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TRANSPORT and ROAD
RESEARCH LABORATORY

DEPARTMENT of the ENVIRONMENT DEPARTMENT of TRANSPORT

Tensile and compressive strength of some stabilised road bases in Kenya

by

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SUPPLEMENTARY REPORT 623

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The work described in this Report forms part of the programme
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CONTENTS

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ABSTRACT

This report describes the measurement of the direct tensile and unconfined compressive strength of samples cut from stabilised roadbases in Kenya.

The test methods used are described, and the strength of the samples is compared with the performance of the roads.

The report concludes that although the bases have lost tensile strength in service, they have not suffered serious structural damage and with routine maintenance these pavements should continue to perform satisfactorily.

1. INTRODUCTION

Previous research at pilot-scale has indicated a relationship between the cracking of a soil-cement roadbase and the tensile strength of the stabilised material at the time of initial trafficking[1]. If the base material is weak, the initial cracks are found to be narrow and closely spaced in contrast to the large but widely-spaced cracks that result if the stabilised layer is strong at the time when it is first stressed.

In 1973 a cooperative programme of research was undertaken by the Overseas Unit and Department of Civil Engineering at the University of Nairobi to measure the strength of existing stabilised roadbases at selected road sites in Kenya to help to assess the condition of the pavements and their performance in relation to the traffic carried.

Transport and Road Research Laboratory staff were responsible for the selection of the road sites and for obtaining samples of the roadbases. Staff from the University of Nairobi were responsible for the preparation and testing of the samples.

2. SELECTION OF THE SITES

The samples of stabilised base material were taken from sections of road that were the subject of another study of road strengthening, apart from one site which was on a new road. The sites were located on roads of different ages that had carried different amounts of traffic at the time of sampling. Details of the location of the sites and the stabilised roadbases are given in Table 1. The deterioration and traffic loading of some of these sections had been monitored prior to sampling and is being continued subsequently.

As the location of the sites ranged from the highlands of Kenya to sea level, the rainfall and subgrade soils vary considerably. Details of annual rainfall, subgrade soils and the dates of sampling are given in Table 2.

3. POSITION AND METHOD OF CUTTING THE SAMPLES

The number of chainages at which the stabilised base was sampled varied according to the length of each site (see Table 2). On Sites 1, 3, 4 and 6 four 'blocks' of stabilised material were removed at each of the selected chainages, one from the verge-side wheelpath and one from between the wheelpaths in each lane (see Figure 1). These locations were selected to see whether differences could be detected between the material extracted from the most heavily-trafficked part of the pavement (the verge-side wheelpath) and material extracted from the least trafficked part of the pavement (between the wheelpaths). On Site 2, a dual carriageway road, blocks were taken at one chainage only, from the verge-side wheelpath and offside wheelpath, and from between the wheelpaths of one slow lane. On Site 5 only four blocks were removed, one from between the wheelpaths in each lane at two chainages.

The blocks were cut from the road using a petrol engined concrete saw (Plate 1) which had been extensively modified for use in dusty conditions. Circular steel and carborundum blades were used for cutting. Water could not be used as a lubricant because of the possibility of softening the weaker pavement materials. Cutting was therefore carried out extremely slowly to avoid damaging the stabilised materials. Four or five samples were cut at each block location. These were approximately 75 mm wide, 200 mm long and deep enough to include the full depth of the surfacing and roadbase (see Plate 2). By cutting a space between each sample and applying pressure at the interface between the stabilised base and unstabilised sub-base it was possible to 'slide' the sample from the sub-base. Once removed the samples were wrapped in polythene to preserve their moisture contents and placed in boxes lined with plastic foam sheeting to protect them during transit to the laboratory.

4. PAVEMENT INVESTIGATION TESTS

After the removal of the stabilised base samples, pavement investigation tests were carried out on the subsequent pavement layers. Measurements of layer thickness, moisture content and in-situ CBR values were made. The results are summarised in Table 3. Site 4 has been divided into two sub-sites because of the significant difference between the subgrade strengths of the two parts. In-situ CBR measurements could not be taken on the samples of roadbase prior to removal because the samples would have been damaged. However CBR and moisture contents were measured at locations near the blocks and the results are reported in Table 4.

5. PAVEMENT SURFACE MEASUREMENTS

Measurements of the transient deflection[2], rut-depth and cracking were made at all sites. Tables 5 and 6 show the mean transient deflection and the rut-depth measured under a 2 metre straight edge at the time of sampling the stabilised base. There were no significant areas of surface cracking at any of the sites at the time of sampling.

6. CUTTING THE SAMPLES FOR TESTING

Figure 2 shows the appearance of a sample after it was removed from the road. Two more cuts had to be made in the laboratory before the sample could be tested. These cuts were made with a bench saw using steel and carborundum blades. To provide adequate restraint during cutting, the sample, still wrapped in polythene sheet, was set in a cement sand mortar. This restraint was necessary to prevent the blade from breaking material from the face of the specimen and thus causing an irregular cross-section. The top of the road surfacing of the sample was left flush with the top of the mould and the mortar was allowed to partially cure around the remaining faces. The top of the road surfacing was then used as a reference for the two cuts shown in Figure 2 which were made through both the mortar and the sample.

A third cut was necessary with the samples that were to be tested in compression to reduce the height: width ratio to 2:1.

7. COMPRESSION AND TENSILE TESTS

The samples were tested for their tensile and compressive strength along the long axis of the sample.

7.1 *Unconfined compression test*

End plates were attached to the samples using plaster of Paris to ensure that the compressive load was applied along the axis of the sample. The square steel end plates, 75 mm x 75 mm x 5 mm, were mounted on the sample in a rectangular steel mould and were held in place by a turn screw whilst the plaster of Paris set as shown in Figure 3. Before testing, the cross-section of the sample was measured with vernier calipers. The mean of three measurements of the cross-section was used to compute the compressive strength. The load was applied gradually in a press to failure using a 50 kN capacity load cell to measure the load.

The Kenya Ministry of Works specify that stabilised roadbase material should attain an unconfined compressive strength of 1.8 N/mm^2 after 7 days curing and 7 days immersion in water. These tests are usually carried out with 100 mm x 50 mm diameter cylindrical samples. Although cylindrical specimens could not be prepared from the samples of base extracted from the road previous work^3 has shown that rectangular samples with a similar height:width ratio give comparable values of unconfined compressive strength. Hence the samples were cut with a height:width ratio of 2:1.

7.2 *Direct tensile test*

A polyester resin was used to attach the samples to end caps as shown in Figure 4. The angle plates were slotted to allow the sample to be positioned centrally with respect to the applied load. The top cap was attached to a rigid steel frame through a universal coupling and a steel container was attached to the bottom plate also through a universal coupling. Dry sand was then slowly poured into the container until the sample fractured. After failure the container, the sand and the lower half of the sample with the bottom end cap were weighed and the cross-section at the fracture measured with vernier calipers.

