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Technical evaluation of wood wool/cement slabs made from Pinus caribaea grown in Fiji (L48)

Tropical Products Institute

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Contents

Summaries

Technical evaluation of wood wool/cement slabs made from *Pinus caribaea* grown in Fiji

Following a TPI techno-economic feasibility study of wood wool slab manufacture in Fiji a request was received for the following tests to be undertaken as a source of data for local assessments of wood wool/cement slab structural properties:

(a) Compressive strength of full-sized slab

(b) Deflection under uniform loading to failure

(c) Failing load of the dowel/wood wool slab joint

(d) Shear strength of full sized slab.

These tests, with the exception of shear, were undertaken by TPI in consultation with the Overseas Division of the Building Research Establishment. Shear testing was undertaken by private consultants under BRE(OD) funding. Methods used and results obtained, together with additional tests including the assessment of fire propagation and wetting expansion and drying shrinkage, are given in this report. Also included as Appendix I is a technical assessment of the minimum chemical and other raw material inputs required to produce wood wool/cement slabs to meet British Standards from *P. caribaea.* Comments were obtained from BRE(OD) and are given in Appendix III.

RESUME

Evaluation technique de panneaux ciment/laine de bois réalisés avec du *Pinus caribaea* des Îles Fidji

A la suite d'une étude préliminaire technico-économique de TPI sur la fabrique de panneaux de laine de bois des îles Fidji, on a demandé que soient réalisés les essais suivants en vue d'obtenir des données pour des évaluations locales des propriétés structurales de panneaux ciment/laine de bois:

(a) Résistance à la compression d'un panneau en grandeur réelle

(b) Flexion sous l'action d'une charge uniforme jusqu' à la rupture

(c) Charge de rupture de l'assemblage cheville/panneau de laine de bois

(d) Résistance au cisaillement d'un panneau en grandeur réelle

Ces essais, à l'exception de l'essai de cisaillement, ont été effectués par TPI en liaison avec le Département Outre-Mer du Building Research Establishment. L'essai de cisaillement a été réalisé par des consultants privés, et financé par le BRE(OD). On décrit, dans ce rapport, les méthodes employées et les résultats obtenus, ainsi que d'autres essais supplémentaires comportant l'évaluation de la propagation des flammes, du gonflement à l'humidité et de la contraction lors du séchage. On trouvera dans l'Appendice I une évaluation technique du minimum de matériaux chimiques et d'autres matériaux bruts nécessaires pour produire des panneaux ciment/laine de bois, à partir de *P. caribaea,* satisfaisant aux Normes Britanniques. Dans l'Appendice III, on donne les commentaires du BRE(OD).

RESUMEN

Evaluación tecnica de placas de unión de pelusa de madera/cemento del *Pinus caribaea* cultivado en Fiji

A causa de un estudio de viabilidad tecno-económico del TPI sobre la fabricación de placas de pelusa de madera/cemento en Fiji, se recibió una solicitud para realizar los siguientes ensayos como fuente de datos para una valoración local de las propiedades estructurales de las placas de unión de pelusa de madera/cemento:

(a) Resistencia a la compresión de las placas de tamaño natural.

(b) Máxima flexión hasta la rotura bajo carga uniforme.

(c) Carga de rotura de los dados de unión de placa de lana de madera.

(d) Resistencia al esfuerzo cortante de la placa de tamaño natural.

Estos ensayos, con la excepción del último, los llevó a cabo el TPI en colaboración con la División de Ultramar del Centro para Investigaciones sobre la Construcción (Overseas Division of the Building Research Establishment). El ensayo sobre el esfuerzo cortante lo llevaron a cabo asesores privados financiados por el BRE(OD). En este informe se habla de los métodos utilizados y los resultados obtenidos, así como de otras pruebas adicionales que incluyen una valoración de la propagación del fuego, la expansión de la humedad y la contracción de secado. También se incluye en el Apéndice I una valoración técnica de las necesidades mínimas de productos químicos y otras materias primas para producir placas de unión de pelusa de madera/ cemento del *P. caribaea* que se ajusten a las Normas Británicas. Se obtruvieron diversos comentarios del BRE(OD) que se facilitan en el Apéndice III.

Technical evaluation of wood wool/ cement slabs made from *Pinus caribaea* grown in Fiji

INTRODUCTION

At the request of the Forestry Department, Suva, Fiji, TPI undertook laboratory trials to assess the suitability of plantation grown *Pinus caribaea* for use in the manufacture of wood wool slabs. The results of these trials are reported in Appendix I. It was later suggested that this project be extended to include the use of wood wool slabs in the lower cost housing field. The design of such a house using wood wool slabs of a fixed size on a modular basis and as a structional component was produced by the Housing Authority, Suva. The general consensus of opinion was that the erection of a demonstration house would show a practical application of wood wool slabs in lower cost housing. Also precise factual data on any erection problems, erection cost, maintenance costs and customer reaction would be provided. Direct comparison could then be made with other more conventional building materials and methods as practised by the Housing Authority.

After consultation with ODM architectural advisers and interested parties in Fiji it was decided that the Housing Authority would build two demonstration houses using wood wool slabs supplied by TPI and made from the local *P. caribaea.* The houses were built in late 1973 early 1974 and duly reported on by Mr Mills, Chief Architect, Housing Authority (personal communication). The general conclusions were basically favourable for the use of wood wool slabs from the construction, maintenance and economic point of view.

A full economic study of the feasibility of wood wool slab manufacture in Fiji was undertaken by TPI and reported on in early 1976 (personal communication). During this study Mr Mills requested that TPI undertake further testing of the wood wool slab components in order to supply data for use by local structural engineers of the Housing Authority. This data would be used to make a complete assessment of the structural use of wood wool slabs in the small housing field and if satisfactory used to present a case to gain Local Authority acceptance of the use of wood wool slabs in this manner in the lower cost housing field and for the establishment of a production plant (assuming proven viability).

The tests required fell partly in a subject area in which, under standing ODM arrangements, the Overseas Division of the Building Research Establishment provides advice. TPI therefore sought BRE(OD) advice on the planning of those tests which were undertaken at the Institute; and BRE financed other tests carried out elsewhere. The object of this report is to present the results obtained for local assessment purposes, where comments have been gathered from other sources it is given verbatim.

METHOD OF MANUFACTURE OF TEST SLABS

The *P. caribaea* samples were debarked, cut into lengths of 50 cms and stored for seasoning for about 4 months. The seasoned billets were soaked in water for 72 hours and drained for 48 prior to setting on a commercially made shredding machine to produce wood wool of dimensions 3.8 mm width and 0.33 mm thickness. The wood wool was soaked in a 5% solution of calcium chloride for 5 minutes and then spun in a centrifuge to remove all excess surface moisture. In this way any cement setting inhibition was minimised and strict control of the cement to water ratio was gained for the later manufacturing stages (Chittenden *et al.,* 1975). The 'spun' wood wool was placed in a modified rotating drum mixer where a cement slurry (2 cement: 1 water) was added. After 5 minutes mixing period the resultant mixture in proportions of 1 cement: 0.4 wood wool (OD Basis): 0.5 water was weighed and hand packed into wooden moulds. The filled moulds were piled and then compressed by means of car jacks against a cross beam and left under pressure for 16 to 24 hours. On demoulding the slabs were stacked and allowed to cure for 28 days under the controlled temperature and humidity conditions of 27°C and 70% RH. Sufficient slabs were made with a nominal density of 450 Kg/m^3 and dimensions 2083 mm x 902 mm x 76 mm for the erection of the two demonstration houses and for testing purposes outlined below.

TESTING

Initially, although the wood wool slabs were of a non-standard size, the procedures laid down in British Standard 1105:1972 *Specification for wood wool slabs up to 102 mm thick* were adopted to assess strength and fire performance. Movement due to moisture changes was measured by means of the same method used to assess concrete blocks as laid down in BS 2028, 1364: 1968 *Specification for precast concrete blocks.* Methods were designed to measure the various other parameters required and because of their non-standard nature could not be related to any British Standard Specification.

RESULTS OF TESTS RELATED TO BRITISH STANDARDS

Strength test (BS 1105:1972 Appendix E)

The slabs were soaked in water at ambient temperature for 2 hours and then allowed to drain for 1 hour. Each slab was supported centrally and at right angles along its length by four, 50 mm wide by 600 mm long timber bearers. The bearers were spaced at 600 mm centres. A load of 2.2 KN, as specified for Type B slabs*, was applied at a rate of 1 KN/minute through a timber spreader at the mid-span of each section and maintained for 1 minute. Although this is the only requirement of the British Standard, TPI normally continue loading (after the 1 minute interval) until failure occurs. With the failing load known, the Modulus of Rupture for the slab can be calculated using the formula $MoR = \frac{3\,wl}{2\,bd^2}$ N/mm^2

where: w = failing load N
l = distance between centres of the bearers mm
b = width of slab mm
d = thickness of slab mm

In this particular instance it was not possible to determine the failing load of the full size slabs due to the limited capacity of the testing machine. In order to overcome this difficulty a spare slab was cut into 4 quarters, each quarter was tested to BS 1105: 1972 Appendix E and the Modulus of Rupture calculated. The results of these tests are shown in Tables 1 and 2, where it can be seen that each slab where applicable complied with the requirements of the standard.

