A COMPARATIVE STUDY OF CONCRETE PAVING BLOCKS

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SUMMARY

During recent years in the United Kingdom concrete blocks and brick pavers have been used increasingly for relatively lightly trafficked areas and are commonly used for more heavily trafficked but relatively slow speed areas but to date their use on the normal road network in the U.K. has been very limited.

In order to investigate the performance of such small element paving, particularly with respect to skid resistance under typical highway conditions, an experimental length of road construction, incorporating nine different concrete blocks from eight manufacturers and five different clay pavers, was constructed during September 1981 on the access road leading to an industrial estate/freight depot near Maidstone in Kent.

The paper describes the first year's results obtained from the section of this trial incorporating concrete paving block and associated investigations.

1. INTRODUCTION

During recent years in the United Kingdom concrete block and brick pavers have been used increasingly for relatively lightly trafficked areas such as open spaces and shared surfaces and in pedestrian precincts and are commonly used for more heavily trafficked but relatively slow speed areas such as marshalling areas at freight depots and port installations. To date their use on the normal road network in the U.K. has been very limited compared to that in Europe. This limited useage appears to have resulted, at least partly, from a lack of information and/or confidence in the performance of road pavements incorporating concrete block and brick pavers under such conditions, particularly with respect to the structural strength of such road pavements and the skid resistance of their surfaces.

In order to investigate the performance of these two types of small element paving under more typical highway conditions with both relatively heavy traffic and relatively high traffic speeds up to 60 km/h., Kent agreed to set up such a trial for the County Surveyors' Society on an appropriate section of their road network. The site finally adopted for the trial was a section of an access road called Beddow Way leading to part of the Forstal Industrial estate/freight depot near Maidstone in Kent. The location of the site relative to the national road network is shown on Figure 1, and relative to the local road network on Figure 2.

The experimental length of road pavement in this trial includes nine different concrete blocks from eight manufacturers and five different brick pavers. During the development and the execution of the trial there has been close liaison with Interpave, on behalf of their concrete block manufacturers and with The Brick Development Association, concerning clay pavers and with the Cement and Concrete Association particularly with respect to the design of road pavements incorporating small element paving.

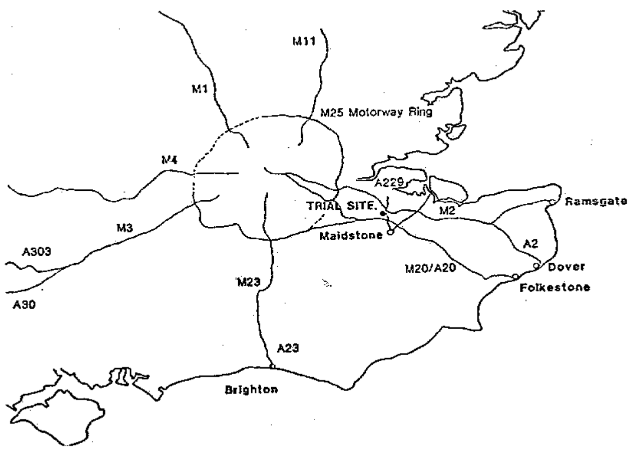

Figure 1: Trial Site and National Road Network

2. TRAFFIC.

As this trial site incorporating concrete paving blocks is located in the access road to an industrial estate and freight depot which also acts as a through route and unofficial by-pass to the nearby village, the traffic using the road includes the whole range of commercial vehicles (over 1.5 tonnes unladen weight) and non-commercial vehicles with a bias towards relatively slow-moving heavy lorries (greater than 25 tonnes laden weight) and relatively high speed cars and light commercial vehicles.

2.1 Traffic Flow

A detailed breakdown of the traffic during mid-1982, at the time of the design and construction of this trial road pavement, is given in Table 1, the 285 commercial vehicles making up approximately 18% of the total vehicular flow. The traffic using the road is being counted automatically using induction loops installed beneath the road surface and this data is utilised in conjunction with that obtained from the fully classified traffic counts at yearly intervals.