8. RESULTS

8.1 *Removal of the samples from the road*

Where the direct tensile strength of the stabilised roadbase was less than 0.06 N/mm^2 the samples were difficult to remove and test without damage. In such cases it was not possible to differentiate between samples that were cracked prior to the cutting operation and those which were cracked by the motion of the blade.

Figure 5 shows that fewer samples were successfully removed from the road and tested at Sites 3 and 6 and block Nos. 1–12 at Site 4. Block Nos. 13–16 at Site 4 have been separated from Block Nos. 1–12 in Figure 5 because they have significantly higher tensile strength. The direct tensile strength quoted for each site is a mean value for all the direct tensile tests that were successfully carried out. The mean direct tensile strengths for Sites 3, 4 and 6 are overestimated because the samples which were too weak to be tested have not been included in the calculation of the mean strength.

8.2 *Effect of traffic loading on the direct tensile strength*

At two sites a comparison can be made between the tensile strengths of samples taken from the same site which have experienced different traffic loadings. The direct tensile strengths of samples taken from the verge-side wheelpaths and the estimated cumulative traffic loadings at Sites 3 and 4 are shown in Table 7. At these sites, where there was a considerable difference in traffic loading between the two lanes, the samples taken from the more heavily trafficked lane had higher tensile strengths. It was not possible to make accurate estimates of the traffic loadings at the other sites because data were not available.

8.3 *Comparison between samples taken from the verge-side wheelpath and between the wheelpaths*

Table 8 shows how the tensile strength of blocks taken from the verge-side wheelpath compares with the strength of those taken from the adjacent position between the wheelpaths. The number of samples from each block tested in tension varies because where there was large scatter in the values of tensile strength additional tests were carried out. Also a number of samples fractured prior to testing as described earlier. The comparison shows that the roadbases are not significantly weaker in the verge-side wheelpath than in the position between the wheelpaths. Details of the samples that fractured prior to testing are given in Table 9.

8.4 *Relationship between the unconfined compressive and direct tensile strength of the samples*

The unconfined compressive strength and the direct tensile strength of all the samples tested are plotted in Figure 6. Each point represents the mean strength of samples taken from one block.

The four blocks taken from Site 5 are considerably stronger than the other blocks for two reasons. Firstly the coral gravel material at this site formed an extremely dense and mechanically stable base. Secondly the samples were taken before the road was heavily trafficked and consequently no deterioration of the base due to traffic would have occurred. Figure 6 shows that the direct tensile strength does not increase significantly with an increase in unconfined compressive strength.

9. DISCUSSION

The road pavements at Sites 3 and 4 conform closely to the pavement design recommendations suggested in Road Note 31[4] for a traffic loading of 2.5×10^6 equivalent standard axles. Both these sites have now carried considerably more traffic than this but there has been no evidence of serious structural failure.

Traffic and axle-load data up to the times of sampling for Sites 1, 2 and 6 is not available. Site 1 has been open to traffic for approximately ten years, Site 2 for fourteen years and Site 6 for four years. At the time of sampling there was no evidence of base failure at any of these sites.

Previous work by the authors shown in Figure 7 indicates that typical gravels in Kenya stabilised with 4.5 per cent of cement attain a direct tensile strength of approximately 0.1 N/mm^2 after four hours curing. These tests were carried out on briquette samples[5] using material which passed a 5 mm sieve compacted at maximum dry density[6] (2.5 kg rammer method). The values of direct tensile strength obtained in these tests may overestimate to some extent the strength of the gravel in the road, however the indications are that the direct tensile strengths of the samples cut from the road are probably considerably lower than they were soon after construction.

Previous work[7] has shown that for laboratory prepared clay-cement-mixtures the ratio between the direct tensile strength and unconfined compressive strength varies between 1:3.3 and 1:6.2. The fact that there was no similar relationship between direct tensile and unconfined compressive strengths for the samples from the roads indicates that it is likely the roadbases were cracked.

Further confirmation of this is provided by the low values of direct tensile strength of the samples extracted from the roads. The cracks are probably caused by traffic during the early life of the road. The fact that the results do not show any relationship between direct tensile strength and cumulative traffic loading indicates that the growth of cracking probably reduced the tensile strength at an early age, and subsequent trafficking has had little effect on the tensile strength. The high values of transient deflection measured on some of the sites as shown in Table 5 indicate that these roadbases are no longer acting as rigid layers but are acting flexibly.

Despite the low direct tensile strength of the samples the results summarised in Tables 4 and 6 show that the bases still had mean CBR values in excess of 100 per cent and that very little deformation or surface cracking had occurred at any of the sites. It thus appears that although the bases contain numerous fine cracks there is sufficient mechanical interlock to provide the strength necessary to carry the traffic over the strong subgrades.

10. CONCLUSIONS

1. The tensile tests showed that the majority of the roadbase samples had a lower direct tensile strength than would be expected of such material soon after construction, nevertheless the roadbases were still carrying the traffic loads satisfactorily.

2. The tests showed that the tensile strength of the samples from the more heavily-trafficked parts of the pavements was not less than the strength of the samples from the lighter-trafficked areas.

3. There was no correlation between direct tensile and unconfined compressive strengths for the roadbase samples.

11. ACKNOWLEDGEMENTS

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The cooperation of the Government of the Republic of Kenya is gratefully acknowledged for allowing the conduct of field experiments on a public road.

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TABLE 1

Location of the sites and details of the stabilised base

Site No.	Location	Road base material	Nominal per cent and type of stabiliser
1	A104 90 km north of Nakuru at Timboroa	Gravel	6% lime
2	A2 Thika bound carriageway at Ruaraka	Gravel	7% cement
3	A109 132 km south of Nairobi at Emali	Gravel	4% cement
4a&b	A109 356 km south of Nairobi at Maungu	Silty clay sand	4% cement
5	A14 40 km south of Mombasa near Mwabungu	Coral	5.3% cement
6	A14 62 km south of Mombasa near Ramisi	Gravel	5% cement

TABLE 2

Sampling details, annual rainfall and subgrade type

Site No.	Date of sampling	No. of chainages at which samples taken	Approximate annual rainfall (mm)	Details of subgrade			
				Description	Liquid limit (per cent)	Plastic index (per cent)	Linear shrinkage (per cent)
1	February 1975	3	1300	Red clay	88	43	21
2	September 1975	1	700	Red clay	70	37	17
3	June 1975 February 1976	3	540	Clayey silt	39	15	9
4a (Blocks 1–8)	November 1975	4	300	Silty clay sand	33	17	10
4b (Blocks 9–16)	November 1975		300	Silty clay sand	26	13	8
5	August 1974	2	1100	Well graded sand/sandy clay	–/42	Non-plastic/22	–/13
6	September 1974	3	1200	Well graded sand	–	Non-plastic	–

