Chapter 4

Laboratory Testing

4.1   Introduction

Chapter 3 describes the manufacturing process of a large number of blocks in August 1987. In October 1987, these blocks were installed in two heavily trafficked sites. In the interim month of September 1987, blocks from the same mixes were also tested in the laboratory, in order to determine their compressive strength, abrasion resistance, etc. In 1993, after six years of traffic, the site blocks were measured for wear (see chapter 5), and this wear was compared with the 28-day laboratory results, making it possible to calibrate the laboratory tests in terms of wear.

This chapter describes the laboratory tests of September 1987.

On the 9th to 12th September 1987 extensive laboratory testing was carried out in the laboratory at the Portland Cement Institute (PCI, now C&CI), Portland Park, Halfway House. At this stage the pavers were 28 days old. A total of 3216 tests were carried out on 2304 paving blocks. Ten different test types were used as detailed in table 4.1.

Forty-eight mixes were subjected to each of the tests given in Table 4.1. For example 48 mixes x 6 blocks per mix = 288 blocks were subjected to each of the three compression tests, and 48 x 5 = 240 blocks were subjected to each abrasion test, etc. (Each of the 48 mixes consisted of one single mix of approximately 1350 kg, sufficient to make all the samples for all the ten laboratory tests, as well as for installation of a road and sidewalk at the test site).

The Initial Surface Absorption Test (ISAT) was done at the University of the Witwatersrand, while McLachlan and Lazar, a commercial laboratory in Johannesburg, did the water content tests. All other tests were done at PCI.

Figure 4.1 Personnel involved in the PCI testing programme

TABLE 4.1 LABORATORY TESTING PROGRAMME			
TYPE OF TEST	BLOCKS	TESTS	APPEN-DICES
1 COMPRESSIVE STRENGTH TO: SABS 1085	288	288	B.1 - B.8
2 COMPRESSIVE STRENGTH TO: ASTM C140	288	288	C.1 - C.8
3 COMPRESSIVE STRENGTH TO: MA20	288	288	D.1 - D.8
4 TENSILE SPLITTING TO: ISO 4108	288	288	E.1 - E.8

5 ABRASION RESISTANCE TO
  WIREBRUSH TEST:
  - DIAL METHOD
  - VERNIER METHOD
  - CLAY METHOD
	
	240
	*
	*
		
		240
		240
		240
			
			F.1 - F.8
			G.1 - G.8
			H.1 - H.9

6 ABRASION RESISTANCE TO: ASTM C418	240	240	I.1 - I.9
7 ABRASION RESISTANCE TO: MA20	240	240	J.1 - J.8
8 WATER ABSORPTION TO ASTM C140 AND DRY DENSITY TO ASTM C642	288	288	K.1 - K.8
9 INTIAL SURFACE ABSORPTION ISAT TO: SABS 0164	*	288	K.1 - K.8

10 WATER CONTENT BY:
  -DRYING AT 100° C
  -FIRING AT 1000° C
  -SUGAR METHOD
  -CALCIUM CARBIDE METHOD
	
	144
	*
	* *
	* *
		
		144
		144
		* *
		* *
			
			L.1 - L.8
			L.1 - L.8
			table 6.2
			table 6.2

TOTAL	2304	3216	

* Same samples as above test also used for this test

* * Fresh concrete used for these tests

4.1.1   Age at testing

Apart from the water absorption tests and water content tests all the other blocks were tested at an age as close to 28 days as was practically possible, bearing in mind the volume of tests that had to be done. To make this possible the following steps were taken:

The blocks were manufactured over a three day period, which made testing at 28 days more manageable. A team of operators was used to man the various testing machines (see figure 4.1). One operator manned a compression testing machine for all three of the compression tests, although the preparation work of cutting the plywood, capping etc was done by others. Another manned a second compression-testing-machine for the tensile

splitting tests. Each of the three abrasion tests had a separate operator. All the operators were either full time laboratory personnel with long experience on their respective testing machines or in the case of the abrasion testing equipment (relatively new equipment) specialised training had been undertaken prior to the tests. All the tests were carried out in close proximity to one another at the PCI laboratory allowing the author to continuously monitor the programme and relate with the operators as required.

In the period between manufacture and testing the blocks all received the same curing regime as described in 3.3.6 and 3.3.8.

4.1.2   Organisation of chapter

The remainder of this chapter will be devoted to a short description of each test method with some diagrams and photographic illustrations. Those test methods that are recognised national or international standard test methods, will only be summarised briefly.

Minimal comment (if any) as to the effectiveness of the various tests will be made in this chapter, as this is done later on in Section 3: Results and Discussion (chapter 6 onwards). Nor is the rationale for the selection of the ten test types given, as this was done briefly in 1.6.1 under the heading 'Laboratory Tests', with further motivation given in the 'Results and Discussion' section of this thesis.

4.2   Compressive Strength to SABS 1058 - 1985

The test method is fully described in SABS-1058 (1984).

A total of 284 blocks (representing the 48 mixes) were tested at Portland Park. The results are recorded in appendices B.1 through B.8 and summarised in column B of table 6.2. Each result in this table is the average of 6 tests.

In this test the specimen is prepared by immersing the specimen in water for 24 hours prior to testing. Next the block is placed in the compression testing machine (see figure 4.2) between two 3 mm thick plywood pieces of area at least equal to that of the specimen and crushed. The maximum force is recorded from which the strength is calculated. The area used in this calculation is the area of the wearing face. Where a block has a bevelled effect around the perimeter (a common feature), or some indented patterns on the wearing face, only the uppermost surface (net area) is considered in the calculation of the compressive strength. Were the bottom face or gross plan area of the block used, a lower result would be obtained. It should be noted by way of contrast, that the MA20 test and the ASTM-C140 method both use the gross area.

The compressive strength of the specimen is calculated from the expression:

$C = F / A$ …… (4-1)

Where: C = compressive strength; F = maximum force; A = net plan surface area

Limiting criteria: The specified strength requirement is an average (for 12 blocks) of 25 MPa for normal applications, and 35 MPa for paved surfaces where severe service or environmental conditions are expected.

It should be noted that South Africa does not have freeze and thaw conditions. Countries where such conditions occur generally have specifications calling for compressive strengths between 50 MPa and 60 MPa.

Figure 4.2 Compression testing machine used for all the compressive strength tests

4.3   Compressive Strength to ASTM C140

The test method is fully described in ASTM C140.

As for the test in 4.2 another sample of 284 blocks (representing the 48 mixes) was tested at Portland Park. The results are recorded in appendices C.1 through C.8 and summarised in column C of table 6.2. Each result in this table is, once again, the average of six tests.

In this test the specimen is prepared by capping the upper and lower faces with a gypsum plaster mixture to obtain two plane and opposite surfaces (see figure 4.3). The next day the specimens are crushed between the two steel platens of a compression testing machine. The maximum force is recorded and the strength is calculated from:

$C = F / A$ ……. (4-2)

where   C = compressive strength
        F = maximum force
        A = gross plan area

This test method differs from SABS 1058 in some ways, namely that:

a. The specimens are prepared beforehand by having the test faces capped with gypsum plaster instead of using 3 mm plywood platens. Generally this results in a slightly higher compressive strength, as the upper and lower surfaces of the paver are frictionally restrained by the very stiff steel platens [Newman(1997d)], rather than a plywood packing that allows some lateral dilation.

b. The blocks are removed from the curing tanks 24 hours prior to testing and tested at the prevailing humidity conditions of the laboratory - tests [e.g. Sukandar(1993)] have shown that this leads to a significant increase in the compressive strength.

c. The gross plan area of the block is used to determine the compressive strength of the blocks - this gives a true reflection of the strength of the block as opposed to the artificially high results achieved by using the net area as is done in SABS 1058.

d. No correction factor for aspect ratio (height to width ratio) is used as in the Australian MA20 test method - this yields unfavourable results for blocks of thickness greater than 60 mm. (See chapter 7 for a more detailed discussion).

The net effect of the above factors, relative to the SABS 1058 test, is that the combined favourable effect of a and b is cancelled by the unfavourable effect of c. This can be seen by the almost identical averages of 284 test specimens for each test. (See averages at bottom of table 6.2 i.e. 21,7 MPa for SABS 1085 and 21,4 MPa for ASTM C140).

Limiting criteria: ASTM C936-82, the 'Standard Specification for Solid Concrete Interlocking Paving Units' states that the average compressive strength shall not be less than 55 MPa with no individual result less than 50 MPa. This is far in excess of the SABS requirement, but it must be noted that the ASTM specification was drafted with resistance to freezing and thawing in mind.

Figure 4.3 Specimens being capped with gypsum on day before testing.