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*The British Standard classifies two types of wood wool slabs:

Type A Slabs intended for non-loadbearing application, eg partitions, ceilings, wall linings, permanent shuttering and roof insulation.

Type B Slabs with a work size thickness of not less than 51 mm possessing greater strength than Type A slabs and intended particularly for use in roof construction. They are also suitable for the purposes indicated for Type A slabs.

Table 1

Strength test on selected samples of wood wool slabs manufactured for demonstration houses

Sample number	Mass	Thick-ness	Length	Width	Density	Mass per square metre	Compli-ance Type B	Failing load	Modulus of Rupture
	Kg	mm	mm	mm	Kg/m^3	Kg		N	N/mm^2
226	71.2	76.24	2,087	905	495	37.70	Yes	$>$5,000	
224	73.0	76.44	2,091	910	502	38.36	Yes	$>$5,000	
236	74.4	77.23	2,090	901	512	39.50	Yes	$>$5,000	
237	72.0	77.22	2,090	902	495	38.24	Yes	$>$5,000	
238	72.4	77.38	2,091	903	496	38.30	Yes	$>$5,000	
BS 1105: 1972		76 ±3				$\not>$41	2.2 KN		0.38

Table 2

Modulus of Rupture

Sample number	Mass	Thick-ness	Length	Width	Density	Mass per square metre	Compli-ance Type B	Failing load	Modulus of Rupture
	Kg	mm	mm	mm	Kg/m^3	Kg		N	N/mm^2
427A	15.9	74.39	1,038	450	457.6	34.04	Yes	$>$5,000	$>$1.81
427B	15.0	74.98	1,034	450	430.0	32.24	Yes	3,775	1.34
427C	16.0	73.79	1,040	450	463.3	34.19	Yes	4,680	1.72
427D	15.5	73.78	1,036	449	451.6	33.32	Yes	4,800	1.77
BS 1105: 1972		76 ±3				$\not>$41	2.2 KN		0.38

Fire performance (BS 476 Parts 6: 1968 and 7: 1971 and BS 1105: 1972. Appendix F)

1. *Fire propagation*

The fire propagation index and sub indices were measured according to British Standard 476: Part 6: 1968 *Fire tests on building materials and structures.* For this the sample under test (maximum thickness 2 inches) is mounted such that it forms one side of a non-combustible chamber. Here it is subjected to controlled sources of heat, gas burners and electrical heating elements. The combustion gases are vented through a cowled chimney where their temperature is measured (at set time intervals). The system is first calibrated by testing asbestos board of well defined specification. A temperature: time graph is drawn in both cases and the index of performance I and sub indices i_1, i_2 and i_3 are calculated by the following formula:

$$I = \underbrace{\sum_{\frac{1}{2}}^{3} \frac{\theta m - \theta c}{10t}}_{(i_1)} + \underbrace{\sum_{4}^{10} \frac{\theta m - \theta c}{10t}}_{(i_2)} + \underbrace{\sum_{12}^{20} \frac{\theta m - \theta c}{10t}}_{(i_3)}$$

where: θm = temperature rise (°C) recorded for the material at time t
θc = temperature rise (°C) recorded for the asbestos standard at time t
t = time in minutes from the beginning of test

The overall performance index I provides a comparative measure of the contribution a material will make to heat build up and thus to fire spread within a compartment (HMSO, 1970). It is possible to arrange materials in descending order of merit on a scale 0 to approximately 100. The sub index i_1 may be considered as an indication of the ignitability and flammability of the material. The results obtained are shown in Table 3b rather than in graph form, and are compared with indices of other materials in Table 4. Although the values are only indicative of performance indices likely to be obtained from different lining materials it can be seen that the wood wool slab not only meets the British Standard but compares well with other materials.

2. *Spread of flame*

This test was carried out by the Fire Research Station of the Joint Fire Research Organisation of the Department of Environment and the Fire Officer's Committee. Their report is as follows:

'We are writing to confirm the results of the Exploratory Surface Spread of Flame tests carried out on your four specimens of cement bonded wood wool slab material which had the references 326A, 324A, 324B and 325A.

All of the materials behaved in a similar manner and the distance of spread of flame over the surface was minimal.

If, therefore, full Surface Spread of Flame tests in accordance with BS476: Part 7: 1971 were carried out, Class 1 in all cases would probably be achieved.

The tests were exploratory as only one specimen of a type was tested instead of six, but as the indications were good we do not feel that at this stage it would be necessary to complete full tests.'

Table 3a

Fire propagation test, sample details

Sample number	Mass	Thickness	Length	Width	Density	Mass per square metre
	Kg	mm	mm	mm	Kg/m^3	Kg
432A 1	1.105	48.21	228	228	440.9	21.26
432A 2	0.945	48.51	228	228	374.7	18.18
432A 3	1.095	49.34	228	228	426.9	21.06

Table 3b

Fire propagation

Time	Temperature °C Sample 432A 1	Sample 432A 2	Sample 432A 3	Average	Calibration
0.5	19	19	18	19	15
1.0	30	28	28	29	20
1.5	36	36	37	36	25
2.0	43	43	43	43	29
2.5	48	47	47	47	31
3	52	51	52	52	37
4	85	84	85	85	66
5	132	131	130	131	105
6	165	165	165	165	135
7	190	190	191	190	153
8	208	208	211	209	170
9	220	223	222	222	183
10	233	233	233	233	192
12	251	251	248	250	206
14	262	261	261	261	215
16	271	274	270	272	224
18	278	280	280	279	229
20	286	287	286	286	234

Performance indices	I	i_1	i_2	i_3
Sample	9.16	4.27	3.35	1.53
BS1105: 1972	≯12.0	≯6	≯6	≯6

Table 4

Comparison of performance indices (HMSO, 1970)

Material	Treatment/facing	Thick-ness	I	i_1	$i_2 + i_3$
Fibre insulating board	–	13	66.4	41.0	25.4
"	Emulsion painted	13	42.0	18.0	24.0
"	Intumescent flame-retardent coating	13	20.0	5.9	14.1
"	Impregnated	13	18.4	6.4	12.0
"	Asbestos paperfaced	13	16.5	3.8	12.7
Softwood	–	18	42.5	17.2	25.3
"	Flame-retardent varnish	19	18.1	4.9	13.2
"	Intumescent flame-retardent coating	19	15.1	5.8	9.3
Plywood	–	6	41.2	19.5	21.7
Hardboard	–	5	30.1	10.5	19.6
"	Stove enamelled coating	9	37.3	13.5	23.8
"	Impregnated	5	24.3	7.2	17.1
"	Intumescent flame-retardent coating	5	16.4	4.0	12.4
Particle board	–	18	36.3	12.8	23.5
Hardwood	–	19	34.9	9.5	25.4
Plasterboard	–	13	9.9	5.8	4.1
"	Emulsion painted	13	9.0	5.2	3.8
"	–	9	9.7	5.7	4.0
"	PVC facing 0.2 mm	9	10.0	5.4	4.6
Wood wool slab (high density)	–	25	11.5	5.2	6.3
Wood wool slab (low density)	–	51	10.3	5.2	5.1
Wood wool slab (sampled from 76mm thick slab as used in demonstration houses)	–	48	9.16	4.27	4.88

Drying shrinkage and wetting expansion (BS 2028, 1364: 1968 Appendix E)

Drying shrinkage and wetting expansion was determined according to methods suggested in Appendix E British Standard 2028, 1364: 1968 *Specification for precast concrete blocks.* Four specimens of nominal dimensions 300 mm long x 50 mm wide were cut from both the length and width of a 75 mm thick slab. Stainless steel balls of diameter 6.3 mm to 6.5 mm were cemented into the centre of the ends of each specimen in order to facilitate accurate measurement of length in a standard jig. The specimens were soaked in water for 5½ days at a temperature of 20 ± 1°C. The wet length of each specimen was measured to an accuracy of 0.001 mm. They were dried in an oven at 55°C and 95% RH, cooled to 20 ± 2°C and measured at specified time intervals. The cycle of drying, cooling, measuring was repeated until a constant length end point was obtained as specified. The drying shrinkage was calculated as the change in length over the original wet length as a percentage. In order to determine the wetting expansion the dried specimens from the above test were immersed in water for 4 days at a temperature of 20 ± 1°C. The length of each specimen was measured in the standard jig to 0.001 mm. The wetting expansion was calculated as the difference between the dry measurement and final wet measurement expressed as a percentage of original length. The results obtained are shown in Table 5 and are compared with other standards and materials.

Table 5

Drying shrinkage and wetting expansion

Sample	Length wet mm	Shrinkage, 14 day value mm	Shrinkage %	Expansion mm	Expansion %
Test conditions: traverse direction					
A	300	0.584	0.194	0.482	0.161
B	300	0.564	0.188	0.414	0.138
C	301	0.571	0.190	0.409	0.136
Test conditions: longitudinal direction					
A	302	0.284	0.094	0.306	0.101
B	302	0.298	0.099	0.282	0.093
C	302	0.354	0.117	0.308	0.102

Comparison with other materials

		Shrinkage %	Expansion %
BS 2028, 1364: 1968 Precast concrete block	A	0.05–0.06	0.02
	B	0.07–0.09	0.02
	C	0.08–0.09	0.02
Duripanel cement bonded chip board			
(Trav. Dir)		0.60	
(Long. Dir)		0.45	
Durisol		0.40	
Lignacite		0.07	

Calcium chloride content (BS 1105: 1972 Appendix A)

It is laid down in BS 1105: 1972 (paragraph 2) that the slab shall not contain more than 2.5% anhydrous calcium chloride based on the dry weight of the slab when determined by certain chemical procedures. These procedures have not been followed as it can be shown from the calculation below (using known chemical and raw material inputs) that this condition is fulfilled.