Pedal Cycles	Motor Cycles	Cars	Light Goods	Commercial Vehicles: Rigid 2	Rigid 3	Rigid 4	Articulated or With Trailer 3	Articulated or With Trailer 4	Articulated or With Trailer 5	Total
27	57	1106	176	204	24	6	4	47	0	1624

Table 1: Classified traffic count

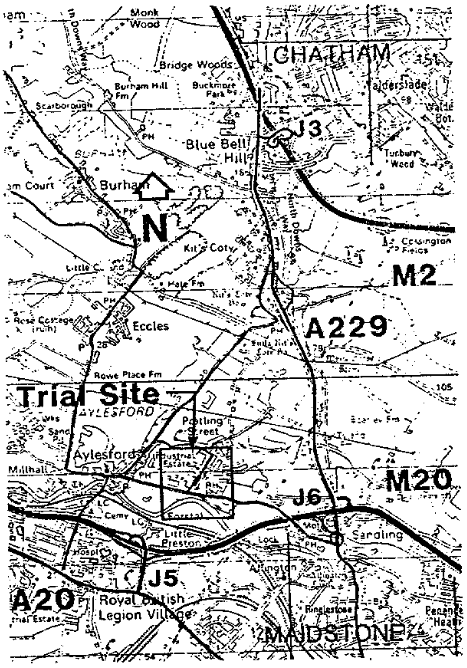

Figure 2: Trial Site and Local Road Network

2.2 Vehicle Damage Factors

Based upon the relative proportions of commercial vehicles in the present total traffic flow and expected future changes in the commercial vehicle traffic spectrum as a result of local and national factors including further development of local industry and the continuing trend towards the use of larger commercial vehicles, the following vehicle damage factors (in terms of 8.18 tonne standard axles per commercial vehicle)-(s.a./c.v.) - were determined using the County Surveyors' Society method developed by the KCC Highways Laboratory (1).

Present Mean Vehicle Damage Factor = 1.5 sa/cv

Future Average Vehicle Damage Factor = 2.1 sa/cv (for 20 years' future life)

2.3 Traffic Damaging Power

The future traffic damaging power during the planned 20 year life of the road pavement was assessed to be 5.4 million standard axles on the basis of the above traffic flow and vehicle damage factor data as well as the envisaged effects of local and national factors including the completion of the M25 motorway ring around London and the associated M2 and M20 links through Kent to the Channel Ports.

3. PAVEMENT DETAILS AND DESIGN

The concrete block paving trial is located in a straight section of the access road which consists essentially of a 7-metre wide carriageway with 2.5 metre wide footpaths either side, separated from the carriageway by kerbs approximately 100 mm high, a total width of approximately 12 metres between property boundaries. The existing road pavement had failed structurally, particularly as a result of the significant and rapid increase in the damaging power of the commercial vehicle traffic during recent years.

3.1 Structural Design

The subgrade of the road was found to be a silty clay, probably of mixed river-alluvium and Gault Clay origin, with an estimated equilibrium California Bearing Ratio (CBR) of 2%. The pavement design, based on this CBR for the subgrade and the estimated 5.4 million standard axles future traffic damaging power during a 20 year road pavement life, was carried out generally in accordance with Road Note 29 (2), D.Tp. Technical Memorandum H6/78 (3) for capping layer design and the recommendations given in the Cement and Concrete Association guidance on such road pavements incorporating concrete blocks (4). However, in order to reduce the resulting road pavement thickness as a means of avoiding underlying services whilst retaining existing threshold levels the capping layer material was replaced with a lesser thickness of hot rolled asphalt ("asphalt substitution"), taking advantage of the improved characteristics of such bound materials compared to unbound materials. The stages in this evolution of the final road pavement design are summarised in Table 2.

