimensions or measured dimensions if taken. Calculate the compressive strength of each cube by dividing the maximum load by the cross-sectional area. Express the results to the nearest 0.5 N/mm2.

7- Report

- date, time and place of sampling and sample identity number;
- time and place of making cubes;
- number and nominal size of specimens;
- identification number or codes of cubes;
- name of person making cubes;
- required age of the specimens at the time of testing;
- conditions of curing and storage;
- age of the specimen at test;
- mass of specimen (as received or saturated);
- maximum load at failure;

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- compressive strength;
- appearance of the concrete and type of fracture if these are unusual.

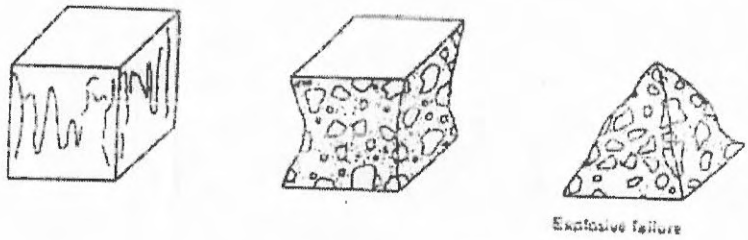

Fig. 9 Satisfactory failures.

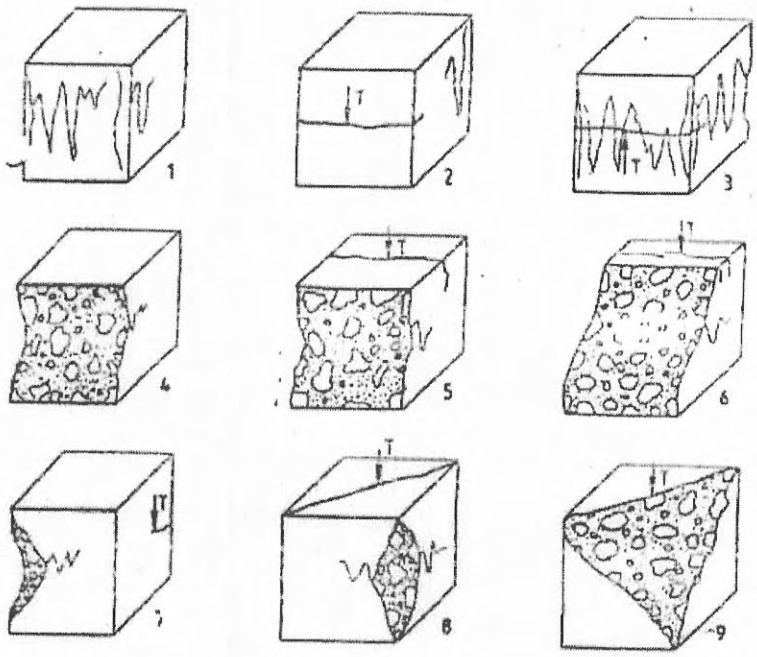

Fig.10 Some unsatisfactory failures.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

3- Rebound hammer test (Schmidt hammer)

1- General

The difficulties of core cutting, and indeed the entire procedure of making curing and testing of standard test specimens would all be avoided if concrete could be tested in situ in a manner harmless to the part tested. Various attempt to devise non-destructive tests have been made but few have been highly successful. One method that has found practical application within a limited scope is the rebound hammer test, devised by Ernst schmidt. It is also known as the impact hammer, or Sclerometer, test.

2- Applications

The test is useful as a measure of uniformity of concrete and is of great value in checking the quality of material throughout structure, or in the manufacture of a number of similar products such as precast sections. The actual strength of the concrete with which successive members are being compared has to be determined by means of the usual crushing test.
A concrete structure can also be tested by means of the hammer to see wether the rebound number has reached a value known to correspond to the desired strength. This is of help in deciding when to remove fals-work or to put the structure into service. Another use of the hammer is to check wether the strength development of a given concrete has been affected by frost at any early age.

3- Theory and procedure

The test is based on the principle that the rebound of an elastic mass depends on the hardness of the surface againest which the mass impinges. in the rebound hammer test (Fig. 11) a spring loaded mass has a fixed amount of energy imparted to it by extending a spring to a fixed position: this is achieved by pressing the plunger againest the surface of the concrete under test. Upon release, the mass rebounds from the plunger, still in contact with the concrete surface, and the distance travelled by the mass, expressed as percentage of the initial extention of the spring, is called the rebound number; it is indicated by a rider moving along a graduated scale.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

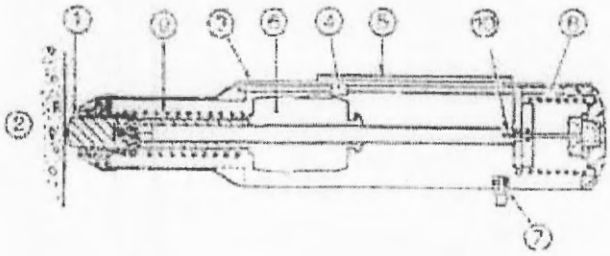

Fig. 11 A schematic diagram of schmidt hammer

4- Surface conditions

The hammer has to be used againest a smooth surface, preferable a formed one. Open-textured concrete cannot therefore be tested. Trowelled surface should be rubbed smooth using carborundum stone. If the concrete under test does not form part of a larger mass, it has to be supported in an unyielding manner, as jerking during the test would result in a lowering of the rebound number recorded.
The test is sensitive to local variations in the concrete; for inistance, the presence of a large piece of aggregate immediately underneath the plunger would result in an upnormally high rebound number; conversely, the presence of a void in a similar position would lead to a very low result. For this reason, it is desirable to take 10 to 12 reading spread over the area to be tested, and to assume average value as representative of the concrete. The standard error of the mean is higher than if the strength is determined by the compression test, but the saving in effort, time and coast is considerable.
The plunger must alwayes be normal to the surface of the concrete under test, but the position of the hammer relative to the vertical will affect the rebound number. This is due to the action of gravity on the travel of the mass in the hammer. Thus the rebound number of the floor would be smaller than that of a soffit, and inclined and vertical surfaces would yield intermediate values; the actual variation is best determined experimentally.

5- Expression of results

The test determineds in reality the hardness of the concrete surface and, although there is no unique relation between hardness and strength of concrete, imperical relationship can be determined for similar concrete cured in such a manner that

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both the surfaces tested by the hammer and in centeral regions, in whose strength we are interested, have the same strength. changes affecting only the surfaces of the concrete, such as the degree of saturation at the surfaces or carbonation, would be missleading as far as the properties of the concrete within the structure are concerned.

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Non-destructive method of test for concrete

4- Measurement of the velocity of ultrasonic pulses in concrete

1- Objective

These method deals with the non-destructive testing of concrete, reinforced and prestressed concrete test specimens, precast components and structures by the ultrasonic pulse method.

2- Definitions

For the purpose of this test the following definitions apply:
(1) *transit time*. The time taken for an ultrasonic pulse to travel from the transmitting transducer to the receiving transducer, passing through the interposed concrete.
(2) *onset*. The leading edge of the pulse detected by the receiving transducer.

3- Applications

The object of this method is basically to measure the velocity of pulses of longitudinal vibrations passing through the concrete. These measurements may be used to establish:
(1) the homoginity of the concrete.
(2) the presence of cracks, voids and other imperfections.
(3) changes in the structure of the concrete which occure with time.
(4) the quality of concrete in relation to standard requirements.
(5) the quality of one element of concrete in relation to another.
(6) the values of the elastic modulus of the concrete.

Pulse velocity measurements made on concrete structures may be used in quality control purposes. In comparison with mechanical tests on control samples such as cubes or cylinders.

4- Basic principles of the method

a- *Ultrasonic pulse propagation in concrete*. A pulse of longitudinal vibrations is produced by an electro-acoustical transducer which is held in contact with one surface of the concrete under test. After traversing a known path length L in the concrete the pulse of vibrations is converted into an electrical signal by a second

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transducer and electronic timing circuits enable the transit time T to be measured.

