A SMALL-SCALE PROCESS FOR MANUFACTURING WOODWOOL/ CEMENT SLABS IN DEVELOPING COUNTRIES

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Bulletin 49

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Overseas Development Administration

The Natural Resources Institute (NRI) is an internationally recognized centre of expertise on the natural resources sector in developing countries. It forms an integral part of the British Government's overseas aid programme. Its principal aim is to alleviate poverty and hardship in developing countries by increasing the productivity of their renewable natural resources. NRI's main fields of expertise are resource assessment and farming systems, integrated pest management, food science and crop utilization.

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Summaries

SUMMARY

Woodwool/cement slabs are made from a mixture of shredded timber (woodwool) and cement, shaped or formed by pressure into required thicknesses and sizes. They are a well-known product already used in many countries around the world.

This bulletin outlines the work undertaken by the Natural Resources Institute (NRI) on the development of a low-cost woodwool/cement slab manufacturing process appropriate for conditions in developing countries. Typically, 500 slabs (35 m^3) can be produced per week on a single shift employing 25 people. Demonstration plants have been introduced into Malawi and Zambia.

Included in the bulletin are historical background information, details and test data on assessing the suitability of timbers, a description of the process developed and the reasons for the processing techniques employed. Methods of handling and the use of the slabs in the construction industry, particularly in relation to the lower-cost housing market in Zambia, are also outlined.

One of the main attractions of the NRI small-scale woodwool/ cement slab process plant is the relatively low initial capital investment required compared with larger, less labour-intensive processes used in Europe and elsewhere. The principal aim has been to develop a low capital cost, labour-intensive plant which could largely be constructed using local manufacturing and craft skills, and operated and maintained on a routine basis by trained personnel.

RESUME

Les dalles en laine de bois-ciment sont exécutées à partir d'un mélange de bois défibré et de ciment, formées ou configurées par pression selon les épaisseurs et cotes requises. Ces dalles sont un produit bien connu déjà utilisé dans nombre de pays du monde entier.

Le présent bulletin schématise les travaux entrepris par l'Institut des ressources naturelles (NRI) en ce qui concerne le développement d'un processus de fabrication peu onéreux de dalles en laine de bois-ciment adapté aux conditions en vigueur dans les pays en voie de développement. L'on peut fabriquer, de manière typique, 500 dalles (35 m^3) par semaine au moyen d'un seul poste de travail employant 25 personnes. Des unités pilotes ont été lancées en Zambie et au Malawi.

Il est inclus dans ce bulletin des informations historiques d'arrière-plan, détails et données de tests quant à l'evaluation de la convenance des bois d'oeuvre, une description du processus mis au point et les raisons applicables aux techniques de traitement utilisées. Il est aussi fourni des informations générales concernant les méthodes de manutention et d'emploi des dalles dan l'industrie de la construction, et plus particulièrement en ce qui concerne le marché des logements sociaux en Zambie.

L'un des principaux attraits de la petite unité de traitement des dalles en laine de bois-ciment du NRI est constitué par les investissements en capitaux initiaux relativement faibles comparé aux processus plus importants et à main d'oeuvre réduite exploités en Europe et ailleurs. L'objectif principal a été de développer une installation de faible coût, à main-d'oeuvre intensive pouvant être, dans une large mesure construite en faisant appel aux compétences techniques et de fabrication locales, l'exploitatoin et l'entretien étant assurés de manière systématique par du personnel formé.

RESUMEN

Tal como indica su nombre, las losas de cemento/lana de madera son una mezcla de madera desmenuzada (lana de madera) y cemento configurada y conformada a presión, para proporcionarle el tamaño y espesor requeridos. Estas losas son un producto bien conocido, que está siendo utilizado ya en numerosos países del mundo.

En este boletín, se pone de relieve la labor realizada por el Instituto de Recursos Naturales (NRI) para desarrollar un proceso económico de favricación de losas de lana de madera/cemento, adaptado a las condiciones reinantes en los países en desarrollo. Con una fuerza laboral de 25

personas, este método hace posible, por término medio, la producción de 500 losas (35 m^3) semanales con un solo turno de trabajo. Se han construido plantas de demostración en Malawi y en Zambia.

El boletín incluye asimismo antecedentes históricos, detalles y datos experimentales sobre la evaluación de la adecuabilidad de las maderas, una descripción del proceso y las razones sobre las que se basan las técnicas de elaboración utilizadas. También se presenta información sobre métodos de manejo y sobre usos de las losas en la industria de la construcción, con especial referencia al mercado de las viviendas de bajo coste en Zambia.

Uno de los principales atractivos de la planta para la producción de losas de lana de madera/cemento a pequeña escala es la relativamente baja inversión inicial de capital requerida, en comparación con otros procesos de mayor envergadura y con menor uso de mano de obra, utilizados en Europa y en otras partes del mundo. El objetivo primordial ha sido el desarrollo de planta de bajo coste y uso elevado de mano de obra que, además de ser construida utilizando personal y métodos locales de fabricación, pueda ser normalmente manejada y mantenida por personal preparado para dicho fin.

Section 1

Introduction

The woodwool/cement slab is a well-known versatile product which is widely accepted as a reliable building component in the construction industry in many developed countries. Slabs are made from a mixture of shredded wood (wood strands or woodwool) and cement which is pressed in a mould to form a panel. They have a wide variety of applications including partitioning, cladding, roof decking, permanent shuttering, exterior walling and as a base for flooring materials. The main application in Europe has been as a roofing material which is weather-proofed with bituminous felt. The product has many useful qualities such as relative lightness in weight; thermal insulation, sound absorption and fire performance; and is easy to nail and saw.

HISTORICAL BACKGROUND

The forerunner of the present day product, which used magnesite (a mixture of magnesium chloride and magnesium oxide) as the binder, was first patented in Austria in 1908. It was traded under the name of 'Heraklith'. Later, in the 1920s, the industry spread to Germany where both magnesite and cement were used as binders. Today, however, cement has mostly replaced magnesite because of its better water resistant properties.

In the early years production was carried out by small family concerns, and methods, raw materials and dimensions varied considerably. During World War II there was a major increase in woodwool/cement slab manufacture in Germany, and a high degree of ingenuity and innovation was applied to improve both the process methods and properties of the product. Regrettably, details of the progress made – which would probably have been useful in the context of small-scale manufacture of slabs in developing countries – were not recorded. However, it is believed that during this period the use of a 'mineralizing fluid', calcium chloride, for pre-treatment of the woodwool was adopted by most of the industry.

This was an important step forward in the development of an improved process. To varying degrees, all cellulosic materials tend to inhibit the setting of cement. This so-called 'cement poisoning' is caused by soluble extractives which are leached out of the cellulosic materials when in contact with cement and water. The identity of these extractives is a complex subject, but it is recognized that wood sugars and/or a group of compounds generally known as hemicelluloses are chiefly responsible. Although there is often apparent secrecy surrounding the use and effect of mineralizing fluids within the industry, they act as localized accelerators causing rapid setting of the cement around each of the woodwool strands and prevent, or at least deter, leaching out of the inhibitors.

There is a limit to the amount of mineralizing fluid which can be used to negate the problems of cement setting inhibition; in extreme cases where the timbers used are high in cement poisoning extractives, a satisfactory product cannot be manufactured. Most commercial producers classify their raw materials in order to limit the use of additives. This keeps production costs to a minimum and minimizes the corrosive effects of excessive use of calcium chloride on metal fixtures such as nails, screws and window frames.

TYPICAL COMMERCIAL PROCESS

Today, the woodwool/cement slab industry is large and highly automated. It has a high capacity and manufactures a wide variety of products for use in the building industry. An example of such a plant is illustrated in Figures 1 and 2. Automated plants typically have a throughput as high as 90 m^3 per eight-hour shift: based on a product size of 2000 × 500 × 25 mm (density 390 kg/m^3), this is equivalent to 750 000 slabs per year of 250 working days. At lower throughputs

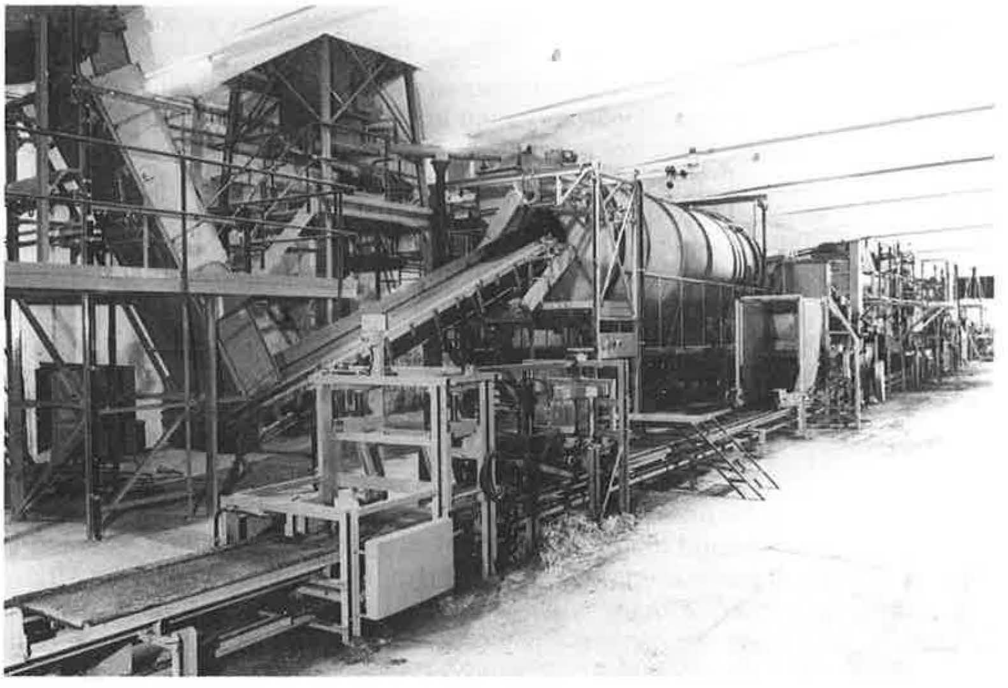


Figure 1 General view of plant from mixer end (courtesy of Elten Engineering)

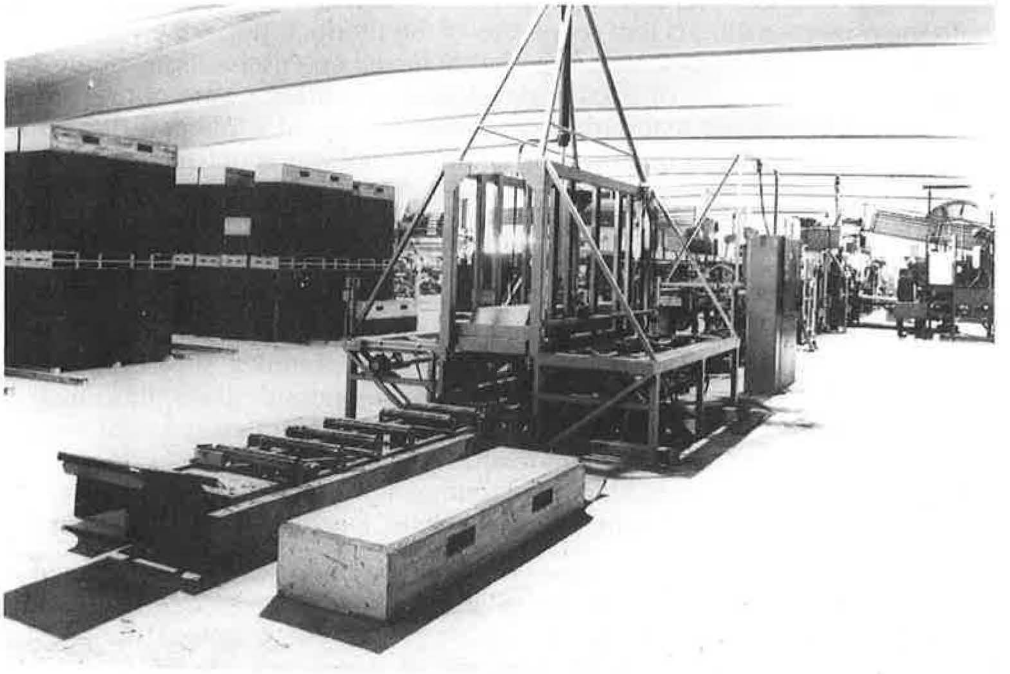


Figure 2 General view of plant from press end and view of board curing area (courtesy of Elten Engineering)

of about 36 m^3 per eight-hour shift – 300 000 slabs per year – semi-automated plants are employed. The NRI small-scale plant on the other hand produces 7 m^3 per shift – 25 000 slabs per year of 250 working days – with a slab size of 2430 × 610 × 51 mm (density 500 kg/m^3). Machinery and equipment for the largest automated plant would cost a minimum of US$ 2 million. Such plants require an installed power supply of 230 kW and a supply of clean water at a maximum rate of 7 500 litres/hour.

