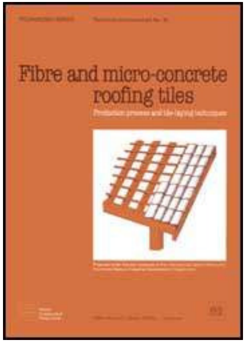

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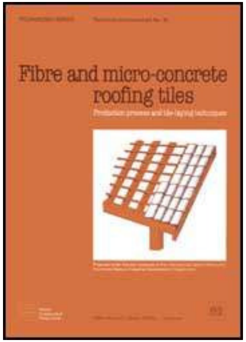

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TECHNOLOGY SERIES

Technical memorandum No. 16

Prepared under the joint auspices of the International Labour Office and the United Nations Industrial Development Organization by Gilbert Brys, Entrepreneurship and Management Development Branch, ILO

International Labour Office Geneva

The ILO's World Employment Programme (WEP) aims to assist and encourage member States to adopt and implement active policies and projects designed to promote full, productive and freely chosen employment and to reduce poverty. Through its action-oriented research, technical advisory services, national projects and the work of its four regional employment teams in Africa, Asia and Latin America, the WEP pays special attention to the longer-term development problems of rural areas where the vast majority of poor and underemployed people still live, and to the rapidly growing urban informal sector.

At the same time, in response to the economic crises and the growth in open unemployment of the 1980s, the WEP has entered into an ongoing dialogue with the social partners and other international agencies on the social dimensions of adjustment, and is devoting a major part of its policy analysis and advice to achieving greater equity in structural adjustment programmes. Employment and poverty monitoring, direct employment creation and income generation for vulnerable groups, linkages between macro-economic and micro-economic interventions, technological change and labour market problems and policies are among the areas covered,

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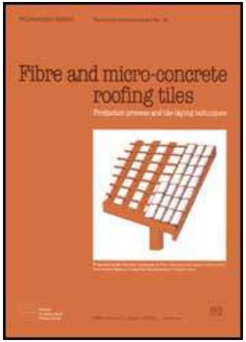

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CHAPTER VII ROOF STRUCTURE

This chapter presents all the factors which must be borne in mind when building roof structures for fibre or micro-concrete tiles. This section also deals with the incidence of prevailing winds on the choice of a structure, roofing timber and typical roof structures.

A few typical examples are given with detailed technical diagrams, including precise measurements for timber and an explanation of the method used for measuring timber consumption.

Sections VI, VII and VIII offer a comparative analysis of a corrugated iron roof as opposed to a fibre or micro-concrete roof. This costing analysis shows that the cost per square metre of roofing is distinctly cheaper if fibre or micro-concrete tiles are chosen.

I. BASIC PRINCIPLES

A roof structure may be built with either timber or metal components. In view of the fact that most developing countries have no domestic iron and steel industry and must import their metal, this report deals only with timber roof structures. However, the same basic principles apply whichever material is chosen.

A roof is composed of two inseparable elements: the structure and the cladding. The installation of a roof structure requires the best manpower available. A sturdy under-structure and well-laid cladding are essential to the installation of a durable roof.

Assemblies (figure 77) should be as rigid as possible. Assembly devices include: wooden pegs, bolts, nails, multinails, glues, etc. The trusses must be securely fastened to the building by means of anchors resisting wind pressure (see below). In hurricane climates special heavy-duty anchors are required.

The use of fibre or micro-concrete technology does not imply any special constraints on the structure of the building. Walls and foundations will be the same as for any other type of roof cladding. They should simply follow good building practices. Special attention should be given to the spanning of wall openings (doors and windows). Lintels should be sufficiently sturdy to avoid a partial collapse of the roof.

Before starting work on the framework a number of precautions should be taken: levelling of wall tops, checking parallelism of walls, checking right angles at all four comers of the building, etc.