TABLE 3

Pavement investigation results

Site No.	No. of tests	Pavement layer	Thickness (mm)		Moisture content (per cent)		In-situ CBR (per cent)	
			Mean	Range	Mean	Range	Mean	Range
1	12	Roadbase	122	100–140	–	–	–	–
		Sub-base	118	60–150	16.5	14.9–17.8	> 75	42–> 100
		Subgrade	–	–	30.2	20.5–35.4	26	8–42
2	3	Roadbase	161	155–170	–	–	–	–
		Sub-base	206	160–250	16.8	15.7–18.9	> 68	40–> 100
		Subgrade	–	–	27.5	27.2–27.7	15	6–28
3	12	Roadbase	143	120–160	–	–	–	–
		Sub-base	130	75–250	17.0	10.2–24.0	42	12–90
		Subgrade	–	–	19.2	16.0–21.1	22	15–28
4a (Blocks 1–8)	8	Roadbase	120	110–130	–	–	–	–
		Compacted subgrade	91	50–120	9.8	7.8–11.9	42	20–52
		Subgrade	–	–	9.3	8.4–10.5	45	26–78
4b (Blocks 9–16)	8	Roadbase	132	120–150	–	–	–	–
		Compacted subgrade	155	130–180	6.9	5.6– 9.0	> 72	> 35–> 100
		Subgrade	–	–	4.9	3.2– 7.9	58	23–96
5	4	Roadbase	134	120–145	–	–	–	–
		Sub-base	133	125–140	4.8	3.9– 5.3	> 85	39–> 100
		Fill	79	57–140	4.5	4.0– 5.1	> 87	66–> 100
		Fill	96	45–160	6.2	4.2– 7.3	> 51	22–> 100
		Subgrade	–	–	9.0	7.5–11.0	19	6–36
6	12	Roadbase	115	90–130	–	–	–	–
		Sub-base	124	90–170	12.6	11.3–14.0	> 46	16–> 100
		Fill	211	120–320	6.9	3.7–10.9	> 41	12–> 79
		Fill	–	–	6.7	4.4–8.4	> 41	8–71

TABLE 4

In-situ CBR results and moisture contents of the stabilised roadbase

Site No.	No. of tests	Moisture content (per cent)			In-situ CBR results (per cent)		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
1	10	16.9	1.3	14.2–18.8	136	26.0	80–170
2	5	17.5	3.4	14.0–21.1	All results > 100		
3	11	13.3	3.2	9.1–17.7	124	29.5	67–160
4 a&b	12	10.7	2.0	8.3–14.2	All results > 100		
5	10	4.7	0.8	3.3– 5.8	All results > 100		
6	12	11.6	1.1	9.8–13.9	All results > 100		

TABLE 5

Transient deflection values in the verge-side wheelpath at the time of sampling

Site No.	Direction	Mean transient deflection (mm x 10^{-2})
1	Towards Eldoret	73
	Towards Nakuru	71
2	Slow lane	61
3	Towards Mombasa	64
	Towards Nairobi	89
4a (Blocks 1–8)	Towards Mombasa	74
	Towards Nairobi	58
4b (Blocks 9–16)	Towards Mombasa	36
	Towards Nairobi	34
5	Towards Lunga-Lunga	13
	Towards Mombasa	14
6	Towards Mombasa	52
	Towards Lunga-Lunga	59

TABLE 6

Rut depth measurements at the time of sampling

Site No.	Direction	Rut depth (mm)			
		Verge-side		Off-side	
		Mean	Range	Mean	Range
1	Towards Eldoret	7.5	3–19	4.4	2–11
	Towards Nakuru	9.1	3–18	5.2	0–12
2	Slow lane	1.8	0–14	1.3	0– 8
3	Towards Mombasa	4.3	0–19	2.5	0– 7
	Towards Nairobi	2.7	0–12	2.7	0–10
4a & b	Towards Mombasa	6.5	2–21	5.1	0–13
	Towards Nairobi	7.2	0–23	6.0	0–23
5	Towards Lunga-Lunga	0	–	0	–
	Towards Mombasa	0	–	0	–
6	Towards Mombasa	3.0	0–10	1.8	0– 4
	Towards Lunga-Lunga	4.5	0–15	2.0	0– 9

TABLE 7

Tensile test results of blocks taken from verge-side wheelpath

Site No.	Direction	No. of samples that fractured prior to testing	No. of samples tested	Mean (N/mm^2)	Standard deviation (N/mm^2)	Range (N/mm^2)	Estimated cumulative traffic loading before sampling (equivalent standard axles)
1	Towards Eldoret	1	9	0.069	0.031	0.031–0.114	Site open to traffic for approximately 10 years
	Towards Nakuru	2	4	0.073	0.021	0.039–0.083	
2†	Slow lane	–	6	0.096	0.053	0.035–0.188	Site open to traffic for approximately 14 years
3	Towards Mombasa	1	8	0.035	0.009	0.023–0.050	1.0 x 10^6
	Towards Nairobi	2	8	0.054	0.014	0.039–0.074	3.0 x 10^6
4a&b	Towards Mombasa	7	7	0.054	0.029	0.028–0.097	1.2 x 10^6
	Towards Nairobi	5	7	0.064	0.020	0.043–0.093	4.3 x 10^6
6	Towards Mombasa	6	5	0.032	0.012	0.022–0.046	Site open to traffic for approximately 4 years
	Towards Lunga-Lunga	2	9	0.057	0.021	0.034–0.085	

† Blocks taken in both verge and offside wheelpaths at one chainage

TABLE 8

Tensile tests of blocks taken from verge-side wheelpath and between wheelpaths

Site No.	Location of blocks	Chainage 1		Chainage 2		Chainage 3		Chainage 4	
		No. of samples tested	Mean tensile strength (N/mm^2)	No. of samples tested	Mean tensile strength (N/mm^2)	No. of samples tested	Mean tensile strength (N/mm^2)	No. of samples tested	Mean tensile strength (N/mm^2)
1	Towards Eldoret verge-side	3	0.074	3	0.089	3	0.045		
	Towards Eldoret between wheelpaths	2	0.048	3	0.078	2	0.045		
	Towards Nakuru between wheelpaths	3	0.039	3	0.073	3	0.049		
	Towards Nakuru verge-side	1	0.078	1	0.083	2	0.059		
2	Slow lane verge and offside	6	0.096						
	Slow lane between wheelpaths	3	0.071						
3	Towards Mombasa verge-side	3	0.037	2	0.025	3	0.042		
	Towards Mombasa between wheelpaths	2	0.019	0	–	3	0.038		
	Towards Nairobi between wheelpaths	3	0.025	2	0.078	3	0.040		
	Towards Nairobi verge-side	2	0.039	3	0.055	3	0.069		
4a&b	Towards Mombasa verge-side	1	0.034	3	0.032	0	–	3	0.081
	Towards Mombasa between wheelpaths	2	0.055	3	0.056	4	0.050	3	0.140
	Towards Nairobi between wheelpaths	3	0.063	3	0.030	3	0.037	3	0.149
	Towards Nairobi verge-side	3	0.062	0	–	2	0.062	2	0.070

