REPEATABILITY OF A MODIFIED MA 20 ABRASION TEST: PRELIMINARY COMMENTS

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SUMMARY

The repeatability of a modified MA 20 test has been examined by carrying out 130 abrasion tests on concrete beams. Using individual test results gives poor repeatability. Using "average of 5" or "average of 10" abrasion test results gives improved repeatabilities. For example tests on the sides of the beam (with an average of all test results of 2.21) gave an "average of 10" abrasion results repeatability, r, of 0.54.

TEST PROGRAMME

Abrasion testing was carried out on the sides and bases of nine 500 mm long concrete beams. Details of the beams are given in Appendix 5.

Abrasion testing was in conformity with MA 20 : 1986 [9] with some variations as described in Appendix 6. A total of 130 abrasion tests were carried out, 87 on the sides, and 43 on the bases of the beams.

REPEATABILITY

The single operator single laboratory repeatability has been calculated following the method of ISO 5725 [1]. Details of the calculations are given in Appendices 1,2,3 and 4. The repeatability was calculated separately for the test results from the beam sides and the beam bases.

Repeatability was calculated using the individual test results, after checking for and discarding one outlier result. Repeatability was also calculated using "averages of 5" and then "averages of 10" sequential test results as the base data.

The results of these calculations for abrasion index are summarised below:

TEST RESULTS	BEAM SIDES		BEAM BASES	
	AVERAGE	REPEATABILITY *	AVERAGE	REPEATABILITY *
Individual	2.11	1.42	2.61	1.30
Average of 5	2.19	0.74	2.58	0.99
Average of 10	2.21	0.54	2.58	0.88

* 95% probability level

Expressing these repeatabilities as a percentage of their respective averages gives the variabilities shown below in figure 1.

FIGURE 1

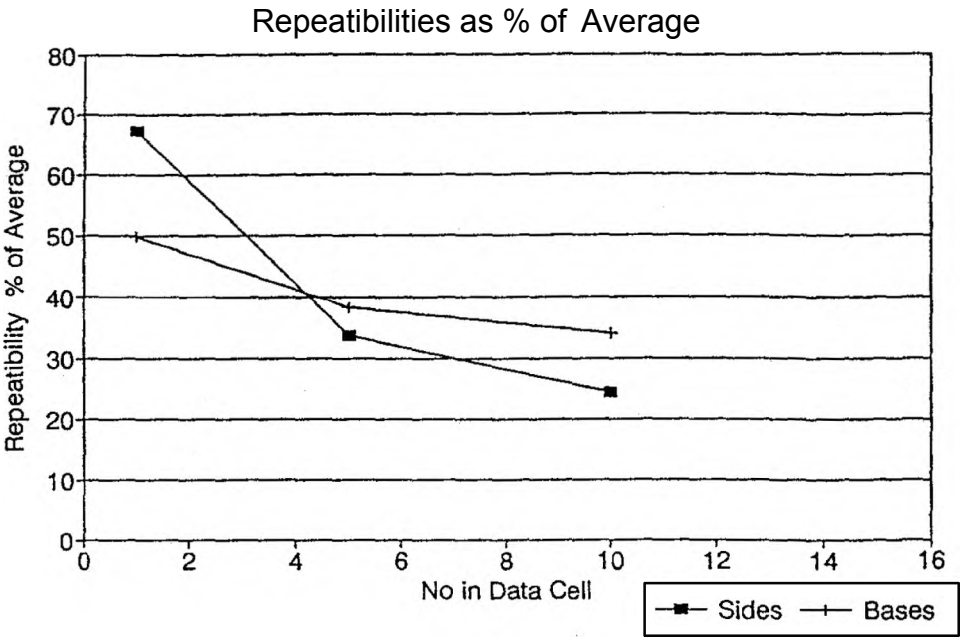

Figure 1 suggests that on an individual results basis the abrasion test has too much variability to allow confident use of the results. Use of an "average of 5" or better an "average of 10" gives much improved repeatability.