4.4   Compressive Strength to MA20-1986

MA20-1986 was the Australian specification for paving blocks until 1997. It has now been replaced with AS/NZS 4456.9

Once again a total of 286 blocks (representing the 48 mixes) were tested at Portland Park. The results are recorded in appendices D.1 through D.8 and summarised in column D of table 6.2. Again each result in this table is the average 6 tests.

The blocks were removed from the curing tanks at age 27 days so that they would be 'dry' rather than 'soaked' at 28 days.

In this test the specimens are crushed in a compression testing machine between two pieces of plywood as in the SABS test. The thickness of the plywood is 4 mm to 6 mm. The maximum force is recorded from which the strength is calculated.

The compressive strength is determined from an expression that has a correction factor for aspect ratio:

$$C = (W/A)(5/[((\sqrt{A})/H)+1.87] \quad \ldots\ldots. \quad (4\text{-}3)$$

Where:

C = compressive strength in MPa
W = total load at which the specimen fails, in newtons
H = nominal height of unit in mm
A = nominal gross plan area, in mm²

The characteristic strength is calculated as follows:

$$C_k = C_{avg} - 1{,}65s \quad \ldots\ldots. \quad (4\text{-}4)$$

Where:

C_k = characteristic compressive strength in MPa
C_{avg} = average compressive strength of the 6 units C1 through C6
s = unbiased standard deviation in MPa
          $= [(C1^2 + C2^2 + C3^2 + C4^2 + C5^2 + C6^2)/5]$

Limiting criteria: Minimum 28-day characteristic strengths are given as:

30 MPa, for pavements for vehicles less than 3 tonnes gross weight and for pedestrians.
45 MPa, Pavements for all other traffic.

Although the appendices include both the average and the characteristic strength, the average is used in all the analyses in this thesis. This allows for comparison with the SABS and the ASTM tests, which both use the average.

4.5   Tensile Splitting to ISO 4108

The test method is fully described in ISO 4108.

Again a total of 284 blocks (representing the 48 mixes) were tested at Portland Park. The results are recorded in appendices E.1 through E.8 and summarised in column E of table 6.2. Each result in this table is the average of six tests.

In this test the block is placed in a compression testing machine and split in half at 90 degrees to the longitudinal axis by means of two steel semi-cylindrical loading pieces making contact with the upper and lower faces of the block. In effect the semi-cylindrical pieces and the plywood strips act as a kind of a blunt knife-edge (see figures 4.4 and 4.5). A four mm thick plywood strip is placed between the steel loading pieces and the block (top and bottom) to prevent concentrated point loads.

The tensile splitting strength is given by the formula:

$f = 2F/(\pi ld)$ ……. (4-5)

Where:

f   = the tensile splitting strength in N/mm²
F   = the maximum load in newtons
l   = the length of the line of contact of the steel loading pieces with the specimen, in mm
d   = is the depth (or diameter) of the specimen in mm

Limiting criteria: Not specified.

Sensitivity to Variables

Spooner(1969) found that the type of packing material used and its width had an effect on the results, with the harder and narrower materials causing earlier failure.

The physical size of the test specimen also played a role, with 150 mm diameter cylinders failing at 94% of the stress for 100mm cylinders.

Hendrikx(1994) noted that the 1992 Belgium specification for concrete paving blocks, NBN-B21-311, replaces compression testing with a splitting test. (Interestingly this test has correction factors, whereby the tensile splitting strength as calculated from splitting force/sectional area varies from 0,9 for 60mm thick pavers, through 1.1 for 100mm thick pavers.)

It is evident that the both Spooner and Hendrikx have reported the same trend, i.e. that the thicker the section the lower the splitting stress, whereas the expression (4-5) does not make allowances for this. (This is similar to the aspect ratio trend that occurs in compression testing, where for example a 300 mm x 150 mm cylinder fails at a stress that is generally only 80% of that for a 150mm cube). Therefore had the Belgium standard been available in 1987, before the experimental work relating to this thesis had been done, it may have been more appropriate than ISO 4108.
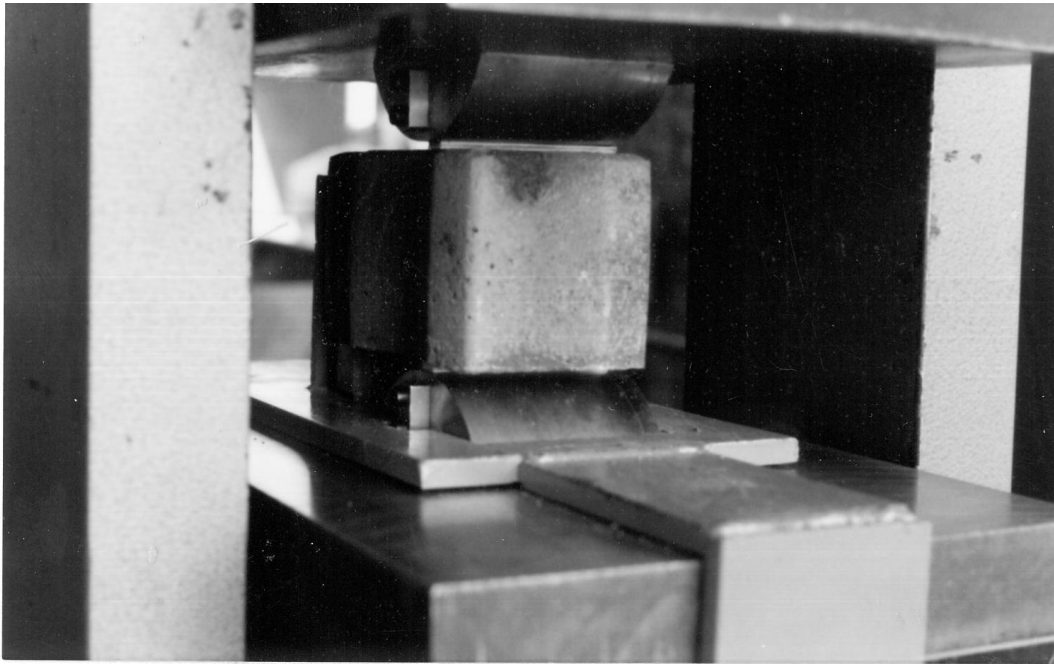
Figure 4.4 Close-up of semi-cylindrical loading pieces. The bracket that was used to centre the lower semi-sphere may be seen in the foreground.

Semi-cylinder loading piece

15 mm x 4 mm plywood strip
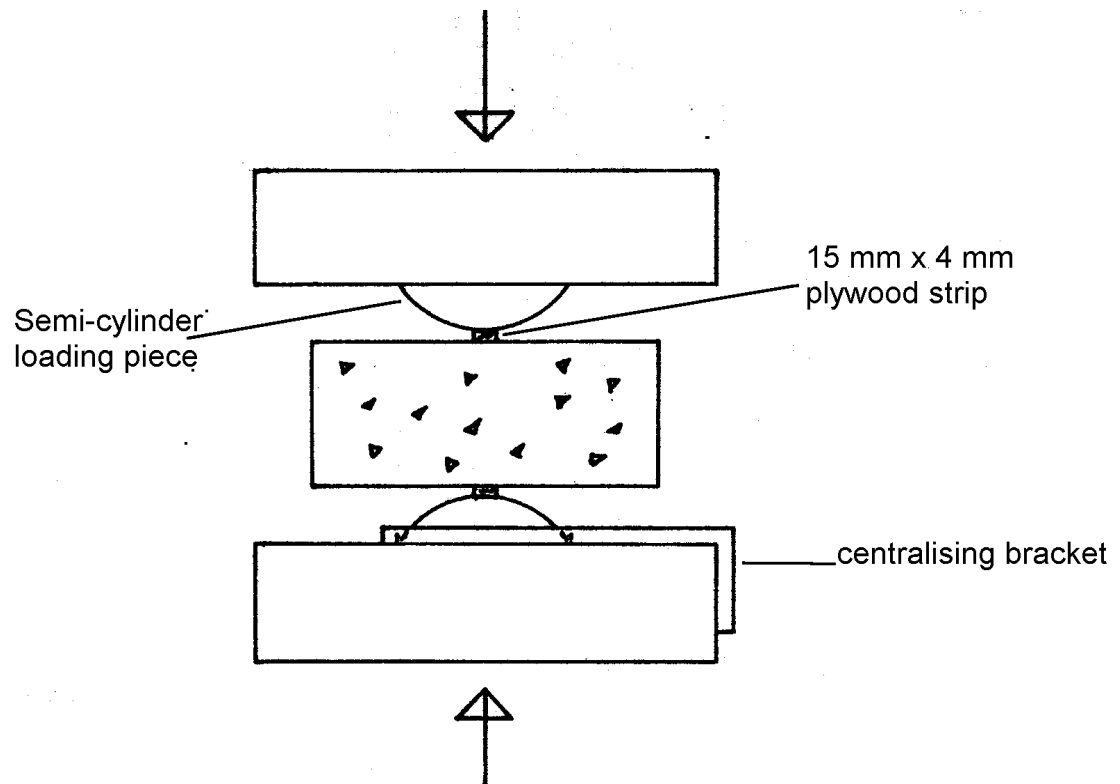
centralising bracket

Figure 4.5 Side view diagram of semi-cylindrical loading pieces

4.6   Abrasion Resistance to Wire Brush Method

This method is the preferred method adopted by the C&CI and is described in C&CI.TM.7.11 (formerly known as PCI.TM.7.11, see appendix A.5 for a view of this specification).