TABLE 8 (continued)

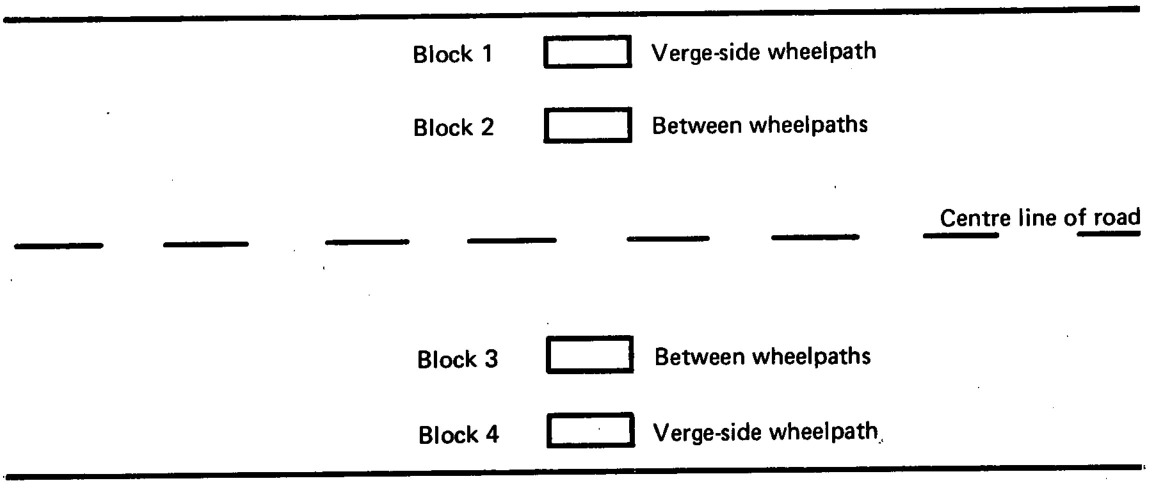
Site No.	Locations of blocks	Chainage 1		Chainage 2		Chainage 3		Chainage 4	
		No. of samples tested	Mean tensile strength (N/mm^2)	No. of samples tested	Mean tensile strength (N/mm^2)	No. of samples tested	Mean tensile strength (N/mm^2)	No. of samples tested	Mean tensile strength (N/mm^2)
5	Towards Lunga-Lunga between wheelpaths	4	0.225	4	0.278				
	Towards Mombasa between wheelpaths	3	0.139	3	0.222				
6	Towards Mombasa verge-side	3	0.029	2	0.035	0	–		
	Towards Mombasa between wheelpaths	2	0.016	2	0.029	3	0.030		
	Towards Lunga-Lunga between wheelpaths	3	0.023	3	0.045	2	0.065		
	Towards Lunga-Lunga verge-side	3	0.051	3	0.045	3	0.074		

TABLE 9

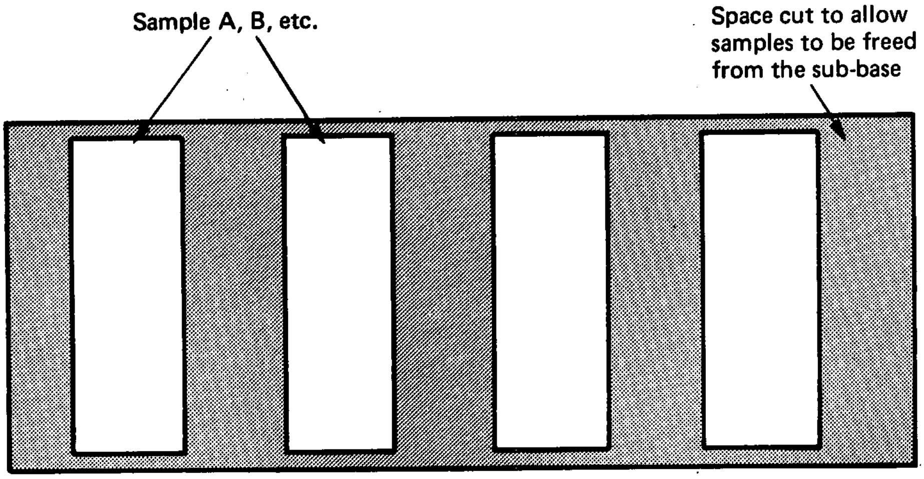
Details of samples that fractured prior to testing

Site No.	Location of blocks*	Number of samples successfully removed and tested	Number of samples that fractured prior to testing
1	VSW	21	3
	BW	24	–
2	VSW and OSW	10	–
	BW	5	–
3	VSW	23	3
	BW	20	6
4a&b	VSW	28	12
	BW	34	6
5	BW	26	–
6	VSW	18	8
	BW	20	6

* VSW = verge-side wheelpath
BW = between wheelpaths
OSW = offside wheelpath



POSITION OF BLOCKS AT A CHAINAGE
(except for Sites 2 and 5)