Surfacing	Bituminous	Concrete Blocks			
Construction Type		Conventional: Capping Layer	Conventional: Sub-Base	Asphalt Substitution	Final Design
Blocks plus sand layer	-	80+50	130	130	130
Bituminous	40	-	-	-	-
HRA Basecourse	50	75	75	40	80
HRA Roadbase	110	-	-	140	100
Sub-base	150	150	500	150	150
Capping Layer	480	480	-	-	-
Tolerance Allowance	-	-	-	20	20
TOTAL	830	835	705	480	480

Table 2: Road Pavement Design

3.2 Surfacing Design and Layout

The trial section of road pavement incorporating concrete blocks and brick pavers extends over a 60-metre length of the access road over which the traffic flow and traffic movements were assessed as being virtually uniform throughout. A general view of the trial site is given in Figure 3, the road pavement being cambered, with kerbs and gullies provided, in order to effect the drainage of surface water.

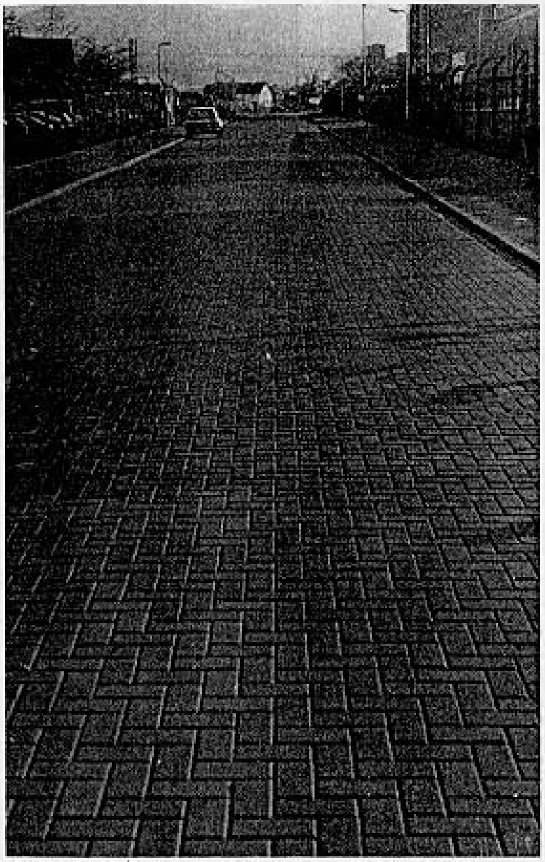

Figure 3: General View of Trial Site

The layout of the different types of concrete blocks and brick pavers with this trial section are shown on Figure 4, the ends of the trial and the junction between the concrete blocks and the brick pavers being marked by a row of stone setts.

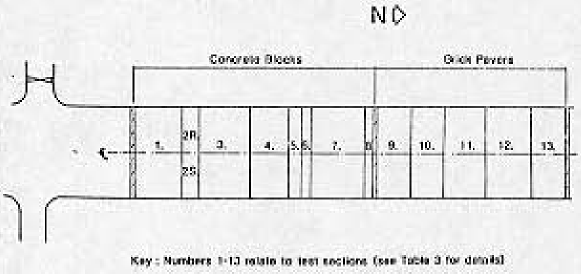

Figure 4: Layout of Trial Site

As shown on Figure 5 the layout of the concrete blocks used throughout the trial was essentially on a 'herringbone' pattern, with the blocks' axes along and at right angles to the centre-line of the road rather than at 45° to it, with continuous stretcher courses one block wide in the channel adjacent to the kerb. This layout was required in order that the pendulum tester could have sufficient swept area in the direction of vehicle traffic.

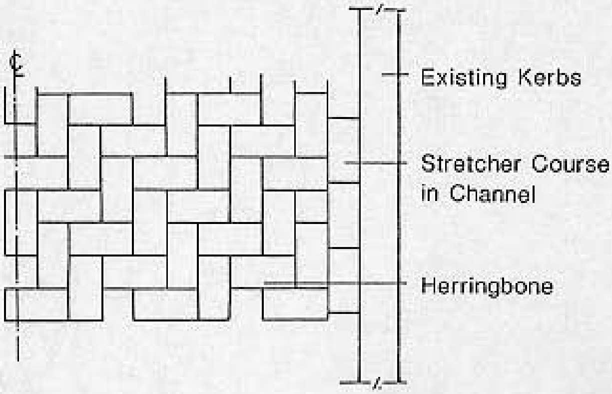

Figure 5: Layout of concrete blocks.