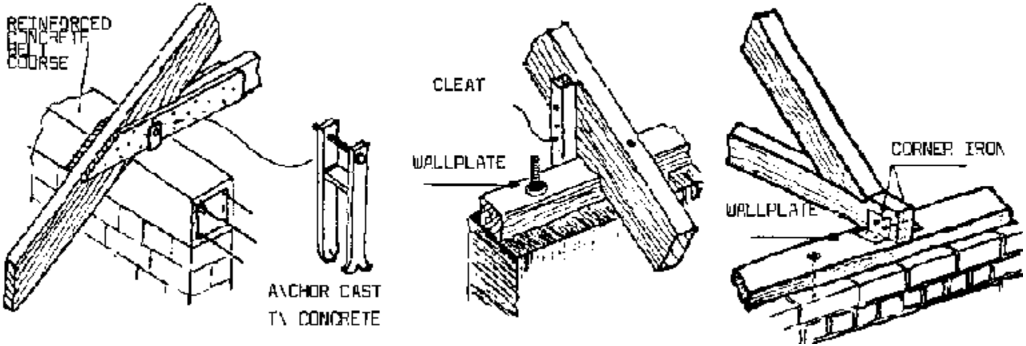


Figure 77. Three examples of anchoring a truss into a wall (ref. 31)

The design of the roof structure should take into account the various criteria which guarantee its adequacy to technical and geographical conditions:

- skilled manpower to build the roof structure;

- adjustment of roof pitch to rainfall, run-off and wind force;

- quality, size and treatment of structural timber. These requirements depend on local market conditions and no rules may be prescribed without a prior market survey.

II. ROOF DESIGN

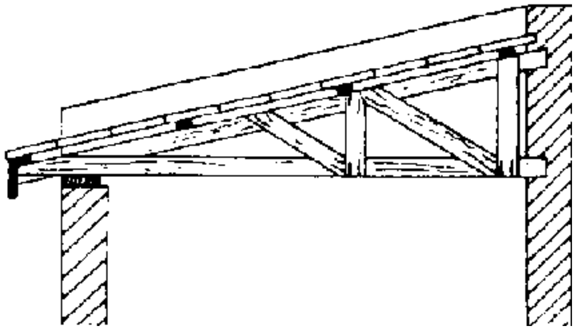
There are many different types of roofs: single, double, triple or quadruple pitch roofs, L-shaped roofs, etc. Fibre or micro-concrete technology implies a number of prerequisites which apply to all types of roofing. This technical memorandum deals only with single and double pitch roofs (lean-to and gabled roofs). For more complex roof designs, skilled carpenters will be required.

<u>The lean-to roof</u> (single pitch) (figure 78) is the simplest of all. If the span is reasonable it does not require cross members. Properly designed trusses are able to span very wide buildings. It is best, however, to keep the span reasonable. The frame is made of rafters anchored in the higher and lower walls of the construction. A lean-to roof should be covered with pantiles, or roman tiles; there are no ridge tiles.

<u>A gable roof</u> (double pitch) is more complex. It can span wider buildings. The frame is composed of a truss made of several cross members and a tie-beam. The truss presents several advantages compared with a lean-to structure:

- **- smaller timber sizes;**
- **- more stable roof structure;**
- **- absence of horizontal loads on the top of walls (the thrust is absorbed by the tie-beam).**

However, a gable roof requires more professional skills. Pantiles, roman tiles and ridge tiles should be used for the cladding.



<u>Figure 78. Lean-to roof</u>

Figure 79. Gable roof

III. WIND LOAD

The roof pitch (slope) should meet two requirements: rain-water run-off and wind resistance. Experiments carried out with scaled down models show that the side of a closed building directly exposed to the wind (windward wall) is subjected to wind pressure, whereas the side of the building which is sheltered from the wind (lee side) is subjected to wind suction. Wind pressure and wind suction may be considered as exerting perpendicular forces on the roof (figures 80 and 81). However, the resultant of regular loads and extra loads (vertical downward) and wind (perpendicular to roof surface) is in a downward direction on the windward side and outward direction on the lee side (figure 82).

Roof overhangs, eaves, ridges, protruding edges and corners are useful construction devices because they protect walls from driving rains and afford better protection against the sun (cast shadow). However, in rough climates and hurricane areas, they should be avoided as offering additional exposure to wind uplift (figure 83).