The pulse velocity V is given by

$$V = L / T \qquad (1)$$

A pulse of vibrations of ultrasonic is used for two reasons:

(1) to give a pulse with sharp onset
(2) to generate maximum energy in the direction of propagation of the pulse.

when the pulse is coupled into the concrete from the transducer, it undergoes multiple reflections at the boundaries of the different material faces within the concrete. A complex system of stress waves is developed and includes both longitudinal and shear waves.
The receiving transducer detects the onset of that component of the pulse which arrives earliest. This is generally the leading edge of the longitudinal vibration. Although the direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer it is possible to detect pulse which have travelled through the concrete in some other direction.
It is therefore possible to make measurements of pulse velocity by placing the two transducers on either:

a.	opposite faces	(direct transmission);
b.	adjacent faces	(semi-direct transmission)or
c.	the same face	(indirect or surface transmission)

These three arrangements are shown in Fig.12a,b and c.
It should be noted that Fig 12a shows the transducers directly opposite to each other on opposite faces of the concrete.It is, however, sometimes necessary to place the transducers on opposite faces but not directly opposite to each other.Such an arrangement is to be regarded as semi-direct transmission.

b- *Coupling the pulse into the concrete.*

To ensure that the ultrasonic pulses generated at the transmitting transducer pass into the concrete and are then detected by the receiving transducer, it is essential that there be adquate acoustical coupling between the concrete and the face of each transducer. For most concrete surfaces, the finish is usually suffeciently smooth to ensure good acoustical contact by the use of a coupling medium and by pressing the transducer againest the concrete surface.

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Typical couplant are petroleum gelley, grease, liquid soap and kaoline / glycerol paste.
It is important that only a very thin layer of coupling medium separates the surface of the concrete from its contacting transducer. For this reason, repeated readings of the transit time should be made until a minimum value is optained so as to allow the layer of couplant to become thinly spread. When the concrete surface is very rough and uneven it is necessary to smooth and level an area of the surface where the transducer is to be fixed.

5-Measuring the pulse velocity in concrete

a. *Choice of transducers arrangement.*

The direct transmission arrangement is generally to be preferred since the maximum energy of pulse is being directed at the receiving transducer and this gives maximum sensitivity.
The indirect transmission arrangement is the least sensitive and, for a given path length, produces at the receiving transducer which has an amplitude of only about 2% or 3% of that produced by direct transmission. Further more, this arrangement gives pulse velocity measurements which are usually influenced by the concrete layer near the surface. This layer is often of different composition from that of concrete in deeper layers and the test results may be unrepresentative of that concrete. This arrangement should be used when only one face of the concrete is accessible, when the depth of a surface crack is to be determined or when the qualityof the surface concrete relative to the overall quality is interest.

6. Influence of test conditions on measurements of pulse velocity

a. *Surface conditions*

It is desirable, where possible, that the transducers should be in contact with concrete surfaces which have been cast againest formwork or a mould. Surfaces formed by other means e.g. trowlling, may have properties defering from those of the main body of material. If it is necessary to work on this surface it is desirable to measure over a longer bath length than would normally be used.
A minimum path length of 150mm is recommended for the direct transmission method involving one unmoulded surfaces and a minimum of 400mm for the indirect method along an unmoulded surface.
Where a particularly rough surface can not be avoided, the area which is to be in contact with a transducer should be ground flat or filled to a level smooth surface

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with a minimum thickness of a suitable material (e.g. plaster of paris, cement mortar or an epoxy resin) due time being allowed to elapse for the filling material to harden.

b. *Moisture content*

The moisture content of the concrete can have a small effect on the pulse velocity. For normal structural concrete in a saturated condition, the pulse velocity may be up to about 2% higher than it is in the same concrete in the dry condition, although in exceptional cases this figure may rise to about 5%.The moisture content has less influence on the velocity in high strength concrete than it does on low strength concrete.

c.*Temprature of the concrete*

Variations of the concrete temperature between 5c and 30c have been found to cause no significant change in the measured pulse velocity in concrete. Outside this range of temperature. Pulse velocity may change without the occurrence of corresponding change in strength or elastic properties. Interpretation of pulse velocity measurements should therefore take this into account for extreme temperature conditions.

d. *Path length*

It is recommended that, the minimum path length should be 100mm for concrete in which the nominal maximum size of aggregate is 20mm or less and 150mm for concrete in which the nominal maximum size of aggregate is between 20 and 40mm.

e. *Effect of reinforcing bars*

The pulse velocity measured in reinforced concrete in the vicinity of the reinforcing bar is usually higher than in plain concrete of the same composition. This is because the pulse velocity in steel is 1.2 to 1.9 times the velocity in plain concrete.

1. *Axis of reinforcing bar perpendicular to the direction of propagation.*

The maximum influence of the presence of the reinforcing bars can be calculated assuming that the pulse traverses the full diameter of each bar during it`s passage.

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Table 3 gives values of correction factors by which the measured velocities should be multiplied to obtain the true pulse velocity in the concrete alone. Values of correction factors are given to three different pulse velocities.

Table 3. Correction factors to allow for the effect of steel bars perpendicular to the direction of pulse propagation

Ls/L	velocity in concrete Vc km/s		
	Vc=3.0	Vc=4.0	Vc=5.0
0.10	0.95	0.96	0.98
0.15	0.93	0.95	0.97
0.20	0.90	0.93	0.96
0.25	0.88	0.92	0.95
0.30	0.85	0.90	0.95

L= total path length
Ls= total length of path through the steel

2. *Axis of reinforcing bar parallel to direction of propagation.*

The position of the path along which pulses are propagated should be chosen whenever possible so as to avoid the vicinity of reinforcing bar parallel to these paths. If this cannot be avoided, measured values of pulse velocity should be corrected to take into account the presence of the steel. This will depend on the distance between the line of the path in the edge of the nearest bar. The pulse velocity in the concrete is given by:

$$V_c = \frac{2aV_s}{\sqrt{4a^2 + (TV_s - L)^2}}$$

where Vs = pulse velocity in the steel bar
Vc = pulse velocity in the concrete
a = the distance from the surface of the bar to the line joining the nearest point of the transducers

The influence of the steel disappears when

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

$$\frac{a}{L} > \frac{1}{2}\sqrt{\frac{V_s - V_c}{V_s + V_c}}$$

we can neglect the influence of steel when

a / L > 0.25 for low quality concrete
a / L > 0.15 for high quality concrete

7- measurement of pulse velocity using the indirect transmission method

The arrangement for this method is illustrated in Fig.12c. When using this arrangement there is some uncertainty regarding the exact length of the transmission path because of the significant size of the areas of contact between the transducers and the concrete. It is therefore perefrable to make a series of measurement with the transducers at different distances apart to elemenate this uncertainty.
To do this, the transmitting transducer should be placed in contact with the concrete surface at a fixed point and the receiving transducer should be placed at fixed increments of distance along a chosen line on the surface.
The transmission times recorded should be plotted as point on a graph showing their relation to the distance separating the transducers. An example of such a plot is shown in Fig. 13.
The slope of the best straight line drawn through the points should be measured and recorded as the main pulse velocity along the chosen line on the concrete surface.
Where the points measured and recorded in this way indicate a discontiuouty it is likely that a surface crack of surface layer or inferior quality is present, see art. 8.