4. DETAILS OF CONCRETE BLOCKS

In Table 3 details of the nine different concrete blocks are summarised, eight of these being rectangular and the remaining one being non-rectangular. As no British Standard has yet been published for concrete blocks, recourse was made to the specification prepared jointly by Interpave, the County Surveyors' Society and the Cement and Concrete Association (5).

Test Section	Length (m)	Block Type	Chamfer (mm) → x ↑
1	6.87	Rectangular	8 x 6
2 Rough	2.93 (half-width)	Rectangular	7 x 4
2 Smooth	2.93 (half-width)	Rectangular	8 x 7
3	6.94	Rectangular	7 x 4
4	5.08	Rectangular	7 x 3
5	1.49	Rectangular	7 x 3
6	1.00	Rectangular	6 x 3
7	7.12	Rectangular	7 x 3
8	1.22	Non-rectangular	7 x 3

Table 3: Test sections and block types

4.1 Dimensional Accuracy

All of the concrete blocks were nominally 200 mm. long, 100 mm wide and 80 mm thick. In general, ten blocks of each type were measured for dimensional accuracy according to Clause 12 and Appendix C of this concrete block specification, each block being measured two times for length, three times for width and four times for thickness. The results obtained are summarised in Table 4 with the mean dimension and standard deviation being given for each block type as well as the percentage of blocks which failed to meet the requirements of the specification.

Block Type	Out of Spec. (%)	Length (mm)		Width (mm)		Thickness (mm)	
		Mean	$\bar{s}$	Mean	$\bar{s}$	Mean	$\bar{s}$
1	0	200.175	0.373	99.98	0.662	80.6	0.681
2 R	0	199.48	0.678	99.1	0.443	81.8	0.978
2 S	30	199.275	0.617	99.23	0.388	78.55	1.324
3	40	199.9	0.308	99.28	0.535	81.275	1.911
4	0	198.225	0.343	98.43	0.41	79.72	0.759
5	20	197.78	0.412	98.2	0.447	80.88	0.524
6	-	Not determined					
7	0	200.5	0.811	100.13	0.586	79.75	0.954
8	-	Non-rectangular					
Spec.		200± 2		100± 2		80±3	

Table 4: Dimensional Accuracy of Blocks

4.2 Compressive Strength

At present, there are two methods proposed in the U.K. for determining the strength of small element paving units such as concrete blocks and brick pavers. This specification for concrete blocks (5), recommends compressive strength as the appropriate strength parameter whereas, in contrast, a draft specification for brick pavers proposes the use of transverse strength.

According to the concrete block specification a minimum average compressive strength for 4 blocks of 54 kN/m^2 is required whereas according to this draft specification for clay brick pavers, a minimum transverse strength (determined as the mean of tests on 3 brick pavers) of 7.0 kN is proposed for highway use.

In the trial both types of test were carried out on both types of small element paving, concrete blocks and clay pavers. The results of these strength tests and the associated density tests are summarised for each block type on Table 5.

All of the types of concrete blocks met the requirements of the specification with respect to compressive strength and transverse strength, although at this stage it is only considered appropriate to utilise the compressive strength specification for contractural purposes.

Block Type	Compressive Strength (N/mm^2)	Density (kg/m^3)	Transverse Strength (kN)
1	55.8	-	-
2 Rough	58.4	2375	-
2 Smooth	79.0	2440	19.0
3	64.2	-	-
4	69.2/56.6	2415/2360	-/16.0
5	67.2	2440	20.2
6	58.2	-	-
7	77.0	2415	22.0
8	74.0	2385	19.0
Specification	≮54	-	(≮ 7)

Table 5: Strength and density of blocks

5. CONSTRUCTION OF TRIAL SECTION

As the trial section including the concrete block surfacing has been constructed in a section of an existing access road, the work had to be organised so as to maintain access for all traffic at all times. These works, which involved the complete reconstruction of the carriageway, therefore had to be carried out in half-road widths.

