FACTORS WHICH WERE CONSIDERED AND A SUMMARY OF RESEARCH WHICH WAS UNDERTAKEN IN THE PREPARATION OF 'MA20 - 1986: SPECIFICATION FOR CONCRETE SEGMENTAL PAVING UNITS' BY THE CONCRETE MASONRY ASSOCIATION OF AUSTRALIA

J.T. ROURKE, B.Arch., ARAIA, Executive Officer, Concrete Masonry Association of Australia

ABSTRACT

Interlocking concrete segmental pavements rely, to a large extent, on the quality of the pavers from which they were built. In order to ensure that a quality of pavers appropriate to the design task is specified and manufactured, the Concrete Masonry Association of Australia embarked on a three-year research program to produce a specification for pavers which would be appropriate for Australian conditions. This paper summarises the major decisions taken during the process of writing 'MA20 - 1986 Specification for Concrete Segmental Paving Units' and highlights those areas of research which led to those decisions being taken. The Specification documented MA20 is appended to the paper.

NEED FOR A NEW SPECIFICATION

In August 1983 the Concrete Masonry Association of Australia (CMAA) re-formed its Paving Committee to consider the production of design aids for industrial pavements which were trafficked by vehicles with axle loads higher than those permitted on roads.

The Committee instituted procedures which eventually led to the production of a computer-aided design and analysis program by Dr B. Shackel of the University of New South Wales (see Shackel 1986).

At the same time, CMAA members were aware of the proliferation of specifications being produced by Local Government Authorities which covered aspects of paving which were not specified in the Interim Specification for Concrete Segmental Paving Units - MA15, produced by CMAA in 1982. It was decided that a new product specification should be written and that it should cover those aspects of the paving unit which the Committee at that time perceived to be critical. These were:

(a) tolerance on dimensions,
(b) flexural strength,
(c) abrasion resistance, and
(d) absorptivity.

After some three years of research, testing and debate the aspects of the paving units which were incorporated in the final document: MA20 - 1986 Specification for Concrete Segmental Paving Units were:

(a) tolerance on dimensions,
(b) compressive strength, and
(c) abrasion resistance.

The Specification MA20 is appended to this paper.

TOLERANCE ON DIMENSIONS

The dimensional tolerances in MA15 are reproduced in MA20 as they have been found to work well in practice (see para. 64 of MA20).

At first sight the tolerances permitted on block manufacture (± 3 mm in thickness and within 2 mm of the theoretical position in plan) may

appear to be generous. In practice, however, the only tolerance that is of practical value is that which encourages the pavements to be laid so that they interlock properly. Most interlocking pavers are manufactured on the flat and the tolerance specified allows for minor variations between each unit of the mould, and for mould wear.

FLEXURAL AND COMPRESSIVE STRENGTH

FLEXURAL STRENGTH

The logic behind using the flexural strength criterion was formed around the following two points.

(a) In a pavement, any segmental pavers which cracked usually did so in flexure, and it was believed that, by specifying flexural strength, a specification more closely related to field conditions would eventuate.

(b) Testing for flexural strength would give results which would not vary with the aspect ratio (i.e. thickness divided by width) of the units being tested, as was the case with compression testing.

Several member companies instituted flexural testing programs, and some were able to derive constant relationships between compressive and flexural strength for any one product, on one machine, with one mix design. Consistent relationships, over a wider variety of products, machines and aggregates proved far more difficult to achieve. After considerable debate, it was decided to abandon flexural strength as a specification item, at least for the time being.

COMPRESSIVE STRENGTH

With the abandonment of the specification for flexural strength, the CMAA was faced with trying to specify some method of compression testing which would accommodate the various aspect ratios to which the pavers were manufactured.

There was always a strong body of opinion within the CMAA that a compressive test should continue to be specified as an alternative to flexural testing because:

(a) it was a well-understood test;
(b) it provided a simple and useful method of determining overall quality;
(c) all manufacturers either possessed or had ready access to the necessary equipment; and
(d) it was contained in the existing interim specification.

The Committee initially favoured a punching test, similar to that specified in the Danish paver specifications. This test had the advantage of being capable of execution on existing machinery, and went a long way towards the elimination of the influence of aspect ratio on the compressive strength.

The test uses two opposing cylindrical dies, about 50 mm in diameter, attached to a standard compression testing machine, between which a paver is compressed. The disadvantage of the test was that there were no test results in this country, and such a body of information was deemed desirable for comparison and calibration purposes.

At the time the compression strength test was under debate, many members of the CMAA Paving Committee were serving on Committee BD4 (Structural Masonry Standard) of the Standards Association of Australia. They felt that the unconfined compressive strength criterion being specified in the masonry code could have applicability to the CMAA paving specification. (In the Unconfined Compressive Strength test, units are placed between platens made up of a group of long needles which allows the specimen to deform under load without being restrained by the platens. These platens give an artificial increase in apparent strength.)

These deliberations on the choice of test methods were taking place just after the Second International Conference on Concrete Block paving held in Delft, The Netherlands, in 1984. At this Conference, a world-wide review of standards and specifications for concrete paving units was compiled (see Houben, Leewis and van der Kreeft 1984).

An examination of these documents led the CMAA to the Italian Concrete Block Paving Standard, which included a correction formula which compensated for the effects of aspect ratio:

$$K = \frac{55}{\left(\frac{13\sqrt{S}}{H} + 24.35\right)}$$

where S = bearing area (cm^2) and H = the height (cm). The standard unit which the Italians chose as having a correction factor of unity was a 200 x 100 x 60 mm rectangular paver.

In the CMAA Specification the formula is expressed slightly differently:

$$C = \frac{W}{A} \times \frac{5}{\left(\sqrt{\frac{A}{H}} + 1.87\right)}$$

where:

C = compressive strength (MPa),
W = total load at which the specimen fails (N),
H = nominal height of unit (mm), and
A = nominal gross area, based on the manufacturing dimensions of the paving unit (mm).

The changes in the formula arose from a desire to change the system of the measurement of A from nett to gross area (chamfers represent about 17 per cent of the gross area); to use a common 80 mm thick shape A classification paver as the shape having a correction factor of unity; and to use a 95 per cent characteristic strength in line with current Australian masonry codes.

The decision to change the basis of determining the strength of pavers from dividing the compressive force by the nett area (on the argument that this is the loaded area) to dividing the compressive force by the gross area, removed the artificial increase in strength value derived from the use of chamfered edges, and produced a better indication of paver quality.

The selection of the final correction formula was taken after determining whether it would be more appropriate to express the result in terms of:

(a) unconfined compressive strength (as used in BD4),

(b) a standard concrete cylinder (300 x 150 mm), or

(c) a common paving shape.

Fig. 1 compares the various proposals which were examined. The adoption of the unmodified 'Italian' formula would ascribe a strength of 1.83 times the strength of the equivalent concrete tested as a cylinder (300 x 150 mm) or 2.26 times the unconfined compressive strength being proposed for masonry units in SAA Committee BD4. This meant that an 80 mm thick shape A paver, the compressive strength of which was currently specified as 45 MPa (on nett area as defined in MA15) would have a defined strength of 37.8 MPa on gross area, or 42.4 MPa using the 'Italian' formula, or 23 MPa if a concrete cylinder correction factor was used.