(a) Moisture content of machined wood wool = 20%

(b) Moisture content of wood wool soaked in 5% solution of $CaCl_2$ and excess surface moisture removed (spun wood wool) = 42%

(c) An 82.6 Kg mix of 1 cement: 0.69 spun wood wool: 0.5 water is put in a mould to form a slab of 450 Kg/m^3 density and 2.083 m x 0.902 m x 0.076 m dimensions:

Amount of spun wood wool in mix $= \frac{82600}{2.19} \times 0.69$ gms

$= 26025$ gms

26025 gms spun wood wool contains 22% of a 5% solution of $CaCl_2$. Amount of $CaCl_2$ solution $= \frac{26025}{100} \times 22$

$= 5725.5$ gms

Amount of anhydrous $CaCl_2$ $= \frac{5725.5}{100} \times 5 = 286$ gms

(d) Weight of air dry slab

Mass = Density x Volume

$= 450 \times 2.083 \times 0.902 \times 0.076$ Kg

$= 64.26$ Kg

(e) Anhydrous $CaCl_2$ content

$$\frac{286}{64260} \times 100\% = 0.445\%$$

Cement testing (BS 12 Part 2: 1971)

A sample of local cement, supplied by Fiji Industries Ltd, was subjected to selected tests to assess its physical properties. The test procedures used were those described in British Standard 12: Part 2: 1971 *Specification for portland cement (Ordinary and rapid-hardening) Part 2 Metric units.* The compressive strength was obtained by testing 3 mortar cubes, given as Method 1 in the Standard. The temperatures specifically mentioned are applicable to temperate climates. Allowance is made to test cement intended for use in tropical climates at temperatures exceeding 20°C but not exceeding 35°C. In these series of tests (where appropriate) a temperature of 25°C was chosen. The results obtained are set out in Table 6 below where comparison is made with an ordinary portland cement of UK origin.

Table 6

Cement origin	Compressive strength 3 day MN/m^2	Compressive strength 7 day MN/m^2	Setting time Initial h	Setting time Initial min	Setting time Final h	Setting time Final min	Standard consistency % water	Density Kg/m^3	Specific surface m^2/Kg	Soundness mm	Insoluble residue %
Fiji Industries	26.6	34.4	3	5	4	37	31.5	3,083	328.5	0.8	0.74
UK	40.1	49.6	2	21	3	22	31.5	3,146	339.0	0.6	0.27
BS12: Part 2: 1971	$\nless$15	$\nless$23		$\nless$45	$\ngtr$10				$\nless$225	$\ngtr$10	$\ngtr$1.5

NON-STANDARD TESTS

Compressive strength

Initially specimens of nominal dimensions 500 mm long x 100 mm wide x 76 mm thick were cut from two slabs. The ends were cut parallel to each other and the cross sectional area accurately measured. Each specimen was placed on a tensile testing machine and its failing load under compression recorded. The compressive strength was calculated as the failing load divided by the cross sectional area. At the request of the Housing Authority, Suva this test was repeated on full size slabs using a modified hydraulic press. The results for both tests are shown in Tables 7 and 8 respectively.

Table 7

Compressive strength (small samples)

Sample number	Length mm	Thickness mm	Width mm	Cross-section cm^2	Weight Kg	Failing load Kg	Compressive stress Kg/cm^2	Density Kg/m^3
272 A	520	74	99	73.26	2.082	1,160	15.83	547
B	514	74	100	74.00	1.833	720	9.73	482
C	514	72	97	69.84	1.495	635	9.09	417
D	524	75	95	71.25	1.910	830	11.65	512
279 A	517	76	100	76.00	2.277	995	13.09	580
B	518	77	101	77.77	2.136	783	10.07	530
C	521	76	99	75.24	1.672	614	8.16	427
D	516	76	96	72.96	2.038	562	7.70	540

Table 8

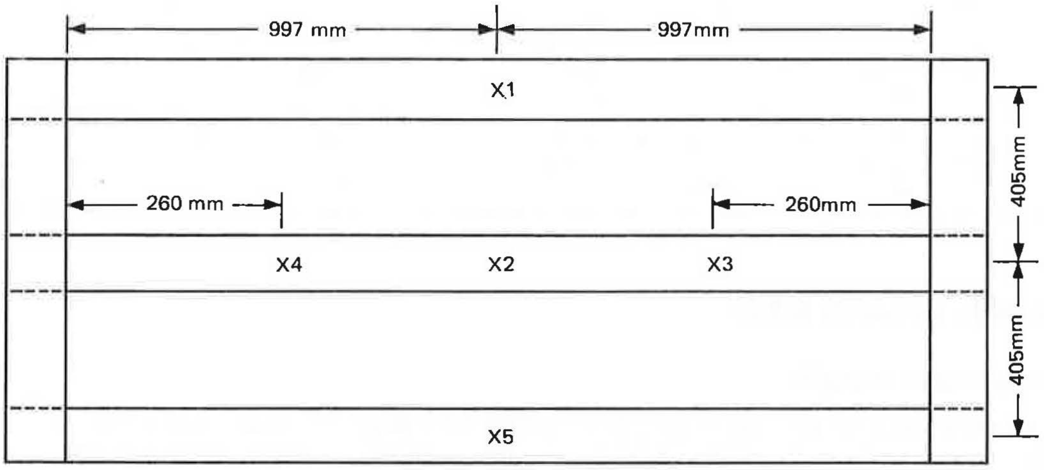
Compressive strength (full size slab)

Sample number	Length	Thick-ness	Width	Cross-section	Weight	Failing load	Compressive stress	Density
	mm	mm	mm	cm^2	Kg	Kg	Kg/cm^2	Kg/m^3
426 A	2,070	74.97	870	652.6	62.0	8,655	13.26	459
426 B	2,075	75.32	873	657.5	61.3	7,636	11.61	449
430 A	2,077	73.67	871	641.7	60.0	8,146	12.69	450
427 A	2,078	74.18	875	649.1	61.3	10,182	15.69	454

Deflection under uniform loading

As no facility was available the following method and apparatus was devised for this assessment. Two timber bearers (or fulcra) 1,000 mm long x 125 mm wide x 146 mm high were rigidly fixed at the ends of 3 timber beams 2,250 mm long x 150 mm wide x 120 mm high equispaced on 405 mm centres. Measuring reference points were marked (and numbered) on the central line of the beams as indicated in Diagram 1.

Diagram 1



(Not to scale)

The wood wool slab under test was placed symetrically on this framework overlapping the inside edge of the end beams by 38 mm. An open ended box marked on the inside in increments of 51 mm in height and of inside dimensions 1,981 mm x 800 mm was placed on the top face.

Sand with a bulk density of 1,192 Kg/m^3 was carefully placed by hand on the wood wool slab to form a layer 51 mm (2 inches) deep giving a loading of 60.8 Kg/m^2 (96.34 Kg overall load). At this stage deflection was measured at the points indicated above and the process repeated until failure occurred. The results obtained and details of the 3 slabs tested are given in Tables 9a and 9b (overleaf).

Dowel joints

In the demonstration houses the wood wool slabs were dowelled together by means of half inch (12.5mm) diameter galvanised mild steel rods inserted into 12mm diameter predrilled holes. Galvanised wire ties (8 swg) were passed over the dowels and used to hold down the roof structure and to provide anchorage in the concrete

Table 9a Slab details

Sample number	Length	Width	Thickness	Mass	Mass per square metre	Density
	mm	mm	mm	Kg	Kg	Kg/m^3
434 B	2,079	904	74.64	62.4	33.20	445
429	2,079	903	74.15	61.1	32.55	439
433 A	2,080	903	74.96	62.1	33.06	441

Table 9b Deflection

Sample number	Deflection (mm) at location	Load Kg/m^2			
		60.8(51 mm)	121.6(102 mm)	182.4(153 mm)	243.2(204 mm)
443 B	1	3	7	13	18
	2	3	7	13	18
	3	2	6	·10	13
	4	1	3	6	9
	5	3	8	14	19
429	1	6	8	14	21
	2	6	7	14	21
	3	5	6	11	16
	4	4	5	12	16
	5	6	8	15	21
433 A	1	5	17	22	
	2	6	16	21	
	3	4	11	14	
	4	3	9	12	
	5	4	16	22	

Figures in brackets give depth of sand.