The first stage of the works was to remove the existing road construction on one side of the road, and to reconstruct it up to the top of roadbase level. The blocks were laid along this half width of the road with traffic passing on the other half, the edge being protected by timber baulks. The traffic was then diverted onto the completed length of blocks whilst the construction of the other half road width was carried out. Traffic was kept about ½-metre away from the unrestrained edge along the road centre-line. Manhole, gulley and other covers were set to level prior to the laying of the concrete blocks.

The Type 1 granular sub-base complied with Clause 803 of the D.Tp. Specification (6) and was laid in a single 150 mm thick layer and compacted in accordance with Clause 802 of that specification using a vibrating roller.

The HRA roadbase material, 65% stone content, complied with Clause 812 of that specification, was laid in 2 layers and was compacted with a vibrating roller to achieve an air voids content of less than 5%.

As recommended by the paving contractor, the sand layer was precompacted by vibratory plate before final screeding and block laying as it was considered that this improves the surface tolerance of the finished road. The sand and blocks were compacted with a Dynapac CMB petrol engined plate vibrator weighing 144 kg. with an output of 3.7 kW and a frequency of 75 Hz and 510 mm by 450 mm plate size. The grading of the sand used (see Table 6) did not quite comply with Zone 2 grading (7) and the blocks were laid with the sand moist but not saturated. The top surface of the blocks was brushed twice with dry Zone 4 sand which was vibrated into the joints. The joints were rescreeded and additional sand vibrated in just before the trial section was

opened to traffic.
One half of the road pavement was opened to traffic on 9th September 1982 and the other on the 15th September 1982.

B.S. Sieve Size	Percentage by Weight Passing Specification (BS 882) Zone 2	Actual
10 mm.	100	100
5 mm.	95 - 100	100
2.36 mm.	95 - 100	100
1.18 mm.	90 - 100	100
600 um.	80 - 100	73
300 um.	15 - 50	2
150 um.	0 - 15	0.5

Table 6: Grading of sand under blocks.

6. PAVEMENT PERFORMANCE

The performance of this trial section of road pavement incorporating concrete blocks and brick pavers has been monitored to date for approximately one year. It is thought possible that various aspects of the performance of such a surfacing are to some extent influenced by the climate, as well as the traffic loading received by the pavement. The weather conditions pertaining during the first year of the trial were somewhat untypical in that the Autumn of 1982 and the Spring of 1983 were significantly wetter than average and the 1983 summer was hotter and drier than average. Further monitoring of the trial, for a period significantly longer than a year, will be necessary in order to determine whether the weather to date has introduced a significant bias into any of the results and the conclusions drawn from them.

Quarter	Mean Temperature (°C.)				Mean Rainfall	
	Ave. Year		This Year		Ave. Year	This Year
	Max.	Min.	Max.	Min.	(mm)	(mm)
Sept/Nov	14.6	9.0	15.3	7.9	66.5	95.2
Dec/Feb	7.2	1.1	7.5	2.0	56.7	52.6
Mar/May	13.3	4.1	12.4	4.4	44.8	83.0
Jun/Aug	20.9	10.7	22.7	12.8	52.0	16.9

Table 7: Weather Record

6.1 Transverse Profile

In order to minimise initial transverse irregularities and subsequent deformation, rutting, the concrete blocks were laid on precompacted sand and then the sand and the blocks were further bedded-down using a vibratory plate compactor. The transverse profile extending for a distance of 2 metres from the kerb line has been monitored, using a 2 metre straight edge, at intervals during the period since this concrete block pavement was opened to traffic. The average deformation of all the types of