A total of 240 specimens (representing the 48 mixes), pre-soaked for 24 hours, were tested at the PCI laboratory, Halfway House and the results recorded in appendices F.1 through H.9, and summarised in columns F, G, and H of table 6.2.

In this test a rotating wire cup brush of external diameter 60 mm (see figure 4.6) abrades the surface of the block under a vertical load of 165 N. The block is firmly clamped into position. Every 30 seconds the direction of the brush is reversed to prevent the bristles from developing a bias. The brush rotates at a speed of 400 rpm. Water is passed through the centre of the rotating shaft onto the surface of the blocks to keep the wire bristles cool, and wash the abraded material away. The duration of the test is 5 minutes. The apparatus is illustrated in figure 4.7 and 4.8.
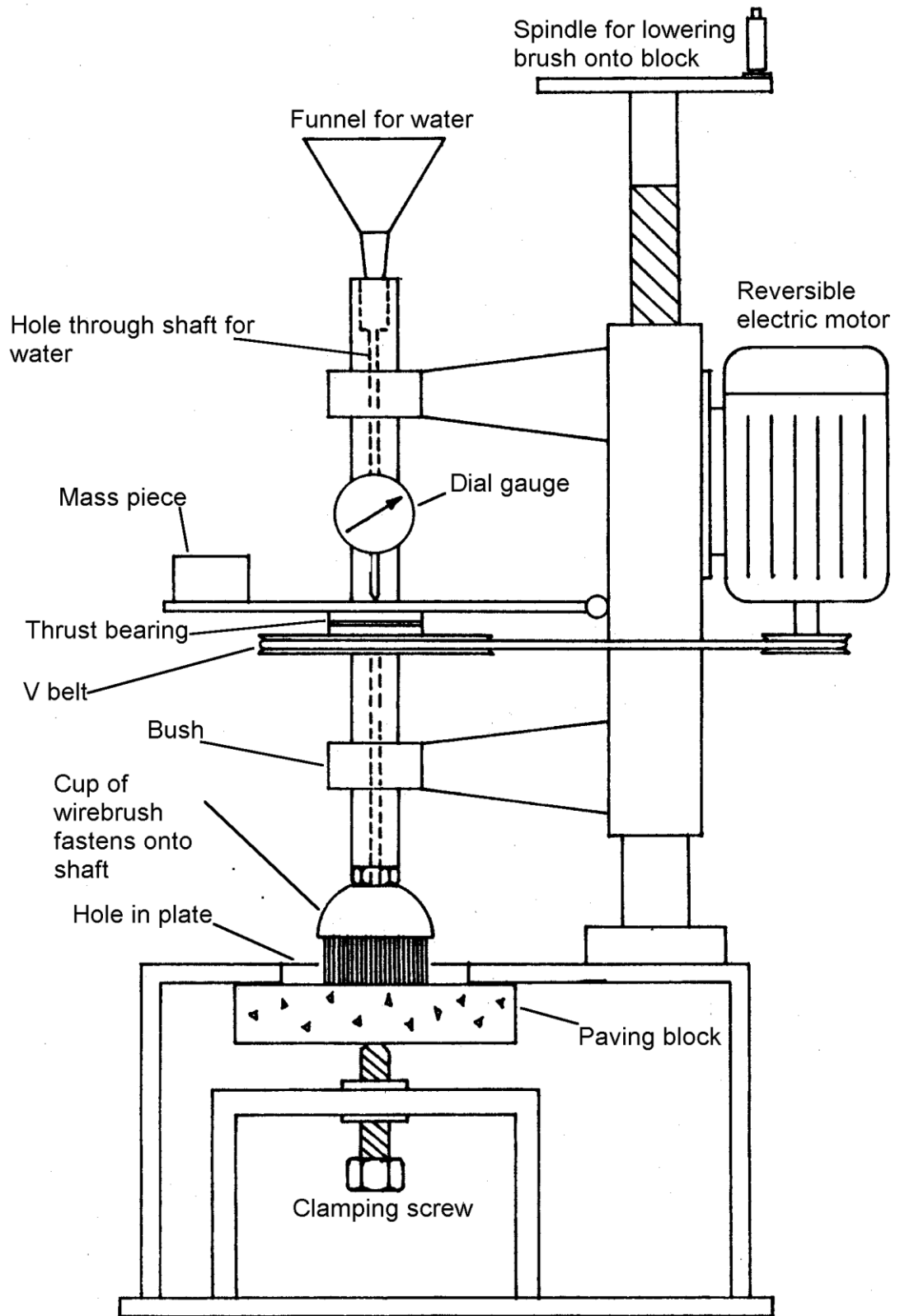

Figure 4.6 Wire cup brush

Spindle for lowering
brush onto block

Funnel for water

Hole through shaft for
water

Reversible
electric motor

Mass piece

Dial gauge

Thrust bearing

V belt

Bush

Cup of
wirebrush
fastens onto
shaft

Hole in plate

Paving block

Clamping screw

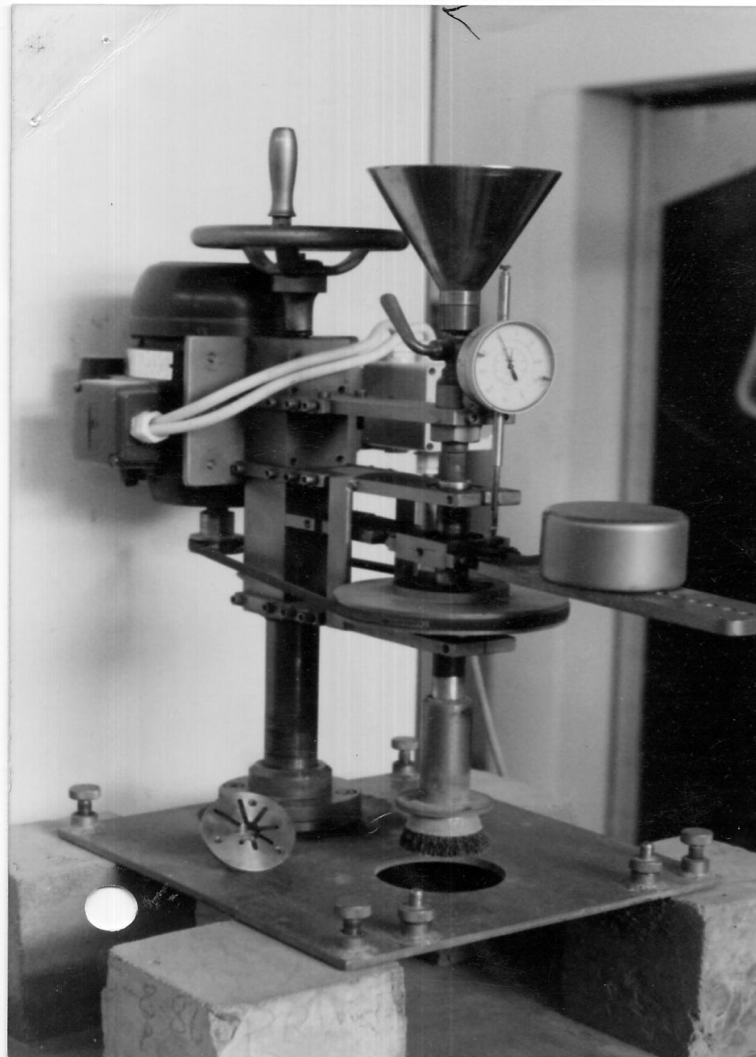**Figure 4.7** Diagram of apparatus used for wirebrush test

Figure 4.8 Apparatus used for wire brush test

For each of the 48 mix variations five samples were tested (each for five minutes). The brush was changed after every five samples i.e. after each mix variation, to limit the wear on the bristles, and apply a uniform testing regime to each mix design. When the results were later analysed it became apparent that each time the brush was changed it abraded the first block at a faster rate owing to the sharpness of the new wires. Much higher abrasion was therefore recorded for the first of the five blocks. This first result was therefore ignored, and the other four results were averaged and recorded in column F, G, and H respectively.

Three different methods were used in order to quantify the abrasion.

