Chapter 1

Introduction

1.1 A Brief Overview of the Product

Concrete block paving (cbp) is generally used for providing a substantially *waterproof and wear resistant* surface for vehicular or pedestrian traffic. Sometimes it is used primarily for *aesthetic appeal*, and pavers may be made in many different shapes and colours. The blocks also serve as a *structural element* since they lock together to spread the applied loads to the sub-base. Cbp is therefore well suited to applications where heavy axle loadings can be expected such as off-loading zones in shipyards (figure 1.1), busy intersections (figure 1.2), industrial hardstandings, etc. More typical applications however involve lesser loads, such as secondary roads (figure 1.3), parking areas, side-walks, shopping malls, and the surfacing of large areas (figure 1.4), etc.

Figure 1.1 Cbp in shipyard off-loading zone; Richards Bay Harbour

Individual concrete blocks typically vary in weight from 2,3kg to 4,6kg and are therefore easy to install with one hand. Paving blocks can also be made in a number of different shapes and colours to add aesthetic value to shopping malls and open city squares. Typically the blocks are 50 mm thick for light applications, while heavy duty applications range from 60 mm to 100 mm.

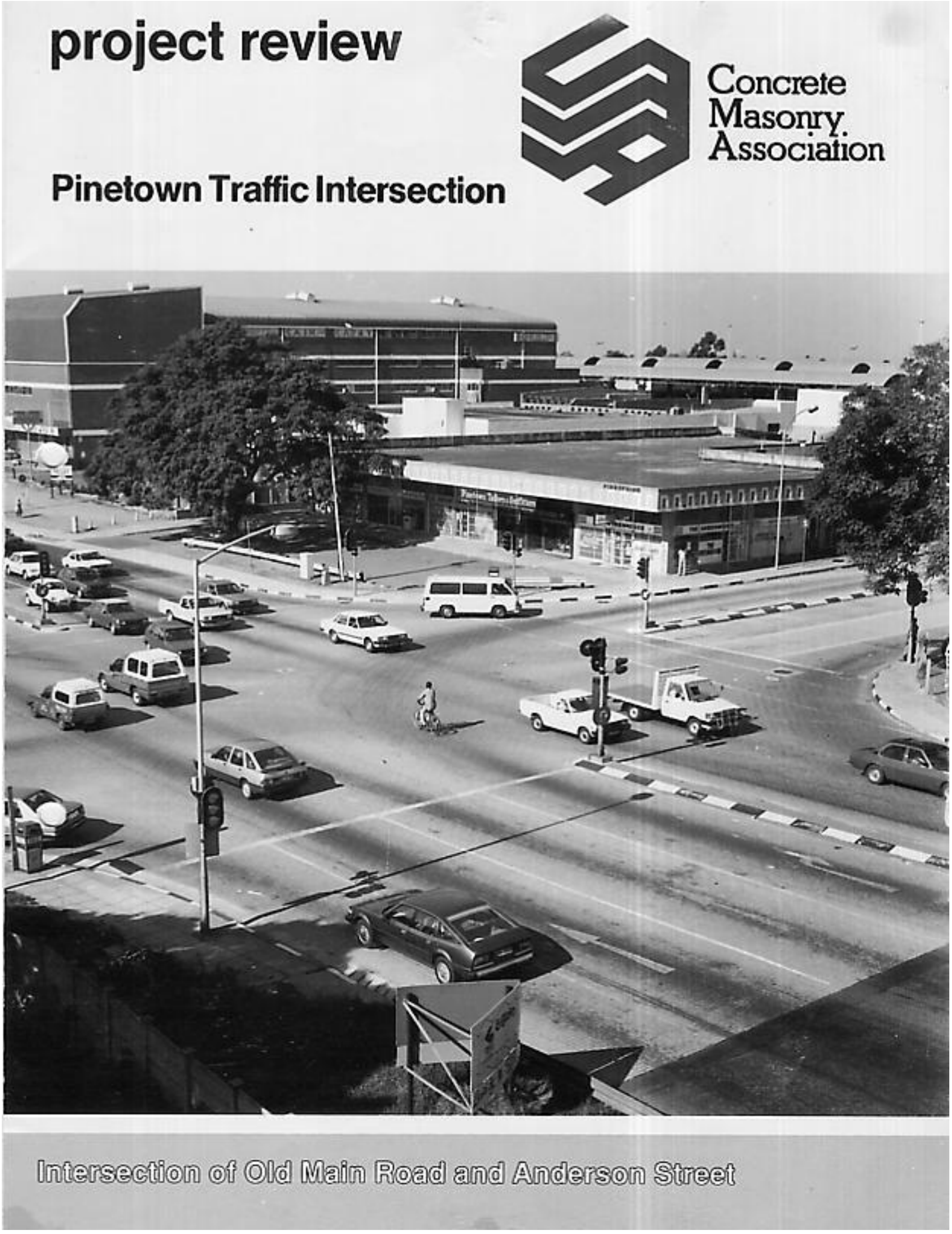
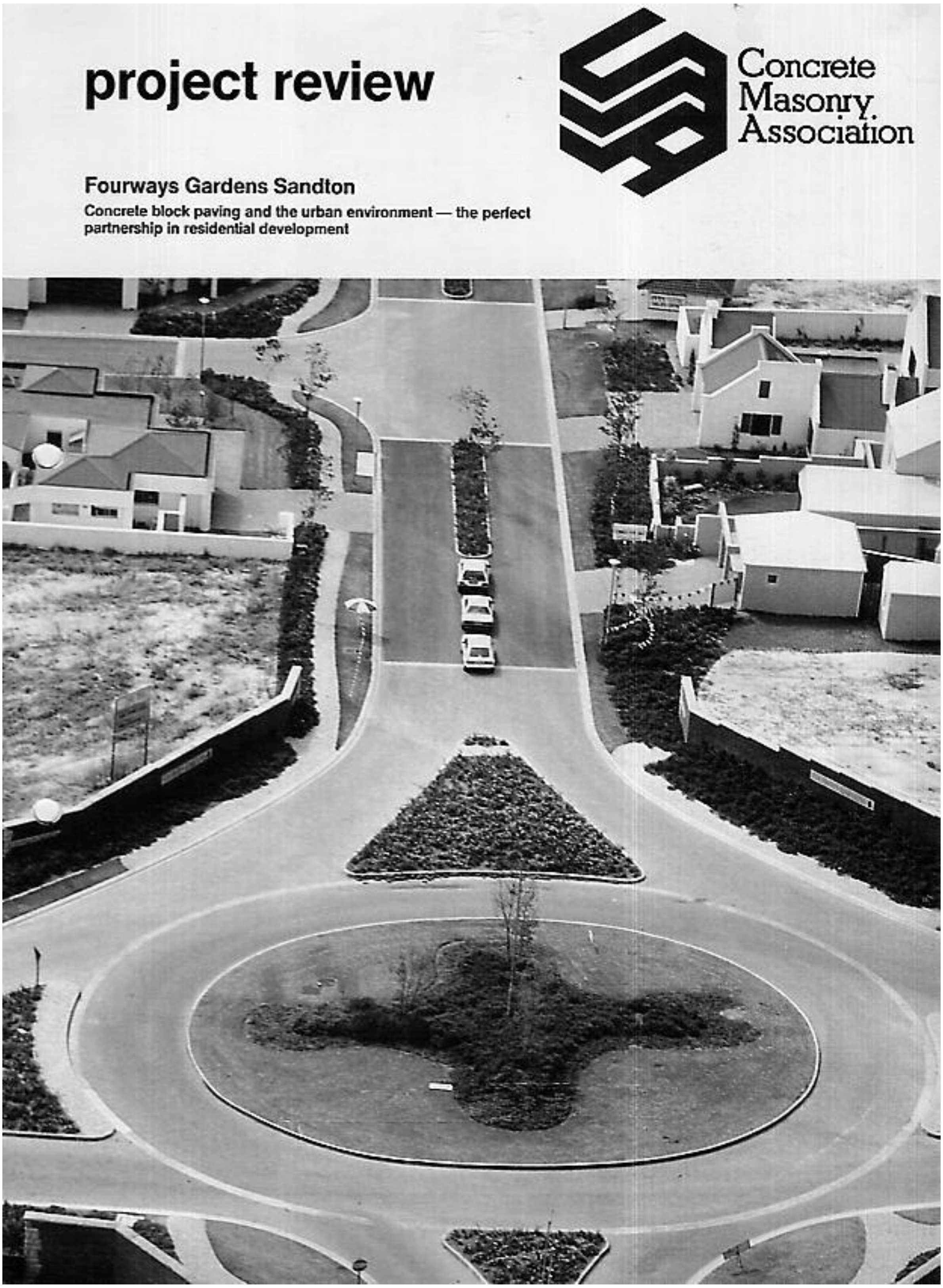