METHOD OF REMOVING SAMPLES FROM A BLOCK

Fig. 1 POSITION OF BLOCKS AND METHOD OF CUTTING SAMPLES

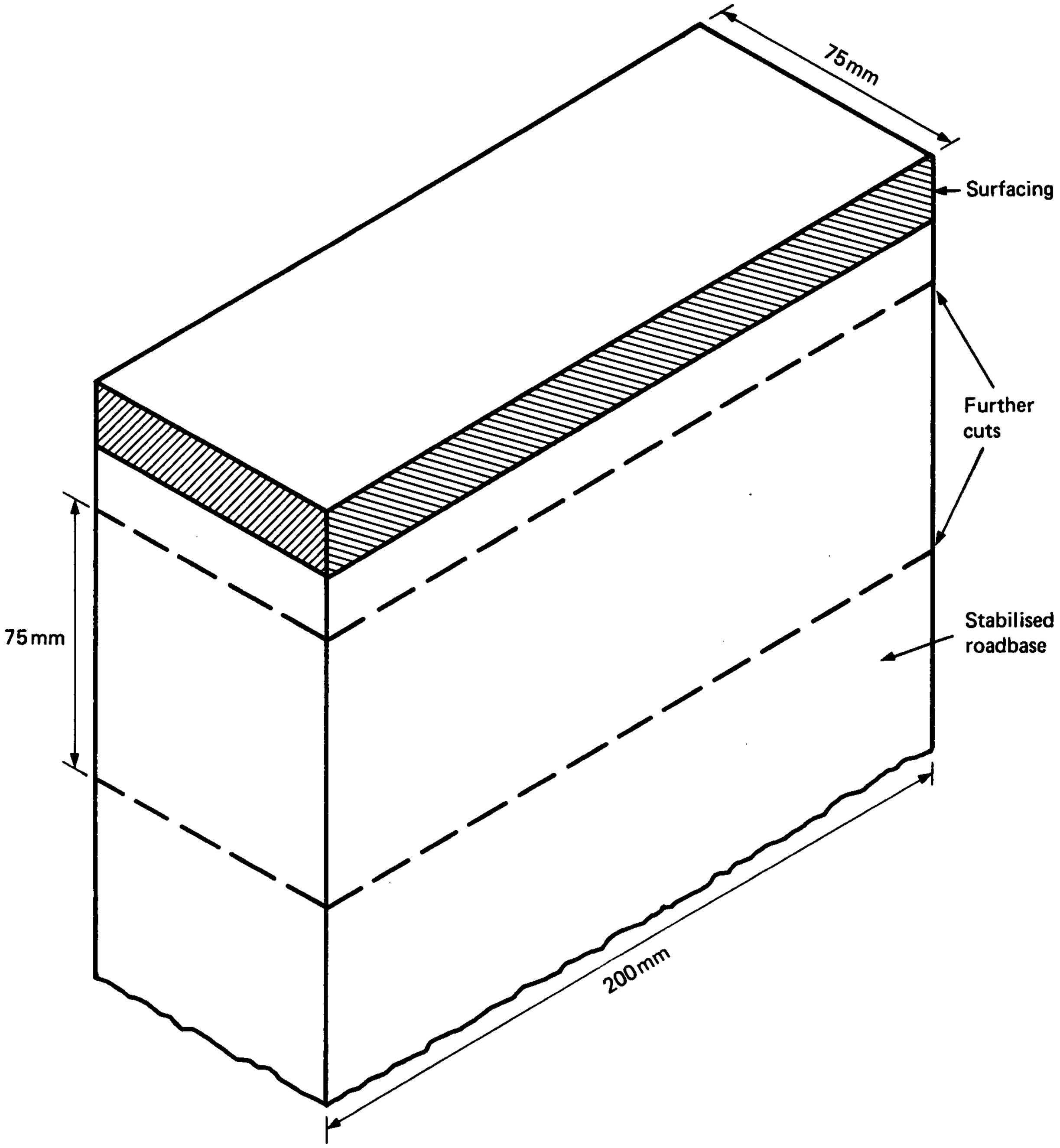


Fig. 2 SAMPLE AFTER REMOVAL FROM ROAD

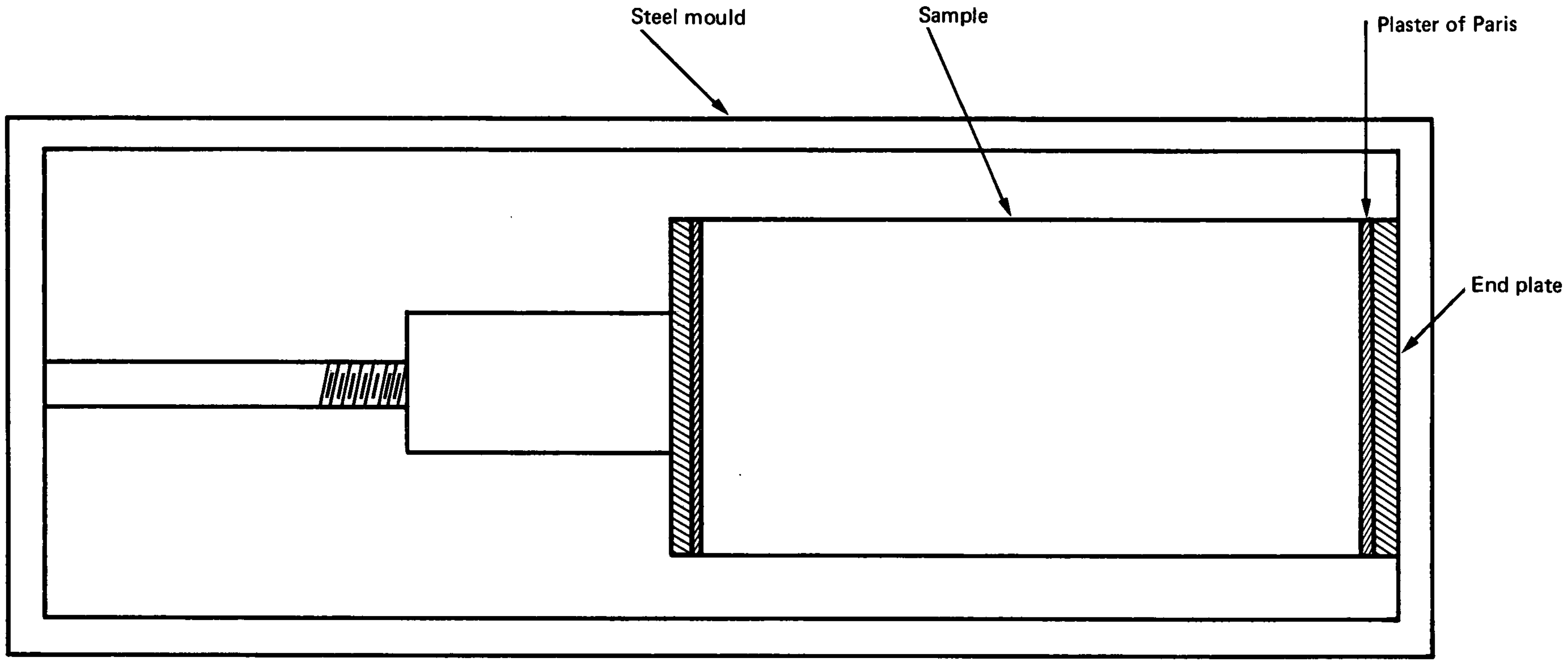