8- Detection of defects

a. *Estimating the depth of a surface crack*

It is sometimes required to obtain an estimate of the depth of a crack which is visible at the surface of a concrete structure. An estimate of crack depth is obtained by measuring the transit time across the crack for two different arrangement of the transducers placed on the surface.
One suitable arrangement in which the transmitting and receiving transducers are placed on opposit sides of the crack and equidistant from it. Two values of x are chosen and the transit times corresponding to these are measured.
Two convenient values of x are 150 and 300mm. If these values are used, the

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

depth of the crack is given by:

$$c = 150\sqrt{\frac{4t_1^2 - t_2^2}{t_2^2 - t_1^2}}$$

where c is the depth of the air-filled crack
t1 is the transit time for x= 150mm
t2 is the transit time for x= 300mm

Equation (3) is drived by assuming that the plane of the crack is perpendicular to the concrete surface and that the concrete in the vicinity of the crack is of resonably uniform quality.

b. *Estimating the thickness of a layer of inferior quality concrete*

Concrete may be suspected as having surface layer of poor quality.This may occur during manifacture, or arise as a result of damaged by fire, frost, sulphate attack etc. The thickness of such a layer of concrete can be estimated from ultasonic measurements of transit time along the surface. The procedures desirable art.7 should be used and the results plotted on a graph as in Fig. 13. At the shorter distance of separation of the transducers the pulse travels through the srface layer and the slope of the experimental line gives the pulse velocity in this surface layer. Beyond a certain distance of separation the first pulse to arrive has passed along the surface of the underlying, higher quality concrete and the slope of these experimental points gives the velocity in that concrete. The distance Xo at which the change of slope occurs together with the measured pulse velocities in the two different layers of concrete enables an estimate of the thickness of the surface layer to be found as follows:

$$t = \frac{X_o}{2}\sqrt{\frac{V_s - V_d}{V_s + V_d}}$$

where Vd is the pulse velocity in the damaged concrete.
Vs is the pulse velocity in the underlaying sound concrete.
t is the thickness of the layer of damaged concrete.

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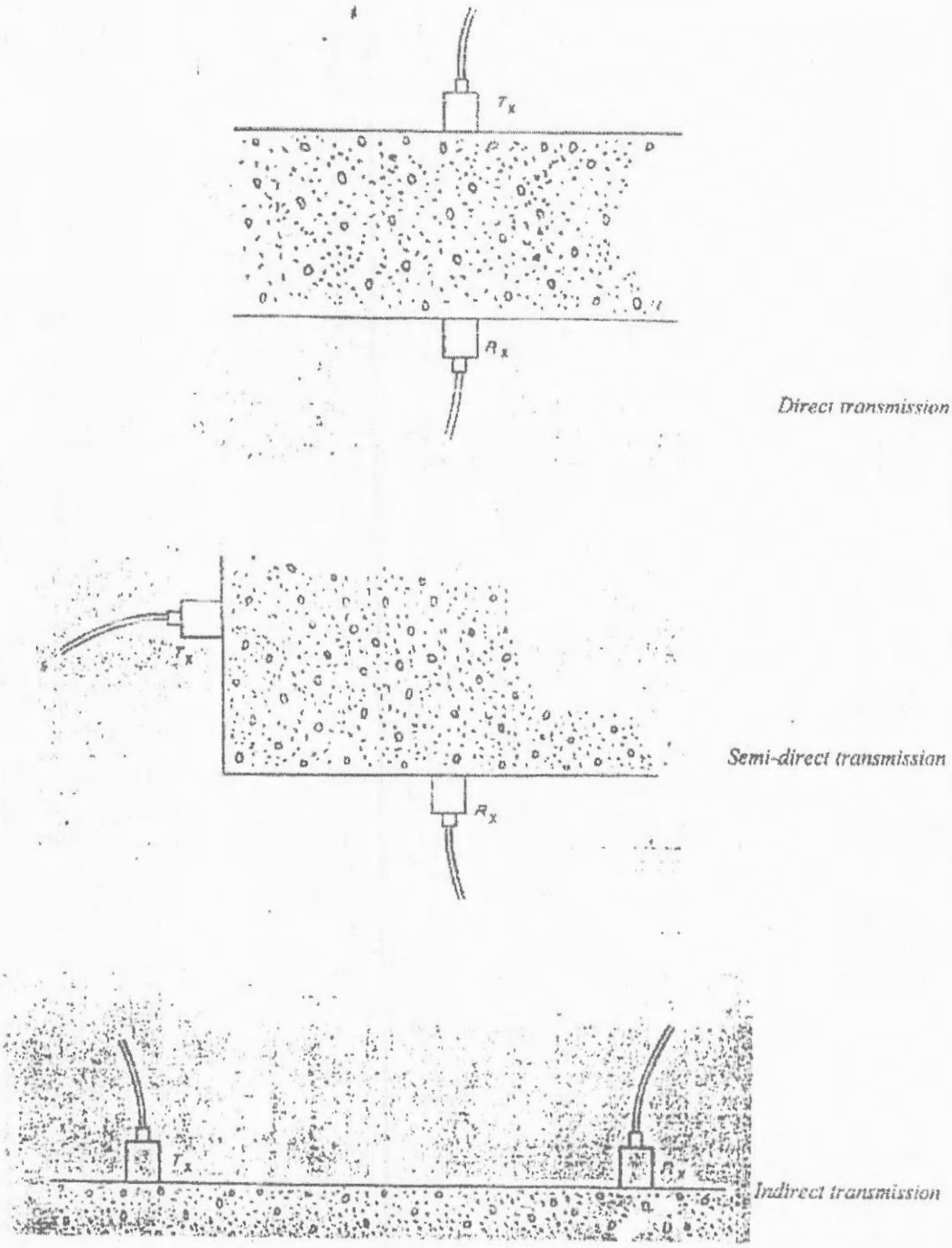

Fig 12 Transsmision arrangements of ultrasonic transducers.

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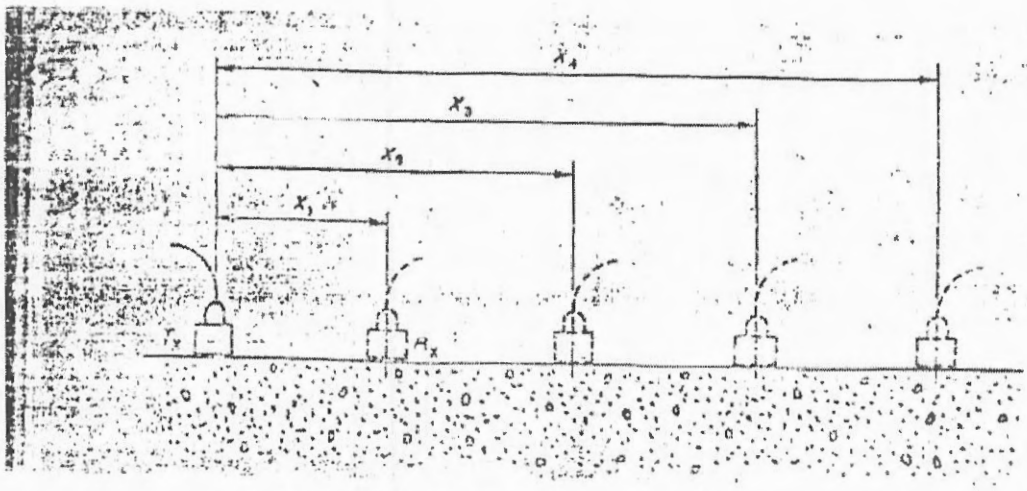

Fig.13 Measuring the velocity of ultrasonic pulses in concrete using indirect transsmision arrangement.