4.6.1   'Wire-dial' method

A reading was taken on a depth gauge at intervals of 400 revolutions. The gauge was mounted on a fixed point on the apparatus while the plunger of the dial rested on a point that moved downwards at the same rate as the brush, and therefore measured the relative movement between brush and frame. The results are recorded in appendices F.1 through F.8, and summarised in column F of Table 6.2.

4.6.2 'Wire-vern' method

After the specimen had completed 2000 revolutions wear was measured with a vernier depth gauge. A steel rule was used as a bridge over the abraded area to establish the datum pre-wear line. These measurements were spaced 45 approximately degrees apart, and an attempt was made to measure what appeared to be an average depth along each of the eight 45 degree radial lines. These measurements are recorded in appendices G.1 through G.8, and summarised in column G of table 6.2.

4.6.3   'Wire-clay' method

After the 'wire-vern' measurement, plasticine of known specific gravity (see appendix H.9) was used to fill the abraded surface (see figure 4.16). By pre-weighing the plasticine before and after this filling operation the volume of the craters was established. The depth of wear was calculated by dividing this volume by the wirebrushes's estimated abraded area, based on the measured average diameter of the crater. These results are recorded in appendices H.1 through H.8, and summarised in column H of table 6.2.

Limiting criteria: A maximum depth of wear of 1.0 mm is recommended for public access or industrial concrete pavements (rigid or segmented) subjected to wheel or foot traffic [Addis (1991)].

This applies to the average depth of wear both in the case of the 'wire-vern' and 'wire-clay' methods. However C&CI.TM.7.11 stipulates that a new brush is to be used for each block, whereas the results in table 6.2 are based on the average of four blocks using a brush that had in effect been run-in for five minutes. The C&CI limiting criteria cannot therefore be readily applied to these results. The results of the first block would of course be valid, but it was felt that using an average of four would give a more representative result. It is of course possible to obtain a ratio between the first block and the average of the subsequent four. This is discussed in chapter 10.

4.7   Abrasion Resistance to ASTM C418

This test method is fully described in ASTM C418-90.

A total of 240 specimens were tested at Portland Park and the results are recorded in appendices I.1 through I.9, and summarised in table 6.2.

In this test the specimen is situated in a protective enclosure after which a pre-weighed quantity (600 grams) of graded silica sand (see figure 4.10) is blasted by means of pressure regulated (414 kPa) compressed air through a nozzle onto the wearing face of the specimen.

The test apparatus is illustrated in figures 4.9 and 4.11, although the latter only shows one block for the sake of simplicity.

The mouth of the air nozzle is fixed 76 mm above a thin shield plate with a central hole of diameter 28,7 mm. The plate is placed over the specimen such that the centre of the hole is also directly beneath the mouth of the nozzle. The test face of the specimen is pressed against the shield, using a fastening bolt from below.

The sand is now applied at a rate of 600 g/min. Thereafter the block is moved to a new position and the process is repeated eight times until eight different craters of diameter 28,7 mm are blasted onto the face of the specimen (see figure 4.15.) Next the craters are carefully filled with plasticine (see figure 4.16) of known specific gravity (see appendix I.9). By pre-weighing the plasticine before and after this filling operation the volume of the craters can be established.

The apparatus used in this investigation was specifically designed to test two blocks simultaneously, since the ASTM C418 takes the longest of the three abrasion tests. It was considered important not to lag behind in this test in order that the blocks would be the same age when subjected to the three abrasion tests.

Limiting criteria: ASTM C936, the standard specification for Solid Concrete Interlocking Paving Units states that the volume loss should not exceed 15 cm^3 for a test surface area of 50 cm² (eight holes of diameter 28,7 mm). This is equivalent to an average depth of 3mm.
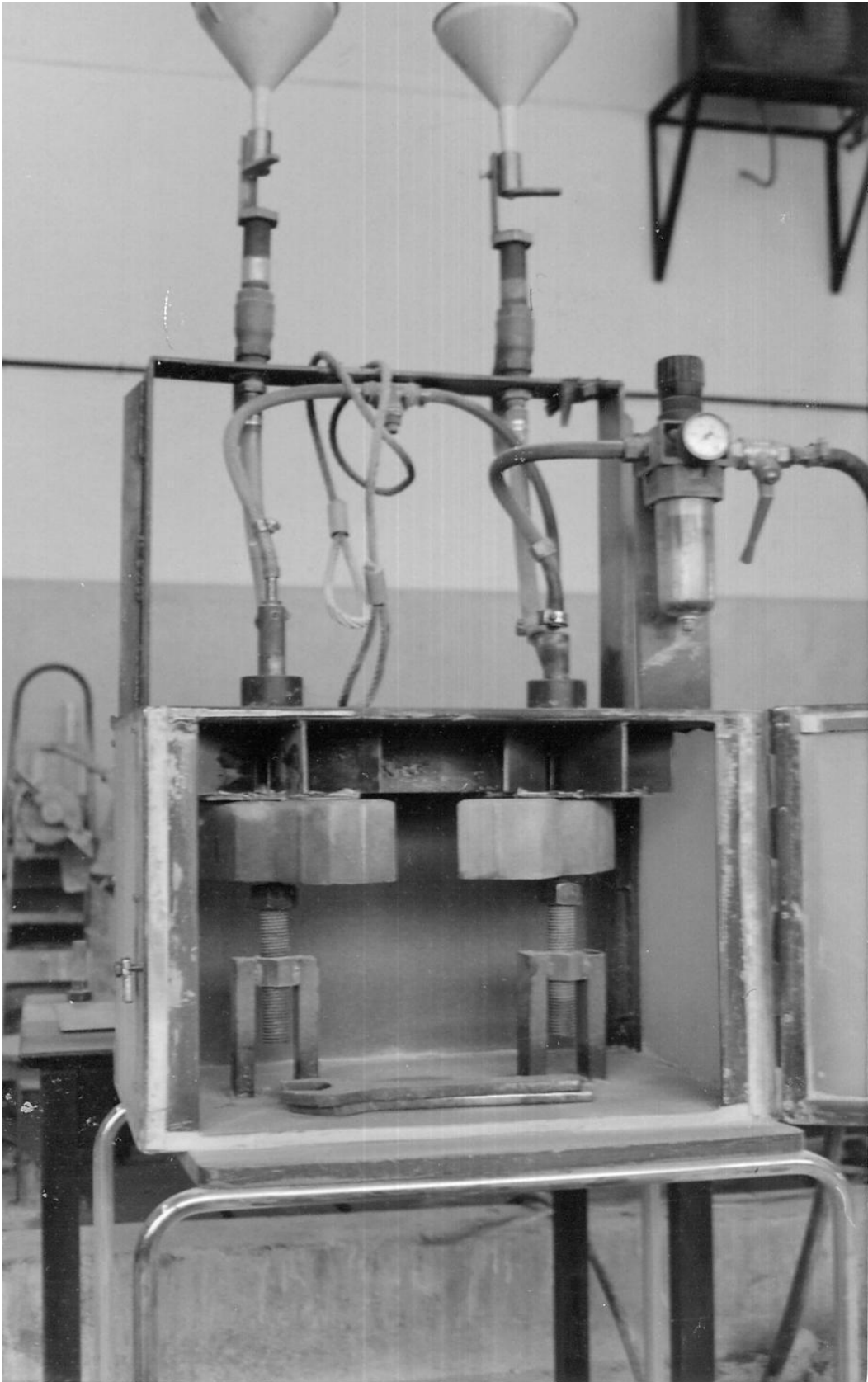
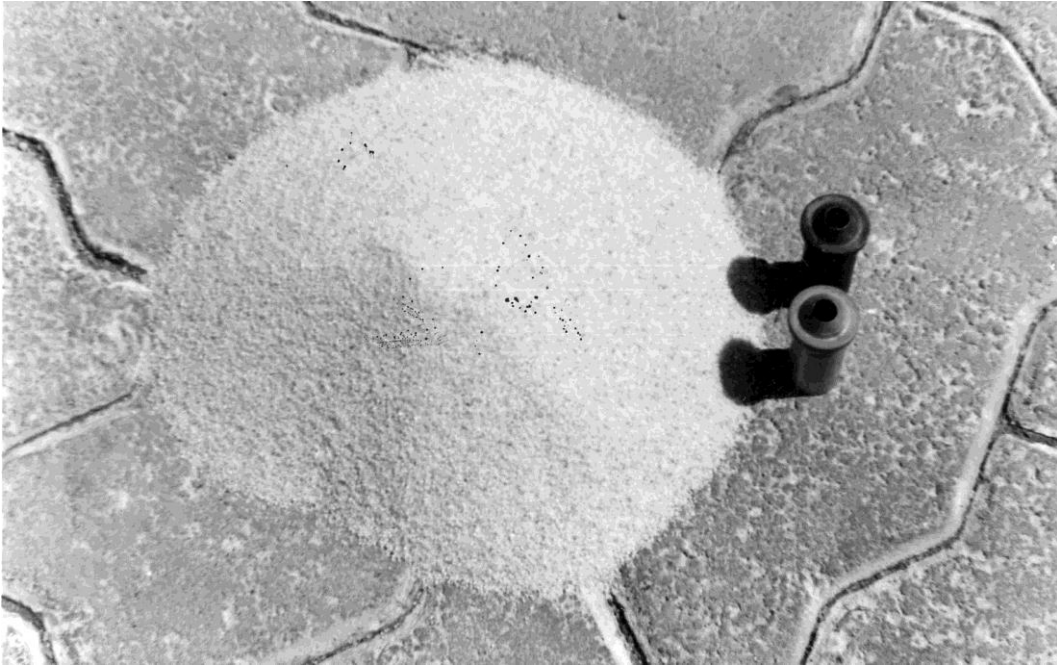**Figure 4.9** Apparatus used to perform two sand-blast tests simultaneously