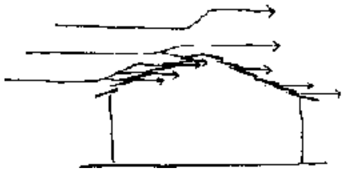


Figure 80. Resultant of wind loads on non-airtight roof (ref. 3)

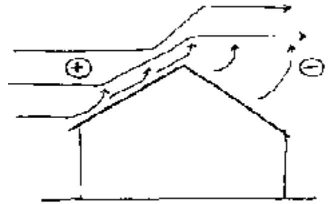


Figure 81. Resultant of wind loads on sealed roof

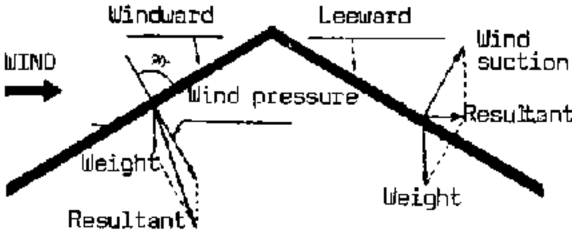


Figure 82. Resultant of wind pressure and loads on roof

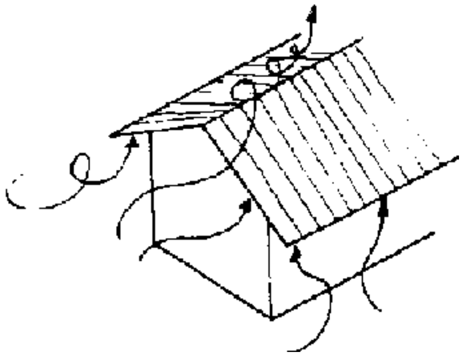


Figure 83. Effect of wind; eaves, ridges

The diagram below (figure 84) shows the relationship between roof pitch and the pressure/suction forces generated by the wind. The flatter the slope, the stronger the wind suction.

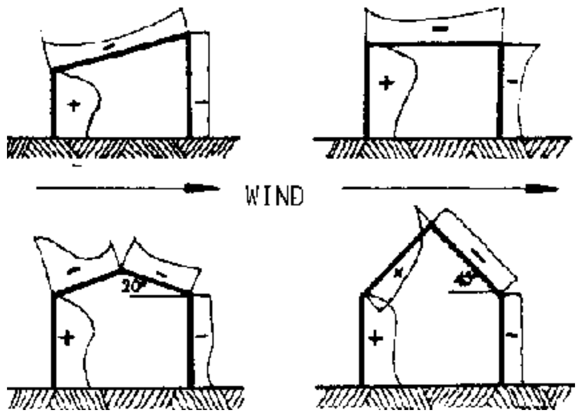


Figure 84. Diagram of wind pressures in relationship to roof pitch (ref. 17)

The pressure exerted by the wind at a 90º angle (expressed in kg/m^2) increases rapidly with wind speed (table 23).

Table 23. Wind load in kg/m^2

	Light breeze	Breeze	Strong breeze	Very strong breeze	Gale	Strong gale	Storm	Hurricane
Pressure	0.53	2.13	4.79	13.30	29.90	53.20	119.70	172.30

kg/m^2

IV. ROOF PITCH

Appropriate roof slopes for fibre or micro-concrete tiles technology range between 22º and 30º.

If the slope is not steep enough (under 20º):

- **the likelihood of water seeping up (trickling up) through the tile is stronger;**
- **both slopes of the roof are constantly subjected to wind suction (figure 84).**

For quick disposal of run-off rain-water, the pitch should be at least 22º. In heavy rainfall areas the pitch should be steeper for faster run-off, i.e. 27º to 30º.

Table 24 gives conversion figures from slope pitches (in degrees) to percentages. This table may be used by carpenters and other building technicians to manufacture a roof template meeting blueprint requirements. The template is made of three wood or metal segments assembled in a triangle. The base of the triangle is one metre long and the height given by the percentage figure in the table. The hypotenuse (long side) of the triangle gives the roof pitch.