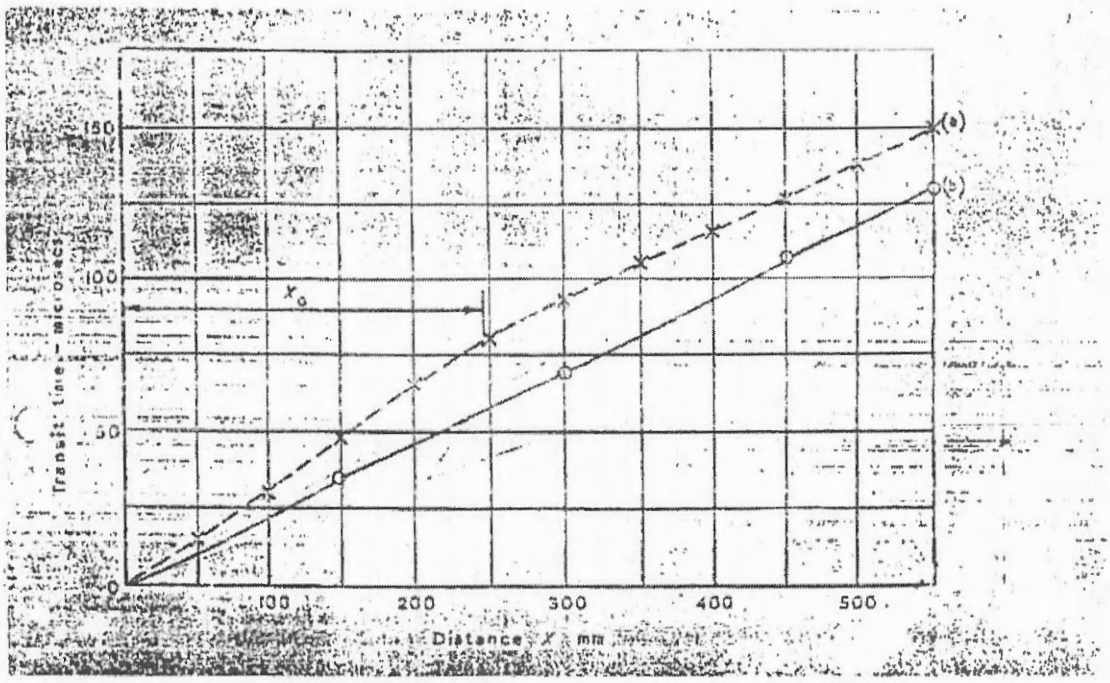

Fig 14 measuring the thickness of a layer of inferior quality concrete.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

Experiment (5)

Method for determination of the compressive strength of concrete cores

1- Objectives

Upon the completion of this experiment student will be able to take cores from concrete and prepare them for testing and for determining their compressive strength.

2- Equipment required

- *Core drilling machine.*
- *Steel collar.* A steel collar with a machined edge suitable for use in capping.
- *steel plate.* A horizontal steel plate having a circular groove suitable for the size of specimens to be capped.
- *Glass capping plate.*
- *Compression testing machine.* A compression testing machine of reasonable accuracy (about 2 KN).

3- Test specimens

1- *Size of cores.* Test specimens shall be 100mm or 150mm diameter, the preferred diameter is 150mm. The ratio of diameter to the maximum aggregate size shall be not less than 3.
The usable length of core shall be such that the length / diameter ratio for strength testing shall be between 1 and 2.

Note. The preferred length / diameter ratio is between 1 and 1.2.

If the whole length of a core is to be tested in compression, the diameter shall be chosen in the specified ratio to the depth of member from which the core is taken.

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١٤ شارع السبكى – خلف نادى هليوبوليس
مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

2- *Drilling*. Unless specifically required otherwise, cores shall be drilled perpendicular to the surface using a diamond core drilling bit and in such a manner as not to damage the core. The drill shall be kept rigidly positioned during coring. Otherwise ridged or curved cores may be obtained. Drilling through reinforcement shall be avoided wherever possible.

3- *Identification*. Immediately after cutting mark each core clearly and indelibly, indicating its location and orientation within the member. Record the direction of drilling of each core relative to the direction of casting.
Mark the core to indicate distances in millimeters from the drilling surfaces so that the location in the element from which the test core came can be confirmed when the ends have been trimmed.

4- *Examination*.

a- *Compaction* Examine each specimen for compaction, for the presence of voids, for honeycombing and for cracks. Note the position at which any honeycombing begins.
Describe the compaction of the concrete by comparing the core surface with Figs. 15(a) to 15(e) by measuring excess voidage which is that amount by which the actual voidage exceeds the voidage of a well made cube of the same concrete.
Where description needs to be amplified, this shall be done by reference to the following terms.
(a) Small voids. A void measuring not less than 0.5mm and not more than 3.0mm across in any direction.
(b) Medium voids. A void having a dimension greater than 3mm but not greater than 6mm.
(c) Large voids. A void having a dimension greater than 6mm.
(d) Honeycombing. Interconnected voids arising from, for example, inadequate compaction or lack of mortar.

In order to avoid extremes of subjective bars, two observes shall compare the surface voids of a given core with those shown in Fig.15, taken care to insure that the voids are viewed in strong light angled so as to high light them with shadows (as in Fig.17). The procedure for the comparison is as follows:
(a) cut a 125mm x 80mm rectangular aperture in a piece of thin card;
(b) place the card on the core with elastic bands;

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١٤ شارع السبكى – خلف نادى هليوبوليس
مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

roughened by hacking or wire brushing. The method given in (a) is suitable for specimens which have been soaked in water and the method given in (b) is suitable for dry specimens.

(a) The capping material consists of a morter composed of three parts by mass of high alumina cement to one part by mass of fine sand (most of which passes a 300 micromillimeter sieve). Place the soaked specimen on a horizontal plate, and rigidly clamp a steel collar of correct diameter and having a machined upper edge to the end of the specimen to be capped, in such a way that the upper edge is horizontal and just extends above the highest part of the concrete surface. Fill the capping material into the collar until it is in the form of a convex surface above the edge of the collar. Press down the glass capping plate, coated with a thin film of mould oil, onto the capping material with rotary motion until it makes complete contact with the edge of the collar. Immediately place the specimen with coller and plate in moist air of at least 90% relative humidity and at temperature of 20 + 5 C, and remove the plate and collar when the morter is hard enough.

(b) The capping material consists of mixture composed of equal parts by weight of sulphur and fine siliceous sand (most of which passes a 300 micromillimeter sieve and is retained on a 150 micromillimeter sieve) together with small proportion (1% to 2%) of carbon black or a small proportion (2% to 4%) of polysulphite rubber. Heat the mixture to a temperature of approximately 130 C to 150 C and then allow it to cool slightly while being stirred continuously. Pour the mixture onto a level machined steel plate that has been slightly warmed and thinly coated with paraffin. Place the specimen into this layer with its axis vertical using a guide. After a few seconds, cut away the surplus material around the specimen with a sharp knife and lift the specimen off the plate. The cap shall not flow or fracture before the concrete fails when the specimen is tested.

4- *Storage.* After capping, immerse the specimen in water at 20 + 2 C for at least 48 h before testing. with cores from high strength concrete do not remove the specimens from the water until the high alumina morter caps reach a higher strength than expected of the concrete.
Store cores to be ground in water at 20 + 2 C except that they may be removed from the water for not more than 1 h for grinding and measurement. Return the specimen to the water for at least 1 h after grinding before testing.

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١٤ شارع السبكى – خلف نادى هليوبوليس
مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

5- Experimental procedure

1- *General.* Test the core in compression not less than two days after end preparation and immersing in water. Cores with cracked or loose caps shall not be tested. Test the core immediately on removal from the water and whilst it is still wet.

2- *Placing the core in the testing machine.* wipe the bearing surfaces of the testing machine and of any auxiliary platens clean and remove any water, loose sand or other material from the ends of the core. Center the core carefully on the lower platen of the machine. Wherever possible use jig to align the specimen stop do not use any cracking other than auxiliary steel platens between the ends of the core and the platens of the testing machine.

3- *Loading.* Without shock apply and increase the load continuously at constant rate within the range of 0.2 N / (mm2.s) to 0.4 N / (mm2.s) until no greater load can be sustained. On manually controlled machines as failure is approached the load-indicator pointer will begin to flow down; at this stage operate the controls rapidly and smoothly to maintain as far as possible the specified loading rate. Record the maximum load.

6- Calculation and expression of results

1- *General.* Calculate the compressive strength of each core by dividing the maximum load by the cross-sectional area, calculated from the average diameter. Express the results to the nearest 0.5 N/mm2.

2- *Estimated in-situ cube strength.*
a- *For cores free of reinforcement.* Calculate the estimated in-situ cube strength to the nearest 0.5 N/mm2 from the equation

$$\text{estimated in-situ cube strength} = [D / (1.5 + 1/\lambda)] \times \text{measured compressive strength of core} \quad (1)$$

where

D is 2.5 for cores drilled horizontally; Or 2.3 for cores drilled vertically;
λ is the length (after end preparation) / diameter ratio.