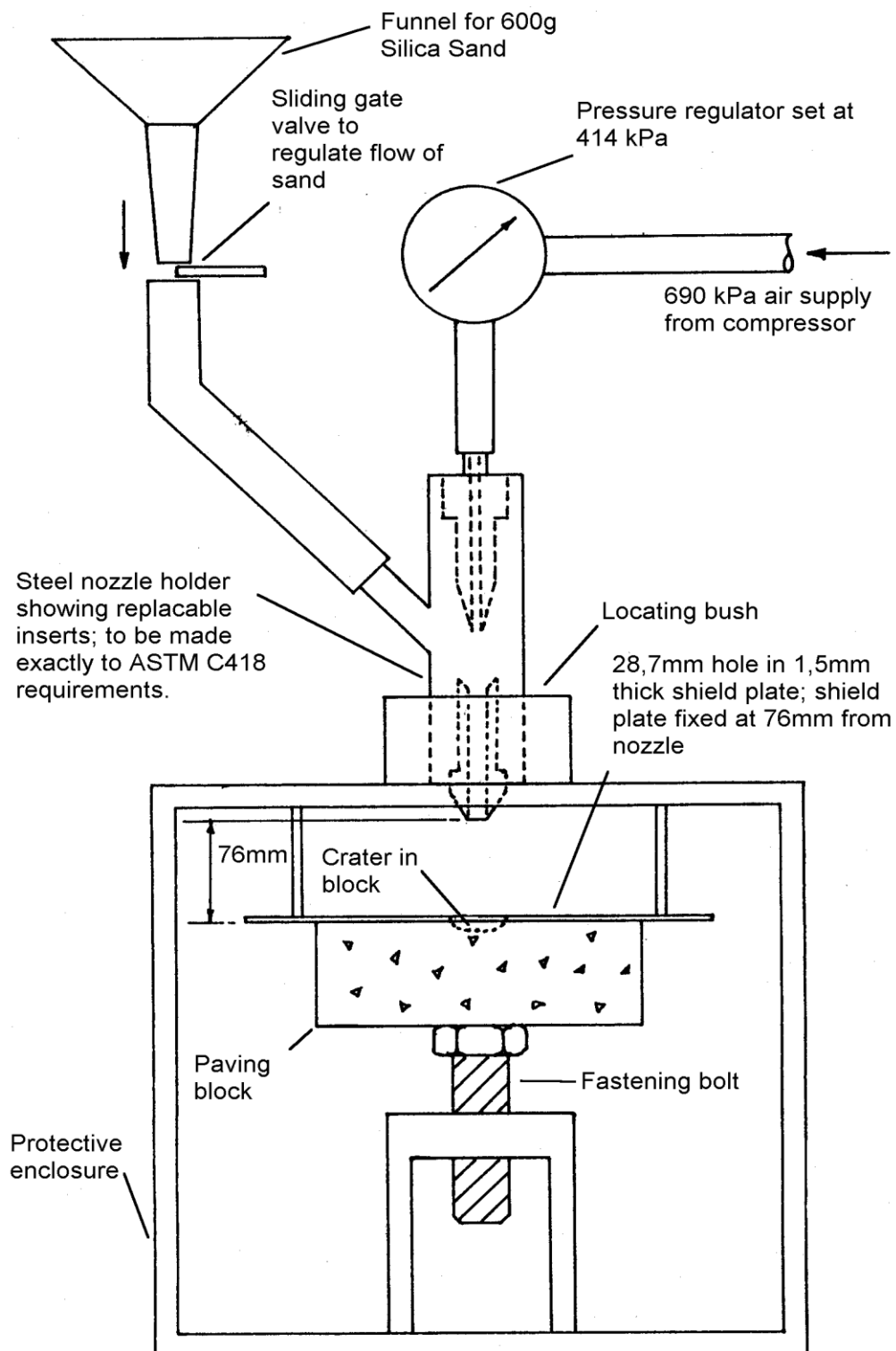**Figure 4.10** Graded Silica sand from Philippi and replaceable nozzles

Funnel for 600g
Silica Sand

Sliding gate
valve to
regulate flow of
sand

Pressure regulator set at
414 kPa

690 kPa air supply
from compressor

Steel nozzle holder
showing replacable
inserts; to be made
exactly to ASTM C418
requirements.

Locating bush

28,7mm hole in 1,5mm
thick shield plate; shield
plate fixed at 76mm from
nozzle

76mm

Crater in
block

Paving
block

Fastening bolt

Protective
enclosure

Figure 4.11 Diagram illustrating ASTM C418 equipment

4.8   Abrasion Resistance to MA20 (or MA20SA)

This test method is fully described in MA20 - 1986.

A total of 240 specimens were tested at Portland Park, and the results are recorded in appendices J.1 through J.16. Appendices J.1 through J.8 contain the recordings from which the abrasion resistance indices are calculated, and are summarised in column J of table 6.2. Appendices J.9 through J.16 calculate the volume of the abrasion grooves. The latter is not part of the official procedure (see chapter 9 for discussion).

In this test the abrasion index of the block is derived from the penetration of steel ball bearings into the surface of the unit when they are driven under a constant load of 17 kg beneath a rotating race-way. The balls are spaced evenly apart by means of light ball-cage assembly. The race-way and the ball-cage assembly are both shown in Figure 4.12.

Care was taken to ensure that the drill driving the ball bearings was free to move in a vertical direction. The specimen was securely clamped. The ball assembly was placed onto the block and the drill-chuck/race-way lowered onto the balls. Enough water was allowed to flow through the chuck to clear away any grinding debris. The drill was run for approximately 3 seconds to seat the race-way. Next the dial-gauge plunger was set to zero and the drill was set in motion, stopping at every 1000 revolutions to measure the penetration. This procedure was continued to 5000 revolutions.

MA20 versus MA20SA test

The apparatus and method of test used in this investigation differs in some respects to the MA20 apparatus used in Australia:

a.   the bearing has 13 balls rather than 12 (see figure 4.12)

b.   the guide bar and guide bracket are spaced further away from the main shaft to prevent sideways wander

c.   the specimen was pre-soaked for 24 hours

d.   the clamping mechanism fastens the block from the top, rather than the side.

It is important to realise that whereas these changes may alter the rate of penetration to a degree, they do not alter any of the fundamental principles of the test. The reasons for the changes are fully discussed in chapter 9.

The test apparatus used in the MA20SA test is illustrated in figure 4.13 and 4.14, while the balls in their housings are shown in figure 4.12.

Figure 4.12 Ball bearing assemblies and race-way, as used in the MA20SA test. These bearings differ somewhat from those used in the official MA20 test. Although they are the same diameter, there are 13 balls as opposed to 12 in the MA20. Also each ball makes contact with both the race-way on the top side and with the block below. The MA20 test differs in that six balls make contact with the race-way, and six with the block. This aspect is fully discussed in chapter 9.

Calculation of Abrasion Index

The abrasion index of each specimen was calculated from the expression:

$I_a = \sqrt{R}/P$ ……. (4-6)

Where;

$I_a =$ Abrasion index (calculated when the ball race revolutions equal 5000 or the penetration equals 1,5 mm whichever occurs first. The latter condition was generally ignored and penetration was allowed to continue well past 1,5 mm.)
$R =$ ball-race revolutions in thousands
$P =$ penetration in mm.