The adoption of the modified Italian formula (eqn (2)) meant that the most common 45 MPa paver could still be advertised as a 45 MPa paver, and avoided what could have been an extensive re-education program for specifiers, yet still allows them to compare the material quality of different paver shapes.

An illustration of the implications of the various correction factors is shown by an examination of Table 1, which lists the results of a series of tests on pairs of matched 180 x 230 x 50 mm pavers tested on flat and on edge, when the three different factors were applied.

ABRASION RESISTANCE

The determination of a satisfactory method of specifying an abrasion test procedure and limits proved to be the most difficult section of all the work undertaken in the preparation of MA20.

As a starting point, CMAA conducted a world-wide review of abrasion test procedures and catalogued some 32 standard procedures and testing rigs in use throughout the world which may have had applicability to paver testing. In order to analyse which of these procedures would be most appropriate to the needs of the segmental paving industry, a list of desirable features for an abrasion test procedure was drawn up. The CMAA determined that the test should be:

(a) fast enough to allow it to be used as a method of production control;

(b) carried out with relatively inexpensive and, if possible, portable equipment;

(c) reproducable and inexpensive on a test-by-test basis; and

(d) by the same as, or similar to, an existing test so that results could be compared.

After a process of elimination, the choice of equipment and test procedure was narrowed down to two:

(a) the French abrasion testing machine as defined in P98 - 303: Pavés en Beton;

(b) a test machine developed by Perth City Council, which is a derivative of, and closely resembles, the equipment specified in ASTM Test C779 - 82 (Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces).

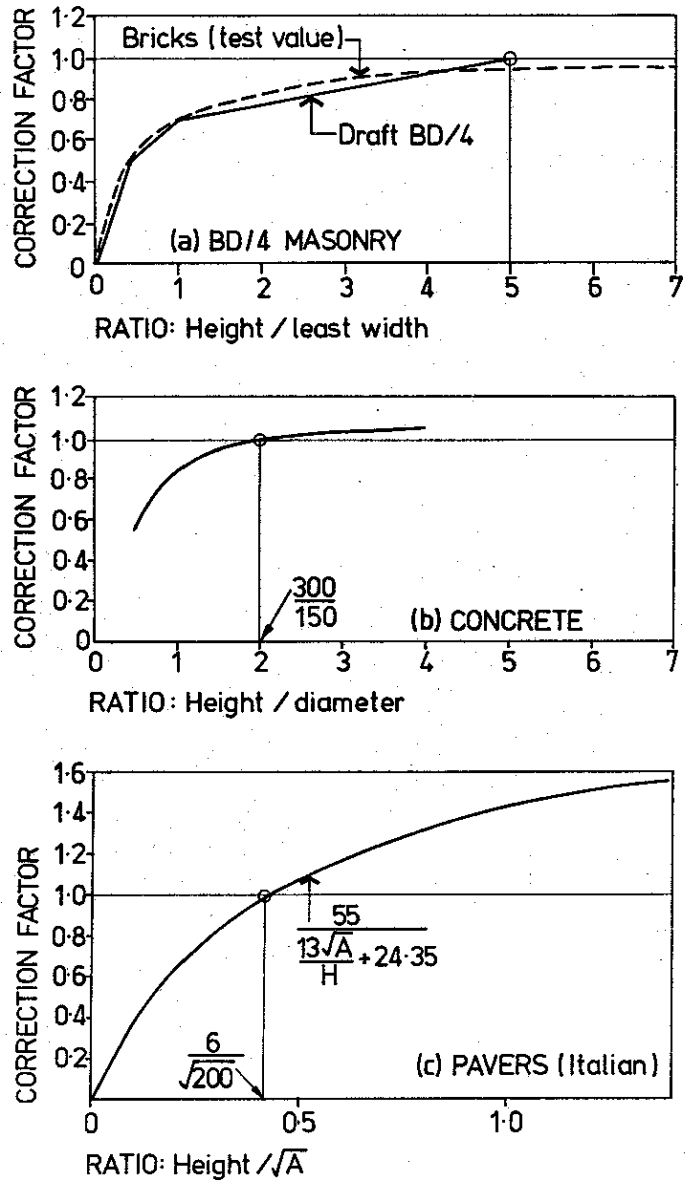


Fig. 1 - Comparison of compressive strength test proposals

Because of the accessibility of the Perth City Council machine, and the body of knowledge they had accumulated using it, it was decided to proceed with a testing program using this machine. Details of the test and machinery are set out in Appendix D of MA20 - 1986, reproduced in this paper, whilst the differences between the ASTM test and the Perth City Council test are set out in Table 2.

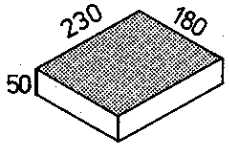
Having selected a testing machine, a program of abrasion resistance testing was carried out on pavers currently in production and pavers which had been in service for some years, in order to quantify the amount of abrasion on surfaces, the performance of which (both good and bad) was known. A range of pavements from pedestrian areas to heavy duty hardstands, was examined. Samples were drawn from 14 pavements, representing a number of different manufacturers from South Australia, New South Wales, Queensland and the A.C.T., which had been in service for a period ranging from 18 months to eight-and-a-half years.

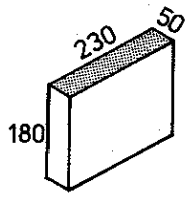
The testing program was undertaken by Unisearch Limited of the University of New South Wales, and the results obtained from these pavers were combined with the test data already available for a freshly-manufactured untrafficked batch of pavers. Typical data are shown in Tables 3 and 4.

These tests showed up some weaknesses in the design of the test

TABLE 1

MATCHED COBBLESTONES TESTED ON FLAT AND ON SIDE





TESTED STRENGTHS	A	Flat	71.0	A	Edge	29.9
	B	Flat	63.8	B	Edge	26.8

CORRECTION FACTORS

PAVER $Kp = \frac{55}{13\sqrt{\frac{A}{H}} + 24.35} = 0.71 - 1.71$

CONC. CYL $Kc = \frac{30}{13\sqrt{\frac{A}{H}} + 24.35} = 0.39 - 0.93$

UNCONFINED $Ku = \frac{24}{13\sqrt{\frac{A}{H}} + 24.35} = 0.31 - 0.75$

CORRECT TO PAVER	(Kp)	A	71.0 x 0.71 = 50.4 - 29.9 x 1.71 = 51.1
		B	63.8 x 0.71 = 45.3 - 26.8 x 1.71 = 45.8
CORRECT TO CONC. CYL	(Kc)	A	71.0 x 0.39 = 27.7 - 29.9 x 0.93 = 27.9
		B	63.8 x 0.39 = 24.9 - 26.8 x 0.93 = 25.0
CORRECT TO UNCONFINED	(Ku)	A	71.0 x 0.31 = 22.0 - 29.9 x 0.75 = 22.4
		B	63.8 x 0.31 = 19.8 - 26.8 x 0.75 = 20.1

TABLE 2

COMPARISON OF THE PERTH CITY COUNCIL TEST PROCEDURE WITH ASTM C779-82

	ASTM	PCC
(a) Wear Tool		
No. of Balls	8	12
Dia. of balls - original	18.25	15.83
(b) Force (N)	120	142
(c) Speed (revs/min)	1000	1025

