THE EFFECT OF MIX DESIGN ON THE DURABILITY

A. J. Dowson B.A., T.Eng. (C.E.I.), M.I.G., Tech.E., M.I.T.O.

Marshalls Mono[1], Halifax, U.K.

SUMMARY

At the first conference on Concrete Block Paving, the author presented a paper on mix design examining the various parameters which could affect the strength and other properties of the concrete.

Following on from the mix design, it is essential that Concrete Block Paving provides the customer with a product that is durable, economic to use and has confidence to use the product in all types of application. No attempt in this paper has been made to offer theories on how the mechanism of saline freeze thaw cycling works, only to examine the concrete units produced using various materials available to manufacturers and by a variety of manufacturers in different locations with different manufacturing plants.

In the U.K. engineer and manufacturer alike, consider the extremes of weather and temperature to be the worst in the world and expect concrete to be durable and this work has indicated our earlier findings of a minimum cement content to be correct along with the selection of sound aggregates. Using this laboratory test the agreed weight loss maximum for compliance will be 0.5 kg/m^2 after 25 cycles.

1. INTRODUCTION

Precast concrete products have a good record to resistance of saline freeze thaw providing they generally comply with existing standards. Concrete Block Paving is one of those products which comes in this category. Although we have no British Standard, blocks produced to the Tripartite Specification (2), which was present at the last International Conference, have proven to be resistant to such attack. Clark (3) in his paper concluded that the compressive strength by itself was not an ideal means of predicting durability. Even absorption, density and initial surface absorption did not give a direct correlation. The only factor to emerge from this work based on a Sutcliffe Speakman Press, was to obtain a minimum cement content. As a manufacturer this led us into continuing such investigation into the freeze thaw cycling to verify this statement.

One large local authority user of concrete block paving, having co-operated in this earlier investigation, and having had tested a range of blocks supplied by various manufacturers to measure their freeze thaw resistance, confirmed this point.

It was in our own interest to conduct this research to find an economical mix which would comply with the Tripartite Specification.

Our investigations included; the addition of chemicals, which according to the suppliers entrained air; the replacement of part of the cement with pozzolanic material; the use of micro silica; using blast furnace material; reducing the actual cement content.

Coupled with these experiments is. A comparison of Continental blocks, obtained from a recent visit to Holland, Germany, Belgium, to visits where blocks of unknown quality had been laid and taken from site.

The laboratory test was suggested as part of a standard method to be included into a British Standard and to this end the reproducability has been checked by other laboratories.

2. TEST METHOD

The test method used is the RILEM freeze-thaw test. It was originally devised some twenty years ago as a mini test, to evaluate durability. This test was used in Canada to prove that precast paving was resistant to freeze thaw cycling. This test is not the complete answer, but goes a long way to provide suitable information of resistance to de-icing salts.

The method used is:-

TEST FOR SCALING RESISTANCE

Apparatus The apparatus shall comprise:-

(a) Water tank maintained at a temperature of 20°C ± 2°C.
(b) Air enclosure maintained at a temperature of 20°C ± 5°C and relative humidity of 80% ± 10%.
(c) 5mm diameter glass rod.
(d) Silicone adhesive.
(e) Chlorinated rubber paint or similar.
(f) Freezer cabinet capable of achieving a temperature at 10mm distance from any specimen of -18°C ± 2°C within 7 hours of placing specimens in the cabinet.
(g) 150mm diameter evaporating basin.
(h) Plastic wash bottle.

(i) Rubber policeman.
(j) Oven maintained at a temperature of 105°C ± 5°C.
(k) Watch glass.
(i) Balance capable of weighing 100g to an accuracy of 0.001g.

Materials

3% Salt Solution This shall be prepared by dissolving 3g of sodium chloride (99.5% NaCl) in 100ml of distilled water.

Distilled Water

Procedure

(a) Conditioning The blocks shall be stored in water at a temperature of 20°C ± 2°C for a period of 14 days. The specimen shall be removed from the water and stored for a further 14 days in air at a temperature of 20°C ± 5°C and relative humidity of 80% ± 10%.

(b) Preparation during the air conditioning period, when the block is surface dry, a rectangular dam shall be constructed on the wearing surface of the block close to the perimeter and enclosing an area of not less than 10,000mm². A suitable construction for this dam is lengths of 5mm diameter glass rod fixed to the surface with silicone adhesive.