Limiting criteria: The following interim abrasion indices were suggested by the CMAA:

Pedestrian applications

Busy shopping footpaths and malls with heavy pedestrian traffic: $I_a = 2,0$
Footpaths in other areas: $I_a = 1,2$

Vehicular applications

Public roadways and industrial hardstandings: $I_a = 1,5$
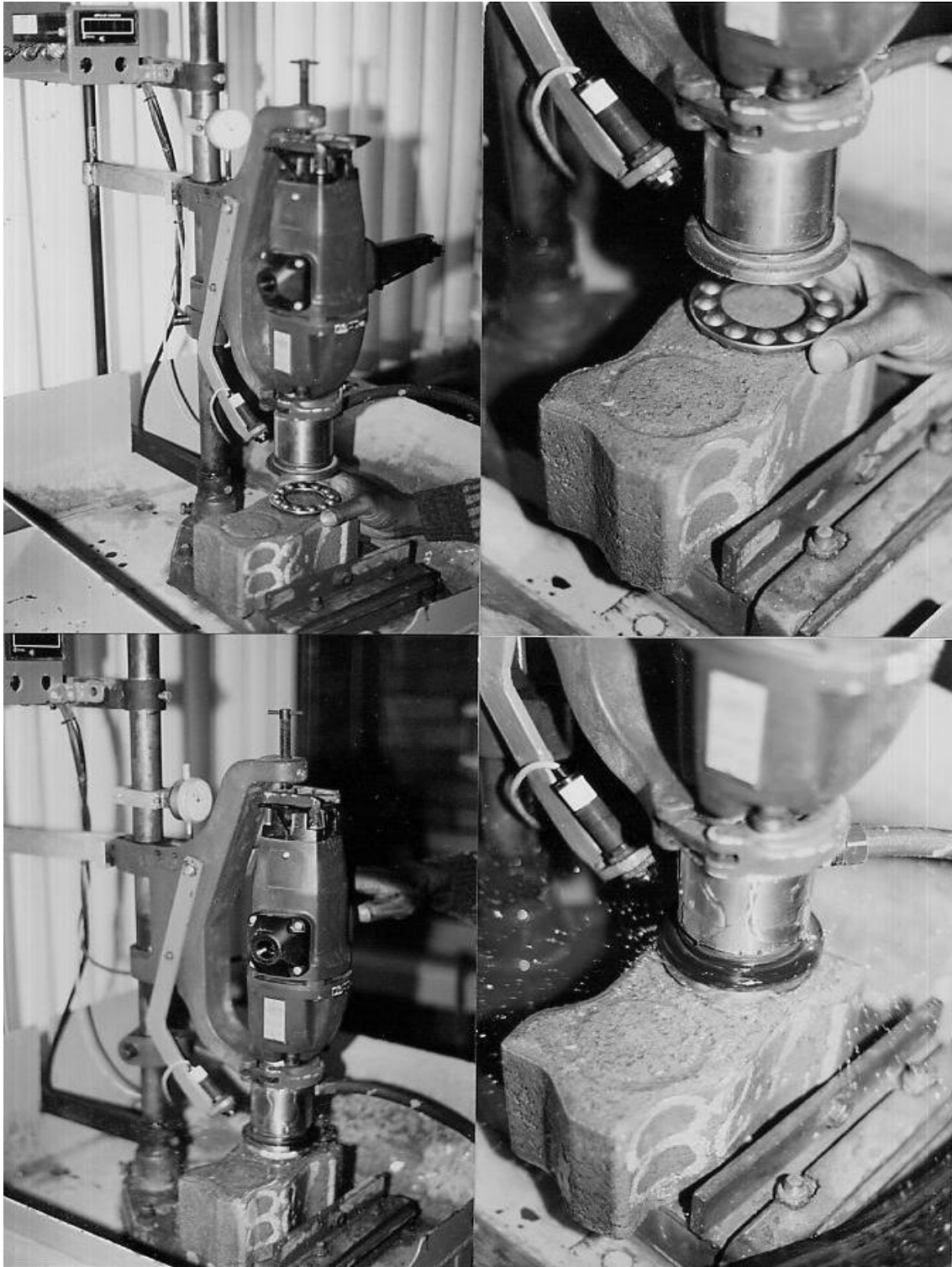Carparks with vehicular traffic under 3 tonnes: $I_a = 1,2$

Figure 4.13 The MA20SA test apparatus: (a) Setting up of the block, (b) Close-up
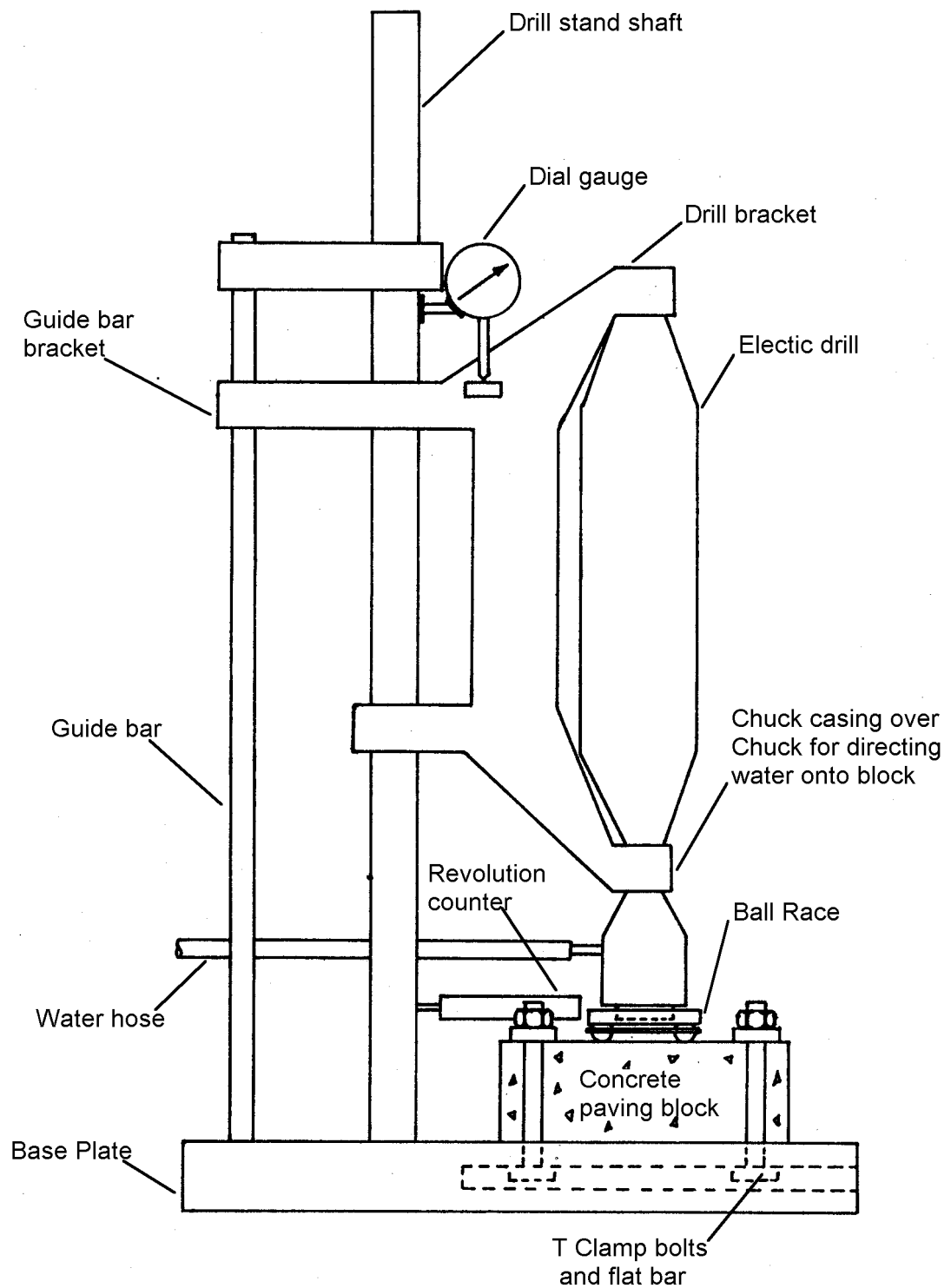(c) Test underway (d) Close-up
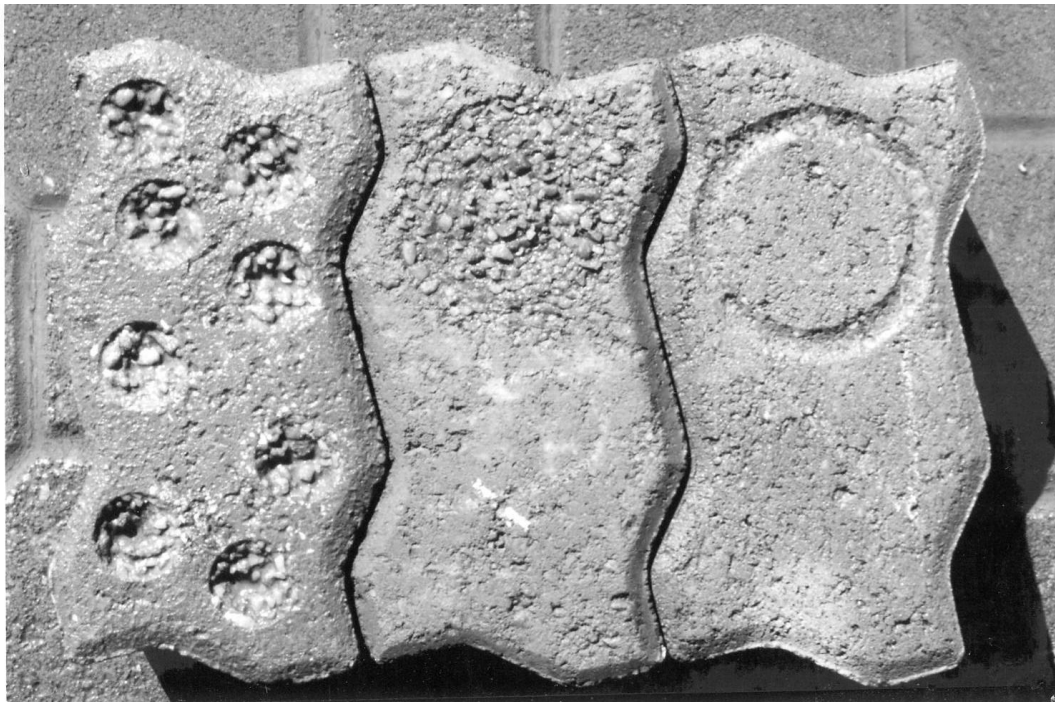
Figure 4.14 Diagram illustrating MA20SA apparatus