TABLE 3

TEST RESULTS FOR 15 NEWLY-MADE UNTRAFFICKED PAVERS

No. of Samples	No. of Tests	Test Condition	Running Time (min)	Penetration (mm) Mean	Std. Dev.
15	45	dry	5	0.726	0.262
			10	0.918	0.315
			14	1.063	0.373
15	45	wet	5	0.802	0.229
			10	0.980	0.293
			14	1.118	0.352

TABLE 4

TEST RESULTS FOR IN-SERVICE PAVEMENTS

Paver Thickness (mm)	Traffic Classif.	Approx. Age (years)	Sample Size	Mean Penetration (mm) 5 min	10 min	14 min
65	T3	4	3	0.450	0.680	0.780
65	T3	3.5	3	0.890	1.007	1.203
85	T5	8.5	3	0.560	0.623	0.700
100	T5	6.5	3	0.770	0.867	0.947
80	T3	8	3	0.826	0.990	1.120
75	T2	6	3	0.730	0.977	1.233
80	T3	4.5	3	0.883	1.223	1.427
80	T4	1.5	3	0.703	0.853	0.963
80	T5	3	3	0.413	0.517	0.587
80	Indus.	2	3	0.560	0.747	0.877
80	Indus.	2	3	0.743	0.843	0.977
80	Indus.	3	3	0.807	0.993	1.047
80	T5	3	3	0.417	0.583	0.693
80	T4	5	3	1.106	1.267	1.390
	General Mean		14	0.697	0.869	0.996
	Standard Dev.		14	0.190	0.225	0.258

Note: Traffic classes are defined in Hodgkinson and Morrish (1982) and NAASRA (1979).

rig and in the test procedure as follows:

(a) the absence of a revolution counter;

(b) a lacks of means of calibrating the force bearing on the ball race;

(c) lack of adjustment of plumbness to the test surface;

(d) inadequate means of anchoring the paver under testing; and

(e) inadequate restraint against sideways wander of the ball race.

These difficiencies were rectified (and are incorporated in the specification now written and appended) and a number of test rigs were built to carry out testing at selected member company factories.

The following conclusions were drawn for the Unisearch (1985) test program:

(a) the mean rate of penetration tended to decrease with an increase in test duration;

(b) samples tested in the 'wet' condition exhibited greater abrasion loss than samples tested 'dry';

(c) the variability in the test results (expressed as the standard deviation) increased with an increase in test duration; and

(d) for a given test duration, the variability in the test results for samples tested 'wet' was always greater than for samples tested 'dry'.

An intensive period of testing followed, with manufacturers submitting results to the CMAA for recording and graphing.

The desirability of having a revolution counter was demonstrated in these tests as it was found that voltage variation in some areas could affect the drill speed by up to ±12 per cent, and the measurement of abrasion penetration by nominal drill speed and elapsed time could have led to correspondingly large variations in the test results.

ABRASION INDEX

Both the Perth City Council testing programs and the work undertaken on behalf of the CMAA by Unisearch Limited reported results on the basis of amount of penetration related to elapsed time of running the abrasion machine.

To eliminate the variability in speed of the drill used in the machine (caused by manufacturing differences and voltage variation) it was decided to plot depth of penetration (P) against revolutions (R) of the ball race. The graphs derived from this plotting generally take the shape of:

$$P \propto \sqrt{R}$$

$$\text{or } \sqrt{R} = IaP$$

where
P = penetration (mm),
R = revolutions of the race (thousands), and
Ia is a constant.

The ability of the paver to resist the penetration of the ball race could then be described by the value of Ia - the abrasion index - the value of which would be:

$$Ia = \frac{\sqrt{R}}{P}$$

In theory, R and P could be taken at any point along the graph, but in practice the graphs do not generally follow a smooth curve but vary from side to side. There may also be some zero error.

It became necessary, therefore, to define a point on the graph where the measurement is taken; this needed to be as high as possible in order to minimise these variables. From the experience gained in the testing that had been carried out, the measurement points of 5000 ball race revolutions or 1.5 mm of penetration (whichever came first) were selected. Typical curves are shown in Fig. 2.

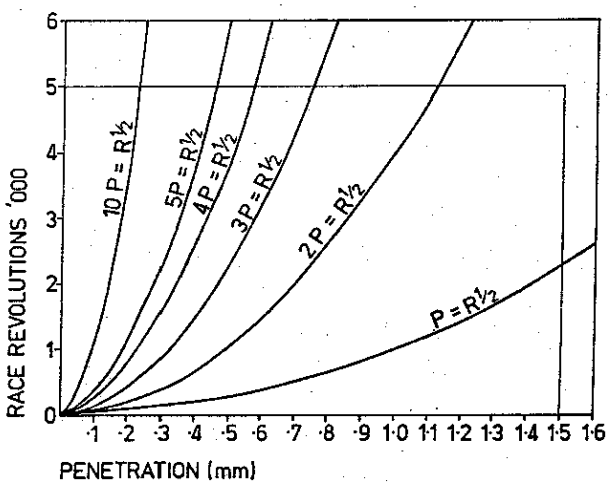


Fig. 2 - Typical abrasion index curves

Four alternative methods of applying an abrasion index to a sample were examined to express this index:

(1) a lower bound of a group of samples;

(2) an average of a group of samples coupled with an absolute lower bound;

(3) an envelope specifying an upper and lower bound; and

(4) a characteristic abrasion index.

When the debate took place on each of these alternatives, it became apparent that the amount of testing which had been carried out to that time (May 1986), even though it was significant, did not allow the decision between the four alternatives to be made with confidence. it was decided to follow the Perth City Council practice and nominate a lower bound (alternative (1)) and to label this section of MA20 dealing with abrasion resistance as "Interim". (The decision to issue an interim abrasion index section was also influenced by acknowledging that further testing needed to be done before firm recommendations could be specified.)

SELECTION OF THE ABRASION INDICES

The results of the testing carried out on the existing pavers were compared, and values ascribed to pavers in jobs which were performing well and those which were performing poorly. Typical graphs showed that the pavers tested by Unisearch fell within an abrasion index range of 2.1-3.3 (Fig. 3), all current manufacture which had been tested fell within the range 1.7-4.0 (Fig. 4), typical examples of pavers which performed exceptionally well had a range of 2.8-4.4 (Fig. 5), and pavers which had performed so poorly that they were replaced had a typical range of 0.2-1.0 (Fig. 6).