The sides of the block shall be painted with two coats of a sealing compound, such as chlorinated rubber etc,. (fig 1)

(c) Testing The wearing surface contained within the dam shall be covered with salt solution to a depth of 2mm to 3mm.

The block shall then be placed in the freezer cabinet which shall already be at a temperature of -18°C ± 2°C.

After a minimum time of 16h, the block shall be removed from the freezer cabinet and placed in air at a temperature of 20°C ± 5°C and relative humidity of 80% ± 10%. The block shall remain in this environment for a period of 8h ± 1h after which any loss of liquid shall be replenished by the addition of more salt solution and the block shall be replaced in the freezer.

This process of freezing and thawing shall be repeated 25 times.

When the 25 cycles are completed and the blocks are totally thawed out, the salt solution remaining on the block and any material scaled from the surface of the block under test, shall be washed through a Whatman No.40 filter paper, which has previously been oven dried and weighed (M1). This process shall be carried out by a fine jet of distilled water from a wash bottle and any loose particles on the surface may be dislodged by gentle pressure from a rubber policeman.

The filter paper and residue is removed from the funnel after decantation and placed in an evaporating basin and shall be evaporated to dryness in an oven at 105°C until constant mass is achieved. The dried material and filter papers shall be weighed to the nearest 0.01g (M2).

Calculation The loss of mass per unit area shall be calculated from the formula

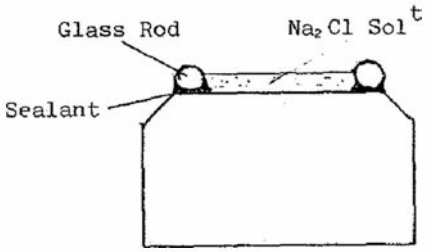
$$S = \frac{M_2 - M_1}{A} \times 1000 \text{ kg/m}^2$$

where A = the area under test (mm²)

M_1 = the mass of the filter paper (g)

M_2 = the mass of the filter paper plus dry scaling product (g)

The result shall be reported to two decimal places.



3. Mechanism of Freezing and Thawing
(As suggested by the Cement & Concrete Association)

In water soaked paste, capillary cavities and gel pores are full or nearly full of water. As freezing begins, ice crystals appear in the larger capillary cavities. The expansion produces hydraulic pressure which will either force water out of the cavity or cause dilation of the capillary cavity. When avenues of escape for the water are blocked or too remote, pressure becomes high enough to stress the surrounding gel beyond its elastic limit or beyond the tensile strength and thus produce permanent damage.

Diffusion of and Freezing of Gel Water in Capillaries

Ice in the capillaries of frozen cement paste is surrounded by unfrozen water in the gel pores. As the temperature drops below that at which capillary water freezes, but still above freezing point for water in the gel pores, the gel water acquires an energy potential enabling it to move into the capillary cavity where it freezes and causes the ice crystal to enlarge. Growth of this ice body produces pressures which may dilate the paste appreciably and cause the concrete to expand. Similar development of ice in the air voids would not normally be sufficient to produce disruptive pressure.

Osmotic Pressure

When the water in capillary cavities contains salts or alkalies the concentration of salts will increase as freezing begins. Water being forced from the capillaries into the surrounding pores will have a higher concentration of salt than the surrounding gel pore water. A pressure differential develops in the direction toward the capill-

ary pore and opposite to the flow of water. Pressure required to overcome osmotic pressure in the capillary is a combination of the hydraulic pressure required to force capillary water into gel pore structure plus the osmotic pressure which resists this flow.

4. Evaluation Programme This programme was developed and expanded as the work progressed and as results were obtained. The first to be considered were the variations which occur during manufacture of the concrete paving block.

From this initial information obtained, it was observed that the blocks varied in density and the first experiment was to observe the difference in performance.