CAUSES OF ABRASION TEST REPEATIBILITY

The repeatibility on a single test result basis is poor. "Average of five" and "average of ten" results show better repeatibility but still not good.

The causes of this repeatibility will include factors in the test apparatus/method and variations in the concrete beams the tests were carried out on.

From appendix 5 the coefficents of variations of several beam properties are known. These are, together with the coefficents of variations of the abrasion test:

COEFFICIENTS OF VARIATION

Compressive Strength	Density		Absorption	Abrasion Index					
				Individual		Averages of 5		Averages of 10	
	Dry	SSD		Sides	Bases	Sides	Bases	Sides	Bases
5%	2%	2%	7%	24%	18%	12%	14%	9%	12%

These coefficients of variation indicate that the varibility of the abrasion test on an individual single result basis is much higher than the varibility of the concrete beams. The trend is similar for the "average of 5" and "average of 10" abrasion results higher but not as pronounced.

This suggests that much of the varibility of the abrasion results is related to the test apparatus/method, or to microfeatures (eg the distribution of the larger stones in the concrete) of the concrete beams.

However I cannot be conclusive on this on the basis of the attached data, nor can I offer an explanation for the difference in variability between the abrasion results beam sides and the beam bases.

I note that compressive strength, density and absorbtion are properties of the entire concrete beam, whereas this abrasion test meaures only a localised portion of the beams. This suggests that a statistical analysis attempting to define the reasons for varibility in the abrasion test on the basis of this data will have only limited success.

CONCLUSIONS

1. This paper does not seek to correlate the abrasion test results with actual in-service wear of interlocking blocks. Nor has it defined the sources of the suggested test repeatability.

2. This paper provides an indication of the repeatibility of a modified MA 20 test. This in itself is useful.

3. Statistical analysis of repeatibility suggests this modified MA 20 abrasion test is not suitable for use on an "individual test result basis". Rather abrasion resistance should be calulated as an "average of 5" (or some statistic other than the average) or better still as an "average of 10" abrasion tests.

4. Combining the repeatibility data for the sides and the bases suggests the following precision statement: "The difference between two "averages of 5" abrasion test results by one operator will exceed (about) 0.85 on average not more than once in 20 cases in the normal and correct operation of this modified MA 20 method for a concrete with an average abrasion index of (about) 2.4".

5. Combining the repeatibility data for the sides and bases suggest the following precision statement: "The difference between two "average of 10" abrasion test results by one operator will exceed (about) 0.70 on average not more than once in 20 cases in the normal and correct operation of this modified MA 20 method for a concrete with an average abrasion index of (about) 2.4".

REFERENCES

1. - "Precision of test methods - Determination of Repeatibility and Reproducibility for a Standard Test Method by Inter-Laboratory Test" ISO Standard 5725. 1986. (Also BS 5497 : PART 1 : 1987).

2. BLACK C D. "Internal Laboratory Report 89/164" Cement and Concrete Association of New Zealand. April 1990.

3. - "Specifications for Concrete Segmental Paving Units (MA 20)" Concrete Masonry Association of Australia. July 1986.

4. HUDSON K C. "Abrasion Test for Concrete Paving Blocks. Report SLR 78" Cement and Concrete Association of New Zealand. August 1991.

APPENDIX 1

TEST RESULTS

Abrasion testing was carried out on concrete beams that had been cast in steel moulds. Three separate concrete mixes were used for these beams, each mix making three beams.

Abrasion tests were carried out on the sides and the bases of these beams. The results from the sides and the bases are analysed separately.

The individual abrasion test results are give below in Table 1.

As the MA 20 :1986 test requires 5 tests per set of samples these have been analysed for mean and standard deviation in groups of 5.