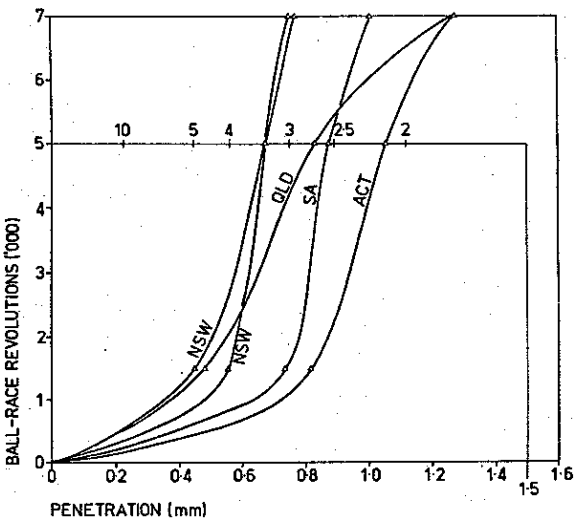


Fig. 3 - Typical curves of abrasion tests on pavers from various States (Unisearch Limited 1985)

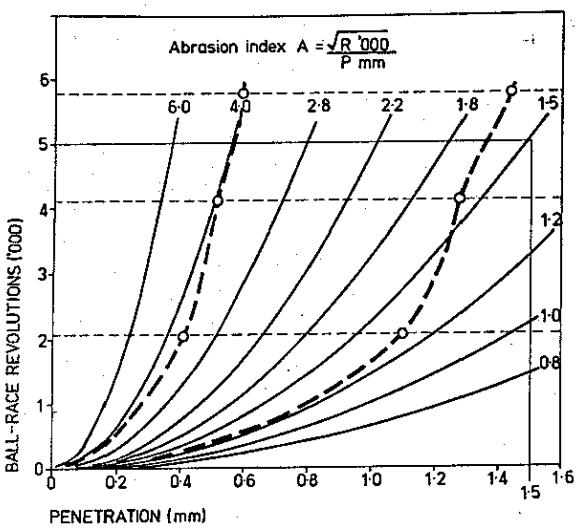


Fig. 4 - Range of abrasion indices on production samples tested in 1985

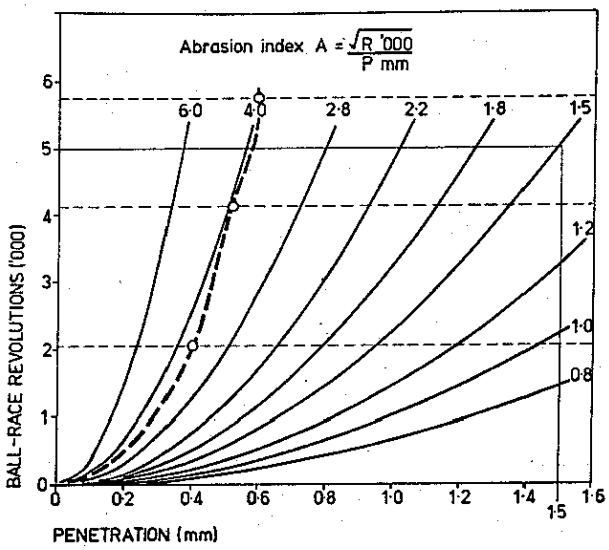


Fig. 5 - Mean of a series of samples tested from a pavement which was performing exceptionally well - range 2.8 to 4.4

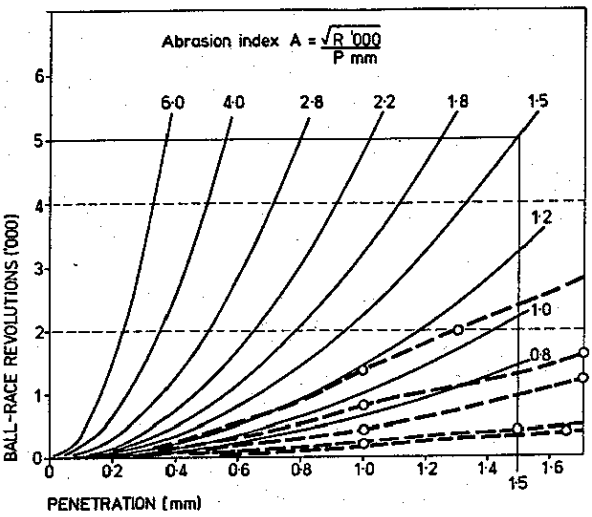


Fig. 6 - Abrasion indices of pavers which were judged to have performed poorly

WEAR - WHERE?

Armed with the research information gathered over two years, it was possible to select abrasion indices which would be appropriate to pavement use, as not all pavements had the same abrasion resistance requirements.

The selection of an index appropriate to an application became a matter of subjective assessment and balancing between such parameters as consumer acceptance, capability of manufacture, appearance, and an analysis of tested pavements. A hierarchy of abrasion resistance requirements is tabulated in Table 2 of MA20.

Pavements carrying pedestrian traffic in concentrated areas have the highest requirement for abrasion resistance, and the highest selected interim index (Ia) of 2.0 was specified. It was felt that public roadways, intersections and industrial hardstandings, all of which are prone to vehicular slewing loads, represented another grouping with a lesser requirement than malls, and an interim index of 1.5 was selected.

In order to preserve a minimum abrasion resistance above that which was known from testing to be unsatisfactory, all other paving was specified to have an interim abrasion index of 1.2.

Although it is possible to identify other groupings of pavements, the requirements of stock control and identification predicated that as small a number of Ia's as possible should be specified.

WEAR - WHEN?

The existing pavements tested had an age range between one-and-a-half and eight-and-a-half years, and the relationship between manufactured strength (on processes which used a curing regime other than autoclaving) and strength over a period of time needed to be established.

To conduct experiments to establish this relationship requires very good factory control. For best results it is necessary to have a number of pavers as nearly identical as possible. This means that all pavers should come from the same mix and the same mould compartment in consecutive cycles. A typical relationship between depth of penetration (in mm) and age (in days) is shown in Fig. 7. It can be seen that significant gains in abrasion resistance are achieved with time.

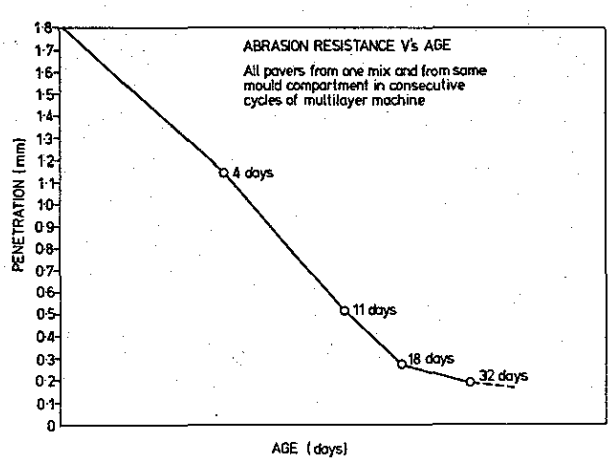


Fig. 7 - Typical relationship between depth of penetration and age

Selecting the time at which abrasion index should be measured becomes a matter of balancing the needs of the manufacturer, who wants the pavers out of his yard as quickly as possible, and the needs of the job to have adequate abrasion resistance.

It was felt that, in practice, few pavements, if any, would receive typical regular service traffic within 28 days of manufacture, and as a 28-day strength specification was common within the concrete inductry, this time period was chosen as an interim measure. It is expected that most manufacturers will carry out testing to establish the relationship between the abrasion index at ages less then 28 days and the 28-day index.

CONCLUSION

Although not all aspects of the work which went into the writing of MA20 are covered in this paper, it has attempted to set down the most significant points, and the points of departure from the philosophies embodied in MA20.