Table 24. Roof pitch conversion table: degrees to percentages

Roof pitch (degrees)	Slope (%)	Roof pitch (degrees)	Slope (%)
20	36	26	49
21	38	27	51
22	40	28	53
23	42	29	55
24	45	30	58

24	45	50	58
25	47		

Note: The roof pitch has a considerable influence on the number of tiles required to cover a building. The number of tiles is the same per square metre, but the number of square metres changes with the roof slope (see chapter VIII, section III). The steeper the roof slope, the larger the roof surface will be.

V. TIMBER SECTIONS

Timber size, assembly and quantity vary locally and with wood quality. The span of roof trusses ranges between 4 and 10 metres.

If the spacing between trusses is under or equal to 1.60 m, the purlins may be fastened directly to the truss rafters (see roof frame type I, section VII. 3 below). However, if the distance between rafters is larger the span between lath supports should be reduced by building a lattice of purlins and rafters (see roof frame type II, section VII. 4 below).

The timber used for a roof structure should be straight (sawn timber). Rough-hewn timber may be used for low-cost trusses. Utmost care should be taken to respect correct levels and planes. Poles and certain species of bamboo may also be used for roof frames.

In tropical climates the wood should be protected against insects and decay (rot, fungi). Standard products such as "Dieldrin" and "Lindane" against insects, and "Creosote" against decay, are strongly recommended. A second-best preservative is used motor oil.

VI. A COMPARISON OF ROOF STRUCTURES FOR CORRUGATED IRON AND FIBRE OR MICRO-CONCRETE CLADDING

VI.1 The problem

One square metre of fibre or micro-concrete cladding is relatively more economical than the same quantity of corrugated iron (particularly if it must be imported). By way of example, table 32 (chapter X, section V) gives the prices of various types of roof covering per square metre for three African countries.

The main argument against fibre or micro-concrete roofing is weight. The reasoning is as follows: "the weight of concrete tiles being twice that of corrugated iron, the strength of the roof structure should be increased accordingly; the increase in the amount of structural material required increases the overall cost of the roof and cancels out the savings made by using cheaper tiles rather than corrugated iron".

The purpose of this section is to show that:

- the amount of wood required for a concrete roof cladding may be smaller than for corrugated iron;

- case-studies show that although there is a slight increase in the amount of timber used for concrete roofing, the total cost of a concrete roof (roof frame + cladding) results in an average 25 per cent saving.

Table 25 (section VIII in this chapter) gives a comparison of production costs per square metre for both concrete and corrugated iron roofing material (Cte d'Ivoire).

VI.2 Economics of concrete cladding

1. Loads on roof include structural loads and additional loads. To calculate the sections of timber required, both structural loads and additional loads should be taken into account.

- structural loads; these include the cladding material and the self-weight of the frame. The weight of the frame depends on the overall roof dimension, intervals

between rafters and mainly timber quality. The self-weight of a roof structure for concrete covering is practically the same as that required for a corrugated iron covering. However, the self-weight of a roof structure for clay tiles is distinctly higher than for concrete tiles. Basically, a comparison between concrete tiles and corrugated iron sheet shows a 10 kg to 20 kg weight increase per square metre depending on tile thickness.

- <u>occasional extra loads;</u> these loads are identical whatever the cladding material. They result from wind pressure (see section III in this chapter) and live loads, e.g. workers moving on the roof during construction or repairs.

Table 21 shows the load variation for different types of cladding materials, expressed as a percentage of the load calculated for the reference material, i.e. fibre or micro-concrete.

<u>Table 21. Load variation for different types of cladding materials</u>

	Fibre or micro-concrete (reference)	Corrugated iron		Clay	tiles
		variation			
	kg/m^2	kg/m^2	in %	kg/m^2	variation in %
Weight of frame	30	30	0	45	+ 50
Weight of cladding	22	10	50	60	+200
Structural loads	52	40	25	105	+100
Extra loads	80	80	0	80	0
TOTAL ROOF	132	120	10	185	+ 40

The table shows clearly that a mere comparison of roofing materials only, excluding extra loads, is not relevant. A valid comparison should be based on the sum of all the forces

applying to the total roof:

- a comparison of concrete roofing versus corrugated iron shows that the total weight of a concrete roof is only 10 per cent heavier than that of a corrugated iron roof. In view of the relevant safety factors this increase is negligible.