Large-scale production is normally on a continuous basis with a minimum of manual handling (Van Elten, 1966). The woodwool is dipped in mineralizing fluid and then conveyed to a mixer where the correct amount of cement is added. The dosage rate of cement is determined by monitoring the weight of the woodwool. The woodwool/cement mix is conveyed to a filling machine where it is distributed on to continuously moving moulds via a belt weigher. The speed of the moulds is electronically controlled to match the amount of woodwool/cement mix necessary to achieve a constant distribution.

The filled moulds are pre-pressed to consolidate the material and cut to the required length. The pre-pressed moulds are stacked in groups of 25, put under pressure in a piling press to obtain the required thickness, and restrained to prevent 'springback'. The slabs are then allowed to set overnight. After the first setting, the pile of moulds is taken by a fork-lift to an automatic stripping machine. The mould bases are returned to the distribution section and the slabs are trimmed to size, labelled and placed in piles for a final setting period of four to eight days. Sample slabs are tested at regular intervals against appropriate standards for quality control.

The various stages involved include:

- **Stage 1** – timber seasoning
  The timber commonly used is round-wood thinnings of pine, spruce or fir with a diameter of 70-200 mm. Timber up to 385 mm diameter can be used, depending on the type of woodwool machine in operation. The thinnings are sawn into suitable lengths for debarking and stacking, and are left in the open to season (usually for three months).

- **Stage 2** – timber preparation
  After seasoning, the timber is further sawn into lengths suitable for the woodwool machine (normally 500 mm).

- **Stage 3** – production of woodwool
  The most common woodwool machine consists of a reciprocating sledge which houses planing and scoring knives. Details of two types of machines are given in Table 1. The prepared timber billets are held by chucks between rotating, toothed rollers which feed the billets down on to the knives and scorers at a pre-set rate. The width of the woodwool is determined by the spacing of the scoring knives, and the thickness by the rate of feed. The outputs from a typical quadruple-acting machine – capable of holding two or four logs at a time – for different classifications of woodwool of 2 mm thickness are also given in Table 1. Woodwool is usually removed from under the machine by means of a mechanical conveyor.

- **Stage 4** – mineralizing
  The woodwool is automatically weighed (either in batch or continuously) and submerged in the mineralizing fluid. This is usually a solution of calcium chloride (1-5% on a weight for weight basis with water). The calcium chloride solution is prepared in a separate make-up tank and automatically replenishes that used for treating the woodwool in the submersion container. The soaked woodwool is pressed through adjustable rollers to remove the excess surface fluid which would otherwise interfere with the cement hydration.

- **Stage 5** – mixing
  The saturated woodwool is transferred to a continuous mixer where it is dosed with cement from an intermediate silo at a rate controlled by the woodwool weighing station. At the same time, the intermediate silo is automatically replenished from the main cement store under the same control.

- **Stage 6** – mould filling
  The woodwool/cement mixture is conveyed to a filling machine where it is agitated prior to distribution via a belt weigher on to continuously moving mould bases. The speed of the moulds is directly controlled by the belt weigher. This ensures a constant delivery of a predetermined weight of material, and results in an end-product of constant density and known properties. The sides and thickness are consolidated in a pre-press arrangement and the material is cut to the appropriate length to leave the filled moulds separated.

- **Stage 7** – pressing
  The filled moulds are automatically placed on top of each other in a piling press to form a stack of the appropriate number or weight. As the stack is consolidated under pressure, steel plates are hydraulically pushed between the mould edges to remove any trapped woodwool strands and thus maintain a constant thickness. The piled woodwool/cement slabs are taken to the first setting area where they are stacked two high. A concrete block weighing one tonne is placed upon the stack in order to maintain the pressure and prevent 'springback'.

- **Stage 8** – initial curing and demoulding
  The concrete block is left in place for 24 hours, at which stage the woodwool/cement slabs are sufficiently hardened to be stripped from their moulds. The emptied moulds are cleaned, oiled and returned to the process line store ready for reuse. This can be a manual operation, but on the larger plants it will be fully automatic. The demoulded slabs are labelled, the edges trimmed, and then cut to the required length. The finished slabs are automatically stacked into piles 1.7 m high.

- **Stage 9** – final curing
  The woodwool/cement slabs are stacked for approximately two weeks to allow them to dry and for the cement to cure fully. Prior to sale, the slabs are trimmed to meet the customer's specification.

Table 1 Details of woodwool machine

Types of machine

Type	*Power* (kW)	*RPM*	*Shipping* Volume (m^3)	Weight (kg)	Length (mm)	*Timber* Diameter (mm)
Double	11	250	3.25	1850	440-520*	70-200
Quadruple	18.5	250	9	3900	320-520**	80-385

(* manual chucking ** pneumatic chucking)

Outputs from a quadruple machine

Classification size (Ref. number)	*Thickness of woodwool produced* (mm)	*Output capacity* (kg/h)
0	0.05	50
1	0.07	84
1a	0.10	126
2	0.14	175
3	0.19	235
4	0.25	320
5	0.33	400

Section 2

The manufacture of slabs in developing countries

PROJECT CONCEPT

The concept of producing woodwool/cement slabs at low cost in developing countries seemed to be an attractive proposition in view of the product's known versatility for a wide range of applications, particularly in the construction industry, and its potential use in lower-cost housing. Successful transfer of the technology to developing countries would require a low-cost woodwool/cement plant of relatively simple design, and which was easy both to operate and maintain.

Developing a manufacturing process, however, can give rise to many problems, both in the technology of the process and in achieving economic viability (Chittenden, 1969). These problems generally revolve around a key piece of equipment which governs both the minimum output and the minimum capital cost of the plant. In the case of woodwool/cement slab manufacture, there is a limited range of equipment available to produce the woodwool. A further constraint is the physical nature of tropical timbers for woodwool-making.

A research programme was subsequently formulated by the Institute on behalf of the Overseas Development Administration (ODA). The main aims of the work included:

- laboratory assessment of individual timber species for their suitability as a raw material for slab manufacture;
- completion of laboratory-scale trials and testing of products for comparison with British Standards; and
- the design, development and construction of a small- scale prototype plant for demonstration overseas.

The early work was conducted in collaboration with the Commonwealth Forestry Institute in Oxford, United Kingdom (now the Oxford Forestry Institute) who were undertaking research into the industrial utilization of fast growing tropical timbers.

LABORATORY AND PROCESS DEVELOPMENT WORK

To determine the most appropriate operating conditions for small-scale processing, investigative experimental work was undertaken in the laboratory (Hawkes and Robinson, 1978a, 1978b). As a result of this work, the importance of various factors emerged.

Assessing the suitability of timbers

The significance of the mineralizing fluid and its effect on the setting of the cement when in contact with different timber species has been highlighted in

Section 1. A 'go/no go' test (Sandermann, 1966) can be used to assess the poisoning effects of cellulosic materials on cement. This test method exploits the exothermic (i.e. heat producing) reaction that occurs when cement sets. The rate of temperature rise and the maximum temperature achieved by a finely ground sample of the timber to be tested mixed with cement and water are compared with a control sample of cement and water only. The inhibiting chemicals leached from the timber sample slow down the cement/water reaction and reduce the maximum temperature reached. This is referred to as the 'hydration temperature'. Measurement of the rate of temperature rise and hydration temperature of the two samples provides an indication of the possible suitability of the timber for woodwool/cement manufacture.

On their own, the results from this test were found to be of limited practical use; repeatability was poor and no correlation between the strength of a woodwool/cement sample and timber density could be found. Each test required a 15 kg representative sample of the timber. The method worked well for extreme conditions, i.e. where very weak or very strong inhibition of the cement setting was apparent, but it gave an unreliable indication of the suitability of the majority of timbers which lie between these extremes.

An alternative test (Sandermann and Kohler, 1964) involves the partial insertion of small sticks of timber into a cement paste. If the stick can be pulled out by hand or with pliers after two days, the timber is considered unsuitable. This method does not require the accurate temperature measuring equipment needed for the hydration temperature method, and is more suited for use in the field as a simple go/no go test for preliminary assessment.

However, except for the extreme cases, neither of these methods give meaningful indications of the suitability of the timber. Nor do they indicate the machineability of the timber under test, which is also an important factor in processing operations.

As a result of the laboratory work undertaken and the practical experience gained, it was concluded that the only reliable and repeatable method which could be recommended for assessing the suitability of timber was to make woodwool/cement slabs and to carry out physical testing according to the appropriate standard for the product (British Standard BS 1105). Details of this standard and the physical properties which need to be considered are summarized in Section 4. The requirements of German Standard DIN 1101 are tabulated in Appendix 1 for comparison.

As part of the experimental programme, the suitability of various timbers for woodwool/cement slab manufacture were assessed by making full size woodwool/cement slabs (Hawkes and Robinson, 1978a). Samples (in triplicate) were made with a range of densities and cement contents, and tested against BS 1105. A list of these and timbers tested by others (Ashiabor, 1973; Hawkes and Robinson, 1978a, 1978b; Sandermann, 1966; Van Elten, 1966; Wong and Ong, 1982), and an assessment of their suitability, are given in Appendix 2.

Preparing timber

Seasoning is important, because during this period the wood sugars and hemicelluloses ferment and their inhibitory effect on cement setting is lessened. Wood dried to moisture contents between 20% and 30% is ideal for making woodwool because it produces less dust, fine particles and splinters during processing. In addition, it maximizes the useful working time of the woodwool machine by reducing the need to sharpen the knives and scorers (Chittenden *et al.*, 1975).

Producing woodwool

Existing machinery for producing woodwool is well developed and proven. The smallest machine commercially available is a manual double-acting unit, i.e. one that holds two billets of timber and is manually chucked. This type of machine was therefore selected for the laboratory work, because it could provide the same range of sizes of woodwool strands as the larger types of machines. It could also be used in experiments to assess the machineability of particular timber species, and to determine throughput capacities and the wear rates of the knives and scorers. The machine is shown in Figure 3.