Conformance with MA20 will require the manufacturer to target his product at a higher level than that which is generally in production at the present time. It will also eliminate the confusion amongst manufacturers and consumers caused by the lack of appreciation of the 'aspect ratio' effect on compressive strength.

It is hoped that this paper will give some insight into the work that has been put into the writing of MA20, and that it will be called-up by specification writers with confidence.

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John Rourke is an architect and a graduate of the University of Sydney. He has had extensive European experience, having completed post-graduate courses at the Universite de Besancon, the Centre Scientifique et Technique du Batiment in Paris and the School of Advanced Architectural Studies in York. He was, for the five years prior to its completion, the co-ordinating architect on the Sydney Opera House. From that time until 1982 he was the Principal of a Sydney-based architectural practice. in 1982 he joined the Cement and Concrete Association of Australia and in 1984 was appointed Executive Officer of the Concrete Masonry Association of Australia.

APPENDIX

CONCRETE MASONRY ASSOCIATION OF AUSTRALIA

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SPECIFICATION FOR CONCRETE SEGMENTAL PAVING UNITS

CONTENTS

INTRODUCTION

BACKGROUND

SPECIFICATION

1 Scope

2 Reference Documents

3 New Materials and Methods

4 Definitions

5 Materials

6 Physical Properties

APPENDICES

A Quality Control

B Sampling

C Determination of Compressive Strength

D Determination of Abrasion Index

INTRODUCTION

This document supersedes the Interim Specification for Interlocking Concrete Paving Units, MA15, of March 1980, prepared by the Concrete Masonry Association of Australia.

BACKGROUND

Since MA15 was introduced some 6 years ago the growth in the concrete segmental paving market has been substantial. This market growth has lead to a greater knowledge of the physical properties, and the desirable performance characteristics of concrete segmental paving under varying traffic conditions.

In 1984 a world congress on concrete segmental paving units was held in Delft in the Netherlands. At this congress a world-wide review of standards and specifications for concrete pavers was compiled.

With the benefit of this research the Concrete Masonry Association of Australia examined various methods of testing and specifying concrete segmental pavers before deciding upon the specification which it thought was most appropriate to Australian conditions. These recommendations are set out in this document.

1 SCOPE

This specification sets out the requirements for concrete segmental paving units intended for use in public areas subject to pedestrian and/or vehicular traffic.

2 REFERENCE DOCUMENTS

The following standards are referred to in this specification:

AS 1129 - 1971	Fly Ash for Use in Concrete
AS 1315 - 1982	Portland Cement
AS 1317 - 1982 & Amendment 2 (May 1984)	Blended Cement
AS 1478 - 1973	Chemical Admixtures for Use in Concrete
AS 1479 - 1973	Code of Practice for the use of Chemical Admixtures in Concrete (metric units)
AS 1672 - 1974	Building Limes
AS 2193 - 1978	Methods for Calibration and Grading of Force-measuring Systems of Testing Machines
AS 2758.1 - 1985	Aggregates and Rock for Engineering Purposes Part 1 - Concrete Aggregates
ASTM C331 - 81	Lightweight Aggregates for Concrete Masonry Units

3 NEW MATERIALS AND METHODS

This specification shall not be interpreted as preventing the use of materials or methods of manufacture not specifically referred to herein.

4 DEFINITIONS

4.1 Concrete Segmental Paving Unit

A unit of less than or equal to 0.09 square metres in gross plan area, manufactured from concrete, with plain or dentated sides, with top and bottom faces parallel and with or without chamfered edges.

4.2 Lot

An aggregate of paving units of a single type and of specified characteristics and dimensions, presented for random sampling at one time.

4.3 Manufacturing Dimensions

The dimensions adopted for manufacture and to which specified tolerances apply.

4.4 Chamfer

The sloping top edge of some paving units.

4.5 Gross Area

The plan area generated by the vertical projection of the outside surfaces of the paving unit.

4.6 Compressive Strength

A measure of the crushing strength of the paving unit.

4.7 Abrasion Index

A measure of the ability of the surface of a paving unit to resist wear under the conditions of test in Appendix D.

5 MATERIALS

5.1 Cement

Cement shall comply with AS 1315 or AS 1317 as appropriate.

5.2 Lime

Lime shall comply with AS 1672.

5.3 Fly Ash

Fly Ash shall comply with AS 1129.

5.4 Aggregate

Aggregate, or the components of the aggregate, shall comply with AS 2758.1, Part 1 or ASTM C331, as appropriate.

5.5 Water

Water shall be free from matter in a quantity harmful to concrete.

5.6 Admixtures

Any chemical admixture used in the concrete shall comply with AS 1478, and shall be used in accordance with AS 1479.

6 PHYSICAL PROPERTIES

6.1 General

Clauses 6.2 - 6.7 specify properties with which concrete segmental paving units shall comply. Where test methods are required, the appropriate test procedures are given.

6.2 Shape

Paving units shall be identified by shape as being one of the following types:

6.2.1 Shape Type A are dentated chamfered units which key into each other on four sides, are capable of being laid in herringbone bond, and by their plan geometry, when interlocked, resist the spread of joints parallel to both the longitudinal and transverse axes of the units.

6.2.2 Shape Type B are dentated units which key into each other on two sides, are not (usually) laid in herringbone bond, and by their plan geometry, when keyed together, resist the spread of joints parallel to the longitudinal axes of the units and rely on their dimensional accuracy and accuracy of laying to interlock on the other faces.

6.2.3 Shape Type C are units which do not key together and which rely on their dimensional accuracy and accuracy of laying to develop interlock.

6.2.4 Shape Type X are units which may or may not conform to the above definitions but which are designed to have specific characteristics to provide interlock.

NOTE: Clause 6.2.4: Shape types A, B and C as defined in this document are referred to in a large quantity of literature on segmental concrete paving. The Association deemed it appropriate to continue with these shape categories, and to add a new type - Shape Type X.
In recent years there has been an increasing tendency to develop paver shapes which have specific characteristics to meet specific requirements. Examples of this are shapes which are designed to be mechanically laid or to resist induced rotation.
These new shapes have been categorised as Shape Type X.

6.3 Sampling

Where the physical properties of a given lot of units are to be tested for compliance with the specification the units shall be sampled in accordance with Appendix B.

6.4 Tolerance on Dimensions

The manufactured dimensions of any unit shall be such that any point on the external vertical surfaces of that unit shall be horizontally within 2 mm of the theoretical position of that point, according to the manufacturer's stated manufacturing dimensions. The thickness of any block shall be within ± 3 mm of the manufacturer's nominated thickness.

NOTE: Clause 6.4: At first sight the tolerances permitted on the block manufacture may appear to be generous.
In practice however, the only tolerance which is of practical value is that tolerance which encourages the pavements to be laid so that they can interlock properly.
Most interlocking pavers are manufactured on the flat and the tolerance specified allows for minor variation between each unit of the mould, and for mould wear.
Rumbled pavers are specifically excluded from this clause.

6.5 Chamfers

The horizontal and vertical projections of any chamfer shall not exceed 8 millimetres.