TABLE 1 INDIVIDUAL ABRASION INDICES : TEST RESULTS

MIX and BEAM	ABRASION INDEX BEAM SIDES	MEAN + STANDARD DEVIATION	ABRASION INDEX BEAM BASES	MEAN + STANDARD DEVIATION
Mix 1 Beam A	2.5 2.5 2.6 2.5 2.2 2.3 2.3 2.5 2.6	2.53 0.050 2.38 0.164	2.6 2.6 2.6 2.9 3.0	2.74 0.195
Mix 1 Beam B	2.1 2.7 2.6 2.4 2.9 3.9 * 2.0 2.2 2.3 2.3	2.54 0.305 2.54 0.770 (2.20) (0.141)	2.4 2.6 2.6 2.3	2.48 0.150
Mix 1 Beam C	2.5 2.2 2.3 2.1 2.3 2.4 2.4 2.2	2.28 0.171 0.296 2.33 0.096	3.1 2.6 3.0 2.8 2.8	2.86 0.195
Mix 2 Beam A	2.4 2.2 2.4 2.3 2.3 2.4 2.3 1.5	2.33 0.096 2.02 0.432	2.9 3.1 3.3 3.2 2.9	3.08 0.179

	1.6			
Mix 2 Beam B	2.2 2.2 2.1 2.2 2.2 2.2 2.1 2.2 2.5 2.4	2.18 0.045 2.28 0.164	2.8 2.6 2.7 3.0	2.78 0.171
Mix 2 Beam C	2.3 2.3 2.3 2.1 1.9 1.4 1.4 1.4 1.4 1.4	2.18 0.179 1.4 0	1.8 1.8 1.6 1.5 1.6	1.66 0.134
Mix 3 Beam A	2.4 2.0 2.4 2.1 2.2 2.6 2.2 2.2 2.0 2.2	2.22 0.179 2.24 0.219	2.6 2.6 2.5 2.7 2.3	2.54 0.152
Mix 3 Beam B	2.1 2.5 2.2 1.9 2.0 2.1 2.0 2.1 2.1 2.4	2.14 0.230 2.14 0.152	1.9 1.9 2.4 2.5 3.1	2.36 0.498
Mix 3 Beam C	2.5 2.3 2.2 2.3 2.3 1.7 2.0 2.3 1.7 1.4	2.32 0.110 1.82 0.342	3.2 2.9 2.9 2.9 3.0	2.98 0.130
		$\sum s^2$ = 1.296		$\sum s^2$ -- 0.466

* STATISTICAL OUTLIER SO IGNORED SEE BELOW

COCHRAN'S TEST

Cochran's test can be used to highlight possible outlier results. [1].

BEAM SIDES

For the abrasion test on the beam sides the standard deviation for each group of five results indicates there may be outlying results for Mix 1 Beam B.

For Cochran's test initial values use p - 18 and n - 5. This gives critical values at 1% of 0.249 and at 5Z of 0.209.

For Mix 1 Beam B applying Cochran's Criterion [1] (where s is the standard deviation)

$$C - \frac{S^2}{\sum S^2} = \frac{0.770^2}{1.296} = 0.458$$

which exceed both the 1% and 5% critical values.

This indicates that one result in Mix 1 Beam B may be regarded as a straggler. This value of 3.9 is noted for later consideration; the evidence so far is insufficient for rejection.

BEAM BASES

For the abrasion test results on the beam bases the standard deviations for each group of five results for Mix 3 Beam B.

For Cochran's test critical values use p = 9 and n = 5. This gives critical values at 1% of 0.425 and at 5% of 0.358.

For Mix 3 Beam B applying Cochran's Criterion

$$C - \frac{0.498^2}{0.466} = 0.532$$

which exceed both the 1% and 5% critical values. This indicates one or more results in Mix 3 Beam B may be outliers.

DIXON'S TEST

Dixon's test can be applied to the test results highlighted as possible outliers by Cochran's test. Dixon's test reveals if extreme values are statistical outliers. [1].

BEAM SIDES

Considering the data (2(1)...2(H)) in order of magnitude and applying Dixon's test statistics to Mix 1 Beam B:

$$Q_{22} = \text{the larger of } \frac{z(3) - z(1)}{z(H-2) - z(1)} = \frac{1.4}{2.7 - 1.4} = 0$$

$$\text{or } \frac{z(H) - z(H-2)}{z(H) - z(3)} = \frac{3.9}{3.9 - 1.4} = 0.48$$

For H - 87 by extrapolation from reference [1] the critical value at 1% is about 0.370 and at 5% is about 0.435.