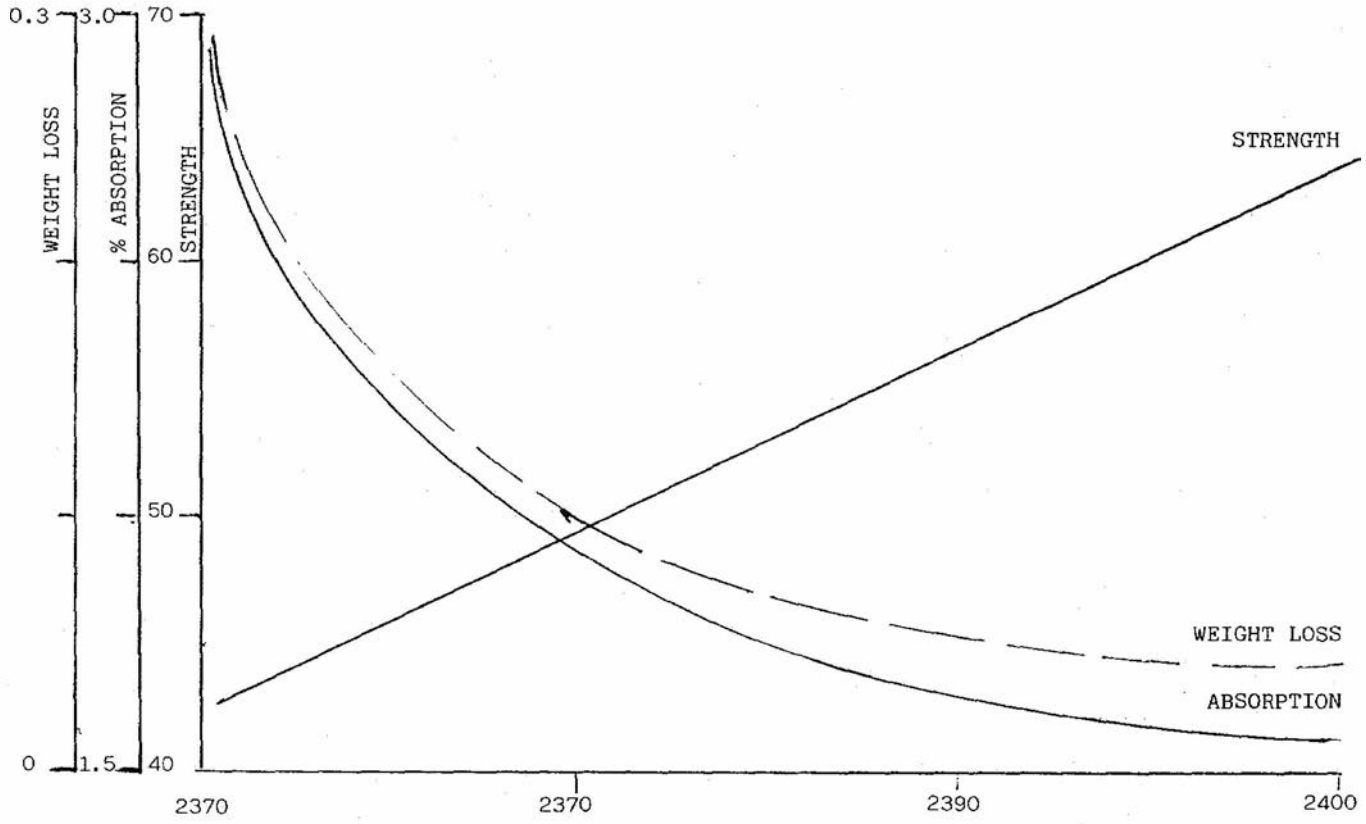
(a) Density These units were made by making adjustments to the machine to vary slightly the density. It was at this time important to try and obtain correlations between other parameters for example the compressive strength of water absorption. The results are shown in Table 1, and are average figures from seven units tested.

Table 1

Density	Absorption	Strength	Weight Loss (50 cycle)
2370	3.1	44	0.34
2372	3.0	42.4	0.12
2375	2.1	44	0.08
2377	3.4	48.2	0.13
2379	2.0	48.2	0.78
2380	1.6	47.8	0.14
2381	1.5	59.4	0.09
2385	1.5	56.7	0.16
2387	2.9	37.6	Failed
2390	1.3	55.5	0.14
2391	1.8	57.2	0.04
2392	1.7	57.7	0.06
2392	1.8	48	0.71
2400	1.7	64.1	0.06
2407	1.5	63.0	0.14

All these figures have been used to produce the graphs, density v strength, density v absorption and density v weight loss.

Fig 2.



The photographs illustrate the various degrees of attack by this test.





To check Clark's earlier work, the cement contents were varied and concrete blocks were made.