Visual Effects of the Respective Abrasion Tests

Figure 4.15 Abraded surface of the ASTM C418, Wire brush and MA20 tests respectively
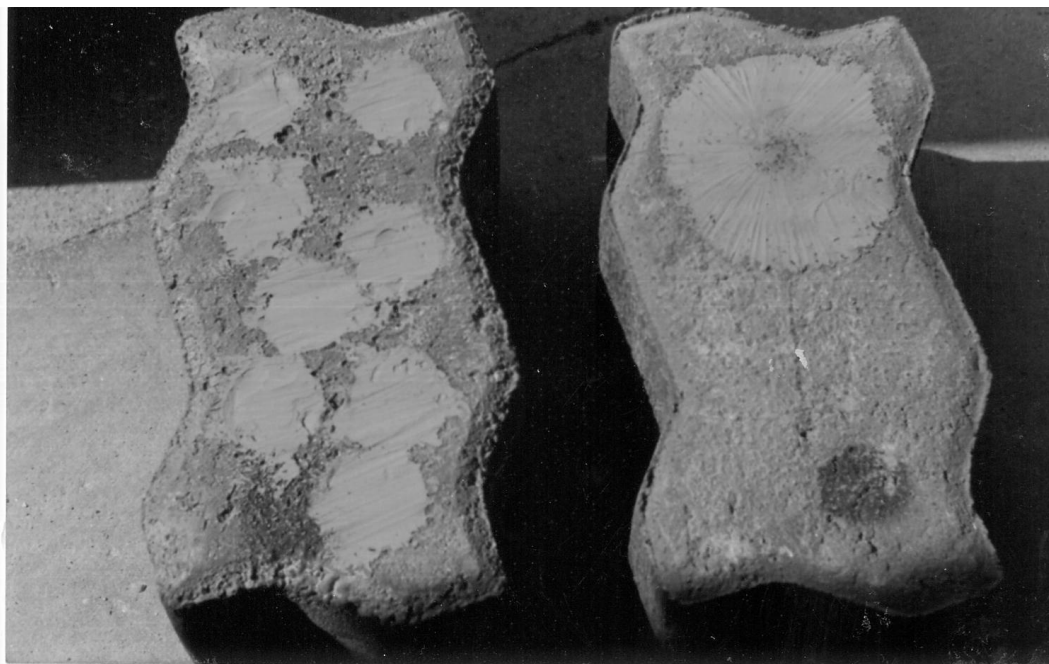

Figure 4.16 Plasticine in fills used respectively in the ASTM C418 and Wire-brush tests

4.9   Water Absorption to ASTM C140 and Dry Density to ASTM C642

These test methods are fully described in ASTM C140 and ASTM C642-82.

A total of 284 specimens (representing 48 mixes) were tested at Portland Park and the results are recorded in appendices K.1 through K.8, and summarised in column K and L of table 6.2. Each result in this table is the average of six tests.

In this test the specimen should be soaked for a minimum of 24 hours in water. Although no boiling water was used, the blocks were soaked for approximately nine weeks, which is not ideal, since this allows the uptake of additional water for the formation of further hydration products, increasing the mass of the product. Fortunately the samples that were tested for compressive strength and abrasion resistance etc. had also been very well cured for the first four weeks, the most sensitive hydration period. These aspects should therefore be borne in mind when correlating density/absorption with strength/abrasion-resistance.

Thereafter each block was weighed suspended from a metal wire while completely submerged in water. Once removed from the water the specimen was dried with a damp towel and immediately weighed again. Finally it was oven dried at 60C (not 100C as specified) to constant mass and the lowest mass recorded. From these readings the water absorption and dry density were calculated.

The percentage absorption and dry density were calculated from the following expressions:

% Absorption $= (A - B) / B \times 100$ ……. (4-7)

Dry density $= B / (A - C)$ kg/m^3 ……. (4-8)

Where:

A = wet weight of unit in kg
B = dry weight of unit in kg
C = suspended immersed weight of unit in kg

Limiting criteria: ASTM C936-82, the standard specification for Solid Concrete Interlocking Paving Units states that the average absorption shall not exceed 5%, with no individual result in excess of 7%.

4.10   Initial Surface Absorption Test to SABS 0164 (ISAT)

This test method is fully described in SABS 0164 (1980). A total of 284 specimens (representing 48 mixes) were tested at the University of the Witwatersrand, Civil Engineering Laboratory. The results are recorded in appendices K.1 through K.8, and summarised in column M of table 6.2.

In this test paving blocks (the same blocks used in 4.9 that had been dried to constant mass in a drying oven) were weighed, and then placed in a special water tray such that the surface of the block was submerged 3 mm deep under the water for a duration of one

minute (see figure 4.17). Thereafter the specimens were rapidly dried with a damp towel
(to remove the surface water) and weighed.
The initial rate of absorption in kg/m^2/min was calculated from:

ISAT = ΔW/LxB, ……. (4-9)

Where;

ΔW =   actual gain in mass of the specimen in kg after one minute of soaking
L =   equivalent length of the specimen in meters
B =   equivalent width of the specimen in meters

Since B and L were the same for all 288 specimens tested, ISAT was simplified to ΔW, i.e.
the gain in mass after soaking the surface for one minute.
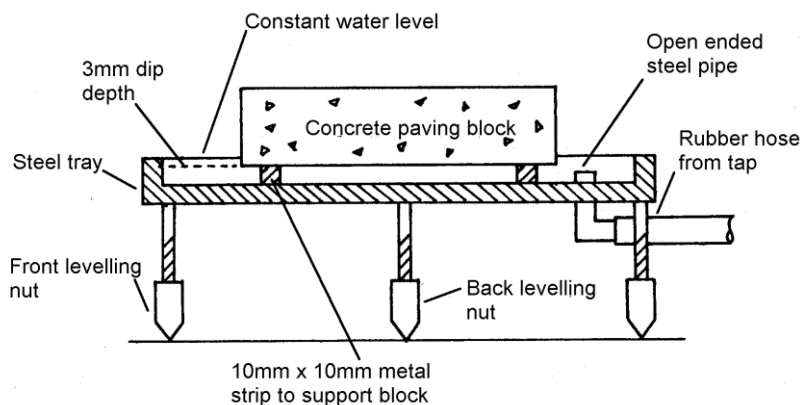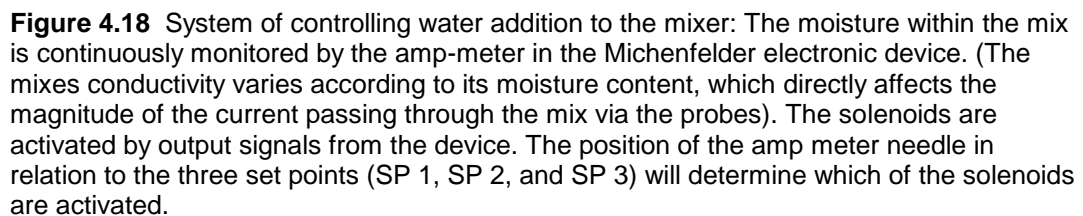
Limiting criteria: Not specified.