Figure 1.2 Cbp in a busy interchange

In some countries such as Australia, the blocks are referred to as ‘concrete pavers’, or simply ‘pavers’. This terminology is used in chapters 14 and 15 of this thesis, as well as in volume 2.

The name ‘segmental block paving’ is sometimes also used, and derives its name from the individual units or blocks, which when put together form a segmented pavement. Once installed, the blocks serve both as a relatively flexible base-course and a hard wearing surface.



project review

Concrete Masonry Association

Fourways Gardens Sandton

Concrete block paving and the urban environment — the perfect partnership in residential development

Figure 1.3 Cbp in an urban road

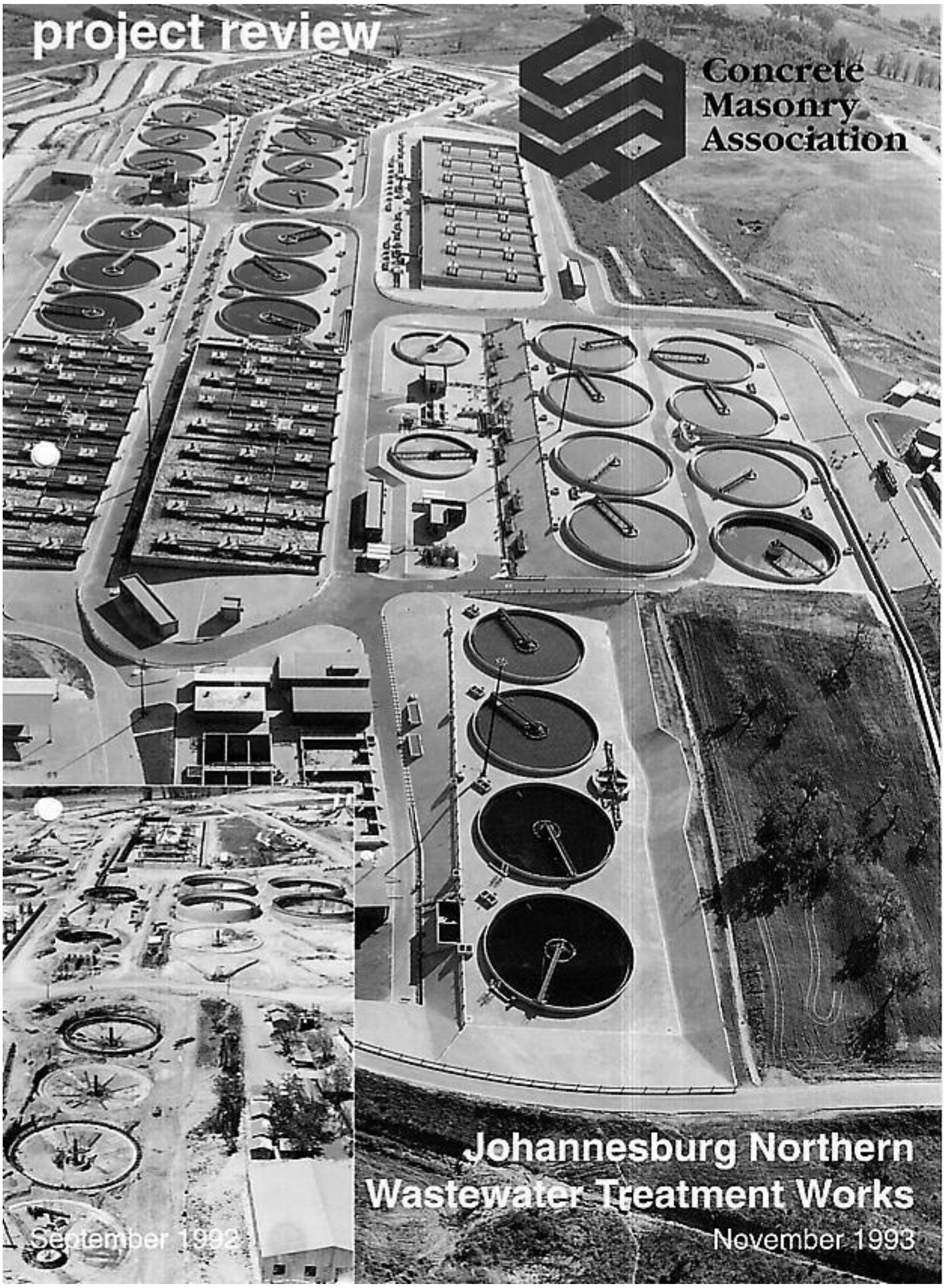


Figure 1.4 Cbp as a waterproof wear resistant surface for large areas

The normal construction practice is to prepare the sub-base to the desired fall for drainage, and compact to the desired MOD AASTHO, to suit the expected traffic loadings. Following this the paving blocks are set on a thin layer of non cohesive uncompacted bedding sand, typically 25mm thick. Next a plate or roller vibrator is used to level the upper surface of the pavers, since not all blocks in a batch are exactly the same height; (SABS permits a variation of $\pm$ 3mm, so that it is possible to have two adjacent blocks differing in height by as much as 6mm). In the process of levelling the upper surface of the pavers, the bedding sand gets compacted. In this process some sand beneath thicker blocks is displaced laterally to the not-so-thick blocks.

Finally jointing sand is worked into the joints of adjacent blocks and after a few more passes of the plate vibrator the surface is ready for immediate use. The jointing sand is of finer grain size containing some cohesive material to facilitate a substantially 'water-proof' seal in the joints. Specifications for the bedding and jointing sands have been defined in SABS 1200 MJ and Shackel(1980) etc.