The Q22 value of 0.48 exceed both these showing the result of 3.9 is a statistical outlier and may be disregarded.

REAM BASES

Considering the data in order of magnitude and applying Dixon's test statistic to Mix 3 Beam B:

$$Q_{22} = \text{the larger of } \frac{1.6 - 1.4}{3.2 - 1.4} = 0.111$$

$$\text{or } \frac{3.3 - 3.2}{3.3 - 1.6} = 0.059$$

For H = 43 by extrapolation from reference [1] the critical value at 1% is 0.426 and at 5% is 0.361.

The Q_{22} value does not exceed the critical values for all the test results for the beam bases should be included.

APPENDIX 2

REPEATIBILITY CALCULATION: INDIVIDUAL TEST RESULTS

From the data in table 1 with the value of 3.9 (Mix 1 Beam B) excluded the repeatibility, r, can be calculated. [1]

BEAM SIDES

From table 1 and the experimental testing set-up the number of laboratories involved was 1, with 86 (one has been excluded) apparently identical tests by the same operator. For these

Average = 2.1125
Standard deviation = 0.50533

$r = 2.8 \sqrt{(\text{standard deviation})^2} = 2.8 \sqrt{(0.50533)^2}$
$= 1.415$

ie. REPEATIBILITY r = 1.415 at the 95% level.

Expressing this in words:

"The difference between two single results found on identical test material (having an average abrasion index of 2.1) by one operator using the same apparatus within the shortest feasible time interval will exceed 1.4 on average not more than once in 20 cases in the normal and correct operation of the method".

BEAM BASES

Similarly from the data in table 1 for the 43 test results

Average = 2.6070
Standard deviation = 0.46363

$r = 2.8 \sqrt{0.46363^2} = 1.298$

ie. REPEATABILITY r -- 1.298 at the 95% level

Expressing this in words:

"The difference between two single results found on identical test material (having and average abrasion index of 2.6) by one operator using the same apparatus within the shortest feasible time interval will exceed 1.3 on average not more than once in 20 cases in normal and correct operation of the method".

APPENDIX 3

ANALYSIS OF MEANS OF GROUPS OF 5 TEST RESULTS

Taking the means of 5 consecutive test results from Table 1 gives the results shown in TABLE 2.

TABLE 2 MEANS OF GROUPS OF 5 TEST RESULTS

ABRASION INDEX BEAM SIDES ("Averages of 5 results")	MEAN + STANDARD DEVIATION	ABRASION INDEX BEAM BASES ("Averages of 5 results")	MEAN + STANDARD DEVIATION
2.46		2.74	
2.36		2.60	
2.52		2.82	2.583
2.30		3.06	0.3533
2.30		2.38	
2.3	2.187	1.98	
2.02	0.2586	2.26	
2.18		2.82	
2.28			
1.40			
2.22			
2.24			
2.14			
2.14			
2.32			
1.82			

REPEATABILITY : BEAM SIDES

From Table 2 and the experimental testing set-up the number of laboratories involved was 1, with now 8 test results (the last six individual results are ignored).

Average = 2.21
Standard deviation = 0.1932

$$r = 2.8\ \sqrt{0.1932^2} = 0.5410$$

ie. REPEATIBILITY r = 0.541 at the 95% level

REPEATABILITY : BEAM BASES

Similarly from Table 2 for the 4 test results (last 3 individual results ignored) from the beam bases.

Average = 2.583
Standard deviation = 0.3158

$r = 2.8 \sqrt{0.3158^2} = -0.8842$

ie. REPEATIBILITY r = 0.884 at the 95%level

APPENDIX 4

ANALYSIS OF MEANS OF GROUPS OF 10 TEST RESULTS

Taking the means of groups of 10 test results taken in sequence from Table 1 gives the results shown in Table 3.