(b) Aggregate Cement Ratio It has been understood the durability is often linked with cement content and forms a very important table in Codes of Practice CP 110 (4). We were not able to translate this table to block production as we were using smaller aggregate than specified. Also, the water contents we use are much lower than the specification stated.

This investigation followed earlier work in trying to use a compressive strength to indicate durability. As a starting point, we knew our existing production gave a satisfactory performance, both in the laboratory test and in the 'field', we increased and decreased the amount of cement and Table 2. gives the results obtained.

Table 2

A/C	STRENGTH	WEIGHT LOSS
Control (1)	56.3	.152
Control (2)	53.8	.322
4.0	53.7	.368
5.0	44	.448
6.0	40	.587
6.8	38.0	.606
7.6	30.0	—
11.2	28.8	1.52*

* 15 cycle
* dam failed

(c) Surface Texture It was noticed different machines produced different surface textures and with customers' concern over the visual qualities of the paving block, samples of visually acceptable and non acceptable were taken and tested.

SAMPLE	A	B
1	0.074	0.022
2	0.018	0.028
3	0.024	0.015
4	0.039	0.127
5	0.016	0.01

A. Blocks of good appearance with close textured face.
B. Blocks with open textured face with coarse aggregate showing.

(d) Use of Partial Cement Replacement As part of new ideas and techniques and also to reduce costs of the product, the major cost factor is the cement content and if this can be reduced without loss of resistance to freeze thaw cycling, then it is commercially viable.

By using pulverised fuel ash and ground granulated blast furnace slag, with ordinary portland cement, it is possible to change the cement from one standard to another i.e BS 12 to BS 146.

The properties of these materials, according to current thinking, improves many things in normal concrete, but we do not know their effect in this type of processing.

(i) Ground granulated blast furnace slag - standard mix.

Level of Replacement % (cement)	Weight Loss
0	0.068
30	0.155
40	0.166

(ii) P.F.A

Level of addition % (by w/w cement)	Weight Loss
0	0.045
10	0.194
25	0.607

(e) Comparison of Blocks Produced in Europe
Knowing this product has been used for many decades in Europe and part of our earlier investigation we need to know how blocks in Holland, Germany and Belgium, compare with the U.K product as we were constantly being quoted continental practice.

Ref No	Strength	Weight Loss
1	51.1	0.09
2	59.6	0.086
3	48.1	0.110
4	65.9	0.090
5	65.4	0.073
6	67.2	0.085
7	49.4	0.078
8	57.7	0.082
9	63.5	0.078
10	52.9	0.072
11	68.8	0.090
12	46.3	0.114
13	66.7	0.085
14	61.3	0.098

(f) Examination of Different Locations of Manufactured Blocks Using Different Machines and Mix Designs
All the research on durability had been evaluated on British machinery, which had been converted from producing bricks to blocks. These tests were performed on blocks from all types of machines and mix designs. All the blocks were obtained from various sites throughout the U.K supplied by a variety of manufacturers.

Location of Plant	Weight Loss
	(25 cycles)
Scotland	0.250
Newcastle	0.358
Midlands	0.175
South	0.072

(g) To Check Variations of Durability Over a Two Week Manufacturing Period
Having tested many blocks and to see if normal variations in materials would effect the units, samples were taken randomly on various days during this two week period.

Ref No		Weight Loss
		(25 cycles)
1/16	Natural	0.015
3/16	Natural	0.015
5/16	Brown	0.014
1/17	Red	0.017
3/17	Marigold	0.012

(h) Reproducibility of Test Method
As a further part of an investigation to check the reproducibility of results, for acceptance by British Standards, several laboratories tested normal production units taken from effectively one pallet sample randomly. These units were then cured and stored under controlled conditions and were delivered to the respective laboratories on the same day. The test proposed gave details of standardising the curing prior to testing, but no details were given for the age of the blocks before commencing the test The results of this investigation were:-