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١٤ شارع السبكى – خلف نادى هليوبوليس
مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

Important Note. It should be noted that in-situ strengths estimated from the above formula cannot be equated to standard cube strength.

b- *For cores with reinforcement perpendicular to the core axis.* Calculate the estimated in-situ cube strength by multiplying the strength obtained from the formula (1) by the following factors

(a) for cores containing a single bar

$$1.0 + 1.5 \times (\Phi r\ d / \Phi c\ \ell) \qquad (2)$$

(b) for specimens containing two bars no further apart than the diameter of the larger bar, only the bar corresponding to the higher value of Or d need be considered. If the bars are further apart, their combined effect should be assessed by using the factor

$$1.0 + 1.5 \times (\Sigma \Phi r\ d / \Phi c\ \ell) \qquad (3)$$

where

Φr is the diameter of the reinforcement;
Φc is the diameter of specimen;
d is the distance of axis of bar from nearer end of specimen;
ℓ is the length of uncapped specimen.

7- Report

- identification of the core;
- date of drilling;
- direction of drilling relative to direction of casting;
- conditions of storage;
- identification of the specimen;
- condition of specimen when received (include poor compaction, honeycombing
- or bad dimensions);
- average diameter;
- maximum and minimum lengths, as-received;
- length after end preparation;
- compaction of concrete, distribution of materials, classification of voids and
- presence of cracks;

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

- date of test;
- maximum load of failure;
- measured compressive strength and estimated in-situ cube strength.

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١٤ شارع السبكى – خلف نادى هليوبوليس
مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

تقييم نتائج اختبار مقاومة الضغط للخرسانة

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مصر الجديدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

مقدمة:

الغرض من اختبار مقاومة الضغط للخرسانة هو تحديد مدى تحقق متطلبات المقاومة وقياس التغير فى قيمتها. يحدث التغير فى مقاومة الخرسانة نتيجة تعرضها للعديد من المتغيرات ونتيجة كونها مكونة من عدة مواد غير متجانسة غير ثابتة الخواص. وقد يحدث التغير نتيجة التغير فى طرق تصميم الخلطات، طرق الخلط، النقل أثناء الصب، الصب، والطرق المستخدمة فى المعالجة. حيث أن التغيير فى أسلوب العمل فى أى من المراحل السابق ذكرها يؤدى الى تغيير ملحوظ فى مقاومة الخرسانة.

والجدير بالذكر أن التغير فى مقاومة الخرسانة هو أمر واقع مسلم به ولكن يمكن تصنيع خرسانات ذات جودة معينة فى ظل وجود هذا التغير اذا تم عمل نظام للتحكم فى جودة الخرسانة، وذلك عن طرية تحليل نتائج اختبارت مقاومة الضغط و الألتزام بحدود التغير الموصى بها.

يتم التحكم فى جودة الخرسانة بتحقق مايلى

١- استخدام مواد مناسبة.

٢- الأعداد الجيد لنسب الخلطة.

٣- الخلط الجيد.

٤- النقل والصب بالطرق المناسبة.

٥- واتباع الأساليب المناسبة فى المعالجة.

٦- اجراء الأختبارات وتحليل نتائجها بدقة.

تحسين التحكم فى جودة الخرسانة يؤدى الى تقليل تكلفتها حيث يمكن الوصول بالمقاومة المتوسطة لمتطلبات والأشتراطات المطلوبة بدقة.

التغير فى المقاومة

تعتمد قيمة التغير فى مقاومة الخرسانة على مدى التحكم فى جودة الخامات، وتصنيع الخرسانة، ودقة الأختبار. يوجد مصدرين أساسيين للتغير فى جودة الخرسانة، كما هو وارد فى جدول (٢)، وهما:

أ- التغير فى خواص الخرسانة ومكوناتها.

ب- التغير فى نتائج من الأختبار.

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١٤ شارع السبكى – خلف نادى هليوبوليس
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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

جدول (٢)

التغير فى خواص الخرسانة	التغير من الأختبار
التغير فى نسبة م/س، وينتج من: ١- التحكم السئ فى كميات الماء ٢- التغير فى نسبة الرطوبة بالركام	الأسلوب الغير سليم فى أخذ العينات
التغير فى متطلبات الماء، وينتج من: ١- التغير فى تدرج الركام ٢- نسبة امتصاص الركام ٣- التغير فى شكل حبيبات الركام ٤- خواص الأسمنت والأضافات ٥- محتوى الهواء ٦- زمن النقل ودرجة الحرارة	الأعداد الغير جيد للعينات حديثة التجهيز، ويشمل: ١- التداول ٢- المعالجة ٣- استخدام قوالب غير صالحة
التغير فى خصائص ونسب المكونات وهى: ١- الركام ٢- الأسمنت ٣- المواد البوزولانية ٤- الأضافات	التغير فى المعالجة، وتشمل: ١- درجة الحرارة ٢- نسبة الرطوبة ٣- التأخير فى جلب العينات الى المعمل
التغير فى النقل، الصب، الدمك التغير فى درجة الحرارة والمعالجة	عدم اتباع الخطوات الصحيحة أثناء الأختبار، وتشمل: ١- تغطية سطح العينات (Capping) ٢- اختبار مقاومة الضغط

أ- التغير فى خواص الخرسانة ومكوناتها

من المعروف أن مقاومة الخرسانة تتوقف الى حد كبير على نسبة الماء الى الأسمنت. وعلى ذلك فانه

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

للحصول على خرسانة ثابتة المقاومة يجب الحفاظ على نسبة الماء الى الأسمنت دون تغيير. من السهل التحكم فى كمية الأسمنت وكذلك كمية الماء المضاف للخلطة، ومع ذلك يحدث تغير فى نسبة الماء الى الأسمنت نتيجة محتوى الرطوبة فى الركام والتغير فى تدرجه ومقاسات حبيباته. وكذلك التغير فى خصائص الأسمنت، والأضافات. ويؤدى ذلك الى تغير نسبة الماء الى الأسمنت عن ماهو مطلوب وبالتالى يحدث تغيير ملحوظ فى المقاومة.

من الجدير بالذكر أن استخدام الأضافات يضييف عامل آخر كمصدر للتغير فى مقاومة الخرسانة. ويتوقف قدر هذا التغير على نوعية وكمية الأضافات المستخدمة، ولذلك يجب استخدام هذه الأضافات بالنوعيات والكميات التي تحددها المواصفات مع عمل الأختبارات اللازمة على خلطات تجريبية لتحديد مدى التغير الذى تسببه هذه الأضافات فى خصائص ومقاومة الخرسانة وكذلك مدى توافق هذا التغير مع الحدود المسموح بها.

ب- التغير الناتج من الأختبار

من الممكن أن تكون اختبارات الخرسانة هى مصدر التغير فى المقاومة، ويتوقف ذلك على المتغيرات التى قد تطرأ على العينات بعد اعدادها. وعلى الجانب الآخر، فان التغير فى طريقة أخذ العينات واعدادها، ومعالجتها، واختبارها، قد يؤدى الى اظهار تغير فى المقاومة والذى لايكون موجود فى الخرسانة التى تم صبها فى الموقع.

ويقلل من هذا النوع من التغير فى المقاومة، اتباع الخطوات السليمة فى اختبار العينات، واتباع الطرق التى تنص عليها المواصفات دون أى تحريف. ويوصى باستخدام ماكينات اختبار دقيقة وألواح تحميل رقيقة السمك وعالية المقاومة وعمل تسويات مستوية ومتوازية لأسطح عينات الأختبار، كما يجب عمل معايرة دورية لماكينات الأختبار لضمان دقة قراءاتها.

<u>تحليل نتائج مقاومة الضغط</u>

١- الأصطلاحات

d_2, $1/d_2$ = معاملات لحساب معاير الأنحراف خلال الأختبار (within-test standard deviation)

f_α = المقاومة المستهدفة

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

f_c' = المقاومة المطلوبة

n = عدد الأختبارات

R = المدى

$\overline{R}_m$ = أقصى قيمة للمدى المتوسط وتستخدم فى منحنيات التحكم للمدى المتوسط المتحرك

$\overline{R}$ = المدى المتوسط

σ = الأنحراف المعيارى

σ_1 = الأنحراف المعيارى خلال الأختبار

σ_2 = الأنحراف المعيارى من خلطة-الى-خلطة

t = رقم ثابت يضرب فى الأنحراف المعيارى وتتوقف قيمته على عدد النتائج المسموح بأن تقع تحت المقاومة المطلوبة f_c'

V = معامل الأختلاف

V_1 = معامل الأختلاف خلال الأختبار

X_i = نتيجة عينة واحدة فى الأختبار

$\overline{X}$ = متوسط نتائج الأختبار

عـــــام

للحصول على أقصى بيانات ممكنة، يجب عمل عدد كاف من الأختبارات لتحديد التغير فى الخرسانة ولأمكان عمل الخطوات الأحصائية اللازمة للتحليل الدقيق لنتائج الأختبارات. ويعطى التحليل الأحصائى الأسس المثلى لأستخدام نتائج الأختبارات فى تعيين الجودة والمقاومة الفعلية للخرسانة وللتعبير عن النتائج فى انسب وأنفع الصور.