With the passing of traffic some minor settlement takes place as the bedding sand and sub-base undergoes a measure of traffic-induced compaction until the blocks are 'locked up' or 'settled in'. After this no further appreciable settlement takes place for the design life expectancy of the pavement.

1.2 The Size of the Industry

In countries such as Germany, the Netherlands and Belgium, the paving industry is very strong and paving is manufactured at the rate of 1m^2 per capita per year. (10 million m^2 were made in Belgium in 1995 [Hendrikx(1996)]).

The production of concrete paving in South Africa is also a relatively sophisticated industry that is substantially mechanised and automated, comprising many factories nationwide. Members of the Concrete Masonry Association, an association of some of the larger producers, reported an output of some 5 million square meters for the year ending 2000. The country's *total* production is estimated at 7 million square meters, representing an installed paving cost of approximately R 260 million p.a. (i.e. at year 2000 prices).

Therefore should the long-term durability of the product be unsatisfactory, this would represent a serious loss. Such waste should not be tolerated in any country, and especially not in South Africa where important political issues such as education and housing for disadvantaged people groups are so in need of funds.

1.3 The Cause and Effect of Abrasion

The main cause of abrasion in cbp in most applications is nearly always heavy volumes of traffic, either pedestrian or vehicular. Heavy pedestrian traffic such as is found in busy malls and side-walks can have a surprisingly high abrasive effect, particularly where funnelling of pedestrians occurs, near entrances etc. Abrasion is significantly accelerated if sand and grit are present on the surface. These aspects are comprehensively considered in section 3.5 of volume 2.