NOTE: Clause 6.5: Chamfers on interlocking paving perform the dual functions of acting as funnels for the introduction of jointing sand between the pavers, and as a device to prevent minor edge spalling in the compression zone at the top of the paving unit.
When selecting the size of a chamfer in pedestrian areas the designer should consider the effects of these chamfers on ladies' high heels. Most manufacturers have information on shapes which have proven to be successful in pedestrian areas. Rumbled pavers are specifically excluded from this clause.

6.6 Compressive Strength

The specified minimum 28-day characteristic compressive strengths for particular applications are given in Table 1. The characteristic compressive strength of a lot of concrete paving units shall be determined in accordance with Appendix C.

NOTE: Clause 6.6: The measurement of compressive strength remains a simple and useful method for determining the overall quality of a paving unit, and it has therefore been retained in this specification.
In line with most new material standards (which nominate unconfined compressive strengths) the compressive strengths specified in this document will enable the designer to directly compare the material qualities in various paving shapes.
Simple compression testing makes no allowance for the aspect ratio of the unit under test. A low squat unit will crush at a higher compressive load than a tall slender unit made of the same material.
The procedure set out in Appendix C introduces a shape factor to accommodate the aspect ratio effect, so that, for example, a paver which has a compressive strength of 45 mPa would contain the same quality of material no matter what its height, depth or breadth.

TABLE 1

Paving Category	Minimum 28-Day Characteristic Compressive Strength
Pavements for vehicles of less than 3 tonnes gross weight and for pedestrians	30 MPa
Pavements for all other traffic	45 MPa

6.7 Interim Guide for Abrasion Resistance

Where the designer wishes to specify an abrasion resistance, the 28-day abrasion indices are given in Table 2 as a guide.

The minimum abrasion index of a sample of concrete paving units shall be determined in accordance with Appendix D.

NOTE: Clause 6.7: This section of the specification is put forward as an interim guide as the Association has not yet completed its research programme into a number of factors affecting abrasion resistance.
The choice of the abrasion measuring tool was arrived at after an exhaustive world-wide search. The test method outlined in the document can be performed reasonably quickly, is repeatable and inexpensive.
The abrasion resistance is specified as the lower bound of a sample of 5 units. The setting of a lower bound will automatically encourage the manufacturer to set a target for abrasion resistance above this lower bound.
The abrasion index is set at a 28-day minimum and it is expected that most manufacturers will carry out testing to establish the relationship between the abrasion index at ages earlier than 28 days, and the 28-day index.
Specifiers are encouraged to accept a manufacturer's results at ages earlier than 28 days if they are satisfied with the manufacturer's recording and controlling techniques.

TABLE 2

Pedestrian Paving Category	Minimum 28-Day Abrasion Index	Vehicular Paving Category	Minimum 28-Day Abrasion Index
Busy shopping footpaths and malls with heavy pedestrian traffic	2.0		
		Public roadways and industrial hardstandings	1.5
Footpaths in other areas	1.2	Carparks with vehicular traffic under 3 tonnes	1.2

APPENDIX A

QUALITY CONTROL

A1 SCOPE

This Appendix offers guidance for the quality control of concrete segmental paving units, but does not purport to fulfil all of the requirements of a purchasing agreement for these units.

A2 ORDERING

In ordering units to this specification, the purchaser should quote the manufacturing dimensions or the relevant manufacturer's code number, the strength classification, any other property requirements as agreed or subject to negotiation, and the number of this specification, ie MA20.

A3 IDENTIFICATION

When units are ordered to be in accordance with this specification, the manufacturer should record the following information on delivery dockets:

(a) Source of supply
(b) Manufacturer's code number
(c) Strength grade
(d) Minimum abrasion index
(e) The number of this specification, ie MA20.

A4 VERIFICATION

A4.1 Test Records

Manufacturers of units complying with this specification may carry out regular testing of their product. It is recommended that purchasers, instead of being put to the expense of sampling and testing individual deliveries of units, take advantage of the manufacturer's test records. The manufacturers may be prepared to:

(a) supply, on request, relevant data on unit properties from their records, or

(b) make such records available for inspection by an independent inspector acceptable to both the purchaser and manufacturer.

A4.2 Independent Testing

Where independent testing of units purported to comply with this specification is required by a purchaser, sampling and subsequent testing of the lot in accordance with this specification should be carried out by a laboratory registered for this purpose with the National Association of Testing Authorities, Australia.

It is recommended that the cost of units required for testing and the cost of sampling and testing should be borne:

(a) by the purchaser if the units conform to limits specified by this specification, or

(b) by the manufacturer if the units do not conform to limits specified by this specification.

A5 WORKMANSHIP AND FINISH

A5.1 Manufacture

Prior to delivery, all units should be sound and free from major defects which would interfere with proper placing or impair the strength or permanence of the pavement or its appearance where the latter is important.

A5.2 Method of assessment

The manufacturer and the purchaser should agree on the quality that is acceptable and on a reasonable method of inspection and assessment at the manufacturer's yard before delivery.

A5.3 Delivery

Methods of delivery should be such as to minimize any damage.

APPENDIX B

SAMPLING

B1 SELECTION

The sample shall comprise concrete paving units selected at random from an identifiable lot and the test results shall apply to that lot.

NOTE: The most important aspect of sampling is to ensure that the units are selected at random. Random selection is easier to accomplish if the sample is taken during stacking.

B2 SIZE OF TEST SAMPLE

The quantity of units used for individual tests shall be in accordance with Table B1.

TABLE B1

Sample Quantities for Individual Tests

Appendix	Test	Quantity
C	Compressive Strength	5
D	Abrasion Index	5

B3 STORAGE

Units selected in sampling shall be stored in a dry place, not in contact with the ground, until tests are made.

B4 RE-SUBMISSION OF LOT

Where the random sample, when tested, does not comply with the requirements of this specification, the manufacturer may vary the lot from which the sample was drawn and re-submit it for sampling.

APPENDIX C

DETERMINATION OF COMPRESSIVE STRENGTH

C1 SCOPE

This Appendix sets out the method for determining the characteristic compressive strength of concrete paving units within a lot.

C2 PRINCIPLE

A unit is placed in a testing machine and subjected to increasing compression until it fails. From the maximum load and gross area, the compressive strength is calculated.

C3 APPARATUS

The following apparatus is required:

A testing machine which complies, as regards accuracy, with the requirements for Grade A or B machines as given in AS 2193. The machine shall be fitted with two steel platens having bearings faces of hardness not less than Rockwell HRC60, one of which, preferably the upper, shall have a spherical seat allowing the platen to rotate or tilt through small angles in any direction.

The bearing faces of both platens shall be at least as large as, and preferably larger than, the test specimen and shall not depart from a plane by more than 0.05 mm. Should the bearing faces of the platens be smaller than the test specimen, steel plates of adequate size may be placed centrally between them and the test specimen. Bearing faces of such plates shall not depart from a plane by more than 0.05 mm and their thickness shall be equal to at least one-third of the greatest difference in dimension between the machine platen and the test specimen but not less than 25 mm.

C4 SAMPLING UNITS

Five units, representing the lot, and selected in accordance with Appendix B, shall be used as test specimens.

C5 PROCEDURE

The procedure for each specimen shall be as follows:

(a) Clean and wipe each test specimen, the bearing surfaces of the platens on the testing machine, and the packing to be placed between the specimen and the platen.