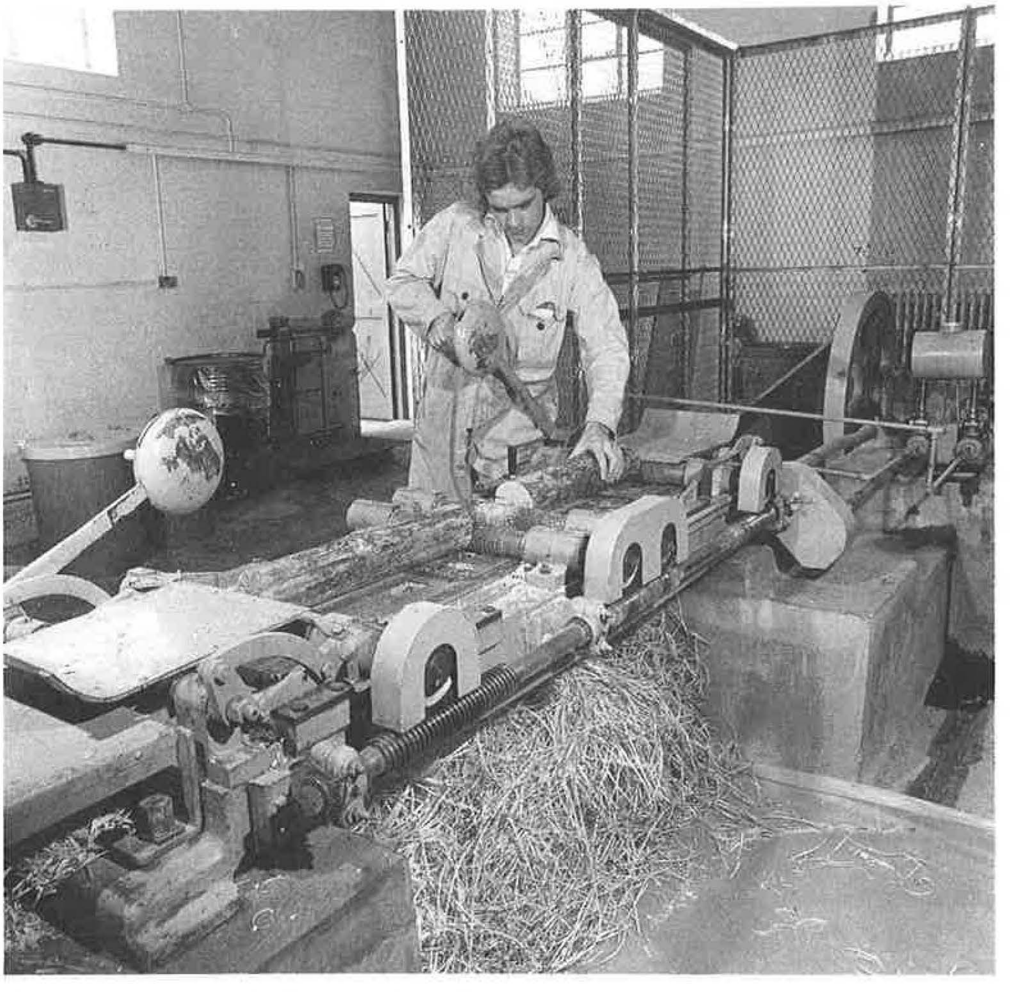


Figure 3 Producing woodwool

Adding mineralizing fluid

In most cases, soaking the woodwool in calcium chloride solution is necessary to inhibit the poisoning of the cement in later stages. However, in developing appropriate processing techniques and reducing the complexity of the equipment, it became evident that the amount of mineralizing fluid (and hence water of hydration) used must be strictly monitored and an in-built control procedure devised. To meet these requirements, a centrifuge (*see* Figure 4) was incorporated into the process. This novel approach ensures that all excess mineralizing fluid is removed from the woodwool, and has the added benefit of controlling the moisture content of the treated material prior to the next stage of the manufacturing process.

This is a significant departure from the normal commercial operation which uses rollers to remove excess surface liquid.

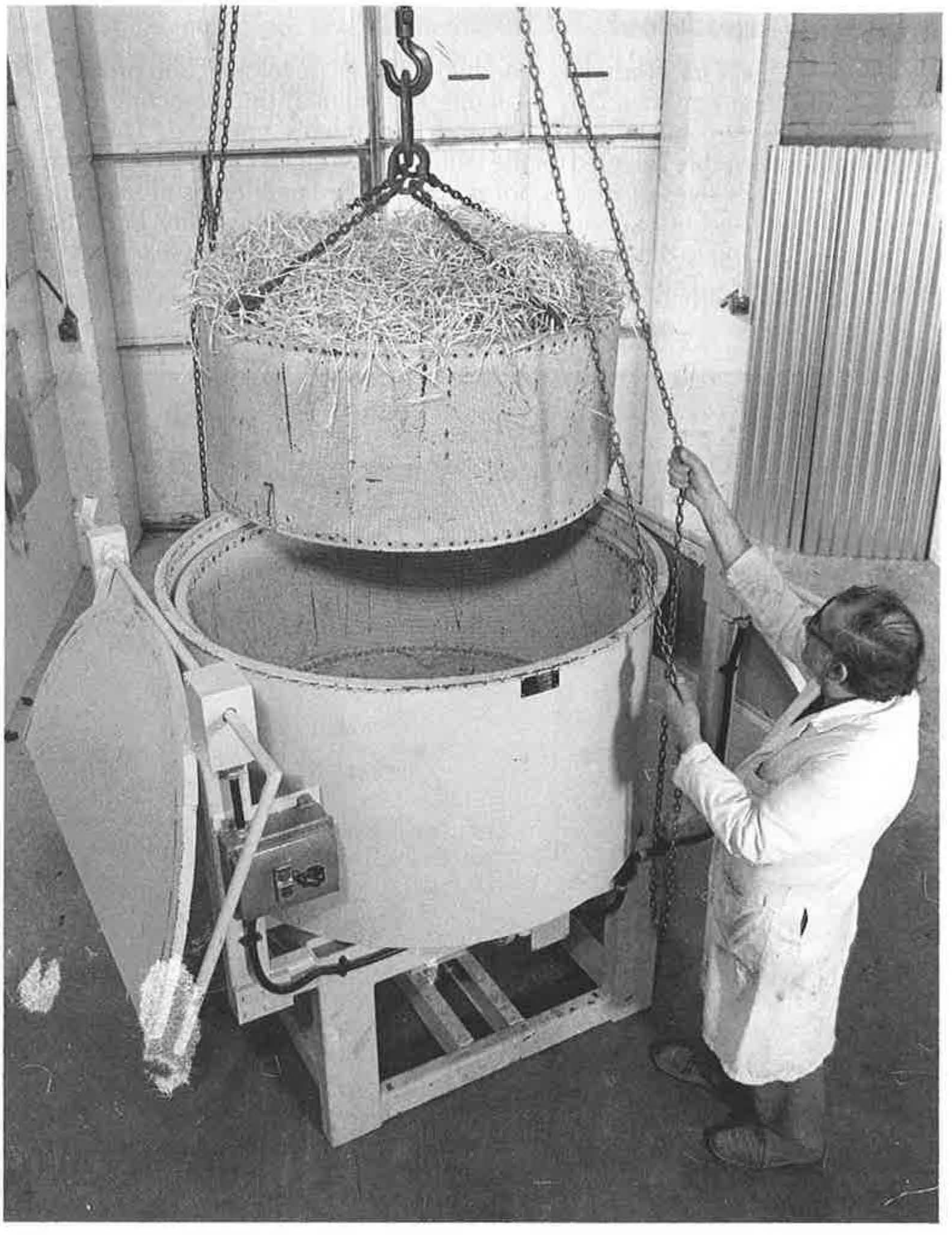


Figure 4 Experimental centrifuge being loaded with woodwool

Adding cement

The automated control systems of large-scale plant allow precise amounts of dry cement powder to be added to known quantities of woodwool and water. These are then carefully mixed together. The simplified process devised at NRI uses a cement/water mix (ratio 2:1) which is handled as a slurry. The slurry is pumped to a predetermined level in a header tank which is located above the woodwool/cement slurry mixer.

The amount of slurry added to the woodwool is controlled by volume. The header tank is calibrated for the levels of slurry required for the different thicknesses of woodwool/cement slab to be produced. Calibration must be carried out before production commences. The tank is emptied into a trough with an adjustable longitudinal slit through which the cement slurry can drain as a curtain on to the woodwool which is being agitated.

Woodwool/cement mixing

Initially, a 21/14 (600 litre unmixed:400 litre mixed) capacity reversing drum cement mixer was used because such mixers are commonly available in the construction industry world-wide. It was modified by replacing the agitator ribbon blades with simple flighted blades in order to mix the woodwool and cement slurry together effectively. Although a good mix was obtained, two problems arose. The total time taken for mixing and emptying was too long, and it became apparent that such mixers could not be obtained as low-cost equipment in developing countries, were not readily available as second-hand equipment, and were almost as expensive as new ones as a result.

The design of a simple purpose-built trough mixer provided a number of benefits:

- it enabled the mixer capacity to be properly matched to processing requirements;
- the header tank could become an integral part of the equipment and allow the slurry to be added as a curtain to give improved mixing;
- the paddle blades could be reversed to assist emptying;
- the mixer chamber could be tilted completely over for emptying the mixture directly into moulds; and
- the design was simple and suitable for local manufacture.

The cost of manufacturing this mixer was found to be similar to that of conventional designs.

Moulding and pre-pressing

There was a need to devise moulding and pressing operations which were suitable for small-scale operation, and flexible enough to provide slabs of different finished sizes. Also, to minimize problems from fungal or insect attack (in particular from termites) which may occur in developing countries, it was decided that no wood or edges should be exposed through trimming operations. This meant using sets of moulds of fixed dimensions to produce slabs of the required sizes. The moulds could be manufactured locally in a carpenter's workshop from sawn timber or plywood, depending upon costs and the availability of materials.

Trials showed that volume of the mixture needed to be compressed to one third in order to obtain a slab of the appropriate density. To simplify operations, the mould was designed in three parts – a base unit, a removable extension piece and a lid for compacting. The base unit is made to the size of the finished slab; the extension piece is the same length and width, but is twice as thick as the base unit; the lid is a slack fit into the extension piece and is used as a pressure plate to compress the woodwool/cement mixture into the mould. Part of the mould arrangement is shown in Figure 5, where it can be seen filled with woodwool/cement mixture and ready for final pressing.

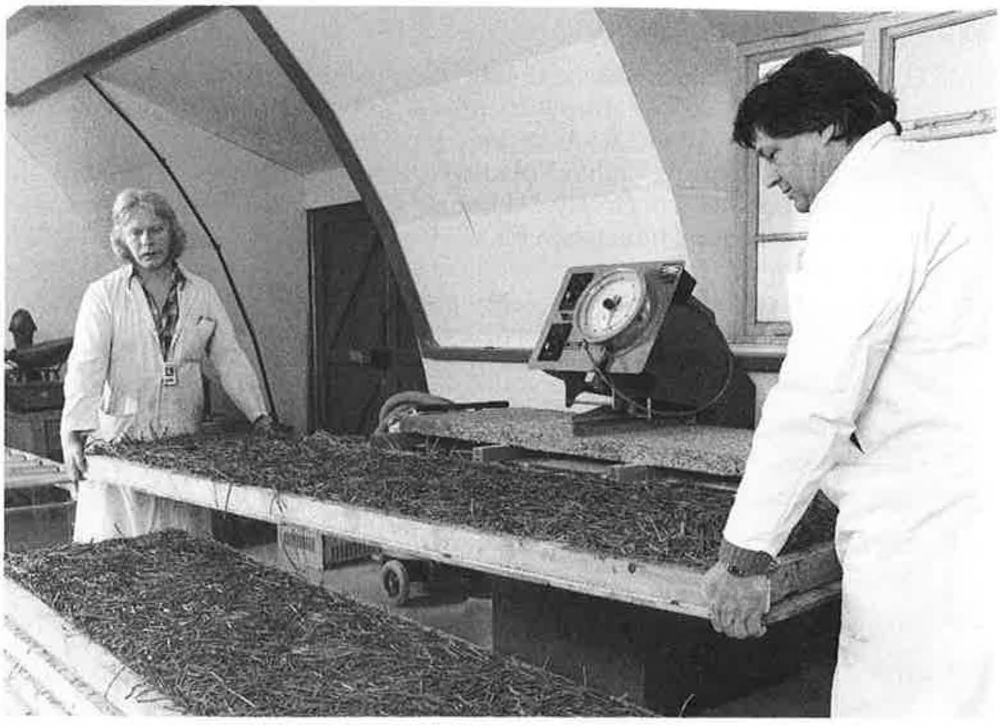


Figure 5 Preparing moulds for pressing

Pressing

Initially, simple adjustable metal frames and hydraulic car jacks were used for pressing operations during the laboratory assessment work. The method was improved for the small-scale plant by using two platen presses operated by hydraulic rams.

When the pressure was released, the slabs were found to re-expand slightly (i.e. to spring back). This problem was overcome by using commercially available belting which could be tightened by a ratchet.