Excessive abrasion results in a rough and unsightly surface. Examples of severely eroded surfaces are shown in chapter 8 under the heading of 'Fourth degree abrasion'. In extreme cases such surfaces become unsafe for pedestrians to walk on and uncomfortable to ride on. They may be dangerous causing bouncing and vibration, have a low skid resistance, and result in reduced visibility from dust. In the extreme, the paved surface breaks up completely, exposing the sub-base to the ravages of abrasion and erosion.

Pavers with inadequate abrasion resistance may therefore cease from performing their intended purpose of providing a waterproof, wear resistant, load-bearing, and aesthetically pleasing surface.

1.4 Motivation for this Research

Between 1980 and 1984 cbp pioneering experimental work was done in South Africa led by Shackel(1979) and Clifford(1984). In particular extensive testing was carried out at the Silverton test site of the CSIR to determine the load bearing characteristics of cbp on various sub-bases. One of the findings was that blocks with a compressive strength of 25 MPa behaved as an effective structural layer in the design of the pavement, and that increasing the strength above 25 MPa was unnecessary. Consequently when the SABS 1058 paving specification was published in 1985 the nominated compressive strength was 25 MPa. This was far lower than other specifications e.g. 49 MPa in the U.K. and 55 MPa in the U.S.A, where freeze-thaw considerations dictate a relatively high compressive strength and hence abrasion resistance.

The effect of the relatively low compressive strength on the abrasion resistance was not fully appreciated. Furthermore although compressive strength is generally a good indicator of quality, research [Sadegzadeh(1984), Holland(1991)] has shown that concrete surfaces made from high strength concrete do not necessarily have good abrasion resistance. This is because compressive strength is a bulk property of concrete, while abrasion resistance is a surface property. Certain processes/materials have a far greater influence on the surface property than they do on the bulk property, including liquid surface treatments, power trowelling, curing, carbonation, aggregate hardness, etc.

Thus the standard that has been established for the industry to provide for an adequate level of quality in the blocks (SABS 1058), does not ensure the durability of the product where abrasion induced wear is of primary concern. It is therefore alarming to see that some surfaces made from blocks that meet the requirements of SABS 1058 and which at first have good aesthetic appeal, nevertheless show signs of excessive wear after some years (or even months). In some cases, such suspect surfaces are approved after the maintenance period has expired (normally 12 months) by the overseeing Engineer/Architect who is not sufficiently acquainted with the signs of early abrasion wear. Thus the client inherits an unacceptable surface that may have to be replaced at great expense. This represents not only a serious loss for the client, but also for the cbp industry as a whole, as the client may thereafter be likely to favour either an asphalt surface, or a paved surface of fired clay bricks, or some other medium. For example the Johannesburg Municipality, who once used cbp very widely, currently favours the use of exposed aggregate precast slabs (at almost double the cost) in areas where high abrasion is anticipated, or for sites where it is deemed important that the aesthetic appearance does not deteriorate with use. Clay pavers may also be specified as an alternative to cbp. This represents an unnecessary loss for cbp producers, considering that with some know-how, it is not difficult to produce blocks that will withstand severe abrasion, and at the same time give the client a saving relative to exposed aggregate precast slabs/clay paving.

1.4.1 The problems facing the industry may be summarised as follows:

a. There is no abrasion resistance test in the current SABS 1058 paving specification.

b. Manufacturers therefore do not test for abrasion resistance.

c. Consequently most manufacturers have not fine-tuned their mix designs, production techniques, curing procedures etc. with a view to improving the abrasion resistance of their blocks.

d. There is a considerable lack of understanding on the part of professional specifiers (architects, engineers, quantity surveyors, property managers etc.) as to what is abrasion, the different degrees of abrasion, and what degrees of abrasion are acceptable in the various applications of cbp. Furthermore, in the absence of a specification with an abrasion resistance test (including limiting criteria), they are not in a position to verify the abrasion resistance of the blocks they order.