- a comparison of concrete and clay tile roofs shows a 40 per cent difference in total weight, due essentially to the covering material. Fibre or micro-concrete tiles will require a lower cost structure than for clay tiles. The latter will need to be substantially cheaper than fibre or micro-concrete tiles in order to yield a lower cost roof.

2. Comparison of theoretical parameters

Table 22 includes all the parameters required to work out an initial comparative estimate of different types of roofs for different types of cladding: self-weight of covering material, section of structural timber, and timber consumption per square metre of roof slope.

Table 22. Comparison of parameters for the calculation of timber consumption

	Unit	Clay 40-80 tiles per m^2	Fibre/ micro-concrete tiles	Corrugated iron sheets	Asbestos sheets
Self-weight of roof cladding	kg/m^2	60	21	10	20
Spacing of rafters (centre)	cm	70	120	110	150
Section of rafters	cm	6 ×20	5 ×10	6 ×12	5 ×10
Spacing of laths (centre)	cm	30	40	100	90
Section of laths (L) or purlins (P)	cm	3 × 4 (L)	3 × 4(L)	3 × 5 (L)	5 × 7.5(P)

Timber consumption per square metre of roof slope	m^3	0.0150	0.0080	0.0090	0.0091

Source: ref. 11.

The following conclusions may be drawn from the above table:

- timber consumption is higher for a clay tile cladding on account of its heavier weight and the larger number of laths required;

- timber consumption is also higher for corrugated iron or asbestos sheets because the larger spans between supports require larger timber sections.

A detailed comparative analysis for different types of roofing is given in section VII of this chapter, including estimates of the type and amount of timber required.

3. Modular measurements

It is worth noting that roof dimensions are decided before timber consumption is calculated. If the material chosen for the roof cladding comes in large sizes (asbestos sheet or corrugated iron) there is bound to be a loss of material through cutting or overlapping. The reduced size of tiles, however, offers added flexibility. This distinct advantage of tile cladding has a direct influence on roofing costs, since the number of square metres purchased is exactly equal to the surface to be covered (see section VII in this chapter).

VI.3 Conclusion

From a strictly economic standpoint, the overall cost of a fibre or micro-concrete roofing should not exceed that of a galvanized corrugated iron roof. In fact, substantial savings

can be made. In Cte d'Ivoire, for instance, a fibre or micro-concrete roof is 35 per cent cheaper than a corrugated iron cover. Economic studies covering three countries confirm this statement (see chapter X, section V).

VII. ROOF DESIGN AND TIMBER CONSUMPTION

The four designs below show different examples of roof structures. There are of course many other possibilities: they may be found in construction manuals for other applications. The three examples given for a gabled structure (VII.2, VII.3 and VII.4) give a comparative breakdown of costs for one corrugated iron roof and two fibre or micro-concrete structures.

Note

The prices used for the cost analysis and comparative table (section VIII) are calculated on the basis of the cost of materials sold in November 1987 by wholesalers in San Pdro, Cte d'Ivoire: timber per m^3 in a sawmill, corrugated iron by the sheet in ironmongeries.

VII.1 Lean-to design (figure 85)

This is a single slope roof. The span is 2.40 m. This small storage shed for FC tiles was built in San Pdro, Cte d'Ivoire. It was built as an extension to the existing tile unit which is itself covered in corrugated iron sheet.