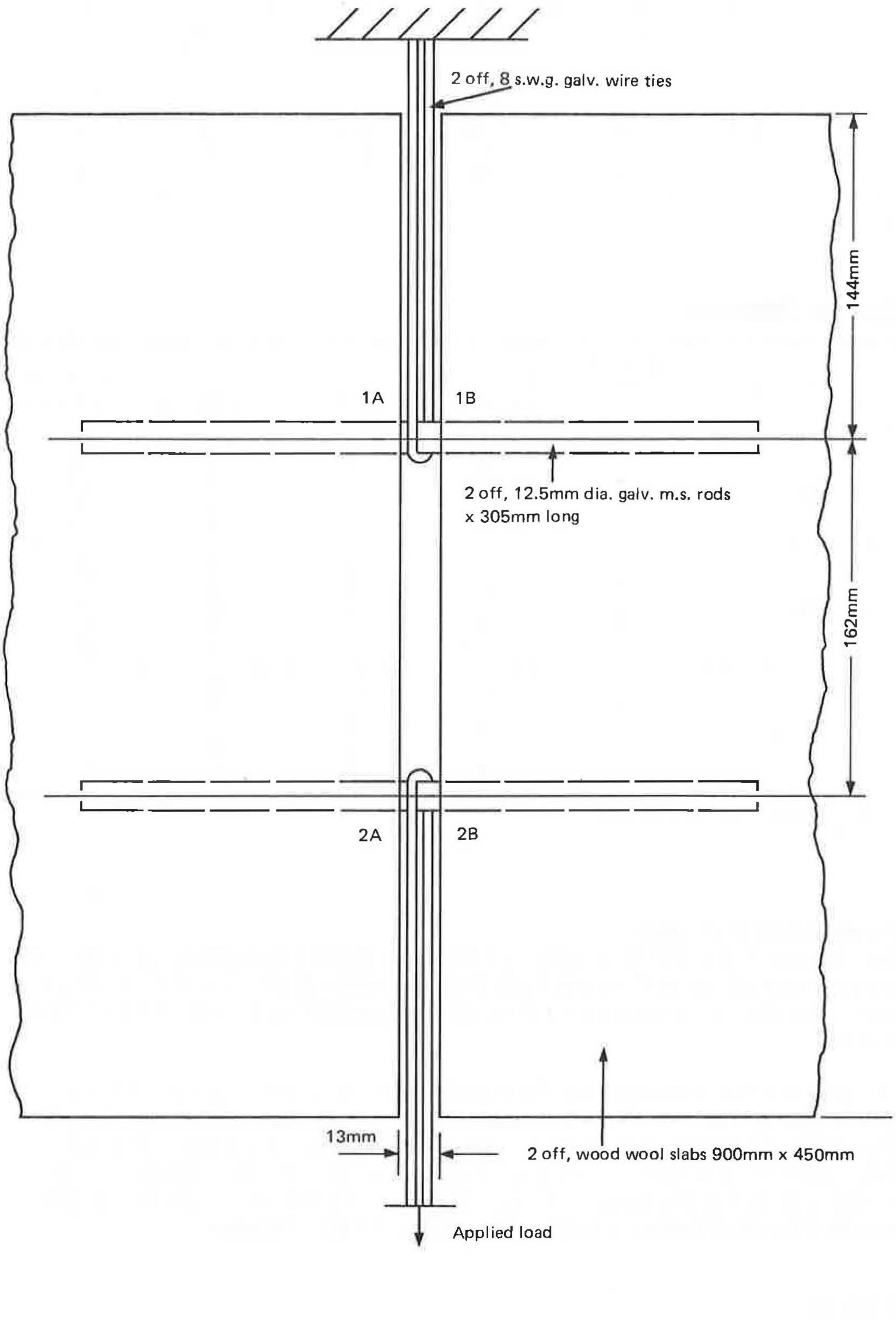
Dowel joints (continued)
foundations. It was not possible to test full size slabs due to machine capacity. Test pieces were made up as shown in Diagram 2, the precise location of the dowel pins taken from the house plans supplied by the Housing Authority (XW–1 Wood Wool House).

The wire ties were threaded over the dowels and through anchorage points on a tensile testing machine. Eight test pieces were made 5 of which (numbers 4 to 8) were filled at the joint with a sand cement mortar (3 sand: 1 cement). The test pieces were placed under tension and a load applied at a rate of 1 cm per minute. In each case one of the tie wires broke and this point was taken as the failing load. This and the dowel holes elongation is recorded in Table 10 below.

Table 10

Sample number	Failing load. Kg	Dowel hole elongation mm			
		1A	1B	2A	2B
1	892	38	38	32	20
2	653	50	65	32	26
3	530	70	90	20	20
4	844	13	14	13	13
5	765			Not available	
6	663	15	13	12	20
7	524	13	15	12	13
8	472	12	15	12	20

Diagram 2



When no mortar filling was used the dowels were bent and the dowel holes elongated, in samples 2 and 3 very severely. However, it should be noted that this effect was exaggerated due to the test pieces moving apart whilst under test. In sample 1 where this did not happen much less bending and hole elongation occurred. The remaining test pieces (nos 4 to 8) had mortared joints. Little or no bending of the dowels or elongation of the dowel holes occurred under load but the mortar joint cracked in several places. Quantitatively the results (although inconsistent) show that the mortared joint gives a large improvement in performance over the unfilled joint under static load conditions. It can also be shown from the worst case (Sample 8, Table 10) that assuming a roof area of 48.3m^2 (520 sq ft), weight of 1.63 tonnes (1.6 tons), uplift of 196 Kg/m^2 (40 lb/sq ft) and 20 wire ties the load acting through each tie is approximately 390 Kg. This compares well with 'failing load' and performance achieved and suggests (depending upon the structural engineers conclusion on this and the other parameters) that this method is worthy of further development.

Shear (racking) test

This test was carried out by a firm of independent consultants under the supervision of TPI and BRE (OD). Their report is given in Appendix II.

COMMENTS

Tests related to British Standards

Wood wool slabs made from *P. caribaea* from Fiji by the method described in this report complied with the relevant British Standard Specification. In the case of drying shrinkage (where no Standard Specification for wood wool slabs exist) the results obtained compare very favourably with those obtained for similar materials.

Non-standard tests

As indicated earlier, the four tests carried out under this heading were designed for local interpretation by the Suva Housing Authority Architect. The following comments are offered, therefore, to assist rather than to supplement this interpretation and are narrowly related to structures using materials and designs very similar to the demonstration houses at present in existence in Suva:

1. The results of the compressive strength tests indicate that the wood wool slabs are of more than adequate strength to support the roof.
2. In general, the mild steel dowel — 8 gauge tie wire system tended to fail before the wood wool slabs.
3. The results of the shear test indicate that the combined wood wool slab — wire tie — dowell fixing system as used in these houses has more than adequate strength to withstand the wind stresses which are likely to be experienced in Fiji *providing* that the existing system is modified so that the wire tie system links foundation and roof plate at each corner and between every pair of slabs.

Additional comments provided by BRE (OD) are contained in Appendix III.

REFERENCES

CHITTENDEN, A. E., HAWKES, A. J. and HAMILTON, H. R. (1975) Wood cement systems. In: *Proc. World Consult. Wood Based Panels, New Delhi.* FAO.

HER MAJESTY'S STATIONERY OFFICE. (1970) The fire propagation test: its development and application. *Fire Res. Tech. Pap.* No. 25. London: HMSO, 10pp.

Appendix I

Technical evaluation trials

As indicated earlier, an investigation was undertaken by Tropical Products Institute to assess the potential use of plantation grown *P. caribaea* as raw material for wood wool/cement slab manufacture. As in normal practice in TPI, this was carried out in two parts:

1. A small scale preliminary trial to assess the suitability of *P. caribaea* by means of laboratory manufacture of small size wood wool slabs and to determine its machining properties.
2. Depending on the findings of the preliminary trials, a larger scale trial to determine the manufacturing parameters for commercial sized wood wool slabs to meet British Standard specifications.

The completion of the preliminary trials connected with a request to TPI from the Suva Housing Authority to produce sufficient full sized wood wool slabs from the local *P. caribaea* to build two demonstration houses in Suva. Since the results of the preliminary trials strongly indicated suitability (with some reservations concerning possible wood wool machining difficulties due to spiral grain) it was decided to go ahead with the production of these demonstration house slabs as an extension of part 2 of our normal testing procedure described above. The results of these part 2 trials are given below.

SLAB MANUFACTURE AND TESTING

Slabs of nominal size 1800 x 600 x 50 mm were manufactured in the laboratory pilot plant using the same methods as described above for the manufacture of the slabs for the demonstration houses.

The variables considered were:

1. Concentration of mineralising fluid.
2. Density of slab.
3. Cement to ovendry wood wool ratio.

Testing of the slabs involved the determination of their bending stress in accordance with BS 1105:1972. Procedures covering this method were the same as those applied in the strength test for the demonstration house slabs.

DISCUSSION OF RESULTS

Table 1 shows slabs manufactured at nominal slab density of 500 Kg/m^3 and a chosen cement/wood ratio of 1:0.4 with varying concentrations of mineralising fluid. Using wood wool soaked in water gave inconsistent results which ranged above and below that of British Standard requirements for Type B. This indicated that there was some interference in the setting of cement from the timber. To overcome the problem trials were conducted treating the wood wool with solutions of

$CaCl_2$. The solutions used were 3% and 5%, the test results showing there was no benefit in using the higher concentration, 3% being sufficient.