   Remarkably this is still the position in 2001 in South Africa, even though the Australians adopted an interim abrasion test in 1986 (MA20), and have included an abrasion test (AS/NZS 4456.9) in their latest specification.

1.5 Aim

The aim of this research therefore is to provide a knowledge base that will lead to improved *abrasion resistant concrete surfaces and in concrete block paving and particular*, and in so doing address the above stated shortcomings.

Clearly an improvement in the durability of cbp will increase confidence in the product and eventually result in greater market acceptance.

1.6 Objectives

In keeping with the aim of promoting improved abrasion resistance in cbp, six objectives have been identified for the experimental work:

1 Improve the mix designs from which the blocks are made.

2(a) Establish relationships between abrasion resistance and other well established criteria such as density and compressive strength.

2(b) Recommend an abrasion test to ensure that standards are maintained in the industry.

3 Classify abrasion wear in terms of quantifiable degrees of abrasion. Applications for cbp may also be classified in terms of these degrees of abrasion.

4(a) Correlate the results of the 28-day abrasion tests with long term wear in the field. This makes it possible to establish meaningful limiting criteria for the tests.

4(b) Correlate mix designs in terms of long term abrasion-wear. This makes it possible to predict that a particular mix will meet certain limiting criteria of an abrasion test, and once in service undergo a predetermined degree of abrasion.

5 Recommend an overall Abrasion Resistance Quality Assurance programme.

6 Highlight shortcomings in the compressive strength test method as described in SABS 1058, and recommend suitable changes.

The remainder of this chapter will be devoted to outlining these six objectives in greater detail. In effect it is a preview of volume 1.

1.6.1 Objective 1 - Improve the mix design

Three mix design variables that are known to have an effect on the physical properties (including the abrasion resistance) of the blocks were selected for the manufacturing of the experimental specimens:

(a) The amount of water that is added to the mix

The writer sets out to prove that *more* water rather than less water is beneficial, since in semi-dry concrete the major problem is to achieve full compaction, as opposed to wet or conventional concrete where the addition of water should be limited to keep the binder/ water (b/w) ratio as high as possible.

This objective was investigated by testing pavers made with 6 different moisture contents, for a given mix design. The m.c. varied from very ‘wet’ to very ‘dry’.

(b) The quantity of binder material

Three variations of cementitious material were examined, 10%, 14% and 18% (relative proportion by mass). Generally 14% can be regarded as the norm used in the paving industry (for frost free climates) and this proportion was therefore selected as the control in this work. Increasing or decreasing this dosage will obviously impact both on the economics and strength of the product. Thus two values considered to be close to the outer limits of these criteria (18% for economics and 10% for strength) were also selected.

(c) The type of binder material

These include Ordinary Portland Cement (OPC), Milled Granulated Blast furnace Slag (MGBS), Fly Ash (FA) and Silica Fume (SF). With the exception of SF and to a lesser degree FA these binders are commonly used in the paving block manufacturing industry. However their relative performance in semi-dry concrete is not so well known. Silica fume in particular was new to the market at the time this research was launched and was therefore included in the programme with a view to discovering how it performs in pavers.

Scope of manufacturing programme

To accommodate the variables described in (b) and (c), eight mix designs were required as given in table 1.1.

Table 1 : Mix Designs Made in September 1987
(relative proportions by mass)

Mix Design Number	OPC %	MGBS %	Fly Ash %	Silica Fume %	Crusher Sand %
1	9	9			82
2	7	7			86
3	5	5			90
4	10		4		86
5	11		3		86
6	12		2		86
7	6.65	6.65		0.7	86
8	6.3	6.3		1.4	86

Thus the manufacturing component of the experimental programme may be described as:
8 mix designs x 6 moisture contents per mix design = 48 mixes.