Fig. 3 FIXING END PLATES PRIOR TO UNCONFINED COMPRESSION TEST

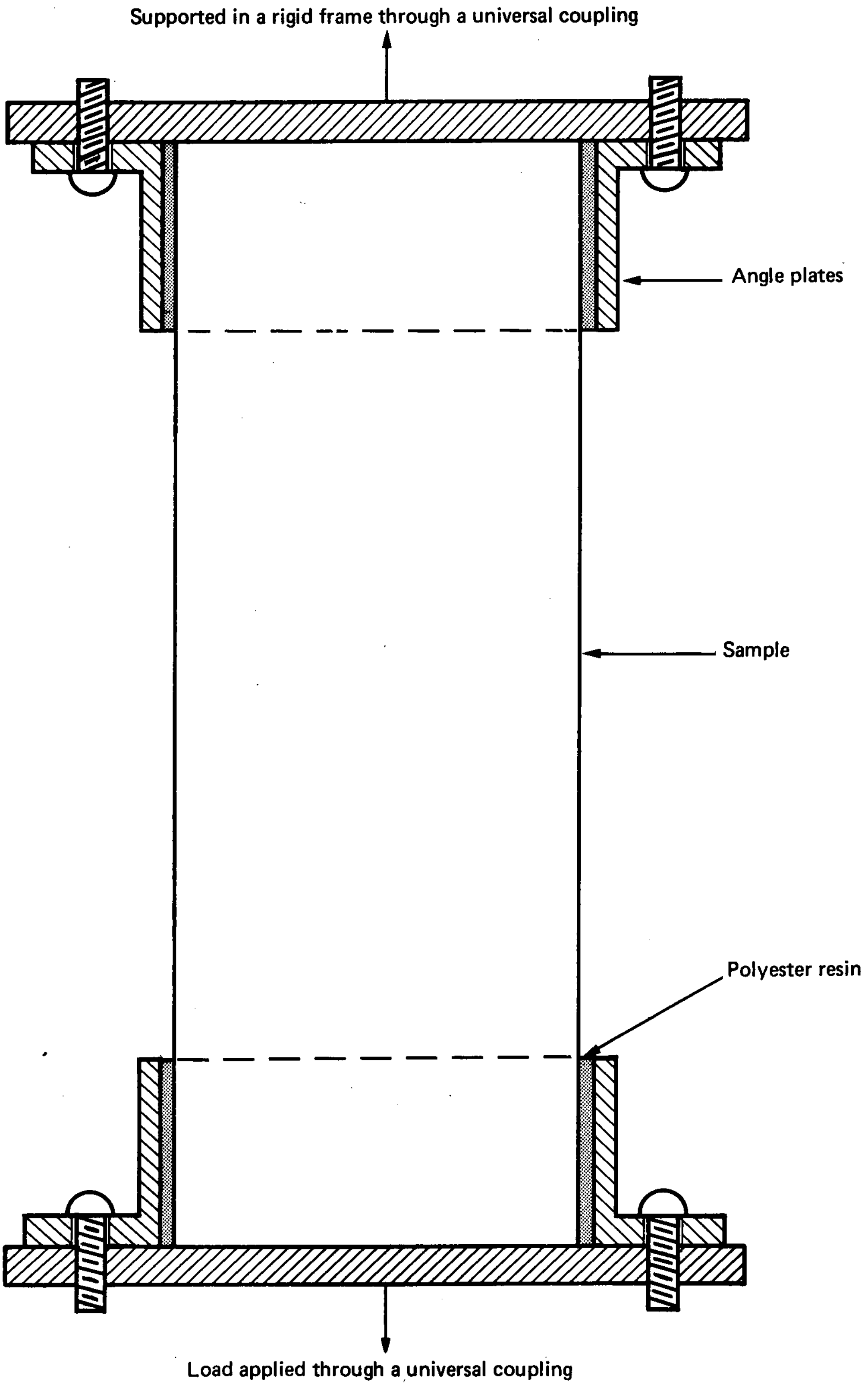


Fig. 4 END CAPS USED IN A DIRECT TENSION TEST

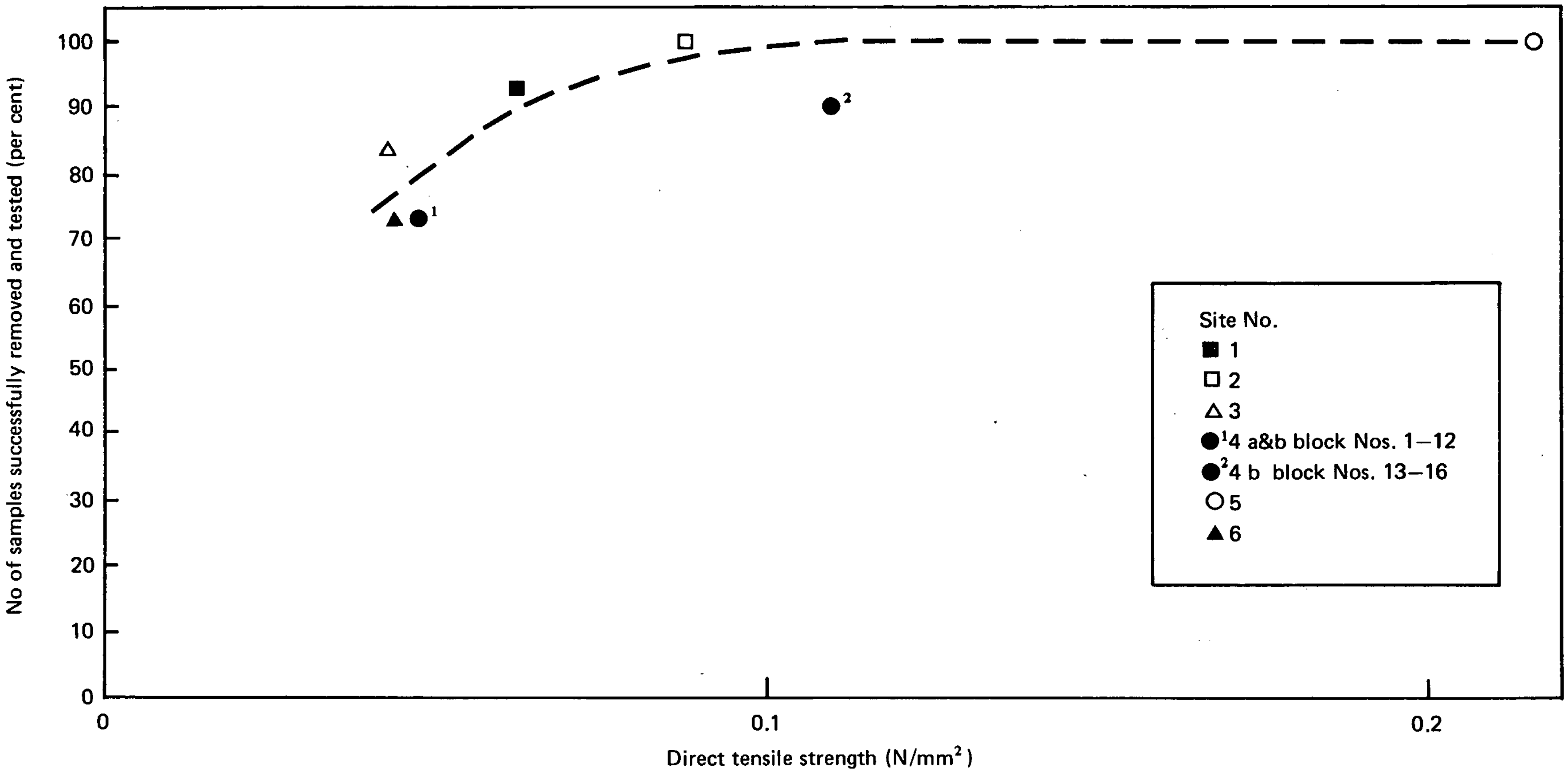


Fig. 5 DETAILS OF THE NUMBER OF SAMPLES REMOVED AND TESTED