TABLE 3 MEANS OF GROUPS OF 10 TEST RESULTS

ABRASION INDEX BEAM SIDES ("Averages of 10 results")	MEAN + STANDARD DEVIATION	ABRASION INDEX BEAM BASES ("Averages of 10 results")	MEAN + STANDARD DEVIATION
2.4 2.4 2.3 2.1 2.2 1.8 2.2 2.2	2.21 0.1932	2.67 2.94 2.18 2.54	2.583 0.3152

REPEATIBILITY : BEAM SIDES

From Table 3 and the experimental testing set-up the number of laboratories involved was 1, with now 8 test results by the same operator.

Average = 2.187
Standard deviation = 0.2586

$r = 2.8 \sqrt{(0.2586)^2} = 0.7241$

ie. REPEATIBILITY r = 0.724 at the 95% level

REPEATIBILITY : BEAM BASES

Similarly from the data in Table 3 for the 4 test results from the beam bases.

Average = 2.583
Standard deviation = 0.3533

$r = 2.8 \sqrt{0.3533^2} = -0.9892$

ie. REPEATIBILITY r = 0.989 at the 95% level

APPENDIX 5

CONCRETE BEAMS

Nine 500 mm long beams were cast in steel moulds, three separate concrete mixes were produced each making 3 beams. All the beams were as close to identical at the time of abrasion testing as we could reasonably achieve.

The abrasion tests were carried out on the sides and the bases of the beams. The abrasion results from the sides have been analysed separately from the results from the bases.

To check the consistency of the beams themselves density, absorption and compressive strength tests were carried out on the beams following completion of the abrasion test. Test results for the beams are shown in Table 4. [4] .

TABLE 4 PROPERTIES OF CONCRETE BEAMS

CONCRETE BEAMS

BEAM ID	Compressive Strength MPa	DENSITY kg/m^3		Absorption %
		DRY	SSD	
1A	55.2	2220	2290	3.1
IB	60.7	2220	2280	3.0
1C	55.4	2210	2280	2.8
2A	53.5	2110	2170	2.9
2B	58.0	2230	2290	2.7
2C	63.3	2230	2290	2.7
3A	58.9	2240	2310	3.1
3B	58.3	2250	2310	2.7
3C	60.9	2230	2310	3.4
MEAN	58.3	2220	2280	2.9
STD DEVIATION	3.0	40	40	0.2
COEF OF VARIATION	5Z	2%	2%	7Z

By inspection the values for the strength and density for 2A appear slightly lower than for the other beams, however deleting all data from these 2A beams makes little difference to the repeatibility results, so 2A data is included in the analysis.

APPENDIX 6

TEST METHOD : MODIFIED MA 20

The abrasion test method used conformed to the Australian MA 20 ; 1986 method [3], with the following variations:

- the concrete block was clamped by a bar screwed down across the top. MA 20 slows the sides of the block clamped.

- wear penetration was measured only after 5000 revolutions; measurement was by micrometer. The micrometer probe had a rounded tip.

- no seating revolutions. MA 20 runs the drill for 3 seconds to the ball race.

In addition to the MA 20 requirements particular attention was paid to details such as cleaning and oiling the drill stand shaft, and checking water flow meter.

The same operator carried out all the abrasion tests.

On the basis of an informal analysis of other test data the use of a micrometer to measure wear penetration appeared to offer improved repeatibility compared to use of a dial gauge. It also reduced the operator time required so reducing the cost of each abrasion test.

APPENDIX 7

ANALYSIS METHOD

The statistical analysis carried out in Appendices 1 and 2 is based on ISO 5725 - 1986. [1] This standard is for the determination of repeatibility and reproducibility by inter-laboratory tests. The standard recognises that slight modifications need to be made to the procedures to cater for the verification of the repeatibility of a single laboratory. ISO propose to deal with this in future International Standards.

As these future International Standards are not yet available I have based my analysis on ISO 5725 - 1986. As there is the possibility that this may have resulted in some deficiencies in my analysis, I have detailed the analysis in Appendicies 1 to 5.