Demoulding and stacking

It was established that after final pressing, the slabs could be demoulded and handled after an initial air curing period of at least 16 hours. The slabs were subsequently stacked with battens placed between each to encourage drying by natural convection. Setting took four days, after which the slabs could be close-stacked (to reduce the storage space required) and would be ready for sale after a further 10 days. The moulds need to be cleaned and oiled each time before re-use.

Prototype processing plant

Based on the experimental work undertaken, a design for a prototype small-scale processing plant was developed and engineering drawings prepared for pilot demonstration work.

Section 3

Small-scale production

THE NRI PROCESS

The small-scale process developed at NRI is similar in some ways to a commercial process; but there are significant differences. For example, essential machinery has been reduced to a minimum and much of the equipment is designed to be manufactured locally, thereby reducing substantially the need for some countries to import. Processing techniques are more straightforward and appropriate to small-scale operation, controls have been built-in, and equipment is simpler and easier to maintain. The process has been designed to be labour-intensive (Flynn and Hawkes, 1980).

The basic raw materials are ordinary Portland cement (OPC), water, chemicals and wood. OPC is readily available in most parts of the world. Water needs to be clean, but not necessarily of drinking quality, and its supply must be reliable. Calcium chloride is generally used for the mineralizing fluid. However, magnesium chloride or sodium silicate may be used if calcium chloride is not available. A large and regular supply of round timber which will provide billets 500 mm long with a minimum diameter of 100 mm is required.

A flow diagram of the process is given in Figure 6, which is more fully described and illustrated in the subsequent pages (pp.15-18).

Prototype small-scale plants designed by NRI have been installed and commissioned in Malawi and Zambia. Local staff have been trained in the operation of the process, quality control, and in the maintenance of the equipment.

The layout for one factory operation is shown in Figure 8, and plant requirements are given in Table 2 together with a list of the equipment necessary for producing the slabs in this way. Raw materials specifications are given in Appendix 3.

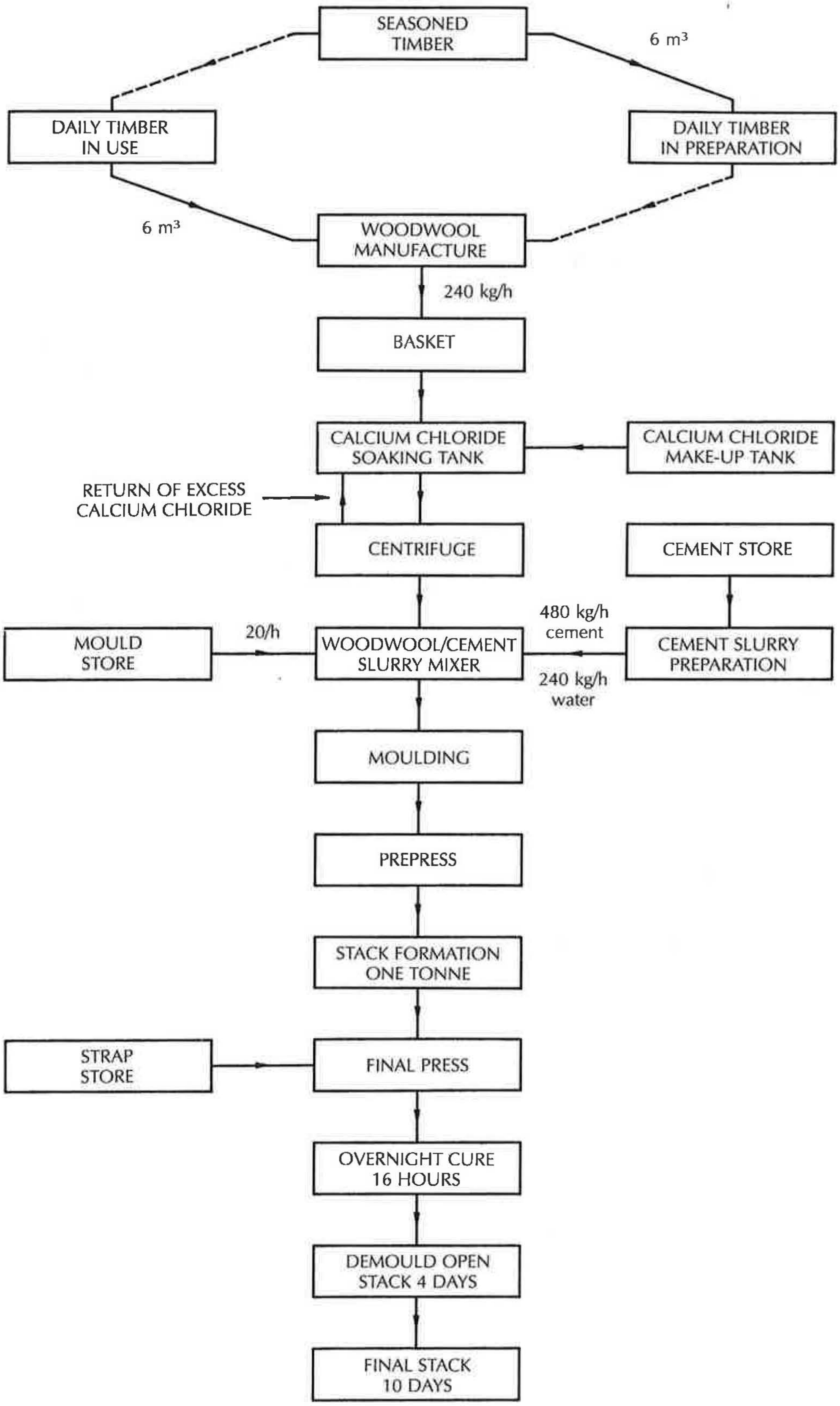


Figure 6 Flow diagram: woodwool/cement slab manufacture (NRI process)

The NRI process involves:

1 – storage
timber is mechanically debarked and then stacked in the open air in a log yard for up to three months to season;

2 – cutting
the seasoned timber is sawn into 500 mm lengths;

3 – woodwool manufacture
the logs are machined to produce strands of wood;

4 – basket, soak and centrifuge
the woodwool is loaded into a steel basket which is lowered into a soaking tank containing the mineralizing fluid (a dilute solution of up to 5% calcium chloride in water). After soaking for about three minutes, the basket is lifted from the tank using the hoist on the overhead gantry and lowered into the centrifuge where it is spun until all surface moisture is removed. The excess liquid is returned to the soaking tank. At this stage the woodwool is in a saturated condition and will not absorb any of the water required for hydration of the cement. Sufficient woodwool for one slab is weighed, and loaded into the mixer via a conveyor;

5 – cement slurry
a cement slurry (2:1 cement:water) is made and emptied into a holding tank, from where it is pumped to the required level in the header tank of the mixer;

6 – woodwool/cement slurry mixer
woodwool is loaded by conveyor into the mixer and the cement slurry added; they are mixed thoroughly until the woodwool is well coated;

7 – moulding
the woodwool/cement mix is emptied into the mould, where it is distributed by hand to ensure that the corners and edges are well filled;

8 – pre-press
the filled mould is pre-pressed to consolidate the mixture to approximately the final thickness required;

9 – stack formation
the lid and extension piece are removed, cleaned, oiled and refitted to an empty base unit ready for re-use; the pre-pressed moulds are stacked 10 high;

10 – final press
the stack is placed in the final press, compressed, strapped, and allowed to cure overnight for 16 hours;

11 – demould
the slabs are demoulded and placed in an open stack for four days; the mould bases are cleaned and oiled, ready for re-use;

12 – store
slabs are stacked on top of each other and left under cover for 10 days, after which time they are fully cured.