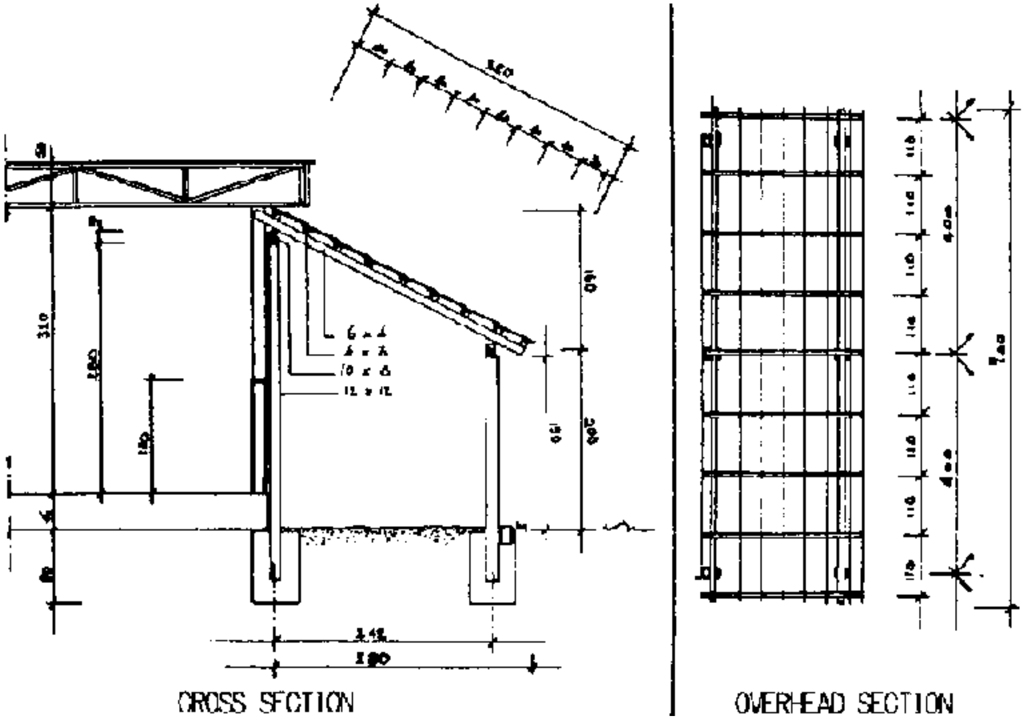


Figure 85. Lean-to design: single slope

VII.2 Costing of galvanized iron sheet roof (figure 86)

The structure is made of three triangular trusses.

The roof-frame design is shown on the opposite page. The dimensions used in the calculation below are based on this design.

1. The dimensions of the building are pre-established: 6.50 m × 5 m.

The roof overhangs allow for optimal use of the sheets since these are supplied in standard sizes of 2 m × 0.82 m.

Placing sheet material on the roof slopes (7.28 m × 3.64 m × 2 = 53 m^2) implies that either:

- **the sheets are cut to size;**
- **the overlaps are increased;**
- **the overhangs are increased.**

2. Timber section: the spacing between trusses (centre) is 3.22 m.

To span this interval, purlins of 0.06 m × 0.08 m section are required. Smaller purlins may be used provided an additional truss is built to reduce the intervals between trusses.

3. The theoretical coverage area of corrugated iron sheet is as follows:

Dimension of sheet: 2 m × 0.82 m
Surface of sheet: 1.64 m^2
Lengthwise overlap: 0.2 m
Widthwise overlap: 0.1 m
Actual vertical overlap: 2 × 2 m - 3.64 m = 0.36 m
Total overlap: (0.2 m × 0.82 m) + (1.8 m × 0.1 m) = 0.344 m^2
Theoretical coverage area: 1.64 m^2 - 0.344 m^2 = 1.296 m^2.

4. Price per m^2 of sheet coverage:

Price of one sheet: CFA francs 1,880 (1.64 m^2)

Price per m^2 of coverage area: 1,880 : 1.296 m^2 = CFA francs 1,450.60.

5. Theoretical cost of roofing: 53 m^2 × CFA francs 1,450.60 = CFA francs 76,882,

6. Actual cost of covering material:

Across slope: 10 sheets
Down slope: 2 sheets
Total number of sheets: 20 × 2 = 40 sheets
Cost of covering: 40 × CFA francs 1,880 = CFA francs 75,200.