الدوال الأحصائية

فى مواقع العمل التى يتم فيها التحكم فى جودة الخرسانة، يمكن تمثيل نتائج اختبار عينات الخرسانة بمنحنى التوزيع الطبيعى (منحنى الجرس) كما هو فى شكل (١). ومن هذا المنحنى، يمكن معرفة درجة جودة الخرسانة، ففى حالة التحكم الجيد فى الجودة يكون جانبى المنحنى أقرب مايكون من المتوسط (المحور الرأسى) ويكون المنحنى طويل وقليل الأتساع. وفى حالة الخرسانة ذات تغير كبير فى المقاومة؛ أى درجة التحكم فى الجودة سيئة؛ يكون المنحنى متسع؛ أى تبعد جوانبه عن المتوسط؛ ويكون المنحن

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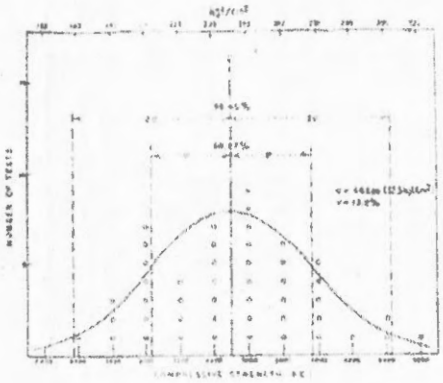
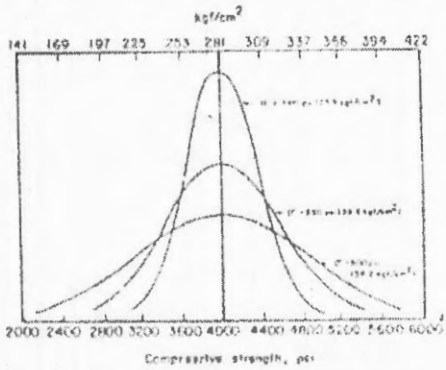
مصر الجـــديـــدة – القاهرة – جمهورية مصر العربية
ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

قصير، كما هو فى شكل (١). وحيث أن خصائص هذا المنحنى يمكن التعبير عنها رياضيا، فانه يمكن حساب دوال معينة للمقاومة كما يلى:





شكل رقم (١)

أ- المتوسط، $\overline{X}$ - متوسط جميع نتائج الأختبارات

$$X = \frac{X_1 + X_2 + X_3 + ... + X_n}{n} \qquad (١)$$

حيث $X_1, X_2, X_3, ...X_n$ هى نتائج المقاومة للأختبارات و n هى عدد الأختبارات التى تم اجراؤها. ويعرف الأختبار بأنه متوسط مقاومة كل العينات التى لها نفس العمر ومأخوذة من نفس العينة من خلطة معينة من الخرسانة.

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

ب- الأنحراف المعيارى، σ

المقياس المعروف للتشتت هو جذر متوسط مربعات انحراف المقاومة عن متوسطها. ويعرف هذا المقياس بالأنحراف المعيارى ويمكن اعتباره نصف القطر الدوار حول محور التماثل للمساحة تحت منحنى التوزيع الطبيعى للمقاومة. ويحسب الأنحراف المعيارى من المعادلة:

$$\sigma = \{[(X_1 - \overline{X}) + (X_2 - \overline{X}) + ... + (X_n - \overline{X})]/n - 1\}^{\frac{1}{2}} \qquad (٢-أ)$$

أو من المعادلة المكافئة:

$$\sigma = \sqrt{\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}} \qquad (٢-ب)$$

والمعادلة رقم (٢-ب) مفضلة عن المعادلة رقم (٢-أ) لسهولة استخدامها.

ويعتبر مقياس الأنحراف المعيارى أدق من المتوسط وذلك لأن مربع الأنحراف عن المتوسط يجنب الوقوع فى الخطا الناتج من أخذ الأشارة فى الأعتبار (+ أو -) كما هو الحال عند حساب المتوسط. ولذلك فمن الأخطاء الشائعة الأعتماد على مقياس المتوسط فى الحكم على مقاومة الضغط المتوسطة.

ج- معامل الأختلاف، V

معامل الأختلاف هو نسبة الأنحراف المعيارى الى متوسط المقاومة ويحسب من المعادلة الآتية:

$$V = \frac{\sigma}{\overline{X}} \times 100 \qquad (٣)$$

د-المدى، R

المدى هو الفرق بين أقل وأعلى رقم لمجموعة من الأرقام. ويحدد المدى خلال-الأختبار بطرح أقل مقاومة عينة من أعلى مقاومة عينة من مجموعة عينات تمثل أختبار واحد. ويفيد تعيين المدى خلال-

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

الأختبارفى حساب الأنحراف المعيارى خلال-الأختبار كما سيرد ذكره لاحقا.

التغير فى المقاومة

كما ذكر سابقا ان التغير فى نتائج المقاومة يمكن تقسيم اسبابه الى مصدرين أساسيين:

أ- التغير فى خواص الخرسانة ومكوناتها، ب- التغير الناتج من الأختبار.

من الممكن بتحليل المتغيرات حساب التغير الناتج من كل مصدر.

أ-التغير خلال-الأختبار(Within-test-variations)

يتم ايجاد التغير فى مقاومة الخرسانة خلال اختبار واحد بحساب التغير فى مقاومة مجموعة من العينات معدة من نفس العينة التى تم أخذها من خلطة خرسانة معينة. من المقبول اعتبار الخلطة التى تم أخذ العينات منها، متجانسة فى النسب والخصائص وأن أي تغير بين العينات وبعضها يرجع الى التغير فى اعداد العينات، أو معالجتها أو التغير الناتج من الأختبار.

ان خلطة واحدة من الخرسانة لاتكفى كمصدر لبيانات كافية للتحليل الأحصائى ويلزم اختبار عشرة خلطات على الأقل مختارة عشوائيا لحساب قيم معقولة لمتوسط المدى، $\overline{R}$. يتم حساب الأنحراف المعيارى ومعامل الأختلاف خلال-الأختبار كما يلى:

$$\sigma_1 = \frac{1}{d_2}\overline{R} \qquad (٤)$$

$$V_1 = \frac{\sigma_1}{\overline{X}} \qquad (٥)$$

حيث:

σ = الأنحراف المعيارى

$1/d_2$ = معاملات لحساب معاير الأنحراف خلال الأختبار (within-test standard deviation)

$\overline{R}$ = المدى المتوسط

V_1 = معامل الأختلاف-خلال-الأختبار

$\overline{X}$ = متوسط نتائج الأختبار

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

ب-التغير من خلطة-الى-خلطة (Batch-to-Batch variations)

هذه تعكس الأختلافات فى المقاومة والتى ترجع الى التغيرات فى:

أ- خصائص و خواص المكونات

ب- اعداد الخلطات والخلط وأخذ العينات

ج- الأختبار بالنسبة للعينات المأخوذة من خلطات مختلفة

وتؤخذ قيم 1/d من جدول (٣)

جدول (٣)

عدد العينات فى الأختبار الواحد	d_2	$1/d_2$
٢	1.128	0.8865
٣	1.693	0.5907
٤	2.059	0.4857
٥	2.326	0.4299
٦	2.534	0.3946
٧	2.704	0.3698
٨	2.847	0.3512
٩	2.970	0.3367
١٠	3.078	0.3249

التغير خلال-الأختبار والتغير من خلطة-خلطة مرتبطين بالأنحراف المعيارى الكلى كما هو فى المعادلة:

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 \qquad (٦)$$

حيث:

σ = الأنحراف المعيارى

σ_1 = الأنحراف المعيارى خلال الأختبار

σ_2 = الأنحراف للمعيارى من خلطة-الى-خلطة

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

منحنيات التحكم فى الجودة

تستخدم منحنيات التحكم فى الجودة، شكل (٢)، فى الصناعة منذ عدة سنوات فى تخفيض التغيرات ورفع كفاءة الأنتاج. ولذلك يوصى باستخدامها فى المواقع التى يتم انتاج الخرسانة فيها باستمرار على مدار فترة مناسبة. ويوجد ثلاث منحنيات تم اختيارهم خصيصا للتحكم فى جودة الخرسانة، شكل (٢). وتمثل هذه المنحنيات اهمية بالغة لأدارات المشروعات.