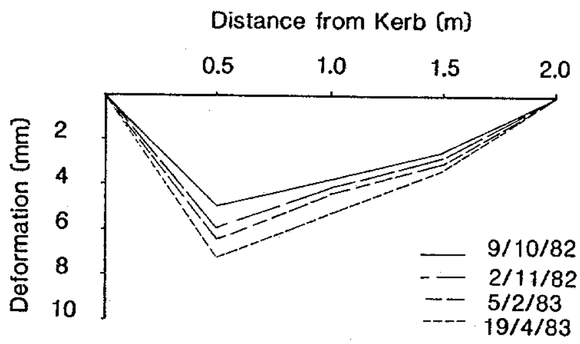

Figure 6: Average transverse profile.

concrete blocks on each of these occasions is shown on Figure 6. The majority of the deformation, 5 mm in the nearside wheeltrack, occurred after a month of trafficking, presumably as a result of further compaction and bedding-in of the blocks, after which a slower rate of deformation has occurred, amounting in a total of approximately 7 mm rut-depth during the first six months of trafficking. It is, therefore, possible that the deformation/rut depth could be further reduced by improved initial compaction using a heavier plate compactor than that used in this trial.
Whilst the transverse profile is fairly uniform throughout the trial, the behaviour of particular sections may have been affected by local variations in the degree of canalization of the traffic. All of the different types of rectangular block exhibited approximately similar transverse profiles with the magnitude of the rut-depth at the end of six months' trafficking varying from 4.5 to 8.5 mm. In contrast, the non-rectangular blocks exhibited a rut depth of only 2.5 mm, but this test section is only 1.2 m long and adjacent to the sett edge restraint. However, there is insufficient evidence from this trial to enable it to be concluded that non rectangular blocks perform better in this respect than rectangular blocks.
The rut depths present after six months' trafficking are significantly below the maintenance intervention level for this category of road.

6.2 Longitudinal Irregularities

The irregularity of the longitudinal profile of the surface of the road pavement in the nearside wheeltrack was measured using a rolling straight edge three times, namely initially at the time the road was opened, one week later and six months later. The results for the concrete blocks on the southbound lane and the northbound lane are summarised on Table 8 where they are also compared with the requirements of the D.Tp. Specification (6) for the construction of a 75 metre length of this category of road (Clause 701 Table 7/2), the results being adjusted, on a pro-rata basis, for the shorter, 33 metre, total length of the trial. Despite the accuracy of laying the HRA roadbase, a surface tolerance of ±6 mm, and precompacting the sand, the initial surface of the concrete block paving, before

	Number of Irregularities								
	Initial			1 Week			6 Months		
	≥4	≥7	≥10	≥4	≥7	≥10	≥4	≥7	≥10
Southbound No. of irregularities in 33 m	19	13	1	19	4	0	11	4	0
Equivalent No. in 75 m	43	29	2	43	9	0	25	9	0
Specification for 75 m	18	2	0	18	2	0	18	2	0
Northbound No. of irregularities in 33 m	9	3	0	11	4	1	10	2	2
Equivalent No. in 75 m	20	7	0	25	9	2	23	5	5
Specification for 75 m	18	2	0	18	2	0	18	2	0

Table 8: Longitudinal irregularities

opening to traffic, failed to meet the requirements of this specification for new works. However, a number of these irregularities were located at the interfaces between different types of concrete blocks, and, if these irregularities are excluded, the concrete block surfaces almost satisfy the specification in the northbound direction and satisfy it in the southbound direction. Hence this type of defect is unlikely to be a problem in practice where normally only one type of block would be used within such a length.

6.3 Spalling and Cracking of blocks

The trial section was inspected rigorously after six months' trafficking in order to assess the extent of any spalling and cracking of the blocks. A $1 m^2$ area of each type of concrete block surface, containing approximately 50 blocks, was examined and the results of the inspection are summarised on Table 9 along with the total number of cracked blocks within each trial area, which was also noted during the inspection.