In Table 2 exactly the same test conditions as in Table 1 were considered but at a lower nominal density of 450 Kg/m^3. Results showed that the lowering of nominal density did not produce slabs of the required strength. Consequently the same applied with a 400 Kg/m^3 nominal slab density shown in Table 3.

In Table 4 the $CaCl_2$ concentration and nominal slab density were kept constant at 3% and 450 Kg/m^3 respectively. The cement/wood wool ratio being varied at each of 1:0.4, 1:0.5 and 1:0.6. The same test conditions were applied in Table 5 but at a nominal slab density of 500 Kg/m^3. Problems arose in mixing, packing and pressing of the wood wool and cement mix at the higher wood wool ratios. A 50% to 200% increase in mixing time was needed to obtain an acceptable coverage and because of the greater bulk, ejection from the mixer into the moulds was increased by as much as 300%.

Additionally, difficulties arose when packing the cement/wood wool mix into the wooden moulds. Because of the greater bulk of the mixes more time had to be spent in hand packing and the pressing involved many prepresses in an attempt to eliminate the high 'springback' of the cement/wood wool mix. The prepressing and final pressing involved far greater pressures than normally encountered which resulted in a high strain and distortion of the wooden moulds.

CONCLUSIONS

1. A slab complying with BS 1105:1972 could be manufactured at a density of 500 Kg/m^3 using a 3% $CaCl_2$ solution and a cement/wood wool ratio of 1:0.4.

2. No benefit was obtained by using a higher concentration of $CaCl_2$ than 3%.

3. Lower density slabs than 500 Kg/m^3 or slabs produced without $CaCl_2$ were significantly weaker.

4. Slabs using the higher wood wool ratios (ie cement: wood wool, 1:0.5 and 1:0.6) took a considerable greater time and effort to produce and effected far greater wear and tear on moulds.

Table 1

Nominal density 500 Kg/m^3

Sample		Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
351	A	1:0.4	Water	–	50.37	26.0	24.1	478	1780	1.05
									1700	1.00
									3290	1.94
	B				51.37	26.8	24.7	481	2960	1.67
									2880	1.63
									3250	1.83
	C				50.41	25.8	23.8	473	3480	2.04
									3230	1.90
									3440	2.02
346	A	1:0.4	$CaCl_2$	3	50.55	27.3	25.1	500	4210	2.45
									2600	1.51
									3350	1.95
	B				50.40	27.3	25.3	501	2980	1.74
									3880	2.29
									3050	1.80
	C				48.51	26.5	24.3	501	2660	1.67
									2590	1.63
									3720	2.34

Table 1—*continued*

Sample	Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
343 A	1:0.4	$CaCl_2$	5	49.91	26.3	24.3	486	3790	2.27
								3470	2.08
								1940	1.16
B				49.78	26.3	24.3	489	2590	1.56
								2930	1.77
								2480	1.49
C				50.27	26.3	24.4	485	2840	1.68
								2120	1.26
								2300	1.36
BS 1105:1972				51± 3		$\ngtr$31	Type B	$\nless$2200	1.32*

*see page 4

Table 2

Nominal density 450 Kg/m^3

Sample	Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
350 A	1:0.4	Water	–	50.87	23.3	21.5	423	2630	1.52
								2790	1.61
								1950	1.12
B				50.68	23.3	21.6	426	2440	1.42
								2590	1.51
								2136	1.24
C				50.74	23.3	21.4	422	2710	1.56
								2670	1.54
								2860	1.65
345 A	1:0.4	$CaCl_2$	3	50.18	22.9	21.2	423	1530	0.91
								1120	0.66
								3250	1.93
B				49.80	23.4	21.7	436	3000	1.81
								2440	1.47
								3360	2.03
C				49.78	23.3	21.6	435	2860	1.73
								3090	1.87
								2560	1.55
342 A	1:0.4	$CaCl_2$	5	49.89	23.7	21.9	439	1870	1.12
								3070	1.84
								1590	0.94
B				49.35	24.1	22.3	452	2700	1.66
								1980	1.21
								2080	1.28
C				50.52	23.9	22.1	438	2820	1.65
								2600	1.52
								1920	1.12
BS 1105:1972				51±3		$\ngtr$31	Type B	$\nless$2200	1.32*

*see page 4

Table 3

Nominal density 400 Kg/m^3

Sample	Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
347 B	1:0.4	Water	–	50.89	21.0	19.5	383	1960	1.13
								1830	1.06
								1770	0.98
C				50.66	20.8	19.1	377	2030	1.17
								2270	1.31
								2010	1.16
354				50.25	21.2	19.5	387	2590	1.52
								1870	1.10
								1890	1.11
344 B	1:0.4	$CaCl_2$	3	50.27	21.5	20.0	397	2200	1.30
								1950	1.15
								1950	1.15
C				49.47	20.9	19.4	393	1440	0.88
								1740	1.07
								1990	1.22
353				50.56	21.9	20.3	401	2050	1.20
								2350	1.37
								2400	1.40
341 B	1:0.4	$CaCl_2$	5	50.53	22.9	21.1	418	2090	1.22
								2565	1.50
								2200	1.28
C				50.85	22.0	20.3	399	1620	0.93
								3010	1.74
								1810	1.04
352				50.28	21.9	20.2	401	2120	1.25
								1940	1.14
								2120	1.25
BS 1105:1972				51±3		≯31	Type B	≮2200	1.32*

*see page 4

Table 4

Nominal density 450 Kg/m^3

Sample	Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
345 A	1:0.4	$CaCl_2$	3	50.18	22.9	21.2	423	1530	0.91
								1120	0.66
								3250	1.93
B				49.80	23.4	21.7	436	3000	1.81
								2440	1.47
								3360	2.03
C				49.78	23.3	21.6	435	2860	1.73
								3090	1.87
								2560	1.55
458 A	1:0.5	$CaCl_2$	3	49.53	22.8	21.0	423	2715	1.65
								2120	1.29
								2715	1.65
B				49.35	23.3	21.6	437	2365	1.46
								2465	1.52
								2495	1.54
C				48.94	22.8	21.1	430	2560	1.60
								2035	1.27
								2165	1.35

Table 4—*continued*

Sample	Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
460 A	1:0.6	$CaCl_2$	3	49.12	22.0	20.3	412	1900	1.17
								2200	1.36
								2240	1.38
B				49.85	22.2	20.6	414	1400	0.85
								2130	1.29
								2320	1.40
C				48.77	22.2	20.4	418	2170	1.36
								2620	1.64
								2390	1.49
BS 1105:1972				51 ± 3		≯31	Type B	≮2200	1.32*

*see page 4

Table 5

Nominal density 500 Kg/m^3

Sample	Cement wood wool ratio	Mineralising fluid Type	%	Thickness mm	Weight Kg	Mass per unit area Kg	Density Kg/m^3	Failing load N	Modulus of Rupture N/mm^2
346 A	1:0.4	$CaCl_2$	3	50.55	27.3	25.1	500	4210	2.45
								2600	1.51
								3350	1.95
B				50.40	27.3	25.3	501	2980	1.74
								3880	2.29
								3050	1.80
C				48.51	27.3	24.3	501	2660	1.67
								2590	1.63
								3720	2.34
459 A	1:0.5	$CaCl_2$	3	49.21	24.9	22.9	467	2480	1.53
								2420	1.49
								2455	1.52
B				48.96	24.9	23.1	472	2510	1.57
								3275	2.05
								3490	2.18
C				49.87	24.8	22.8	457	2430	1.45
								2660	1.59
								2520	1.50
461 A	1:0.6	$CaCl_2$	3	49.43	24.6	22.7	459	2620	1.60
								3490	2.13
								2450	1.50
B				49.25	24.3	22.5	458	2200	1.36
								1935	1.20
								3780	2.34
C				49.05	24.6	22.7	462	2040	1.26
								3250	2.01
								2700	1.67
BS 1105:1972				51 ± 3		≯31	Type B	≮2200	1.32*

*see page 4

Appendix II

Independent consultants' report on the shear test for wood wool panels

R.H. HARRY STANGER

(Proprietors:– HARRY STANGER LTD.)

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TESTING and INSPECTING ENGINEERS
METALLURGISTS and ANALYTICAL CHEMISTS

(APPROVED TEST HOUSE: D.Q.A.B. & C.A.A.)

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YOUR REF. ____ OUR REF. 1126/77/PT/PJ 28th June, 19 77

YOUR REF. ____ OUR REF. ____ ____ 19____

Building Research Establishment,
Building Research Station,
Garston,
Watford,
Herts,
WD2 7JR.

For the attention of Dr. K.J. Eaton

REPORT ON THE SHEAR TEST
FOR WOOD WOOL PANELS.

1. INTRODUCTION:

Strength tests were carried out on two pairs of wood wool panels at our laboratories on 26th May and 16th June 1977.

Instructions for these tests were contained in your contract letter reference F3/3/342 dated 29th March, 1977.

Contd/.............

REGISTERED OFFICE: THE LABORATORIES, FORTUNE LANE, ELSTREE, HERTS WD6 3HQ
REGISTERED IN ENGLAND No. [illegible]

SCOTTISH OFFICE. 5 CLAIRMONT GARDENS, GLASGOW, G3 7LW. TEL. 041-332 5431 TELEX No. 779272 A/B TESLAB
WELSH OFFICE MITRE BUILDINGS OFF BROOK STREET WREXHAM, CLWYD. TEL. WREXHAM [illegible]

To Building Research Establishment.