Figure 7.1 Storage

Figure 7.2 Cutting

Figure 7.3 Woodwool manufacture

Figure 7.4 Soaking tank

Figure 7.5 Cement slurry

Figure 7.6 Woodwool/cement slurry mixture

Figure 7 Stages in the NRI process

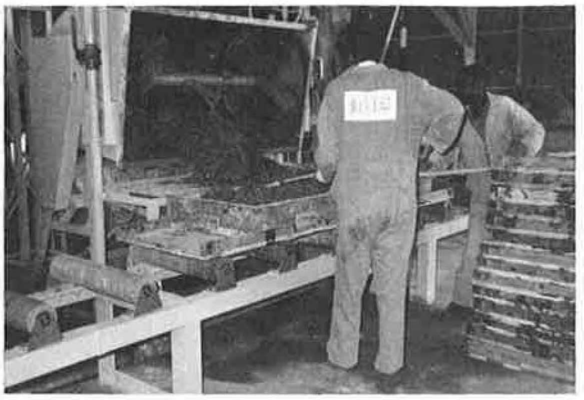


Figure 7.7 Moulding

Figure 7.8 Pre-press

Figure 7.9 Stack formation

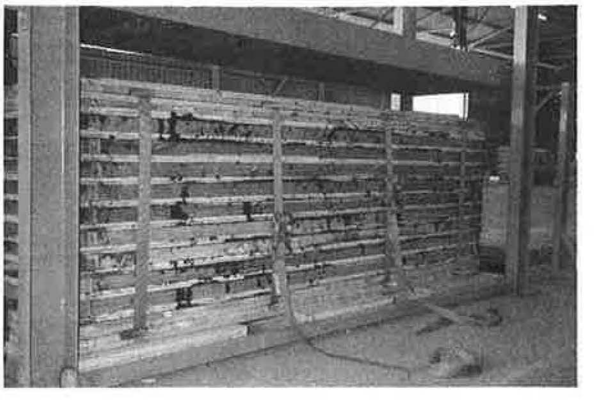


Figure 7.10 Final press

Figure 7.11 Demould

Figure 7.12 Store

Figure 7 Stages in the NRI process—continued

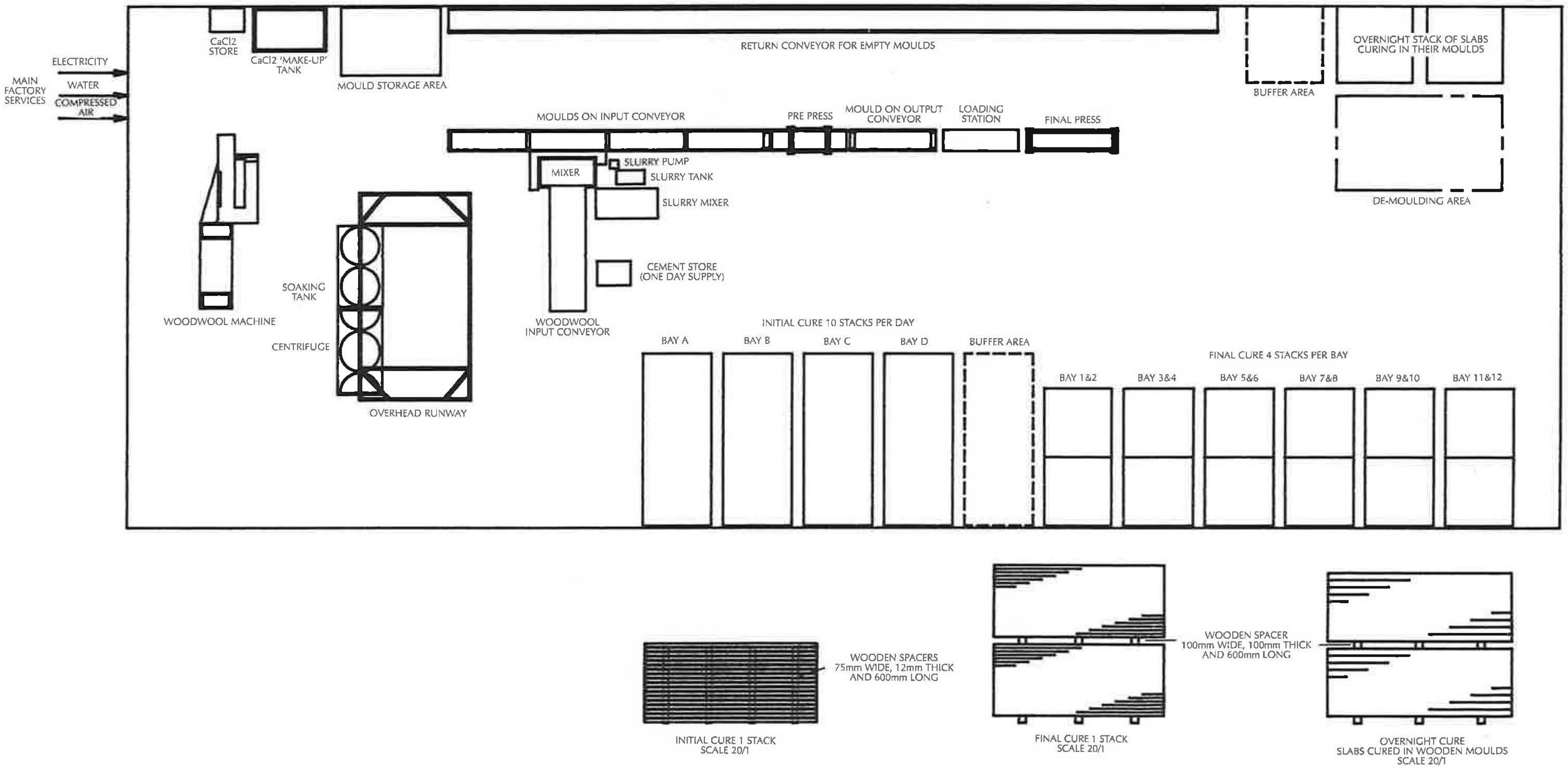


Figure 8 Factory layout woodwool/cement slab plant

Table 2 Plant requirements and equipment

Plant

Capacity per 8 hour shift (m^3)	7
equivalent to	500 slabs
(slabs density 500 kg/m^3; size 2430 × 610 × 50 mm thick)	
Labour	25 typical
Land area (m^2)	6000
Building size (m)	50 × 18 typical
Timber as raw material (tonne/year)	350
Cement (tonne/year)	500
Water (l/year)	1200
Calcium chloride (tonne/year)	12
Installed electrical power (kW)	75
Power consumption (kWh/tonne)	44

8 hour shift, 250 working days per year assumed

Basic equipment requirements

Description	Quantity	Power(kW)
Chain saw	1	
Debarker	1	15.0
Cross cut saw	1	2.0
Woodwool machine	1	18.5
Compressor	1	5.5
Hand carts	2	
Preparation tools	1 set	
Centrifuge	1	3.0
Basket	3	
Electric hoists	1	1.1
Slings	3	
Gantry	1	
Overhead electric rail	1	
Scales	1	
Liquor transfer pumps	2	0.5
Woodwool conveyor	1	0.7
Woodwool/cement mixer	1	0.7
Slurry mixer	1	2.3
Slurry pump	1	0.4
Slurry tank	1	
Roller conveyor	1	
Hydraulic prepress	1	2.3
Hydraulic final press	1	2.3
Straps	as required	
Mould base units		
Mould extension pieces		
Battens		
Spacers		
Pallet trucks	2	
Panel saw	1	2.3
Dust extraction unit	1	4.0

Section 4

Properties and classification of slabs

GENERAL PROPERTIES

Some of the advantages of using slabs over other constructional materials include:

- lower overall cost;
- speed of construction;
- good thermal insulation values;
- consistent dimensions;
- light and easily handled;
- resistance to vermin and termite attack;
- good sound insulation and performance in fire.

Health

There are no known health hazards when woodwool/cement slabs are used in the normal way. In common with other materials, precautions should be taken to avoid inhaling dust when sawing.

Durability and resistance to decay

Experience in the building industry in Europe and many tropical countries including Burma, Indonesia, Thailand, Fiji, Malawi, Zambia and several in South America, has shown the product to be highly durable. It does not sustain rot or fungal growth and has a high resistance to insect and termite attack.

CLASSIFICATION OF SLABS

The British Standard Specification for 'Woodwool/cement slabs up to 125 mm thick' (BS 1105: 1981) classifies the product into three types as follows:

Type A – slabs intended for non-loadbearing application, e.g. partitions, ceilings, wall linings and roof insulation. They are also suitable for permanent shuttering;

Type B – slabs with a nominal thickness of not less than 50 mm possessing greater strength than type A slabs, and which are intended to be used for roof construction provided that the safety precautions of the Construction (Working Places) Regulation 1966, are followed where applicable. They are also suitable for purposes indicated for type A slabs;

Type SB – slabs with a nominal thickness of not less than 50 mm possessing greater strength than type A slabs and greater resistance to impact than type B slabs, and intended particularly for use in roof construction without being subject to the requirements of Regulation 36(1) of the Construction (Working Places) Regulation 1966. They are also suitable for the purposes indicated for type A slabs and type B slabs.

PHYSICAL PROPERTIES AND PERFORMANCE DETAILS

A summary of various physical properties of slabs and their performance are given below using slabs produced by the NRI process.

Physical properties

Table 3a Physical properties of woodwool slabs

Nominal thickness (mm)	Type	Average density (kg/m^3)	Average weight per unit area (kg/m^2)	Minimum average bending stress (N/mm^2)	Maximum unsupported width (mm)
20*	A	650	13.0	1.16	N/A
25*	A	600	15.0	0.94	N/A
50	A,B	500	25.5	1.14	600

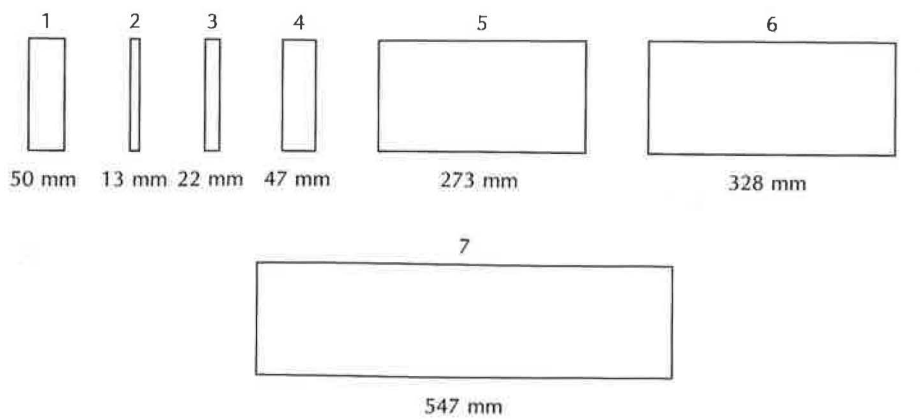
Table 3b Dimensional tolerances

Parameter	Length (mm)	Width (mm)	Thickness (mm)
Tolerance	+0 −6	+0 −6	+3 −3

Note: * Not covered by BS 1105: 1981. The physical properties shown are those suggested by NRI as reasonable levels of quality.

Thermal performance

The woodwool/cement slab has good thermal insulating properties giving a typical thermal conductance U-value of less than 2.6 W/m^2 K. It has a low thermal conductivity value (k) which, for a 50 mm thick slab with a moisture content of 8% and density of 450 kg/m^3, is less than 0.13 whilst offering other advantages. A comparison is given in Figure 9 to illustrate the thicknesses of different materials required to achieve a similar level of insulation performance.



Note: Blocks to scale 1:10

KEY:
1 Woodwool/cement slab (typical k = 0.13 W/m K)
2 Expanded polystyrene (0.034)
3 Fibre insulation board (0.057)
4 Particle board (0.12)
5 Hand tamped clay brick (0.71)
6 Brick (0.85)
7 Concrete (dense) (1.42)

Figure 9 Comparison of thermal performance

Fire performance

Woodwool/cement slabs inhibit combustion and typically have a class 1 spread of flame rating determined according to BS 476: Part 7. They have fire propagation indices of I less than 12 and i_1 less than 6, and are classed as 'not easily ignitable' as determined in accordance with BS 476: Part 6. 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. The sub-index i_1 can be considered as an indication of the ignitability and flammability of the material. It is possible to arrange materials in a descending order of merit on a scale 0 to approximately 100. Fire propagation indices obtained for woodwool/cement slabs compare very favourably with other wood and wood-based materials, as shown in Table 4.

Table 4 Comparison of performance indices

Material	Treatment/facing	Thickness (mm)	I	i_1	i_2+i_3
Fibre board	—	13	66.4	41.0	25.4
	Emulsion painted	13	42.0	18.0	24.0
	Intumescent flame-retardant 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 retardant varnish	19	18.1	4.9	13.2
	Intumescent flame-retardant 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-retardant 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 0.2mm	9	10.0	5.4	4.6
Woodwool/cement slab (high density)	—	25	11.5	5.2	6.3
Woodwool/cement slab (low density)	—	50	10.3	5.2	5.1
Woodwool/cement slab (made from Zambian cement and *P. kesiya*)	—	50	7.9	4.2	3.7

Fire performance was assessed according to BS 1105: 1972. However there is no difference between this and the present standard BS 1105: 1981 with regard to levels of performance and test requirements.

Section 5

Applications

GENERAL

Safety recommendations

Slabs less than 50 mm thick are intended for non-loadbearing applications only. Where woodwool/cement slabs are used, for instance as roof decking, they must be 50 mm or more in thickness. In addition:

- maximum recommended spans must not be exceeded;
- roofboards/crawl-boards should be used during fixing;
- woodwool cement slabs must not be used as a working area for other building operations; and
- permanent walkways with warning notices should be incorporated in any platform or roofing structure likely to have foot traffic.

Handling

Slabs should never be carried flat. When off-loading manually, slabs must not be dragged across each other as this may cause damage. They should be lifted on to a long edge and carried with a long edge uppermost.

Usage

Woodwool/cement slabs can be cut to size, nailed, drilled and painted using normal hand or power tools, and can be easily rendered with mortar or gypsum. A single panel (2430 × 610 mm) covers an area equivalent to 19 concrete blocks (200 × 400 mm).

Stacking

Slabs should be stacked on level ground on bearers not less than 75 mm wide and separated by not more than 750 mm. For ease of handling and for stability, the height of a stack should not exceed 1600 mm.

Protection

Slabs should be protected from the weather by storing in a warehouse or by means of securely fixed covers such as tarpaulins with adequate ventilation. This prevents the woodwool/cement slabs from becoming saturated and presents the material in the proper condition for use in construction.

Non-loading bearing uses

All woodwool/cement slabs can be used in non-loadbearing applications for partitions, external cladding, thermal insulation to walls and roofs, permanent shuttering, sarking and ceilings.

Roof decking

Only woodwool/cement slabs 50 mm or more in thickness can be used as structural roof decking. The slabs should be laid across the joists with the end joints staggered and fixed by means of large galvanized steel nails, five across the width at each point of support. A typical roof deck arrangement is shown in Figure 10. The ends should be nailed last and normally have a minimum bearing surface of 25 mm at each end support.