Block Type	No. of blocks with chips				No. of cracked blocks	
	No. of chips per block				(in $1 m^2$)	Total in Trial Area
	1	2	3	4		
1	1	1	-	-	1	1
2 R	10	1	-	-	-	-
2 S	6	1	-	-	-	-
3	2	-	-	-	-	-
4	6	1	-	-	-	-
5	5	1	-	-	-	-
6	3	-	-	-	-	1
7	5	1	-	-	-	-
8	2	-	-	-	-	-

Table 9: Spalling and cracking of blocks.

Only two blocks in the whole trial of concrete blocks were cracked after 6 months' trafficking and on average, approximately 4½ blocks out of every 50, i.e. 9% of the blocks, exhibited a small chip from one corner at that time. However as no similar inspection was carried out earlier, and particularly before the blocks were laid, some of the observed spalling of the corner of particular types of blocks may have originated during their palletisation and transport rather than as a result of laying the concrete block surface and the subsequent trafficking.

It appears to be logical that poor dimensional accuracy would result in increased spalling due to localised concrete to concrete contact, rather than a uniform sand cushion and that greater deformation would also lead to increased spalling as a result of corner to corner contact at the upper edge. However, the presence of the chamfers on all the concrete blocks would appear to have been effective in significantly reducing the incidence of spalling, compared to that which occurred in the unchamfered brick section.

6.4: Skid Resistance including texture depth

The principal objective of the trial was to measure the performance of the concrete blocks with respect to skid resistance. In the U.K. the principal methods of monitoring the skid resistance are the Sideways-Force-Coefficient Investigation Machine - SCRIM (8) and the TRRL portable (pendulum) skid resistance tester (9) which measures Skid Resistance Value (SRV). As SCRIM is a high-speed testing vehicle which measures an average skid resistance in terms of Sideways-Force-Coefficient (SFC) over a 10-metre length of road pavement surface, it could not be meaningfully used at the trial site to measure the performance of each type of concrete block and hence the pendulum tester had to be used.

6.4.1: SRV Measurement. The skid resistance of the road surface has been measured at intervals since the surface was laid and in accordance with standard practice a 76.2 mm wide slider was used over a 127 mm length of the road surface in the direction of trafficking. In order that this test could be carried out on the surface of one block, the blocks were laid in a herringbone pattern with the axes parallel to and normal to the direction of the traffic, rather than at 45° to the traffic. Five blocks, located in the wheeltracks, of each of the different sections of the trial, were chosen to be representative of that particular block type and these blocks were tested every time in order to avoid the introduction of further variables. The Skid Resistance Values (SRV) obtained were corrected for temperature according to the relationship given in Road Note 27 (9). Whilst a seasonal correction is normally applied to SRVs of bituminous surfacings in order to obtain the predicted mean summer value, no such seasonal correction has been applied to the quoted SRV results.

6.4.2: SRV Results from trial site. The mean SRVs measured for each block type during the first year of the trial are summarised on Fig 7.