أ- منحنى مقاومة الأختبارات المفردة، (Chart for individual strength test)، وفيه يتم رسم نتائج جميع الأختبارات كما تم استلامها. ويرسم على هذا المنحنى خط يمثل المقاومة المتوسطة المطلوبة، f_{cr} ، وخط أخر يمثل المقاومة المميزة، f_c .

ب- المتوسط المتحرك لمقاومة الضغط، (Moving average for strength)، وفيه يتم رسم متوسط المقاومة لآخر خمسة اختبارات لليوم الواحد، أو الوردية الواحدة. وفى هذا المنحنى تمثل المقاومة المميزة الحد الأدنى. ويفيد هذا المنحنى فى اظهار اتجاه المقاومة وتأثير التغيرات من يوم الى الأخر او وردية عمل الى الأخرى، التغير فى الخامات،...الخ.

ج- المتوسط المتحرك للمدى، (moving average for range)، وفيه يتم رسم متوسطات المدى لآخر عشرة اختبارات لليوم الواحد، أو الوردية الواحدة. ويرسم على المنحنى أقصى متوسط مسموح للمدى لدرجة جودة جيدة بالمعمل. ويتم حساب أقصى متوسط للمدى من المعادلة:

$$\overline{R}_m = f_{cr} V_1 d_2 \qquad (٧)$$

حيث:

V_1 = معامل الأختلاف خلال الأختبار

f_{cr} = المقاومة المستهدفة

d_2 = معاملات لحساب معاير الأنحراف خلال الأختبار (within-test standard deviation)

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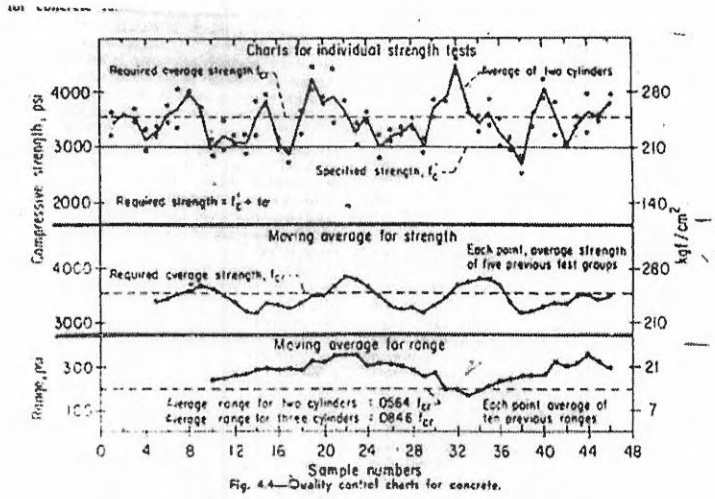

Fig. 4.4—Quality control charts for concrete.

شكل (٢) منحنيات التحكم فى الجودة

ويوضح الجدول (٤) درجات جودة الخرسانة محسوبة على أساس معاير الأنحراف ومعاير الأختلاف خلال الأختبار. تطبق القيم الموجودة فى جدول (٤) على نتائج اختبار مقاومة الضغط فقط ولاتصلح للأستخدام فى تقييم نتائج اختبارات لأنواع أخرى للأجهادات.

جدول (٤) درجات التحكم فى الجودة

التغـــــير الكـــــلى					
	الأنحراف المعيارى لدرجات جودة مختلفة (كجم/سم٢)				درجة الجودة
	ضعيفة	مقبولة	جيدة	جيدة جدا	ممتازة
فى الموقـــع	اكبر من ٤٩,٢	٤٢,٢ الى ٤٩,٢	٣٥,٢ الى ٤٢,٢	٢٨,١ الى ٣٥,٢	تحت ٢٨,١
فى المعـــمل	أكبر من ٢٤,٦	٢١,١ الى ٢٤,٦	١٧,٦ الى ٢١,١	١٤,١ الى ١٧,٦	تحت ١٤,١
معامل الأختلاف خلال-الأختبار					
	معامل الأختلاف لدرجات جودة مختلفة (%)				درجة الجودة
	ضعيفة	مقبولة	جيدة	جيدة جدا	ممتازة
فى الموقـــع	اكبر من ٦,٠	٥,٠ الى ٦,٠	٤,٠ الى ٥,٠	٣,٠ الى ٤,٠	تحت ٣,٠
فى المعـــمل	أكبر من ٥,٠	٤,٠ الى ٥,٠	٣,٠ الى ٤,٠	٢,٠ الى ٣,٠	تحت ٢,٠

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

مثـــــال تطبيقى

معطى نتائج مقاومة الضغط، جدول (٥)، لمكعبات مأخوذة من خلاطة مركزية بموقع لأنشاء منشأ خرسانى. مطلوب رسم المنحنيات الثلاثة للتحكم فى جودة الخرسانة مع تعيين كل المعايير والمقاييس الأحصائية الخاصة بنتائج مقاومة الضغط. مقاومة الضغط المستهدفة تساوى ٣٥٠ كجم/سم٢.

الحـــــل

١- المتوسط $(\bar{X}) = \frac{12398}{30} =$ ٤١٣ كجم/سم٢

٢- الأنحراف المعيارى $= \sqrt{\frac{5146896 - \frac{(12398)^2}{30}}{29}} = 28.3$ كجم/سم٢

٣- معامل الأختلاف $= \frac{28.3}{413} \times 100 = 6.85\%$

٤- متوسط المدى $= \frac{1013}{30} = 34$ كجم/سم٢

٥- الأنحراف المعيارى خلال-الأختبار = ٣٤ × 0.5907 = ٢٠ كجم/سم٢
تم اختيار 0.5907 من جدول (٢) حيث أن عددالعينات فى الأختبار الواحد = ٣

٦- معامل الأختلاف خلال-الأختبار $= \frac{20}{413} \times$ ١٠٠ = 4.84%

٧- القيمة القصوى للمدى المتوسط = ٣٥٠ × ٠,٠٤٨٤ × ١,٦٩٣ = ٢٩ كجم/س

شكل (٣) يوضح منحنيات التحكم فى الجودة.