Figure 4.17 Apparatus used in ISAT

4.11   Water Content

The water content of the mixer was controlled by adjusting the potentiometer of the
'Michenfelder' water meter, an electronic device. The principle of the device is to pass a
low voltage current through the mix in the mixer. As the water content of the mix increases
with the addition of water to the mixer, there is a corresponding increase in conductivity
resulting in turn in an increased current passing through the mix. This current is monitored
by an electronic amp meter, which, in turn, is programmed to regulate the addition of water
to the mixer (see figure 4.18). At given set points water addition is progressively slowed
down.

From the results in column N of table 6.2, it can be seen that the settings of the
potentiometer varied between 400 for the driest mixes to 650 for the wettest mixes,
generally in steps of 50, resulting in 6 different water contents per mix design.

Although the Michenfelder water meter can accurately reproduce the same water content
for a given setting of the potentiometer, it cannot quantify the water content. In order to do
this, four different methods were attempted with varying degrees of success:

1/2" valve

3/4" valve

1" valve

Earth for low
voltage

Paddle mixer

Insulated probes

Low voltage current

S P 1   S P 2   S P 3

Output to 1"
solenoid actived by
set point 1

AMP
meter

Michenfelder electronic
device

Potentionmeter

Output to 1/2" solenoid
actived by set point 3

Figure 4.18 System of controlling water addition to the mixer: The moisture within the mix is continuously monitored by the amp-meter in the Michenfelder electronic device. (The mixes conductivity varies according to its moisture content, which directly affects the magnitude of the current passing through the mix via the probes). The solenoids are activated by output signals from the device. The position of the amp meter needle in relation to the three set points (SP 1, SP 2, and SP 3) will determine which of the solenoids are activated.

4.11.1   Drying at 100° C

Three blocks were carefully removed from the production line (for each of the 48 mixes) soon after the blocks had been ejected from the machine. These blocks were sealed in plastic sample bags and immediately weighed on an electronic scale. A few days later they were taken to McLachlan and Lazar, a commercial laboratory, where they were dried at constant mass at 100° C as recorded in appendices L.1 through L.8 and summarised in column P of table 6.2. The discussion of these results may be found in 6.2.3.

The water content was calculated from the expression:

% Water Content = $(W_{wet} - W_{dry}) / W_{dry}$ x 100 ……. (4-10)

Where:

W_{wet} = mass of wet block fresh from machine
W_{dry} = mass of dry block after drying to constant mass at 60° C

4.11.2   Firing at 1000° C

After drying to 100° C as in 14.11.1 above the blocks were fired in a furnace to 1000° C. In this way it was hoped that water that had been chemically bound in the hydration process would also be liberated and thus a true reflection of the water addition or water content be obtained. The '1000° C' water contents are also recorded (average for three blocks) in appendices L.1 through L.8 and summarised in column Q of table 6.2. The discussion of these results may be found in 6.2.4.

The water content was calculated from the expression:

% Water Content = $(W_{wet} - W_{1000}) / W_{1000}$ ……. (4-11)

Where:

W_{wet} = mass of wet block fresh from machine
W_{1000} = mass of dry block after firing at 1000° C

4.11.3   Sugar method

In this method 15 g of sugar was added to a pre-weighed fresh sample of the mix in question. Enough water was then added to achieve a porridge type consistency and to allow all the sugar to fully dissolve. The resultant sample was then dried at approximately 100° C in an oven and then weighed again.

The water content was calculated from the following expression:

Water Content = $[W_{fresh} - (W_{dried} - W_{sugar})] / [W_{dried} - W_{sugar}]$ ……. (4-12)

Where:

W_{dried} = mass of oven dried sugar contaminated mix
W_{sugar} = 15 g
W_{fresh} = mass of freshly made concrete before adding sugar
The results are summarised in column R of table 6.2. The discussion of these results may be found in 6.2.5.

4.11.4   Calcium carbide method

In this method 15 g of fresh mix (for each of the 48 mixes) was inserted into a hand held pressure vessel together with a glass capsule containing a measured quantity of calcium carbide. Some steel marbles were also inserted into the vessel after which it was sealed by a lid fitted with a pressure gauge (see figure 4.19). The vessel was then shaken vigorously resulting in the release of the calcium carbide. The calcium carbide (CaC_2) reacts with the moisture to form acetylene gas as follows:

$CaC_2 + H_2O \rightarrow C_2H_2 + CaO$ .... (4-13)
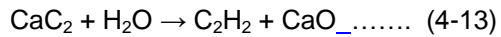
A calibrated chart given by the manufacturer of the pressure vessel was read to obtain the water content for the corresponding pressure (from the acetylene gas) on the gauge.

The results are summarised in column S of table 6.2. The discussion of these results may be found in 6.2.2.
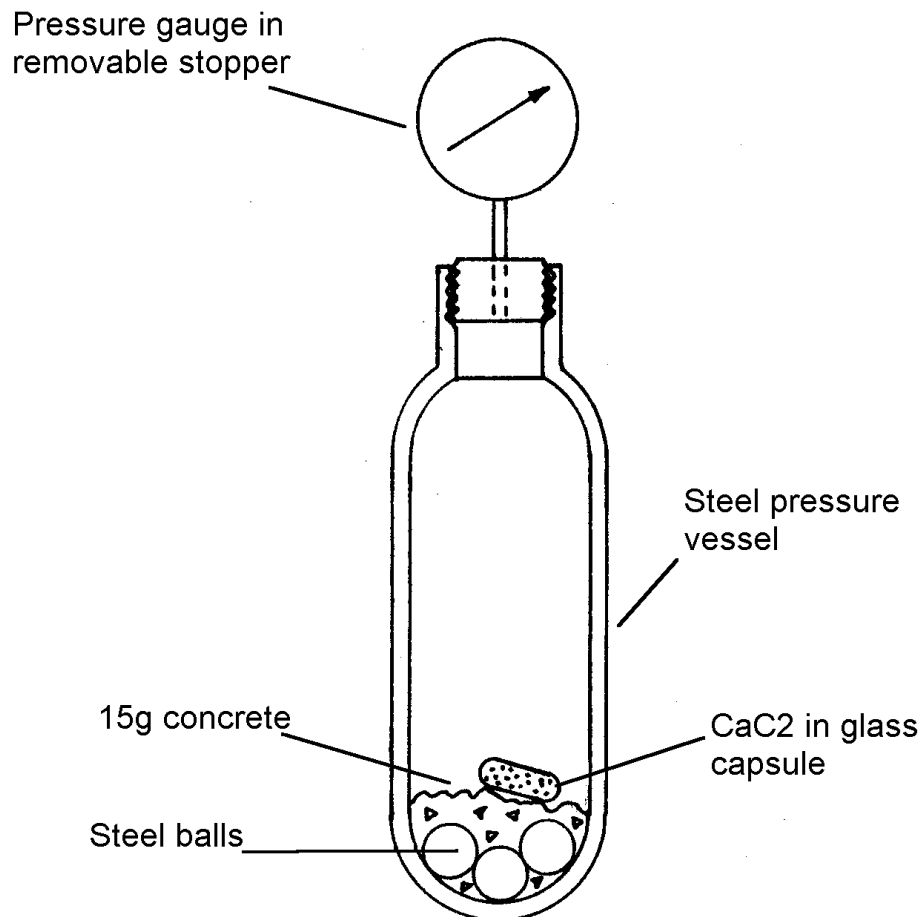

Figure 4.19 Calcium carbide pressure vessel

4.12   Conclusion

In this chapter, the ten different laboratory tests used in the experimental phase of this thesis are briefly reviewed. From this relatively broad base of test types, the blocks corresponding to the 48 mixes can be thoroughly assessed for such attributes as compressive strength, abrasion resistance, tensile splitting strength, dry density etc. More specifically the effect of variations in the water content, binder content, and binder type become evident from the tests. (See chapter 6). *Objective 1* is thus achieved.

Furthermore, the large range of laboratory tests make it possible to establish how the surface tests (the three abrasion resistance tests and ISAT) correlate with other well established benchmark quality indicators such as compressive strength and density. This includes a comparison of variability and other criteria.

Considering the test results of the various *surface* tests and comparing them against one another is also an important aspect of the testing programme (see chapters 9, 10, 11, 12 and 13). Hopefully one of the four surface tests will emerge as a suitable indicator of abrasion resistance for incorporation into a national standard. These actions are designed to meet the requirements of *objective 2*.

In similar fashion it will be possible to make a critical comparison of the three compression tests (see chapter 7), thereby fulfilling the requirements of *objective 6.*

The following chapter describes the installation of blocks in a road and a pedestrian sidewalk, and a method of measuring the wear on the blocks. The blocks were made from the identical mixes as those tested in the laboratory, thus making it possible to do a meaningful comparison between wear on site and laboratory test results. This analysis is done in chapter 14.

This allows the laboratory tests of this chapter to be calibrated in terms of actual wear, thus satisfying *objective 4b.*