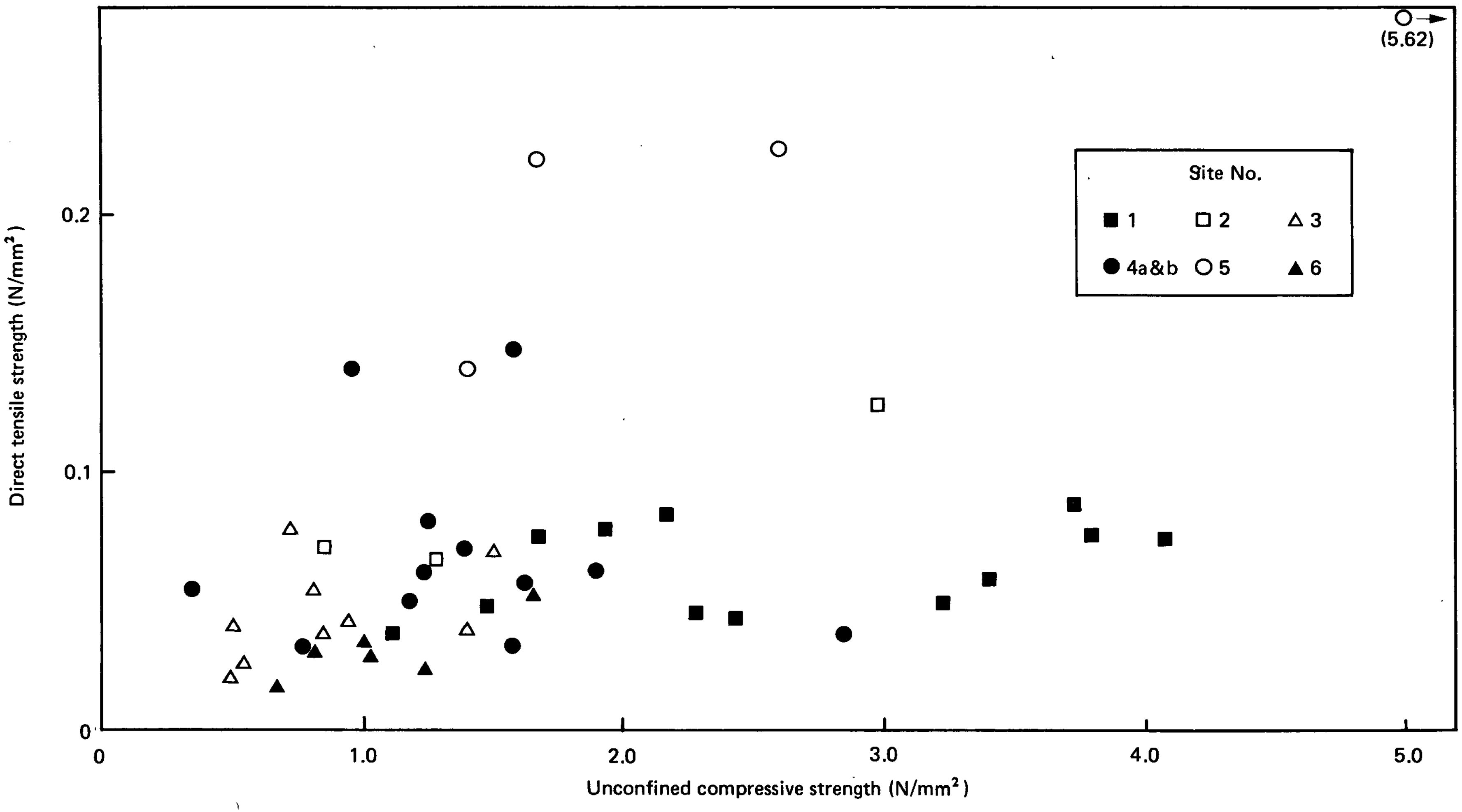


Fig. 6 UNCONFINED COMPRESSIVE STRENGTH AND DIRECT TENSILE STRENGTH AT ALL SITES

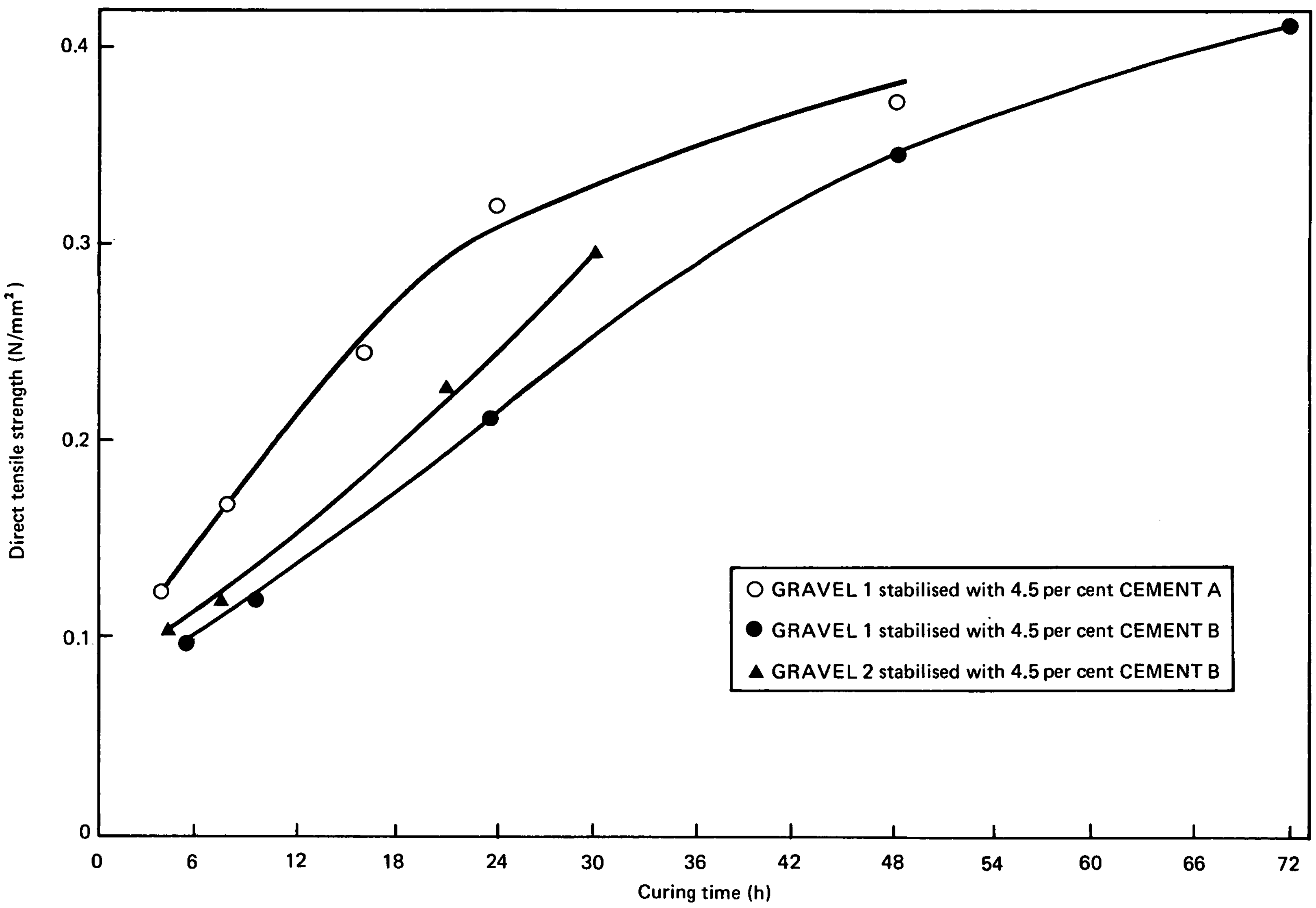


Fig. 7 RELATIONSHIP BETWEEN DIRECT TENSILE STRENGTH AND CURING TIME