7. Ridge covers are sold in lengths of 2 metres.

Number of units: 4 for 7.28 linear metres
Unit price: CFA francs 3,830
Theoretical price per metre: CFA francs 1,915
Theoretical price of ridge: 7.28 m × CFA francs 1,915 = CFA francs 13,941
Real price of ridge covering: 4 × CFA francs 3,830 = CFA francs 15,320.

8. Timber consumption per m^2 of roof structure is calculated as follows:

Timber measurements: see diagram

Price of timber per m^3: CFA francs 38,000/m^3

Cost: 0.6641 m^3 × CFA francs 38,000 = CFA francs 25,236.

9. The total cost of the roof (structure + covering) is indicated in the final table in section VIII of this chapter.

ROOF STRUCTURE FOR CORRUGATED IRON SHEET

I. DIMENSIONS

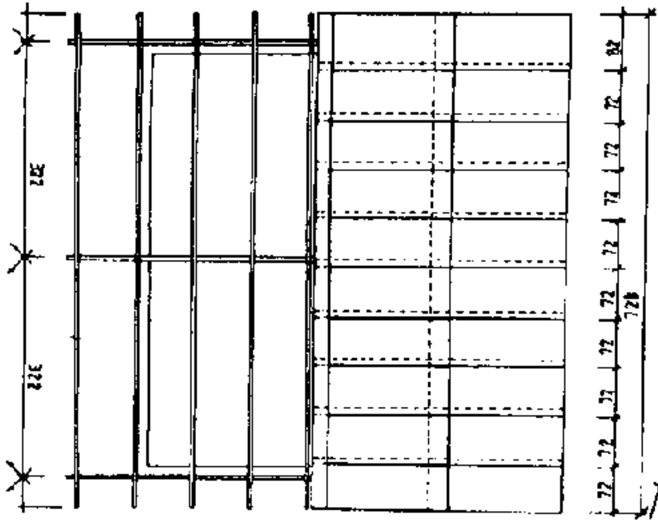
Building	6.50 x 5 m
Slopes	7.28 m x 3.64 m x 2 = 53 m^2
Structure	3 trusses 3.22 centre; slope 10° (18%); span 5 m

II. TIMBER CONSUMPTION

No	Designation	Dimension m x m x m	Quantity U	Volume m^3
1	Main rafter	0,06x0,10x3,60	6	0.1296
2	Tie beam	0,06x0,10x5,60	3	0,1008
3	Strut	0,06x0,08x2,90	3	0,0417
4	Wallplate	0,04x0,08x6,50	2	0,0416
5	Purlins	0,06x0,08x7,30	10	0,3504
			TOTAL	0,6641 m^3