Date 28th June, 1977

2. DETAILS OF SPECIMEN:

The following items were delivered to our laboratories on 14th April, 1977.

4 No. Wood wool panels 6'10½" x 2'11½" x 3"
14 No. 12" x ½" Dia, Mild Steel Rods
8 s.w.g. Galvanised Steel Wire
2 No. Bags of Mortar Filler.

3. METHOD OF TEST:

3.1 Test One

3.1.1 The wood wool panels were assembled as shown in drawing No. 11009 Project No. 547 Tropical Products Institute.

3.1.2 Micrometer dial gauges monitored the deflection at various points as shown in Figure 1.

3.1.3 Load was applied in increments via a 11 ton load cell coupled to a digital gemini transducer meter.

3.1.4 At each load increment deflection readings were taken until failure occurred.

3.1.5 Visual performance of the panels under load was also recorded.

3.1.6 Photographs of the specimens before and after test are shown on mountings 1 and 2.

3.2 Test Two

3.2.1 For this test the two panels were assembled as above in 3.1.1 accept for the 8 swg tie which was wrapped round the top loading joist and round the channel bolted to the floor as shown in Figure 2.

3.2.2 Four micrometer dial gauges monitored the deflection of the panels as shown in Figure 2.

3.2.3 The loading procedure was then carried out as above in 3.1.3ta 3.1.5.

Contd/.............

3.2.4 Photographs of the panels before and after tests are shown on mounting No. 3

3.3 To simulate the roof weight, 5 No. 56 lbs · weights were uniformally distributed on top of the panels.

4. RESULTS OF TESTS:

4.1. Test One

Load Kg	Vertical Top Gauges 1	2	3	Top side Gauges 4	5	6	End Gauges Top LH 7	Base LH 8	Base RH 9	Bottom side Gauges 10	11	12	Channel LH 13	RH 14
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	35	5	-17	0	13	21	14	4	-14	-25	-15	3	1	2
50	141	42	-66	0	30	48	67	31	-56	-23	-20	7	1	3
*45	-	368	-58	107	279	287	377	97	-220	+40	-31	6	2	5

* Load fell back to 45 kg at failure (rotation of the panels)

50 Bottom left hand corner lifted 30 mm. Centre of panels lifted 10 mm

55 Bottom left hand corner lifted 66 mm. Centre of panels lifted 31 mm

Failure occurred at the bottom left hand dowel pin owing to crushing of the wood wool and bending of the dowel pin ($\frac{1}{2}$" Dia. x 12" Bar).

N.B. Some of these readings cannot be relevant to the test owing to the poor stability of the panels.

Contd/............

4.2 Test Two

(With the wire ties holding down the panels to the channel).

Load (lbf)	Deflection (ins x 10^{-3}) 1	2	3	4	Remarks
0	0	0	0	0	
100	25	0	11	0	
200	50	0	23	0	
300	85	0	44	0	
400	132	6	61	0	
500	185	17	85	0	
600	280	36	136	0	
700	390	59	200	0	
800	500	79	251	0	
900	-	-	-	-	Panels rotated from the loading ram. load released and test repeated from 900 lbf.
900	320	47	155	0	
1000	400	64	-	0	
1100	520	87	-	0	
1200	700	130	18 mm	0	
1300	975	166	-	0	
1400	1420	201	30 mm	0	
1500	1940	253	37 mm	0	
	-	-	-	-	Gauges removed, too dangerous to read.
1700	reached momentarily				Bottom left hand corner lifted 55 mm.

The left hand wire tie was stretching with the applied load to the extent that unravelling of the wire took place allowing the panels to rotate.

P. S[signature]

for R.H. HARRY STANGER.

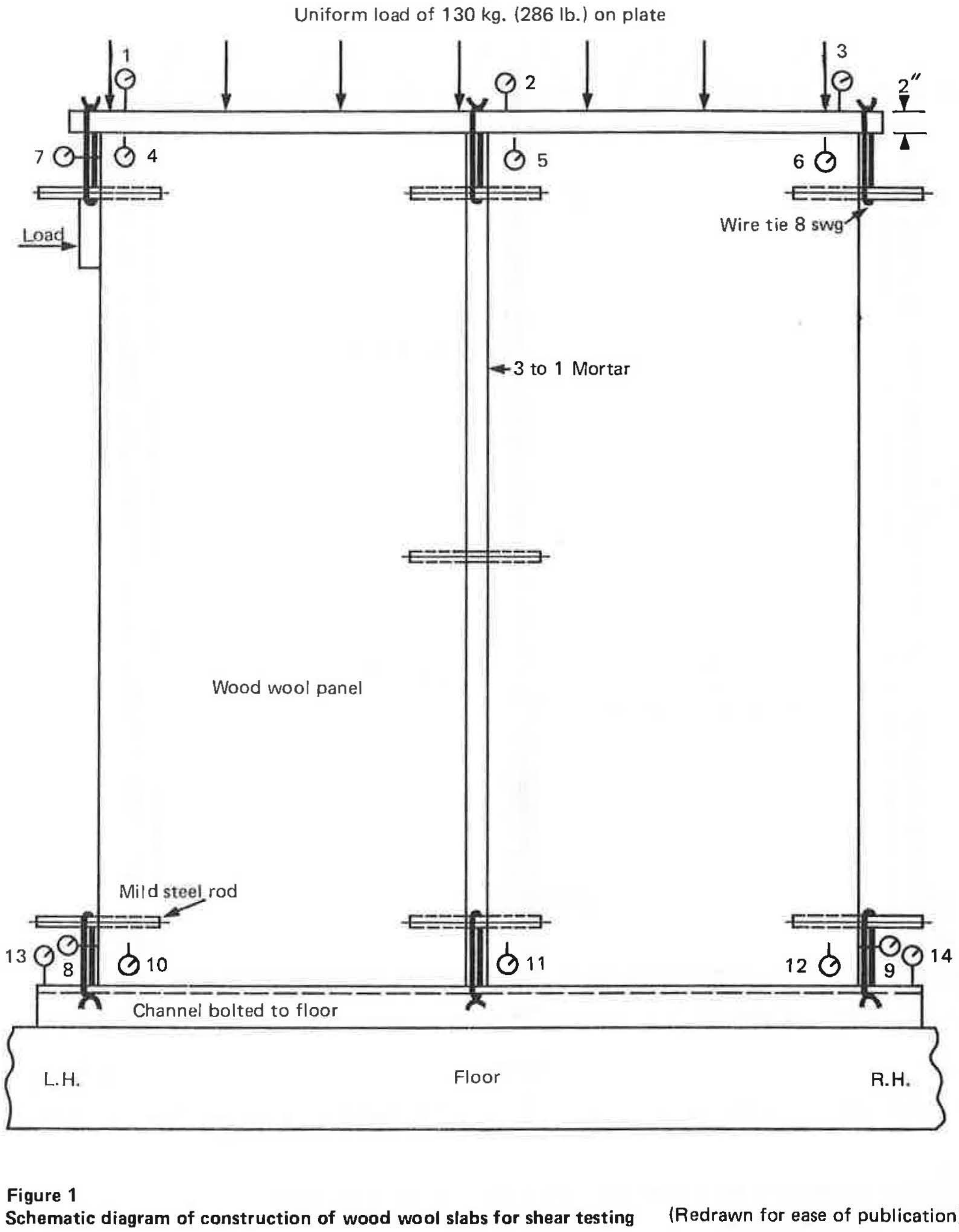


Figure 1
Schematic diagram of construction of wood wool slabs for shear testing (Redrawn for ease of publication)