Plate 1 CONCRETE SAW

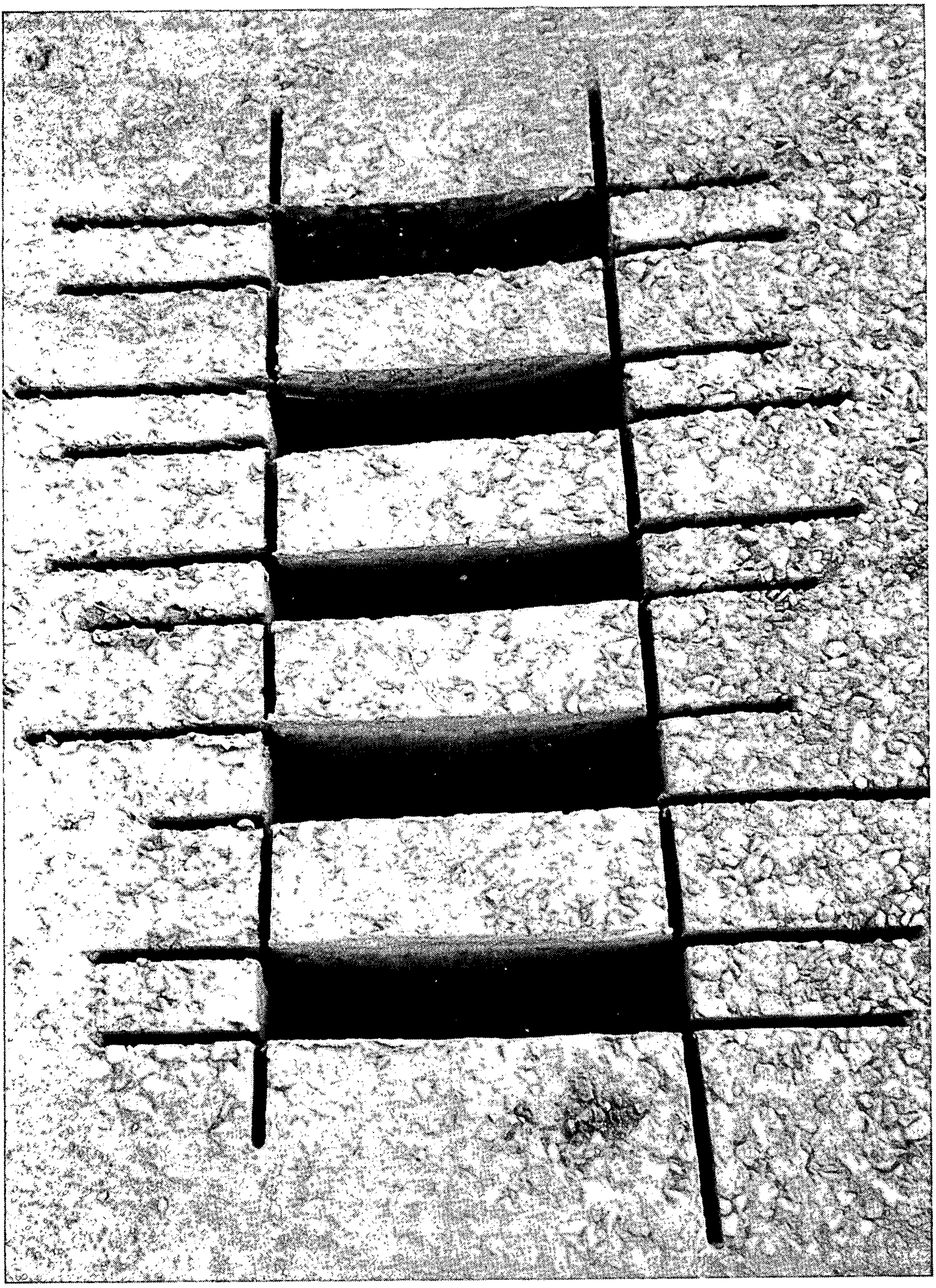


Plate 2 SAMPLES AFTER CUTTING

(1907) Dd0536380 1,400 10/80 HPLtd So'ton G1915
PRINTED IN ENGLAND

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