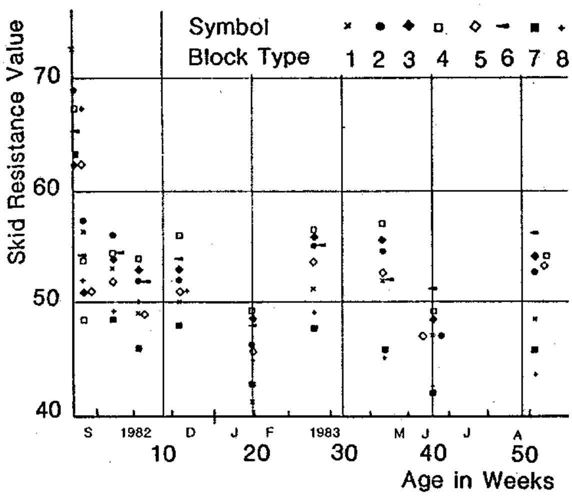

Figure 7: Skid Resistance Values

The SRV's of unused concrete blocks were generally found to be 75 or greater but after laying and before opening to traffic the SRV's of the blocks had reduced to be between 67 and 73. During the first week of trafficking the SRV's reduced further to between 48 and 58. Subsequently the skid resistance values have been somewhat erratic possibly as a result of climatic effects with particularly low sets of values being recorded in January and June 1983. However, by the end of the first year's trafficking the SRV's of many types of blocks were similar to those recorded within the first weeks after opening to traffic.
However, within this overall pattern, different types of block appear to have performed in different manners, most exhibiting a near-constant SRV after the first few weeks' trafficking, some consistently above the average for the trial and others consistently below it, whereas a few appear still to exhibit a loss in SRV albeit at a much lower rate than initially. Attempts to relate the skid resistance performance of the blocks to the mineralogy of their constituents has so far been unsuccessful. Further monitoring will be required to determine whether the performance of the blocks to date accurately indicates their long-term behaviour. In this context it is apparent that the initial SRV of the untrafficked blocks appears to be a poor guide to their long-term skidding resistance and hence the further development and use of accelerated wear equipment for evaluating concrete blocks would be advantageous in develop- their optimum utilization on the road network. However, on the evidence obtained to date from the trial, the SRV's of the concrete blocks included in the trials are above those required for roads such as the trial site and for a number of similar traffic and risk levels on the highway network (9) (10).

6.4.3: Related investigations. Road surfaces incorporating concrete blocks are entirely different in character to conventional bituminous road surfaces, and are probably most similar in performance to a grooved concrete road pavement, with the chamfered joint between adjacent blocks forming a type of macro-texture or texture depth of the road surface. The sensor-measured texture depth obtained using a hand-propelled laser texture depth meter was between 0.8 mm and 1.8 mm (no correlation is as yet available with the conventional sand-patch texture depth) but the results approximately correlated with the size of the chamfers on the blocks.
At the trial site, in order to avoid introducing further variables, the pendulum tester was used only on the surface of blocks whereas the vehicle tyres interact with both the block surfaces and the chamfers/joints between blocks. Tests carried out with the pendulum used in a random way on the surface of the trial showed a significant increase in the scatter of the results depending upon the width, orientation and chamfer with respect to the rubber slider and upon the accuracy of the road surface. There was a marginal increase between the mean SRV reading taken randomly, 55, and taken on a block surface, 51.
In addition, in order to investigate this aspect further, skid resistance tests were carried out on the concrete block road surface at another, developing, industrial estate. At this site, the same block, similar to Block type 3 had been used throughout and, as the road was curved throughout the length investigated, the orientation of the blocks varied between 60° to the direction of travel and the 90° to the direction of travel used in the trial section. This albeit limited investigation indicated that the orientation of the blocks to the direction of travel of SCRIM did not significantly affect the measured Sideways Force Coefficient (SFC). Also the results of these tests on this particular concrete block surface could be approximately represented by:-

$$SRV = 100\ SFC + 10$$

Further investigation of these factors is thought to be necessary, and particularly there is a need to check whether the present basic levels of SRV, SFC and texture depth required for more conventional surfacings are appropriate for concrete block surfacings in order to provide the same degree of safety to the road user.

7. CONCLUSIONS

The results obtained from the first year's performance of this experimental length of road pavement indicate that, with respect to structural strength and skid resistance, this type of road pavement incorporating concrete block surfacing is suitable for use at sites throughout the highway network where similar traffic and risk levels pertain.
In order to improve the performance of the surfacing with respect to longitudinal irregularities and transverse deformation the use of a significantly heavier plate vibrator than that used in the trial is recommended both for precompacting the sand layer and for "bedding-in" the blocks.

In order to optimise the use of concrete blocks in such highway situations the further development and use of accelerated wear machines is recommended as the initial skid resistance value of the blocks was found to be a poor guide to their long-term performance.
Concrete block surfacings differ significantly from more conventional bituminous and concrete surfacings particularly as a result of the form of surface texture provided by the chamfers around the top edges of the blocks. If concrete block surfacings are to be used safely and economically, the inter-relationship between this type of texture depth, skid resistance parameters and safety of the road user must be determined so that appropriate levels for new works and maintenance intervention can be confidently set and used.

8. REFERENCES.

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