File no. 1126/77

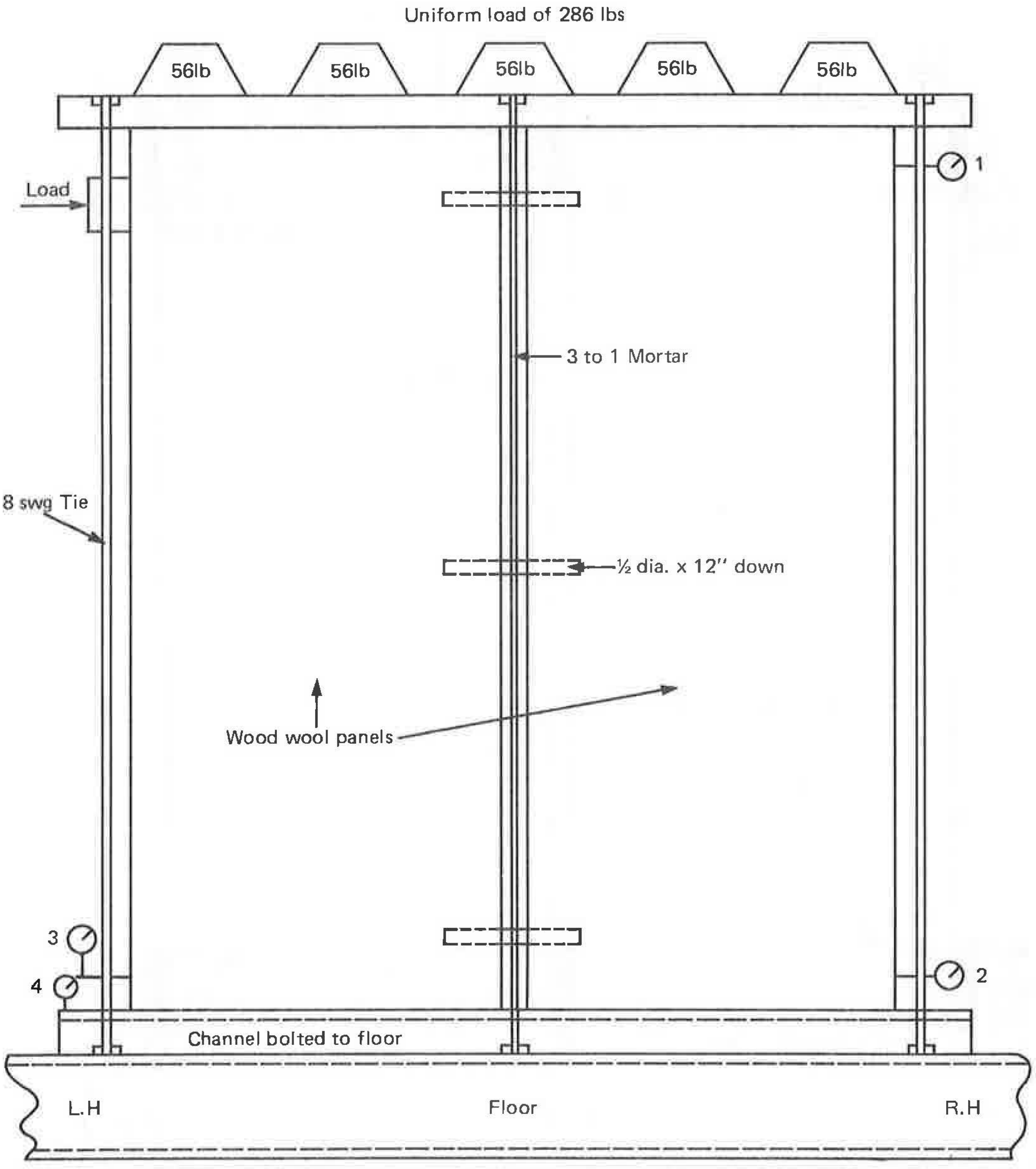
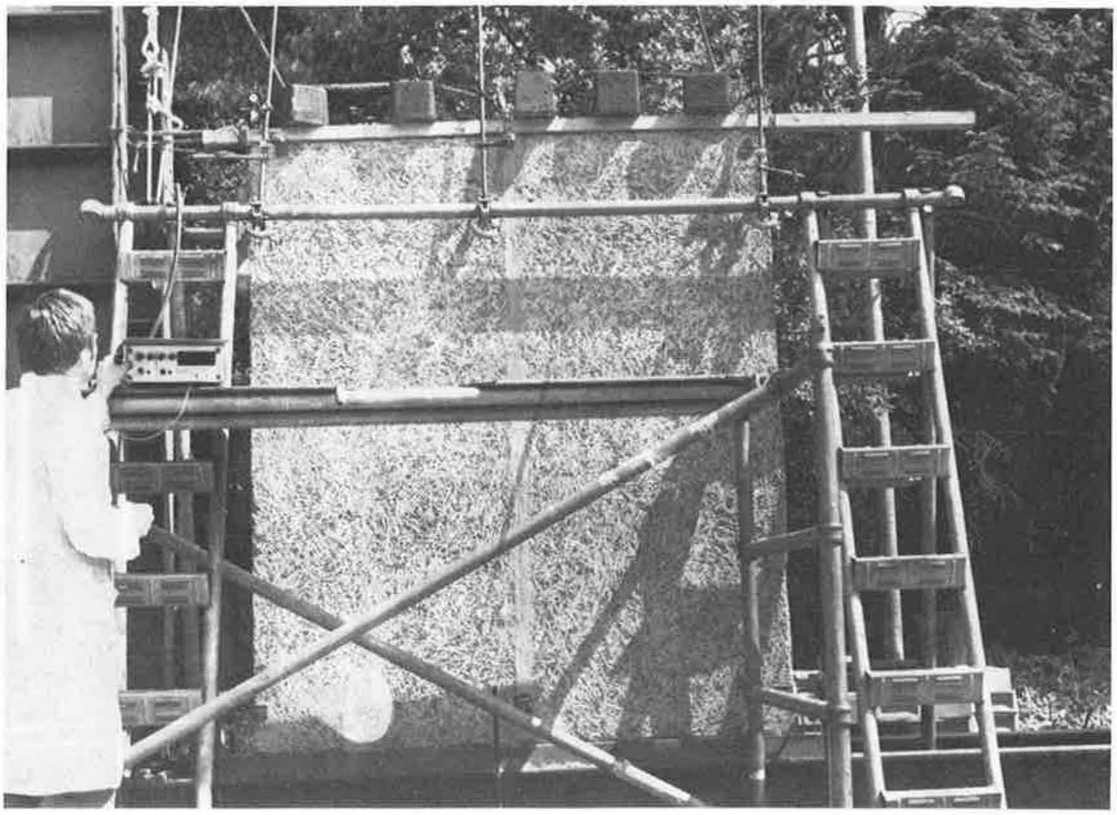
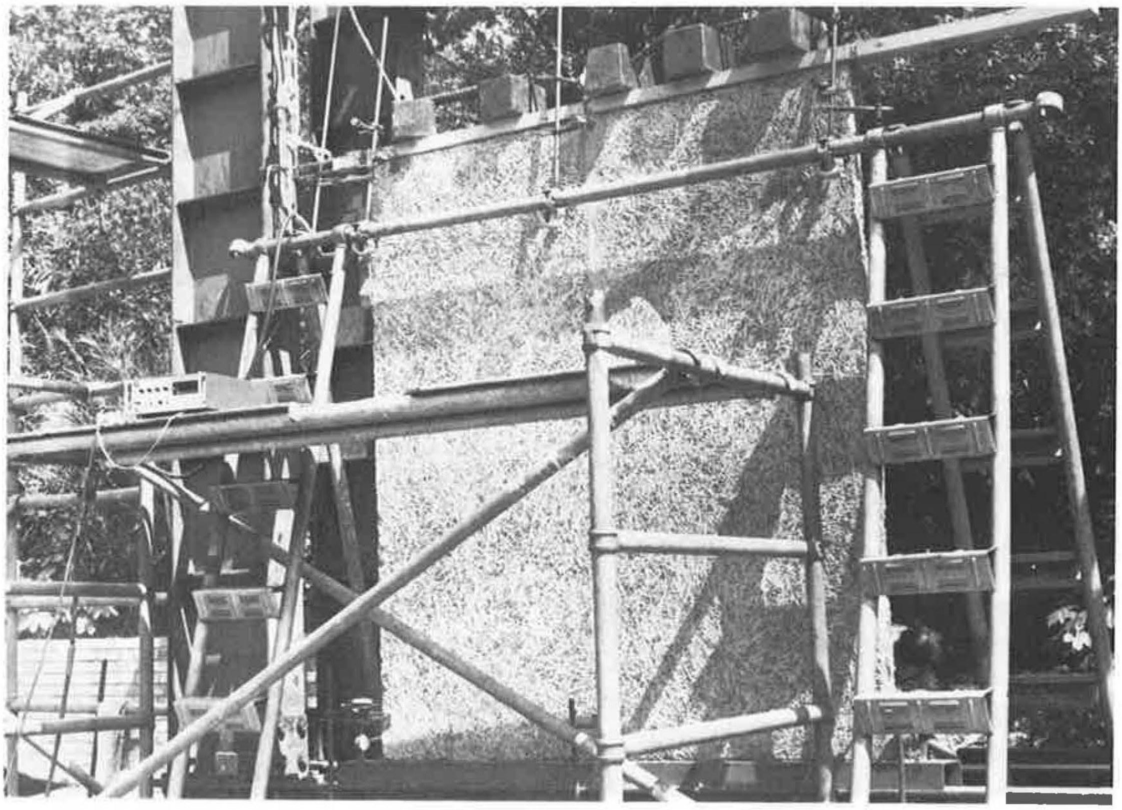


Figure 2
Construction of wood wool slab for shear tests (Redrawn for ease of publication)