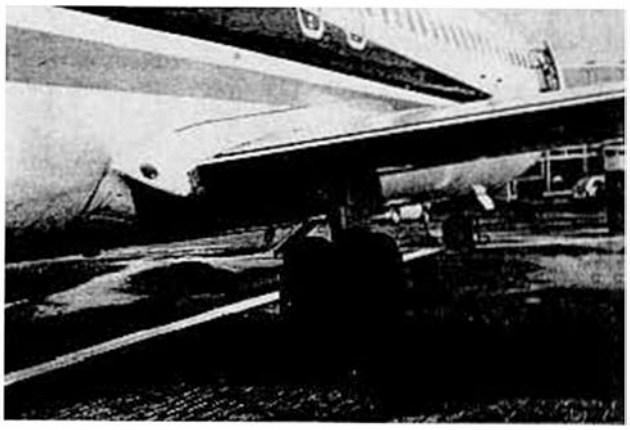
Laboratory	Weight Loss	S.D
1	0.167	0.051
2	0.049	0.025
3	0.152	0.119
4	0.118	0.047

(i) Effect of Age at Test

Age	Weight Loss
6 months	0.228
1 month	0.239

(j) Effect on Different De-Icing Solution
With the development of new uses of concrete blocks, particularly in airports where different chemicals are used for de-icing. This photograph illustrates the use of the blocks

Type of De-icer	Weight Loss
Salt	0.20
Urea	0.15



(k) Discussion on Results The results obtained have been under laboratory conditions and a standard method of test, and in my opinion it is impossible to correlate the cycling of the laboratory tests to actual freezing and thawing cycles. The only conclusion which can be reached is that the cement content and the type of aggregate is all important to the performance of the block in use.
Interpave were concerned over the implications of the laboratory results and conducted an independant survey of blocks. The objective of the survey was to examine selected sites and to collect information and photograph blocks with respect to their durability. The range of sites was limited. An observation of the matrix in the laboratory tests indicated the failure generally occurred where there was a large piece of aggregate just below the surface. This observation lead us to examine the way aggregates themselves behave in freeze thaw conditions.

(1) Aggregate Durability The method was to take aggregate passing the 10mm sieve, but retained on the 5mm sieve. The samples were covered, in shallow trays, with a 3% (W/V) solution of NaCl, kept at room temperature for six hours. The solution was decanted off and the samples were then subjected to the freezing cycle of -18°C for 16 hours. The weight loss was expressed as a percentage of the original weight. The cycling was continued 25 times. As a side issue, a check was made of the particles and these closely resembled the grading of particles of the original samples.
The results obtained were:-

Type of Aggregate	% Weight Loss
Midland Granite	9.15
Limestone	25.58
Midlands Gravel	18.37
Midlands Gravel	23.92

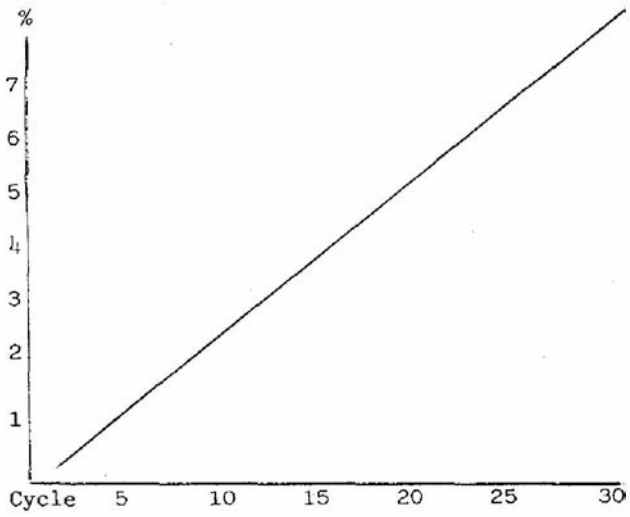
Sieve Analysis of Spalled Matrial

5 Cycle

Sieve Range	Passing	Retained
2.4	100	
1.2	50.4	49.6
600	27.6	22.8
300	12.0	15.6
150	6.9	5.1
Pan		6.9

15th Cycle

2.4	100	
1.2	48.5	51.5
600	19.0	29.5
300	10.2	8.8
150	5.6	4.8
Pan		5.6



Conclusion
From this work carried out, we would conclude the best product that can be supplied to any site subjected to saline treatment is one that contains a minimum cement content of 380 kg/m^3 and sound aggregate which does not contain soft or honeycombed particles.
This work is continuing and as other new materials are tried then a review will be made on these factors.

REFERENCES
(1) Member of Interpave
(2) Tripartite Specification for Concrete Block Paving
(3) Clarke - Freeze Thaw - 1st International Conference.
(4) CP 110 - British Standards Institution