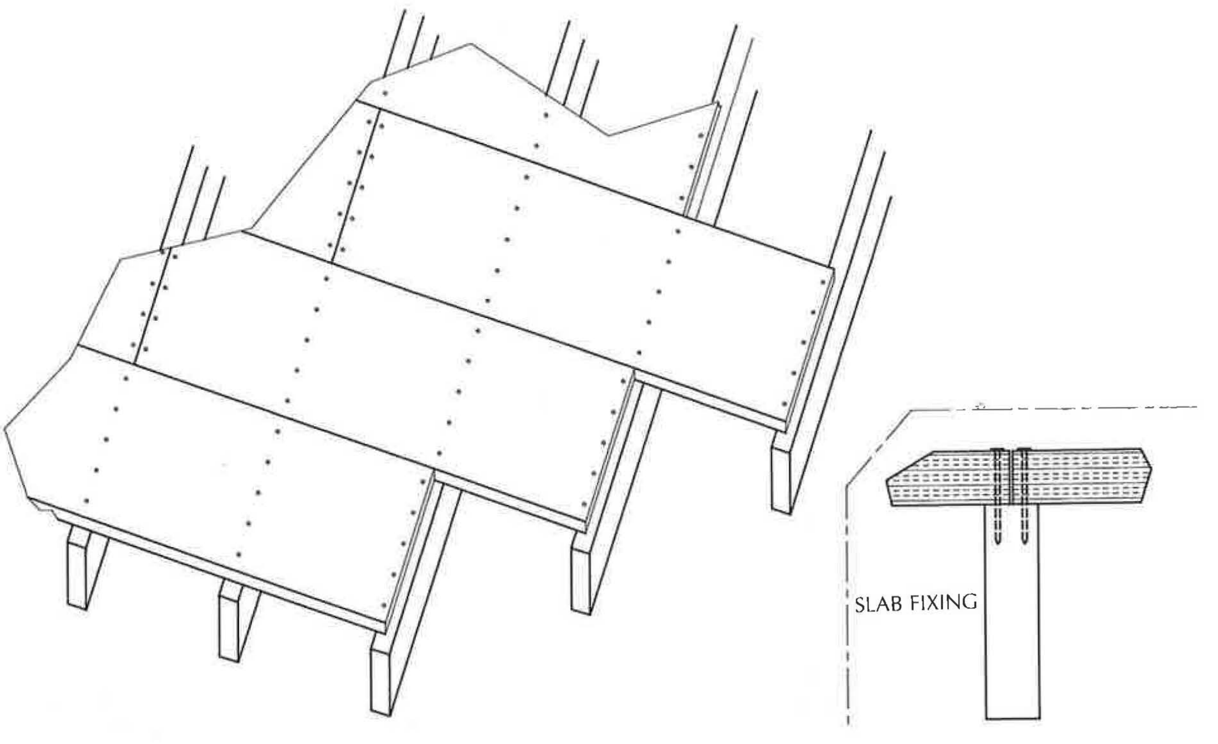


Figure 10 Roof decking – unreinforced woodwool/cement slabs

Local building regulations

Whilst the slabs are versatile, their usage may need to comply with local building regulations and codes of practice. These vary from country to country and requirements and specifications must be checked, particularly for load-bearing applications.

HOUSING

The major manufacturers of woodwool/cement machinery have advocated the use of woodwool/cement slabs in the lower cost housing sector, and have produced various designs for this purpose. The material is used in the construction industry world-wide; extensively in Europe, and in various developing countries including Brazil, Mexico, Thailand, Burma and Indonesia.

Project work at NRI had shown that *Pinus caribaea* from Fiji is a suitable raw material for woodwool/cement slab manufacture. In consultation with the ODA Architectural Adviser, the project was extended to produce woodwool/cement slabs as specified for the construction of houses designed by the Chief Architect of the Suva Housing Authority. The houses were of unique design and construction in that the woodwool/cement walls were load bearing. All the walls were constructed with woodwool/cement slabs 75 mm thick and dowelled together with 12.5 mm diameter mild steel rods. The walls were tied to the foundations and to the roof structure by means of 4 mm galvanized wire. A schematic diagram of this design is shown in Figure 11. The houses built in different parts of the island have been erected for more than 10 years and have withstood two hurricanes. It is reported that these houses require no more maintenance than other types operated by the Housing Authority. In common with Zambia, it is reported that fungal and insect attack have not been problems.

In Malawi, the woodwool/cement slabs are used mainly for ceiling boards. A wider product range is manufactured in Zambia where the company involved has designed various housing styles using a post and beam construction with woodwool/cement slab infill (Cox, 1992). Plan and construction details of a basic two-bedroomed house are illustrated on the following pages in Figures 12 to 19 (courtesy of TAP Building Products Ltd.). Various styles of housing have been provided for agricultural and government workers using the construction techniques indicated above. It is expected that this market, coupled with other products such as suspended ceilings, will continue to expand. Purchasers of panels now include international donor agencies, private individuals, commercial and public sectors and, increasingly, those involved with self-help projects and extension programmes.

CONCLUDING COMMENTS

The small-scale process developed by NRI embraces several innovative techniques which are built in to the system to ensure that consistent production standards can be maintained. Demonstration plants have operated successfully in Africa for several years. Opportunities exist to benefit from this technology to provide a locally produced building material appropriate to local needs. Whilst the product has a wide number of potential uses, housing for both the private and public sectors can be seen as being an important market.

In view of its suitability for application in developing countries (particularly in maximizing the utilization of forest thinnings), this technology should be considered as a potential component in forest products selection programmes, both as a means of diversification and as a means of providing added-value products locally.

The overall aim of NRI's forest products programme is to improve the performance of existing forest products industries in developing countries, and to foster the creation of sustainable technologies through co-ordinated research and development programmes. Enquiries on this particular publication and woodwool/cement slab processing should be sent to the Programme Manager, Forest Products Programme, at NRI.

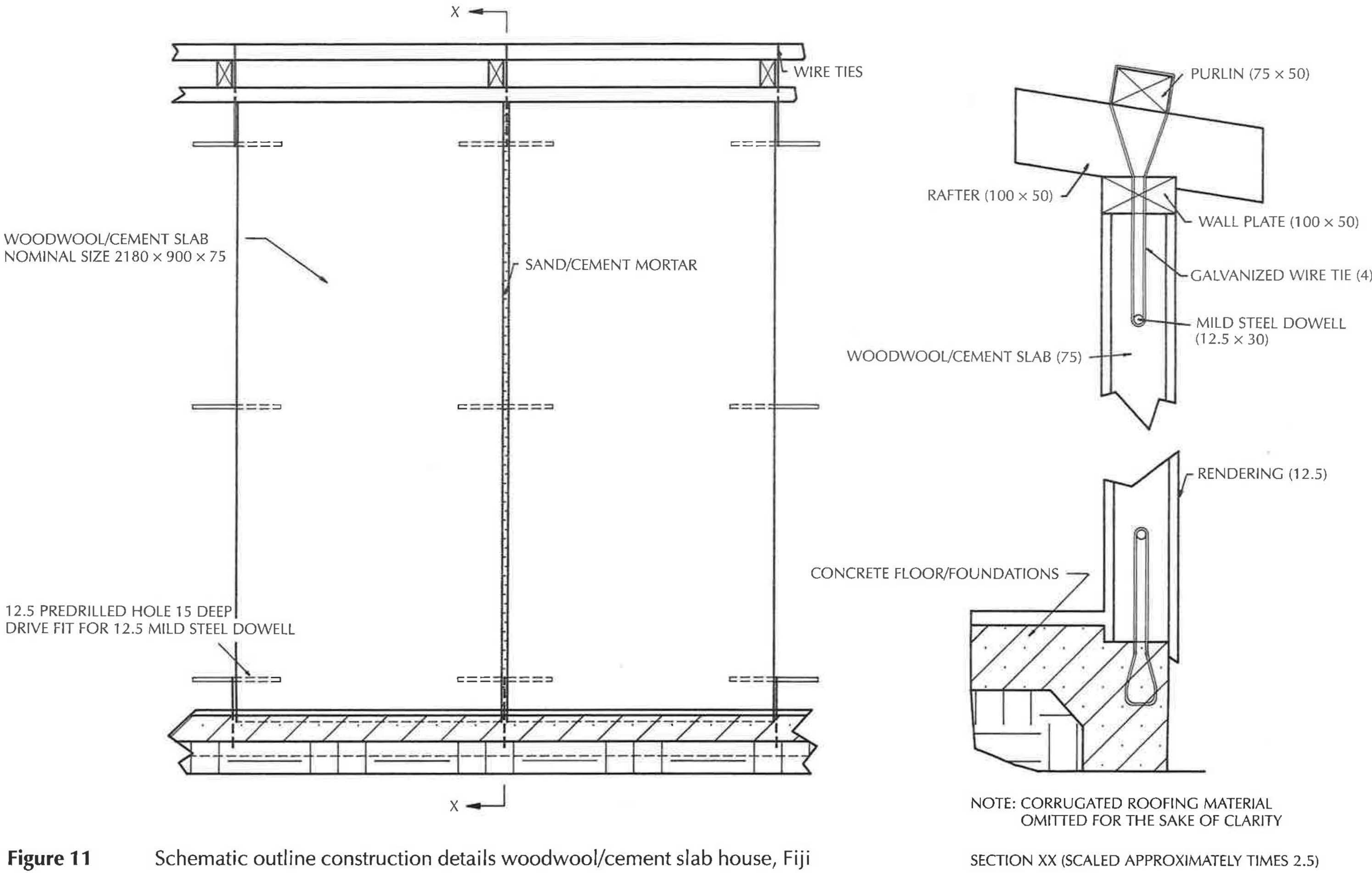
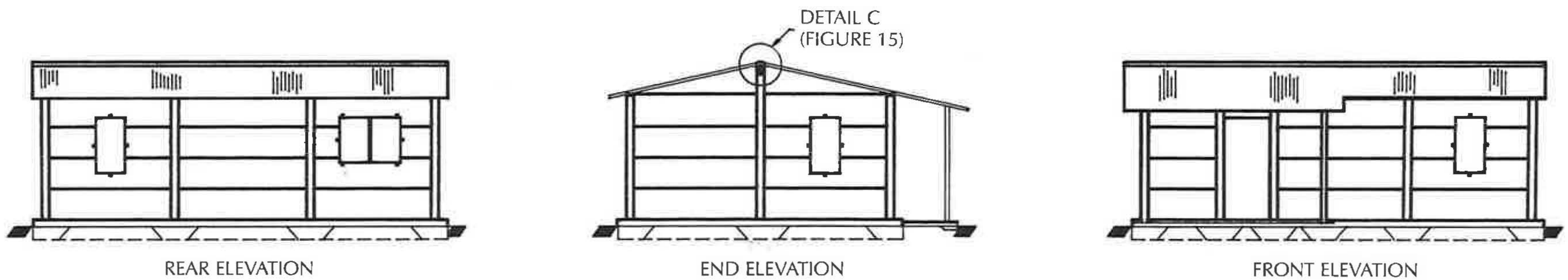


Figure 11 Schematic outline construction details woodwool/cement slab house, Fiji