File no. 1126/77

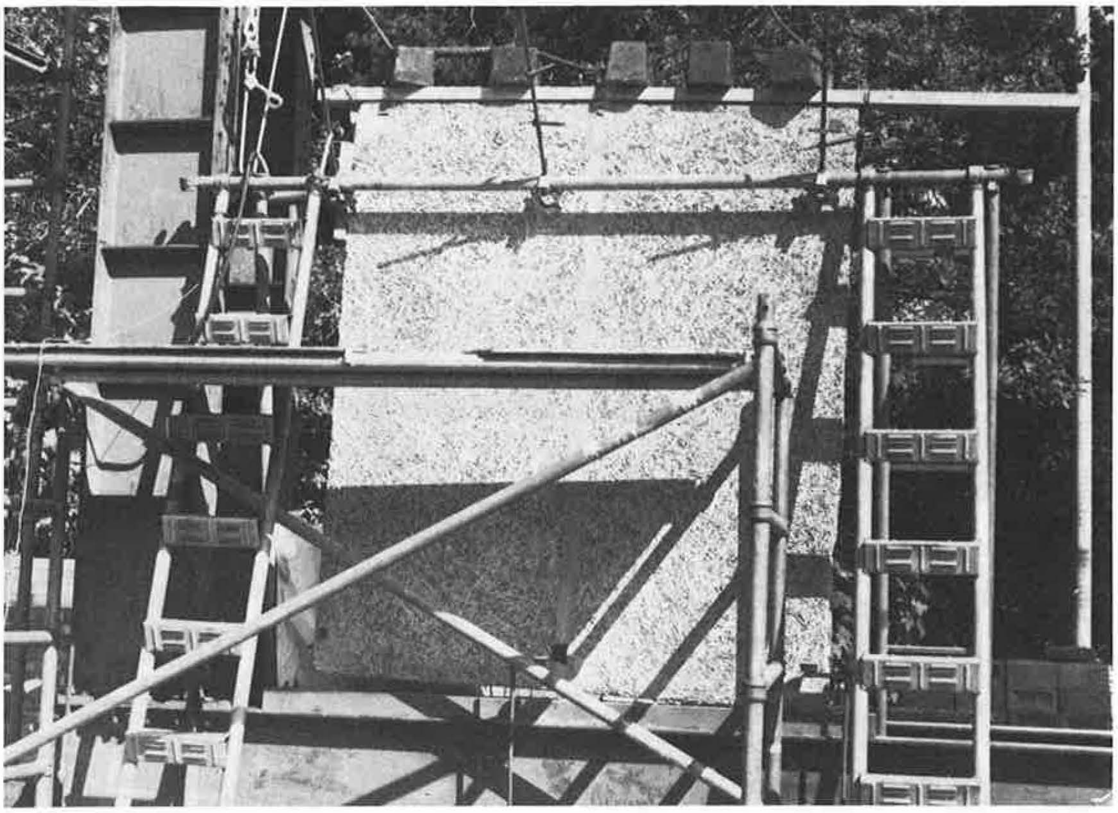


Arrangement of shear test no. 1

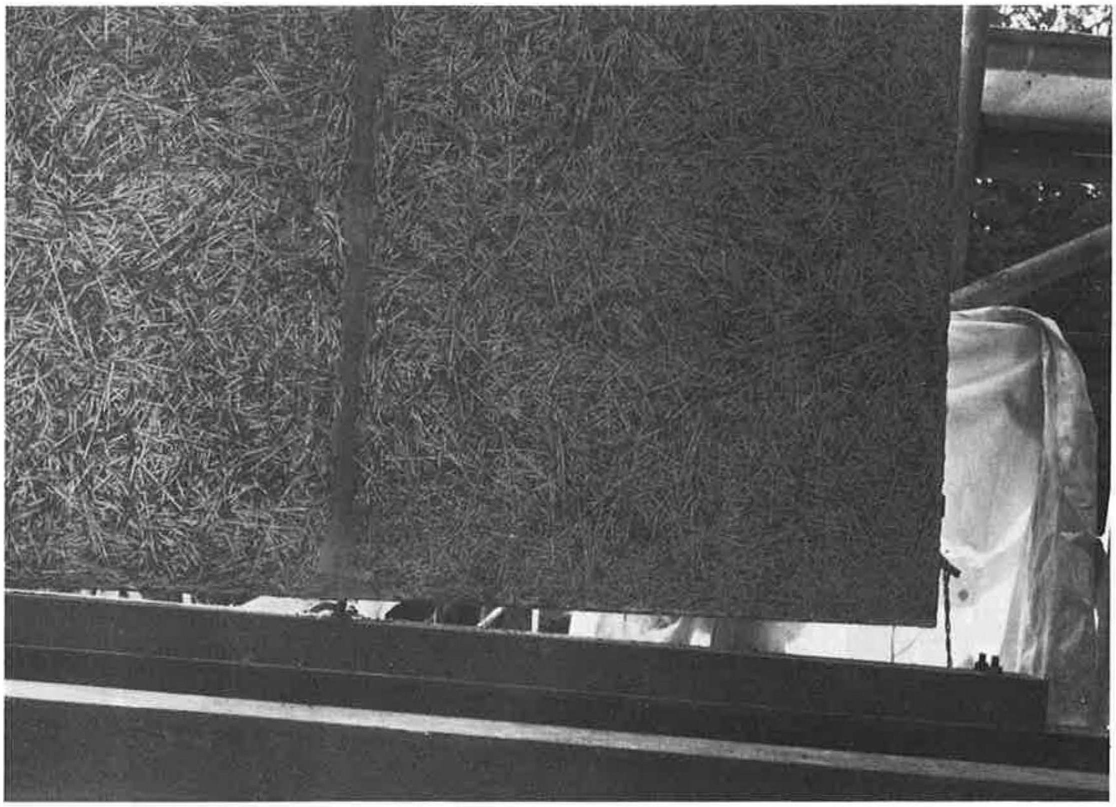


As above. Test no. 1

Plate 1

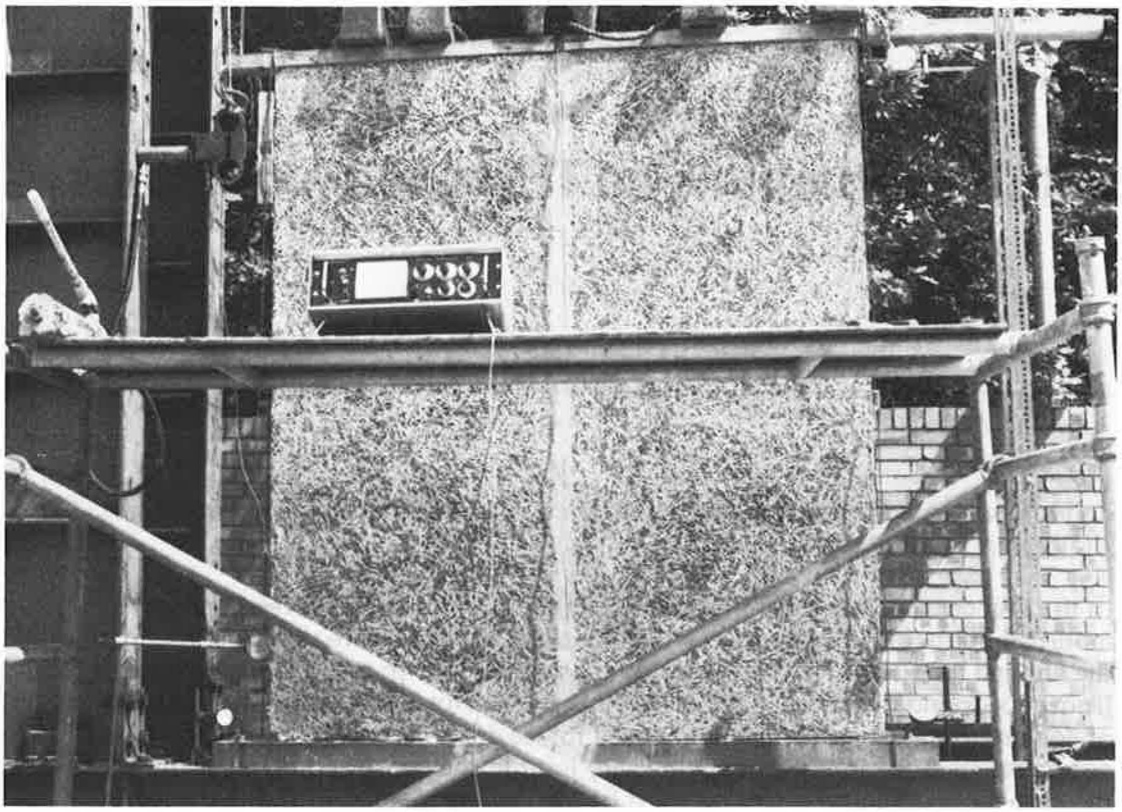


Specimen at failure. Test no. 1



As above

Plate 2



Arrangement of shear test no. 2

Specimen at failure. Test no. 2

Plate 3

Appendix III

BRE observations on TPI wood wool slabs

'In areas subjected to earthquakes and hurricanes, fixing methods and details are vitally important.

In the Stanger report, a clear difference can be seen in the second test with its modified method of fixing. In test 1 (wire tie roof-dowel, wire tie dowel-foundation) the applied load to rack the panels only reached 99 lbf. In test 2 (wire tie directly from roof-foundation) the load reached 1700 lbf. This is the recommended method of construction, otherwise likely imposed forces due to winds and earthquakes will not be resisted. It should be used at every joint in the construction, particularly at the corners, and careful attention must be paid to the method of fixing the roof to the wall plate — preferable the wires from the foundations should go right round the roof members.

NB. Although the wire ties no longer rely on the steel dowels being in position, nevertheless the dowels should still be used to resist transverse forces and to share loads between adjacent panels.

In the TPI report, there is a section reporting on tests of the Dowel Joints. In the Fiji demonstration houses the rods are inserted into "predrilled holes". In the Stanger tests the rods were just driven into the edge of the slabs. I can see pros and cons for both methods; I am not sure which is best from the strength viewpoint.'

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