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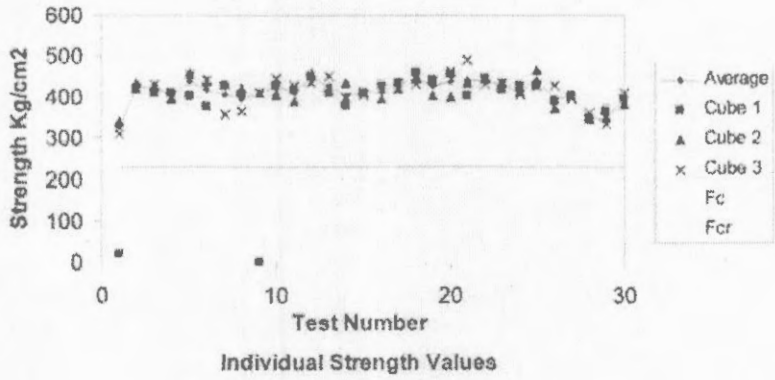
جدول (٥): نتائج مقاومة الضغط

رقم الأختبار	مكعب (١)	مكعب (٢)	مكعب (٣)
١	٣١١	٣٤١	٣٢٢
٢	٤١٩	٤٣٥	٤١٧
٣	٤٣١	٤٢٩	٤١٢
٤	٤٠٠	٣٩٧	٤١١
٥	٤٥٤	٤٥٩	٤٠٤
٦	٤٤١	٤٣٩	٣٧٥
٧	٣٦٠	٤٣٢	٤٢٩
٨	٣٦٦	٤١٩	٤٠٨
٩	٤١١	٤١٠	٢٥
١٠	٤٤٤	٤٠٨	٤٢٦
١١	٤٢٦	٣٩٠	٤١٧
١٢	٤٣٤	٤٦٠	٤٥٣
١٣	٤٥٣	٤١٥	٤١٠
١٤	٤٠٠	٤٣٥	٣٨١
١٥	٤٠٨	٤١١	٤١٠

رقم الأختبار	مكعب (١)	مكعب (٢)	مكعب (٣)
١٦	٤٢٢	٣٩٥	٤٢٦
١٧	٤٣٦	٤٢٢	٤٣٦
١٨	٤٣١	٤٤٤	٤٦٠
١٩	٤٣٩	٤٠٢	٤٤٠
٢٠	٤٦٢	٣٩٩	٤٥٥
٢١	٤٨٩	٤٣٥	٤٠٣
٢٢	٤٣١	٤٤٦	٤٤٤
٢٣	٤٣٣	٤٣٣	٤١٧
٢٤	٤٠٦	٤١٣	٤٢٦
٢٥	٤٢٧	٤٦٦	٤٢٧
٢٦	٤٢٧	٣٧٣	٣٩١
٢٧	٣٩٥	٤٠٤	٤٠٥
٢٨	٣٦٢	٣٥٠	٣٤٨
٢٩	٣٣٣	٣٥٣	٣٦٤
٣٠	٤١١	٣٨٤	٣٩٥



شكل (٣-أ) منحني قيم المقاومة المفردة

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ت : ٨٤٣ / ٧٤٤ / ٢٤١٩٠٢٧١ (٢٠٢) ف : ٢٢٩١٩٣٤١ (٢٠٢)

جدول (٦): تحليل النتائج

رقم الأختبار	مكعب (١)	مكعب (٢)	مكعب (٣)	المتوسط	المدى	المتوسط المتحرك	المدى المتحرك	مربع المتوسط
١	٣١١	٣٤١	٣٢٢	٣٢٨	٣٠	***	***	107584
٢	٤١٩	٤٣٥	٤١٧	٤٢٤	١٨	***	***	179776
٣	٤٣١	٤٢٩	٤١٢	٤٢٤	١٩	***	***	179776
٤	٤٠٠	٣٩٧	٤١١	٤٠٣	١٤	***	***	162409
٥	٤٥٤	٤٥٩	٤٠٤	٤٣٩	٥٥	404	***	192721
٦	٤٤١	٤٣٩	٣٧٥	٤١٨	٦٦	422	***	174724
٧	٣٦٠	٤٣٢	٤٢٩	٤٠٧	٧٢	418	***	165649
٨	٣٦٦	٤١٩	٤٠٨	٣٩٨	٥٣	413	***	158404
٩	٤١١	٤١٠	***	٤١١	١	415	***	168921
١٠	٤٤٤	٤٠٨	٤٢٦	٤٢٦	٣٦	412	36	181476
١١	٤٢٦	٣٩٠	٤١٧	٤١١	٣٦	410	37	168921
١٢	٤٣٤	٤٦٠	٤٥٣	٤٤٩	٢٦	419	38	201601
١٣	٤٥٣	٤١٥	٤١٠	٤٢٦	٤٣	425	40	181476
١٤	٤٠٠	٤٣٥	٣٨١	٤٠٥	٥٤	423	44	164025
١٥	٤٠٨	٤١١	٤١٠	٤١٠	٣	420	39	168100
١٦	٤٢٢	٣٩٥	٤٢٦	٤١٤	٣١	421	36	171396
١٧	٤٣٦	٤٢٢	٤٣٦	٤٣١	١٤	417	30	185761
١٨	٤٣١	٤٤٤	٤٦٠	٤٤٥	٢٩	421	27	198025
١٩	٤٣٩	٤٠٢	٤٤٠	٤٢٧	٣٨	425	31	182329
٢٠	٤٦٢	٣٩٩	٤٥٥	٤٣٩	٦٣	431	34	192721
٢١	٤٨٩	٤٣٥	٤٠٣	٤٤٢	٨٦	437	39	195364
٢٢	٤٣١	٤٤٦	٤٤٤	٤٤٠	١٥	439	38	193600
٢٣	٤٣٣	٤٣٣	٤١٧	٤٢٨	١٦	435	35	183184
٢٤	٤٠٦	٤١٣	٤٢٦	٤١٥	٢٠	433	32	172225
			٤٢٧			433	35	193600
						424	37	157609
						416	37	160801
						401	36	124609
						388	35	122500
						380	31	157609

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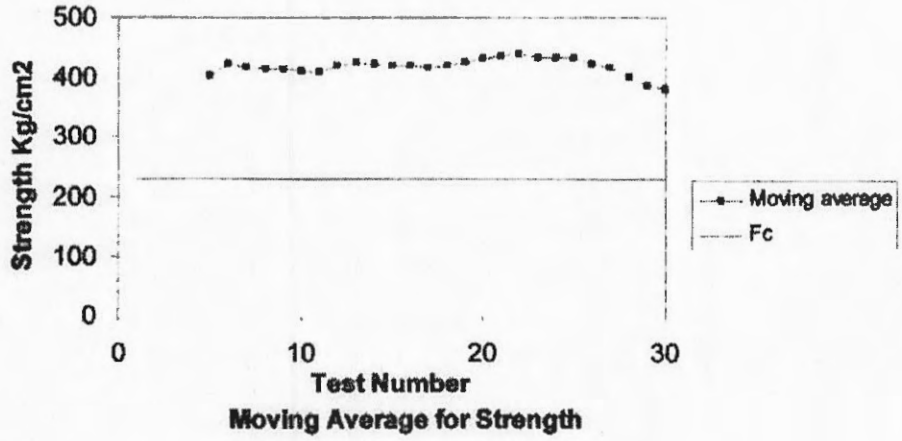
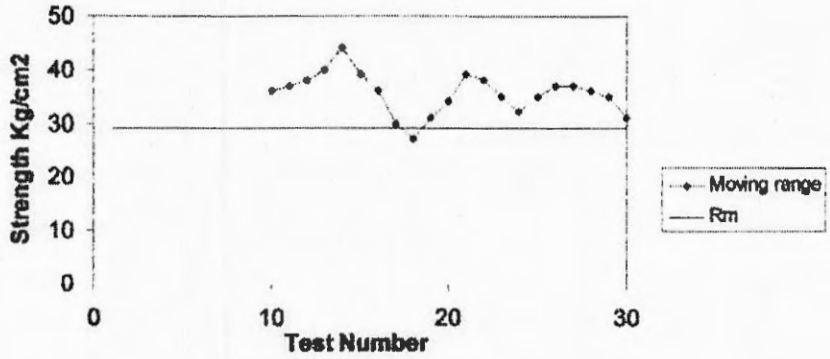
			٣٩	٤٤٠	٣٩١	٤٦٦	٤٢٧	٢٥
			٥٤	٣٩٧	٤٠٥	٣٧٣	٤٢٧	٢٦
			١٠	٤٠١	٣٤٨	٤٠٤	٣٩٥	٢٧
			١٤	٣٥٣	٣٦٤	٣٥٠	٣٦٢	٢٨
			٣١	٣٥٠	٣٩٥	٣٥٣	٣٣٣	٢٩
			٢٧	٣٩٧		٣٨٤	٤١١	٣٠
٥١٤٦٨٩٦			١٠١٣	١٢٣٩٨				المجموع



Moving Average for Strength



Moving Average for Range

شكل (٣-ب) منحنى المتوسط المتحرك للمقاومة ومنحنى المتوسط المتحرك للمدى

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