(b) Place the specimen between two pieces of plywood, chipboard or medium density hardboard of thickness between 4 mm and 6 mm, the length and width of which shall exceed the corresponding dimensions of the specimen by between 15 mm and 25 mm. The specimen shall be aligned with its height in the vertical direction.

(c) Carefully align each piece of capping material with the centre of thrust of the spherically seated platen. Bring the upper platen to bear on the specimen and, by hand, gently rotate the seated platen so that uniform seating is obtained.

(d) Apply the load without shock and increase it continuously until failure occurs, in accordance with the following provisions:

(i) In testing machines of the screw type, the moving head shall travel at a rate of about 2.5 mm/minute when the machine is running idle.

(ii) In hydraulically operated machines, the load shall be applied at a constant rate within a range equivalent to a stress of 150 kPa/s to 700 kPa/s.

(iii) During the application of the first half of the anticipated maximum load required to produce failure, a higher rate of loading shall be permitted. No adjustment shall be made in the controls of the testing machine while a specimen is yielding rapidly immediately before failure.

(e) Observe the maximum load (W) carried by the specimen.

NOTE: In order to avoid damage to the spherical seat of the platen, the load should be quickly released as soon as it falls below the maximum.

C6 CALCULATION OF RESULTS

The compressive strength of each specimen shall be calculated from the following expression:

$$C = \left(\frac{W}{A}\right) \times \left(\frac{5}{\frac{\sqrt{A}}{H} + 1.87}\right)$$

WHERE:

C = compressive strength, in megapascals
W = total load at which the specimen fails, in newtons
H = nominal height of unit, in millimetres
A = nominal gross area, in square millimetres, based on the manufacturing dimensions of the paving unit. Where the unit is halved for testing, the area of the tested half should be measured and treated as A.

The characteristic compressive strength of the lot shall be calculated from the following expression:

$$Cc = \bar{C} - 1.65\ S'$$

WHERE:

Cc = characteristic compressive strength, in megapascals

$\bar{C}$ = the average of the individual compressive strengths of the specimens, in megapascals

$$= \frac{C1+C2+C3+C4+C5}{5}$$

S' = the unbiased standard deviation, in megapascals

$$= \sqrt{\frac{C1^2+C2^2+C3^2+C4^2+C5^2-5(\bar{C})^2}{4}}$$

C7 RECORDS

The following information shall be recorded:

(a) Identification mark
(b) Date of manufacture
(c) Date of test
(d) The maximum load, in newtons, carried by each specimen
(e) The compressive strength, in megapascals, of each specimen
(f) The average compressive strength of the sample
(g) The unbiased standard deviation of the sample
(h) The characteristic compressive strength of the sample
(i) The nominal gross area of each specimen to the nearest 100 square millimetres as calculated from the manufacturing dimensions.

C8 REPORT

If a report is prepared it shall include the following information:

(a) Identification of the lot, lot size and manufacturer
(b) Age of units, in days, at the date of test
(c) Date of test
(d) The compressive strength, in megapascals, of each specimen of the sample
(e) The characteristic compressive strength, in megapascals, of the lot.

NOTE: Where the units are of such a size and strength as to exceed the capacity of the testing machine, it shall be permissible to cut the units in half and test one half of each unit.

APPENDIX D

DETERMINATION OF ABRASION INDEX

D1 SCOPE

This Appendix sets out the method for determining the minimum abrasion index of a sample of paving units.

D2 PRINCIPLE

The abrasion index of a paving unit is derived from the penetration of steel ball bearings into the surface of the unit when they are driven under constant load within a rotating ball-race. If the top surface has already been eroded unevenly by abrasive action the test procedure may be unsuitable and the results invalid.

D3 APPARATUS

The following apparatus is required:

Electric Drill - (1000 watts minimum, "WOLF 3814" or equivalent)
Drill Bracket + Guide Bar + Guide Bar Bracket ("WOLF 0421" or equivalent)
Drill Stand + Paving Unit Clamp welded to Base Plate
Drill Stand Shaft
Dial Gauge (calibrated 1 full revolution = 1 mm)
Chuck + Ball-race (as per Figure D2)
Chuck Casing with Water Hose connection (as per Figure D3)
Revolution Counter (laser or electronic) to measure total revolutions or r.p.m. of Ball-race

The arrangement of the apparatus is detailed in Figure D1.

The output shaft of the drill shall be set at a speed setting of between 1000 and 1050 revolutions per minute.

When the test drill is rigged the total sliding mass of the drill and attachments shall be 14.5 kg with a tolerance of ± 0.25 kg. The test rig shall be maintained in this condition. Before testing, the rig shall be checked to ensure that there are no external factors affecting the sliding mass.

It is most important that the drill stand shaft and guide bar be lubricated to ensure free sliding at all times.

D4 SAMPLING OF UNITS

Five units, representing the lot, and selected in accordance with Appendix B, shall be used as test specimens.

D5 PROCEDURE

(1) Check that the mass of drill and fittings is free to slide on the drill stand shaft with no obstruction.

(2) Place and clamp the dry specimen on the drill stand base plate. Place the ball-race on the specimen and lower the chuck onto the ball-race. Leave the drill unclamped on the shaft.

(3) Ensure water is flowing at a sufficient rate to clear grinding debris.

(4) Run the drill for approximately 3 seconds to seat the ball-race.

(5) Lower the dial-gauge plunger onto the bearing surface of the drill bracket and rotate the chuck by hand through one revolution in each direction.

(6) Set the dial-gauge zero to the mean of the needle readings.

(7) Run the drill, stopping it at approximately every 1000 revolutions and measure the penetration. Continue the test until the ball-race has complete 5000 revolutions, or until the dial-gauge has indicated a penetration of greater than 1.5 mm, whichever occurs first.

NOTE: If the drill and drill-stand appear to wander from side to side causing the ball-race to alter its path on the paver surface then either the drill has been set at the wrong speed or the guide mechanism is worn and needs replacement.
Results from the test are valid only if a clearly defined circular impression has been made on the paver surface upon completion of the test.

(8) Penetration shall be measured by rotating the chuck by hand through one revolution in each direction and noting the mean dial gauge reading.

(9) Note the number of revolutions of the ball-race.

D6 CALCULATION OF RESULTS

The abrasion index of each specimen shall be calculated from the following expression:

$$Ia = \frac{\sqrt{R}}{P}$$

WHERE:

Ia = abrasion index (calculated when the ball-race revolutions equal 5000 or the penetration equals 1.5 mm whichever occurs first)
R = ball-race revolutions, in thousands
P = penetration, in millimetres.

The abrasion index representing the sample shall be the minimum value obtained from the 5 specimens and shall be denoted Iamin.

D7 RECORDS

The following information shall be recorded:

(a) Identification mark
(b) Date of manufacture
(c) Date of test
(d) The sliding mass of drill and fittings in kilogrammes
(e) The intermediate and final numbers of ball-race revolutions for each specimen (if this figure was measured as r.p.m. X minutes, then these figures shall be recorded)
(f) The intermediate and final penetrations in millimetres, for each specimen appropriate to the ball-race revolutions recorded in (e)
(g) The abrasion index of each specimen
(h) The minimum abrasion index of the sample.