EXTERNAL FINISH

First coat	rough cast
Second coat	10 mm plaster
Final coat	rough cast

INTERNAL FINISH

First coat	rough cast mortar
Final coat	10 mm plaster with brush finish

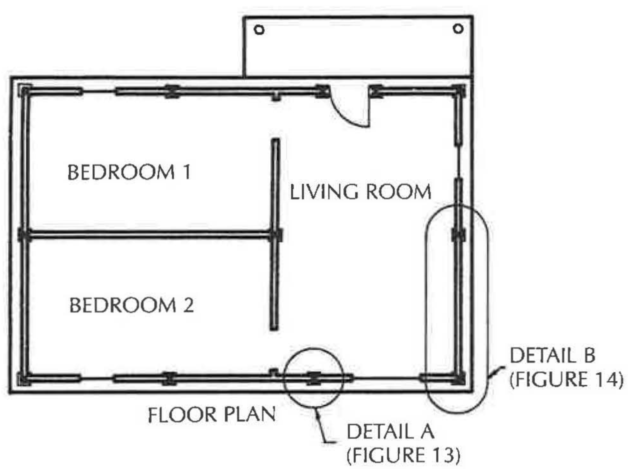


Figure 12 Two bedroomed lower cost house, Zambia

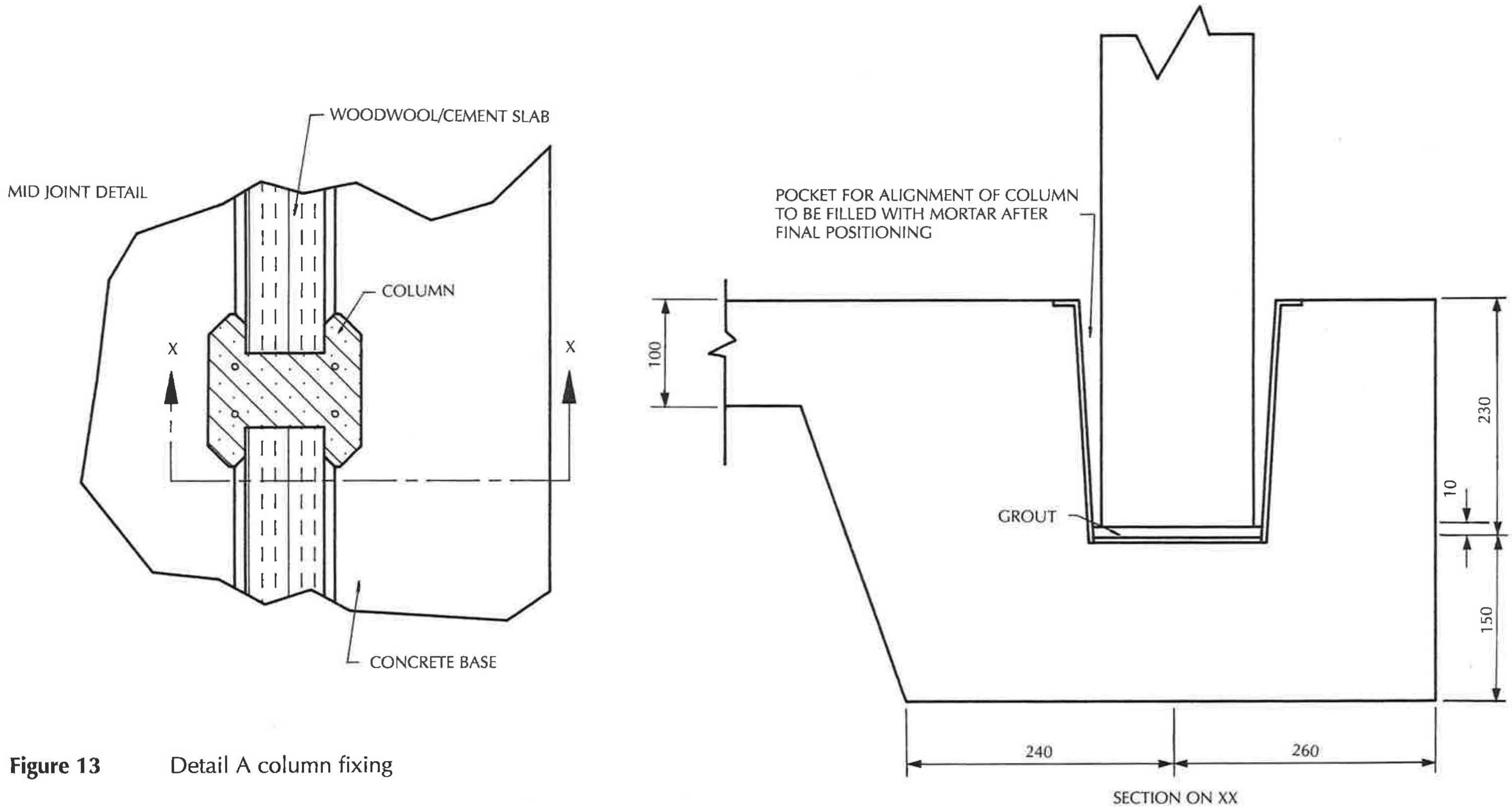


Figure 13 Detail A column fixing

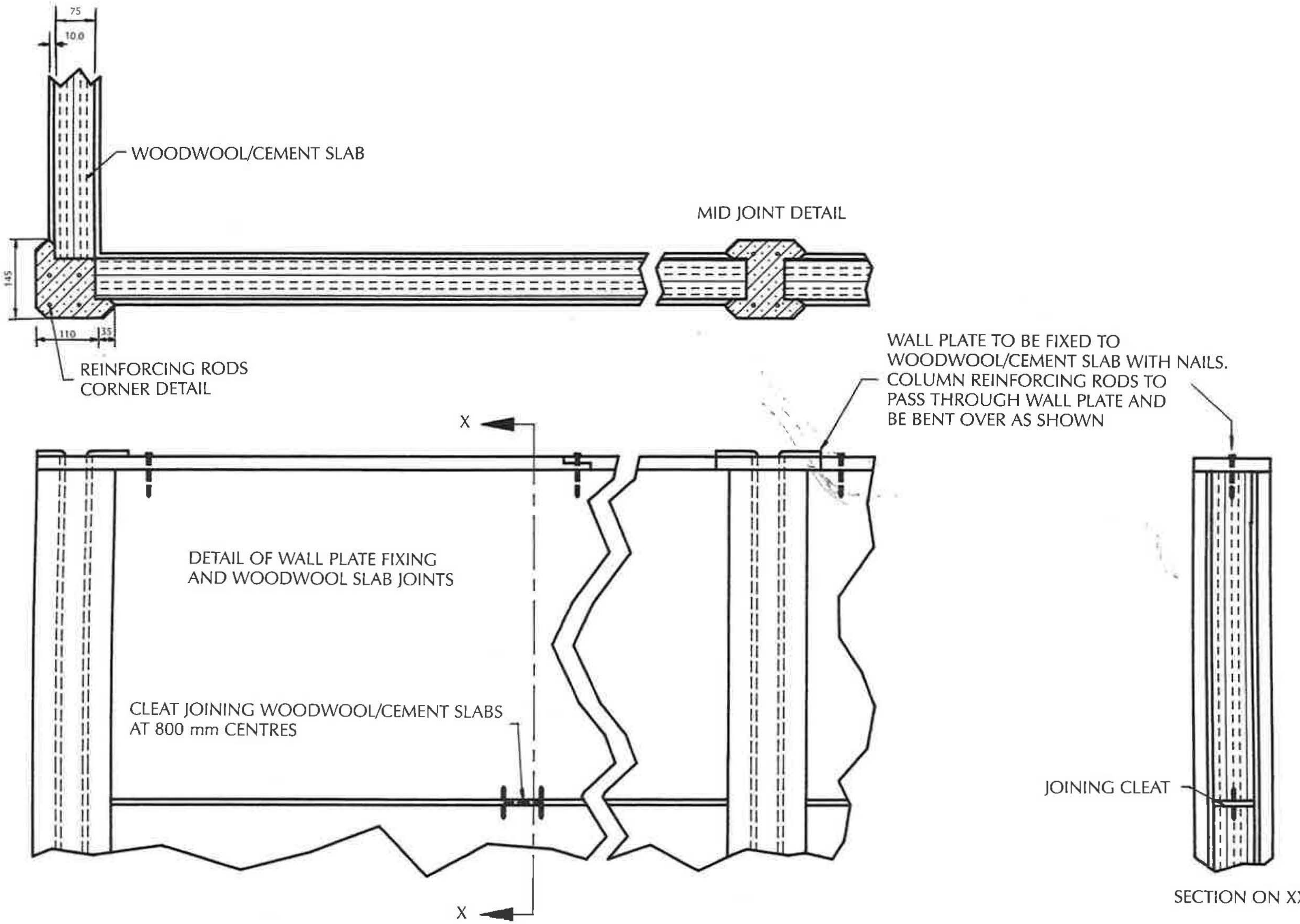


Figure 14 Detail B wall construction

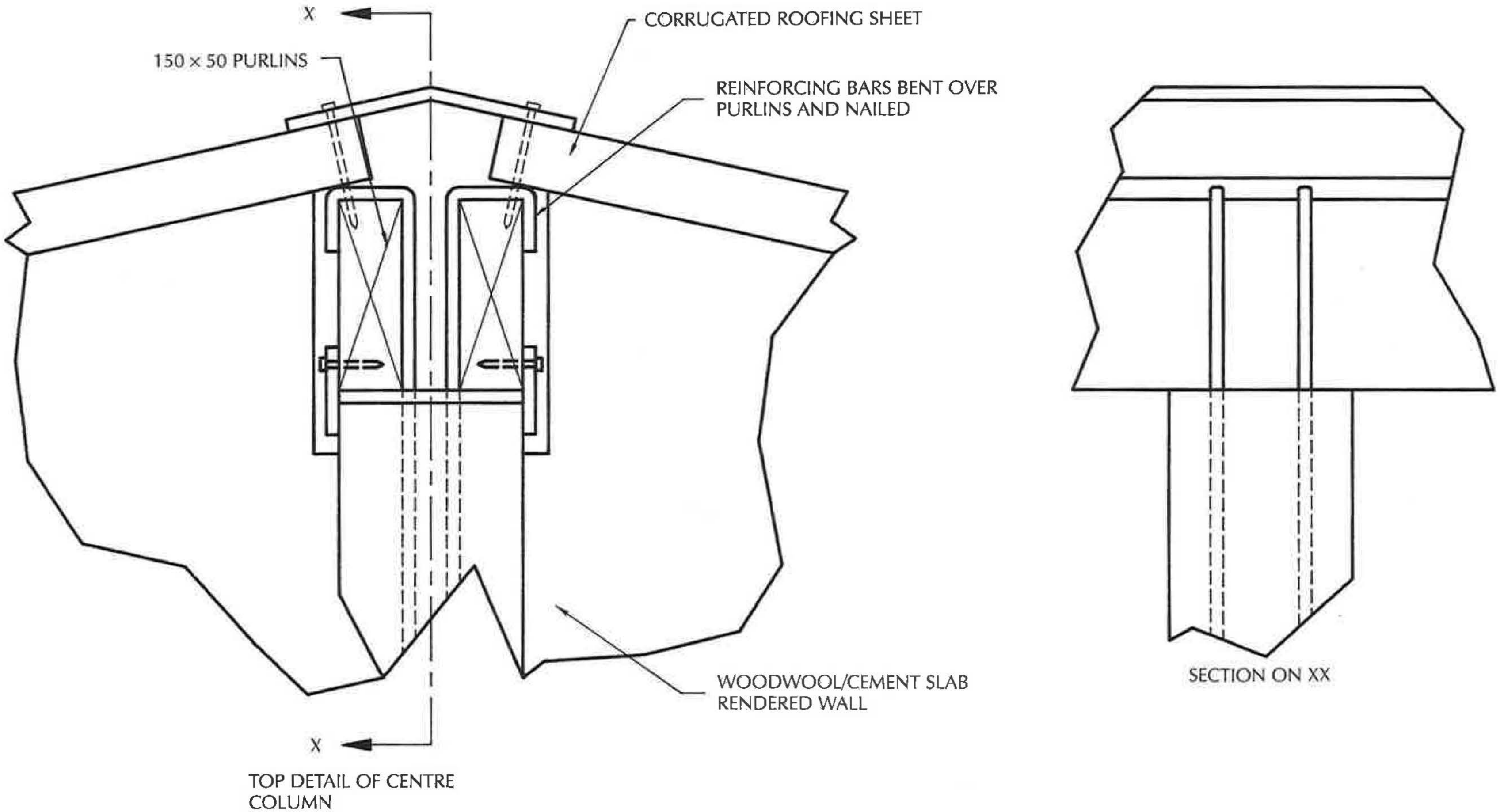


Figure 15 Detail C roof section

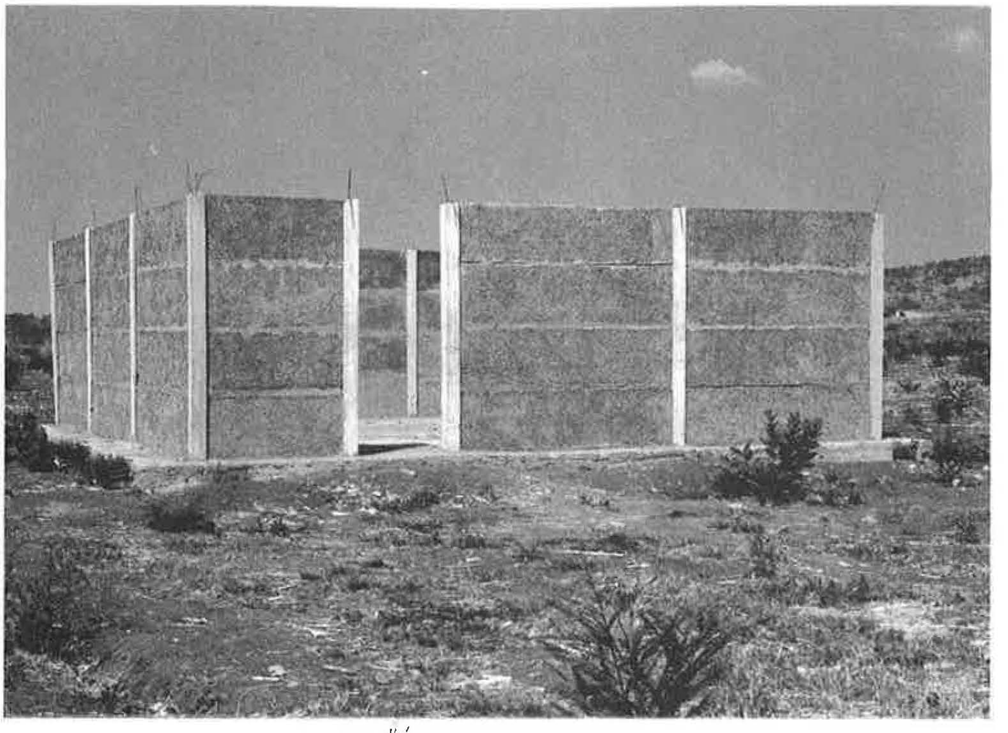


Figure 16 Basic framework for two-bedroomed house

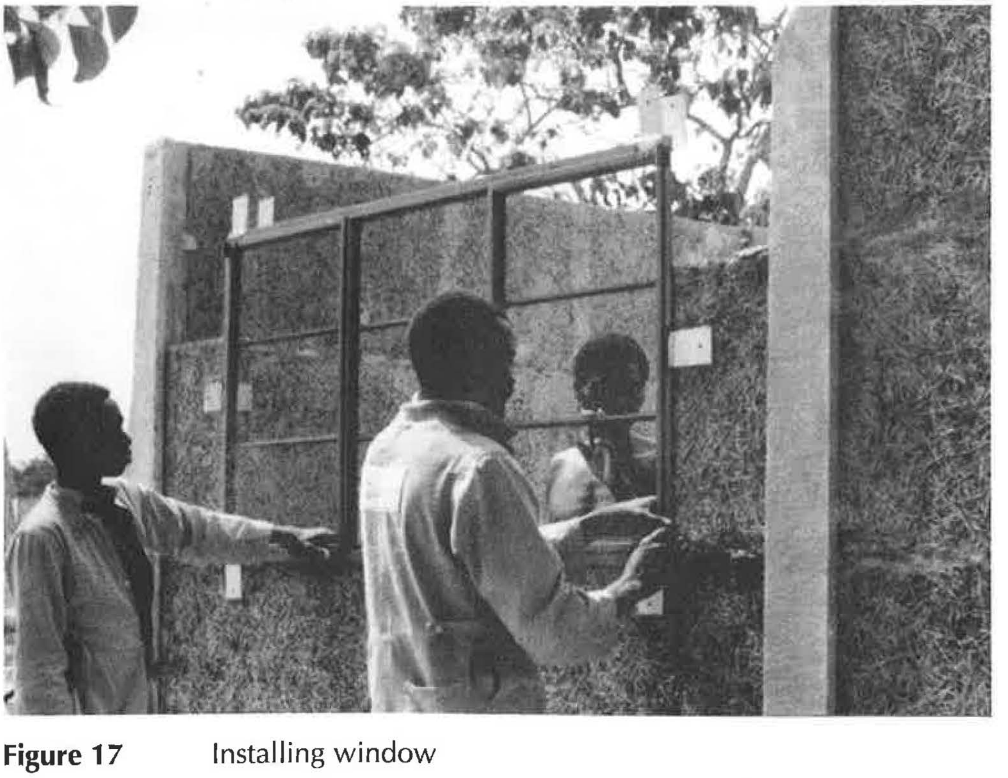


Figure 17 Installing window

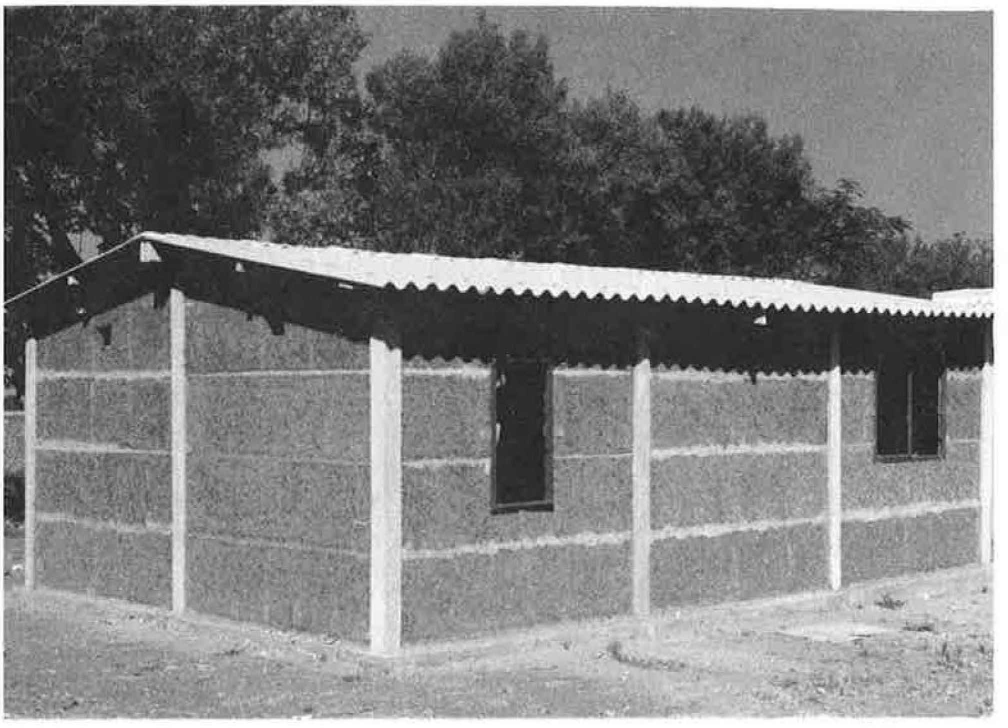


Figure 18 House ready for rendering and plastering

Figure 19 Larger house design

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Appendices

APPENDIX 1 DIMENSIONS AND PROPERTIES OF WOODWOOL BUILDING SLABS (DIN 1101: 1980)

Parameters	Length mm	Width mm	Thickness mm	Average weight per unit area kg/m²	Average density kg/m³	Minimum average bending strength N/mm²	Maximum average compressibility N/mm²
Tolerance	Individual values			Individual value +15% Average value +10%		Individual value -10%	> =
	+5 −10	+5 −5	+3 −2				
Nominal values	2000	500	15	8.5	570	1.7	–
			25	11.5	460	1.0	0.20
			35	14.5	415	0.7	0.20
			50	19.5	390	0.5	0.15
			75	28	375	0.4	0.15
			100	36	360	0.4	0.15

APPENDIX 2 TIMBERS TESTED FOR WOODWOOL/CEMENT MANUFACTURE

Results of tests carried out by NRI on sample slabs

BOTANICAL NAME	SUITABILITY
Albizzia falcataria	s
Albizzia lebbek	s
Azadirachta indica	ns
Calophyllum inophyllum	s
Cassia siamea	rs
Dacryodes excelsa	s
Dalbergia sissoo	s
Eperus falcata	ns
Eschweilera sp.	ns
Eucalyptus grandis	rs
Licania laxiflora	ns
Mora excelsa	ns
Pinus caribaea	s
Pinus kesiya	s
Pinus patula	s
Pterocarpus indica	ns
Sandoricum indicum	ns
Cinnamomum seylanicum	ns
Simaruba amara	rs
Swietenia macrophylla	ns

Results of tests carried out by others (Ashiabor, 1973; Elten Engineering; Sandermann, 1966; Wong and Ong, 1982)

Afzelia bipindensis	ns
Antiaris africana	ns
Antrocaryon micraster	ns
Berlinia grandiflora	s
Canarium achweinfurthii	rs
Cedrella odorata	s
Ceiba pentandra	ns
Celtis zenkeri	ns
Chlorophora excelsa	ns
Chrysophyllum africanum	s
Chrysophyllum albidum	s
Cola gigantea	rs
Cylicodiascus granunensis	s
Daniellia ogea	rs
Distemonanthus benthamianus	ns
Entandrophragma angolensis	s
Entandrophragma utile	s
Entandropragma cylindricum	rs
Guarea cedrata	ns
Khaya sp.	ns
Lovoa trichilioides	s
Mansonia altissima	rs
Mitragyna atipulosa	rs
Musanga cercropioides	s
Nauclea diderrichii	ns
Nesogordonia papaverifera	rs
Ongokea gore	ns
Pericopsis elata	ns
Piptadeniastrum africanum	ns
Pterygota macrocarpa	ns
Tarrietia utilis	rs
Tectona grandis	s
Terminalia ivorensis	rs
Terminalia spread	ns
Terminalia superba	s
Tieghemella heckelii	ns
Triplochiton acleroxylon	rs

Results of tests carried out on Malayan timbers using a modified 'go/no go' test

The force required to pull a timber sample from a cement block was measured on a tensile testing machine (Instron). The results were compared to those obtained with a timber of proven suitability for slab manufacture, and therefore simply indicate the compatibility of the timbers tested with cement. Further work would be required to prove their suitability or otherwise for woodwool/cement slab manufacture.