Laboratory tests

The above stated mix design variations were tested in terms of nine different laboratory tests applied to the experimental paving blocks:

1. Compressive Strength	- SABS 1058	chapter 6
2. Compressive Strength	- ASTM C140	chapter 6
3. Compressive Strength	- MA20	chapter 6
4. Tensile Splitting Strength	- ISO 4108	chapter 6
5. Abrasion Resistance	- PCI-TM-7.11	chapter 6, 10
6. Abrasion Resistance	- MA20	chapter 6, 9
7. Abrasion Resistance	- ASTM C418	chapter 6, 11
8. Water Absorption	- ASTM C140	chapter 13
9. Initial Surface Absorption	- SABS 0164	chapter 13

A full discussion of the results and the merits of the tests are discussed in the chapters indicated.

It may be seen that apart from the three abrasion resistance tests, a number of other tests were selected. The results of the abrasion tests can therefore be interpreted in the light of well-established criteria such as compressive strength and density. The *rationale for selecting* the various tests is more fully discussed in the following paragraphs.

Compressive strength tests. Since the traditional means of assessing the strength of paving blocks in most countries of the world, including South Africa, is still the compressive strength test, the inclusion thereof seems to be an obvious choice. The American (ASTM C140) and Australian (MA20) compressive strength test methods (which vary considerably from the South African test method) were also selected for two reasons:

a. To make it possible to compare the work done in this programme with work done in Australia and America.
b. The MA20 compression test has none of the shortcomings of the South African compression test (SABS 1058). In this investigation the MA20 results are therefore generally used to express the compressive strength of the blocks. (It should however be noted that compression testing in Australia is not a requirement of the *new* paving specification, AS/NZS 4456.9: 1997, which calls for a bending test instead).

Tensile splitting test - ISO 4108. This test is less affected by the aspect ratio (height/width) of the block. Furthermore as the tensile strength of concrete is considerably lower than the compressive strength, a lower capacity and hence cheaper press can be used. This will be of particular interest to some of the smaller manufacturers who do not have the resources to purchase elaborate laboratory test equipment, or for mobile plants in remote areas. If it can be shown that the coefficient of variation is of a similar order to that of the compressive strength tests then it may be adopted as a reliable alternative to compression testing (see chapter 6).

Abrasion resistance tests. The selection of the three abrasion resistance tests is an important part of this work. The inclusion of the three tests are respectfully motivated for in chapters 2, 9, 10 and 11.

Water absorption - ASTM C140. The water absorption test is included in the program for two reasons:

a. to calculate the dry density of the various blocks tested in the laboratory. In this way it is possible to study the relationship between density and compressive strength, abrasion resistance etc.;

b. to study the relationship between water absorption and actual wear on site.

Initial surface absorption test - SABS 0164. Since abrasion is a surface phenomenon, including into the programme a test that measures the porosity of the surface of the blocks seems to be an obvious choice. If good correlation exists between the initial surface absorption and the actual wear on site, then this test could be used as a useful non-destructive alternative to abrasion testing. In addition, it can serve as a very useful early indicator, say at 24 hours as to what the final abrasion resistance is likely to be. The version of this test used in this work has the added advantage of being a very simple test requiring minimal capital outlay.

Water absorption and initial water absorption are fully discussed in chapter 13.

To summarise: Once the three variables (water content, binder content and binder type) have been fully tested in terms of the nine laboratory tests, it should be possible to identify those constituents which improve the strength of cbp, especially the abrasion resistance. This information will be of great value to manufacturers who need to meet particular abrasion resistance requirements of specifiers, architects, engineers etc. Objective 1 is therefore in keeping with the aim of promoting good abrasion resistance in cbp.

1.6.2 Objective 2 - Recommend an abrasion test

After a survey of current tests used nationally and abroad for concrete floors and cbp in particular (discussed in chapter 2), three tests have been selected for this research:

1. ASTM C418 - sand blast test
2. MA20 - ball bearing test
3. PCI-TM-7.11 - wire brush test

240 specimens were subjected to each of these tests, and the results expressed in terms of an index quantifying either the abrasion resistance or the abrasion-wear (the reciprocal of abrasion resistance). A comparison of the various coefficients of variation, as well as other comparisons such as initial cost of equipment, cost of individual tests, the degree to which the test simulates actual wear etc. is made in chapter 12.