D8 REPORT

If a report is prepared it shall include the following information:

(a) Identification of the lot, lot size and manufacturer
(b) Age of units, in days, at the date of test
(c) Date of test
(d) The abrasion index of each specimen of the sample
(e) The minimum abrasion index of the sample.

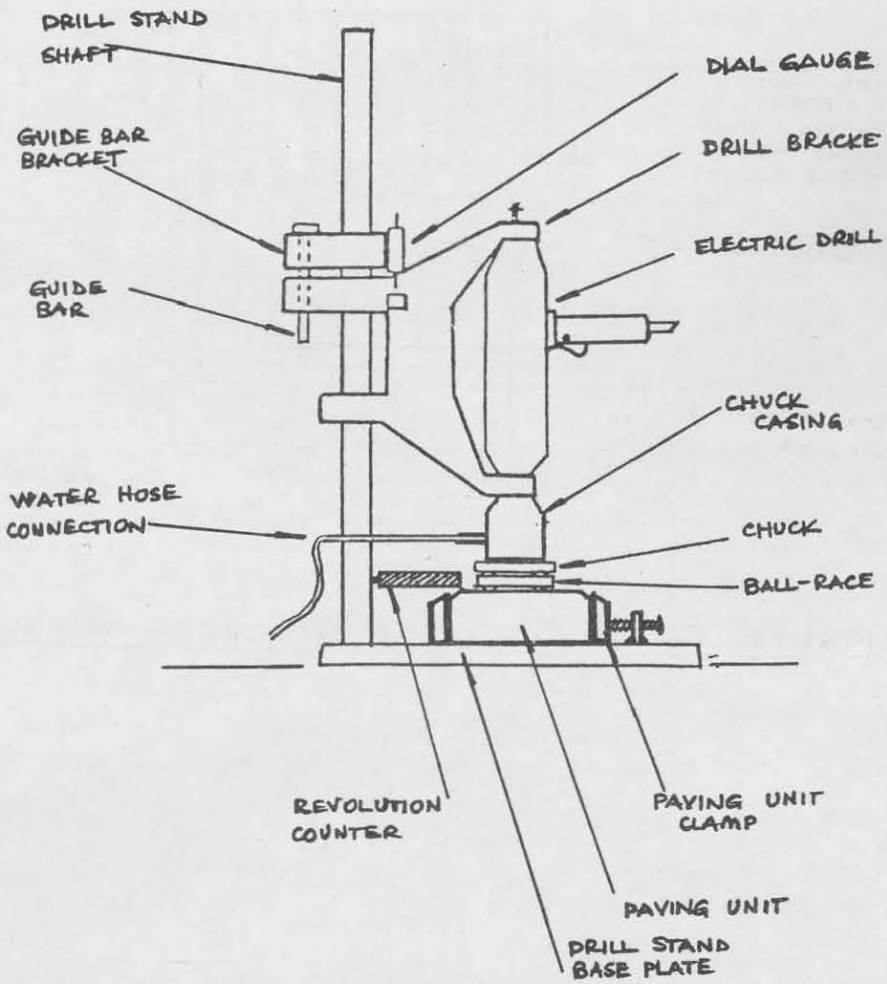


FIGURE D1

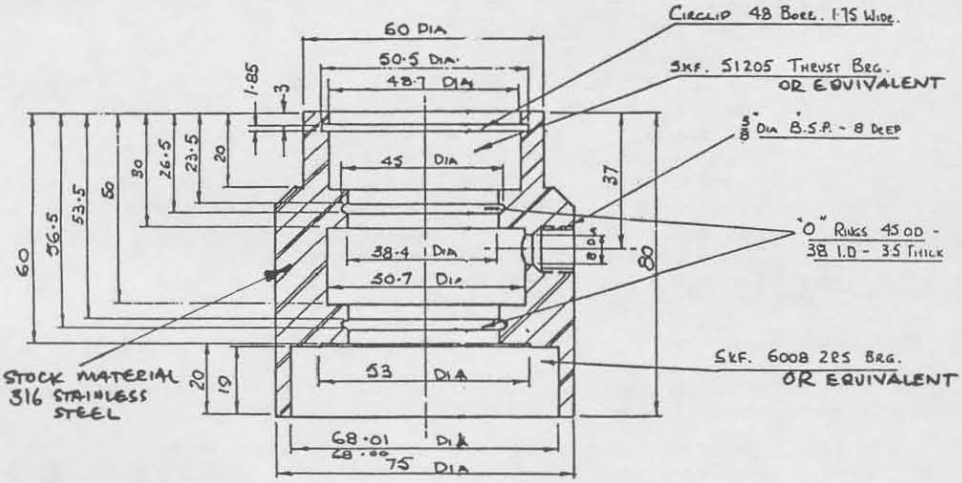


FIGURE D3 — CHUCK CASING — Not to Scale

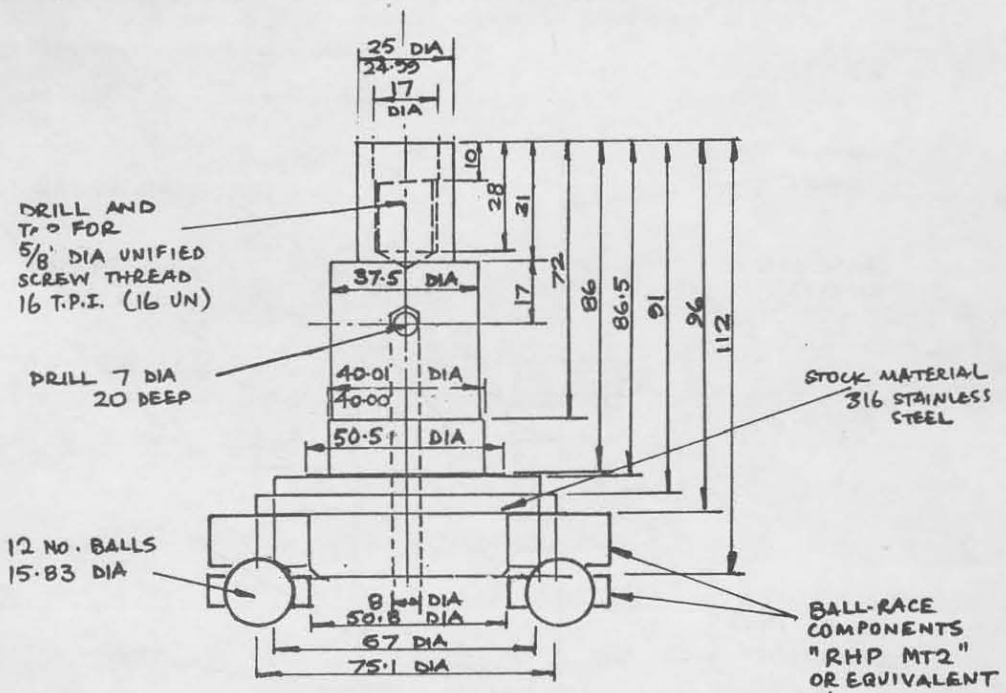


FIGURE D2 — CHUCK AND BALL-RACE — Not to Scale