Acacia mangium	ns
Albizia falcataria	ns
Alstonia spp.	ns
Anacardiaceae	s
Anisoptera spp.	ns
Anonaceae	ns
Artococarpus spp.	ns
Burseraceae	ns
Campnosperma spp.	ns

Cratoxylon spp.	s
Dillenia spp.	rs
Dipterocarpus spp.	rs
Dyera costulata	ns
Endospermum malaccense	rs
Eucalyptus grandis	ns
Gmelina arborea	s
Gonystylus spp.	rs
Heritiera spp.	rs
Hevea brasiliensis	ns
Kokoona spp.	s
Koompassia excelsa	s
Koompassia malaccensis	rs
Mangifera spp.	rs
Myristicaceae	ns
Pinus caribaea	s
Pometia spp.	ns
Scorodocarpus borneensis	s
Shorea macroptera	ns
Shorea rugosa	rs
Shorea spp.	rs
Sindora spp.	ns

s – suitable
ns – not suitable
rs – restricted suitability

APPENDIX 3 RAW MATERIAL SPECIFICATION

Cement – ordinary Portland cement (OPC) meeting the requirements of British Standard BS 12: 1971 'Specification for ordinary and rapid-hardening Portland cement' is suitable for the manufacture of woodwool/cement slabs.

Timber – timber for the production of woodwool must be proven to be compatible with cement, with or without the use of a mineralizing fluid. It must also machine readily without causing undue wear and tear on the knives and scorers of the woodwool machine. The recommended method to assess the suitability is to manufacture test samples. The timber is required in lengths of multiples of 500 mm and with diameters of between 100 and 300 mm. It must be debarked and stacked in a log yard for air seasoning for a period of three to four months in order to reduce the moisture content. Seasoning also reduces the effect that any extractives might have on the setting of cement.

Chemicals (mineralizing fluid) – calcium chloride, $CaCl_2$, has the most widespread use. In the NRI process, it is used in a 3% (SG 1.042) or a 5% (SG 1.025) solution in the woodwool soaking tank, depending upon the process quality control requirements. Commercial calcium chloride is supplied in flake form with a 70 – 80% solids content. A typical analysis is as follows:

Calcium chloride	78.0%
Sodium chloride	2.3%
Calcium sulphate	0.1%
Calcium oxide	0.05%
Iron	15ppm
Ammonia	0.01%
Water solubles	0.05%

When calcium chloride is not available, magnesium chloride, $MgCl_2$, or sodium silicate, $NaSiO_3$, may be used as alternatives. If either of these chemicals is chosen, the amounts required and the solution concentration needed will have to be determined by experiment.

Calcium chloride content

The British Standard Specification (BS 1105: 1981 Appendix A) requires that woodwool/cement slabs shall not contain more than 2.5% anhydrous calcium chloride based on the dry weight of the woodwool/cement slab when determined by specified chemical analysis. NRI does not determine calcium chloride content by analysis, since it can be shown from calculation that the specification is complied with when using the known chemical and raw material inputs. When producing a woodwool/cement slab with a density of 500 kg/m^3 and dimensions 2400 × 610 × 50 mm, this equates to 0.41% $CaCl_2$ content using a 3% solution and 0.68% using a 5% solution.

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