Finally one of the three tests is recommended for use in the cbp industry (chapter 12, 15) in keeping with the aim of this work to promote improved abrasion resistance. However following a much deeper investigation into the mechanisms of abrasion wear in volume 2 for some 66 surface tests, it was concluded that three other abrasion tests should also be investigated, and that these may in fact be a better measure of abrasion resistance relative to those considered here in volume 1.

1.6.3 Objective 3 - Classification of abrasion

Professional specifiers from the ranks of architects, engineers, property managers etc. generally lack the specialist knowledge and experience required to assess abrasion wear in cbp. Therefore a system for qualitatively and quantitatively defining the different degrees of wear is proposed. A classification is also proposed stating what degrees of abrasion are acceptable in the various applications of cbp. This objective is addressed in chapter 8.

1.6.4 Objective 4 - 'Calibrate' the abrasion tests and mix designs relative to actual wear on site

(a) 'Calibration' of mix designs

The pavers installed in the bus lane and pedestrian sidewalk at the Westgate test site (representing the various mix designs) were measured after six years of traffic in terms of 'degrees of abrasion wear' (chapter 14). As a result, it is now possible to predict that a particular mix, once in service, will undergo a predetermined degree of abrasion. (This however, applies to a specific set of conditions, i.e. climatic conditions, raw materials, factory processes etc. Later it will be shown how to compensate for other conditions/materials/processes.) To assist in this process, wear on the site blocks is supported in a visual sense by means of 'before traffic' and 'after traffic' photographs (appendices Y and Z respectively).

(b) 'Calibration' of laboratory tests in terms of wear on site

Altogether 2304 blocks were tested in the laboratory, of which 720 were subjected to the three abrasion tests mentioned in the second objective. The results of these 28-day laboratory tests were correlated with the six-year wear in the companion blocks (chapter 14), making it possible to establish meaningful limiting criteria for the laboratory tests (chapter 15). Determining the relationship between laboratory tests and insitu wear is a very crucial aspect of this research.

1.6.5 Objective 5 - Abrasion resistance quality assurance

In chapter 15 the respective responsibilities that the specifier and manufacturer have in assuring abrasion resistance in cbp are laid down in a logical procedure. It brings together some of the more important aspects of this research, showing how the findings of the various chapters may be combined to ensure adequate abrasion resistance.

1.6.6 Objective 6 - Recommend changes to compressive strength test

The current SABS 1058 specification has a number of shortcomings. Firstly it has no correction factor for the height to width ratio of the blocks. This means that blocks currently made 60mm thick may be made about 30 % weaker than 100m thick blocks and still register the same result in the compression machine. Vice versa also applies. Secondly the net surface area (obtained by subtracting the chamfered area from the gross plan area) of the blocks is used for calculating the compressive strength. This effectively boosts the results of chamfered blocks, and penalises blocks made without chamfers. Thus blocks with chamfers can be made with substantially less cement than blocks without chamfers. These two aspects may be exploited such that inferior paving (with a low resistance to abrasion) can comply with the SABS requirements.

A compression test such as the MA20 test gives a much truer reflection of the actual compressive strength and the principles of this test should be incorporated into the existing national specification.

1.7 Summary

In this, the first of the two introductory chapters of Volume 1, a strategy for improving and verifying abrasion resistance in cbp is proposed. Six objectives are outlined, and the remaining chapters of this thesis are organised around these objectives.

If these measures are adopted by the industry and result in an increased knowledge base and understanding of abrasion resistance, leading to a significant reduction in abrasion-wear, then the stated aim of this thesis will have been achieved.

The second chapter of this introductory section introduces concrete pavers as a surfacing system, leading to a discussion on the present status of abrasion testing worldwide and in South Africa, and ending in justifying the selection of three abrasion tests for this investigation.