III. LENGTH COVERED

N° of sheets 20 x 2 = 40 sheets
Ridge 7.28 metres



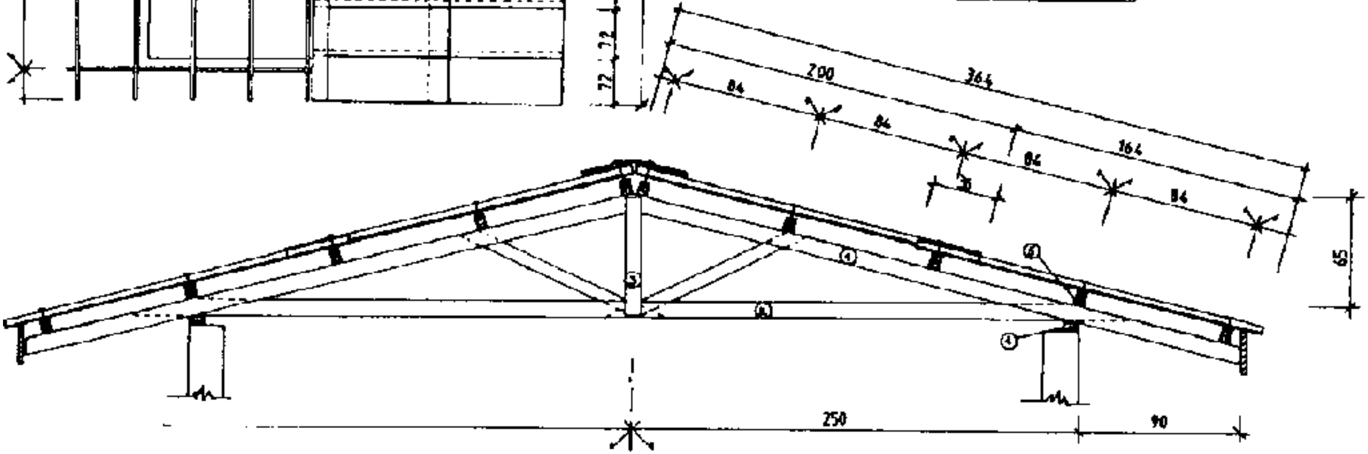


Figure 86. Costing of iron sheet roof

VII.3 Costing of short-span fibre or micro-concrete roof (type I) (figure 87)

1. This is a roof for a small 6.5 m × 5 m building. The span is fairly short: 5 m. The roof structure is made of five triangular trusses. The roof frame design is shown on the next page. The dimensions used for the calculation below are based on this design.

2. Timber sections: intervals between rafters = 1.61 m.

To span this interval, the laths should be placed on their narrow side.

A lattice of rafters and purlins is not necessary.

3. The dimensions of the building are given. The dimensions of the slopes are such that the length and the width of the roof may be divided by an exact number of tiles (see section VI.2.3 in this chapter).

4. Tile consumption:

Height of slope: (3.60 m + 0.2 m) equivalent to 9 tiles + ridge
Width of slope: 7.25 m equivalent to 36 tiles
Surface of slopes: 7.25 m × 3.80 m × 2 = 55.1 m^2

Surface to be covered with pantiles:	Subtract ridge coverage area
	: 7.25 m × 0.2 m × 2 = 2.9 m^2
	: 55.10 m^2 - 2.9 m^2 = 52.2 m^2

Theoretical number of tiles per m^2: 12.5
Theoretical number of tiles: 52.2 m^2 × 12.5 = 652 tiles

Actual number of tiles: 36 × 9 × 2 = 648 tiles
Number of tiles to be ordered (+5% breakage): 648 + 5% = 680 tiles.

5. Real cost of tiles: 680 × CFA francs 80 = CFA francs 54,400.

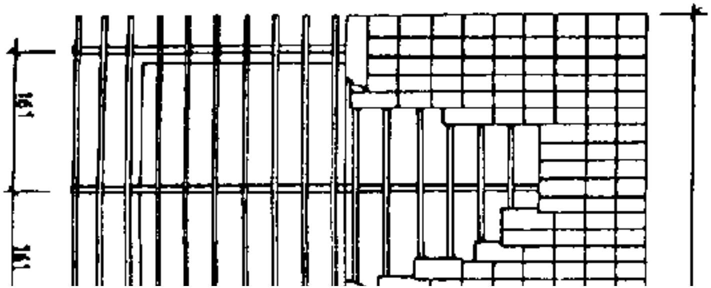
6. Ridge tiles are 26 cm wide:

Number of ridge tiles: 7.25 m : 26 = 28 units
Number of ridge tiles (+5% breakage) = 30 units
Cost of ridge tiles: 30 × CFA francs 105 = CFA francs 3,150.

7. The cost of 1 m^3 of structural timber is calculated as follows:

Timber consumption: see diagram below.
Price of timber per m^3: CFA francs 38,000/m^3
0.818 m^3 × CFA francs 38,000 = CFA francs 31,084.

8. The total cost of the roof is indicated in the summary table in section VIII of this chapter.



ROOF STRUCTURE FOR FIBRE CONCRETE TILES TYPE I

I. BLDG. : 6.50 m x 5 m
Slope : 7.25 m x 3.80 m = 55.1 m^2
Structure : 5 trusses 1.61 m centre; slope 25°

II. TIMBER CONSUMPTION

No	Designation	Dimension m x m x m	Quantity U	
1	Main rafter	0.06x0.12x3.70	10	0
2	Tie beam	0.06x0.12x5.50	5	0
3	Strut	0.06x0.10x4.60	5	0

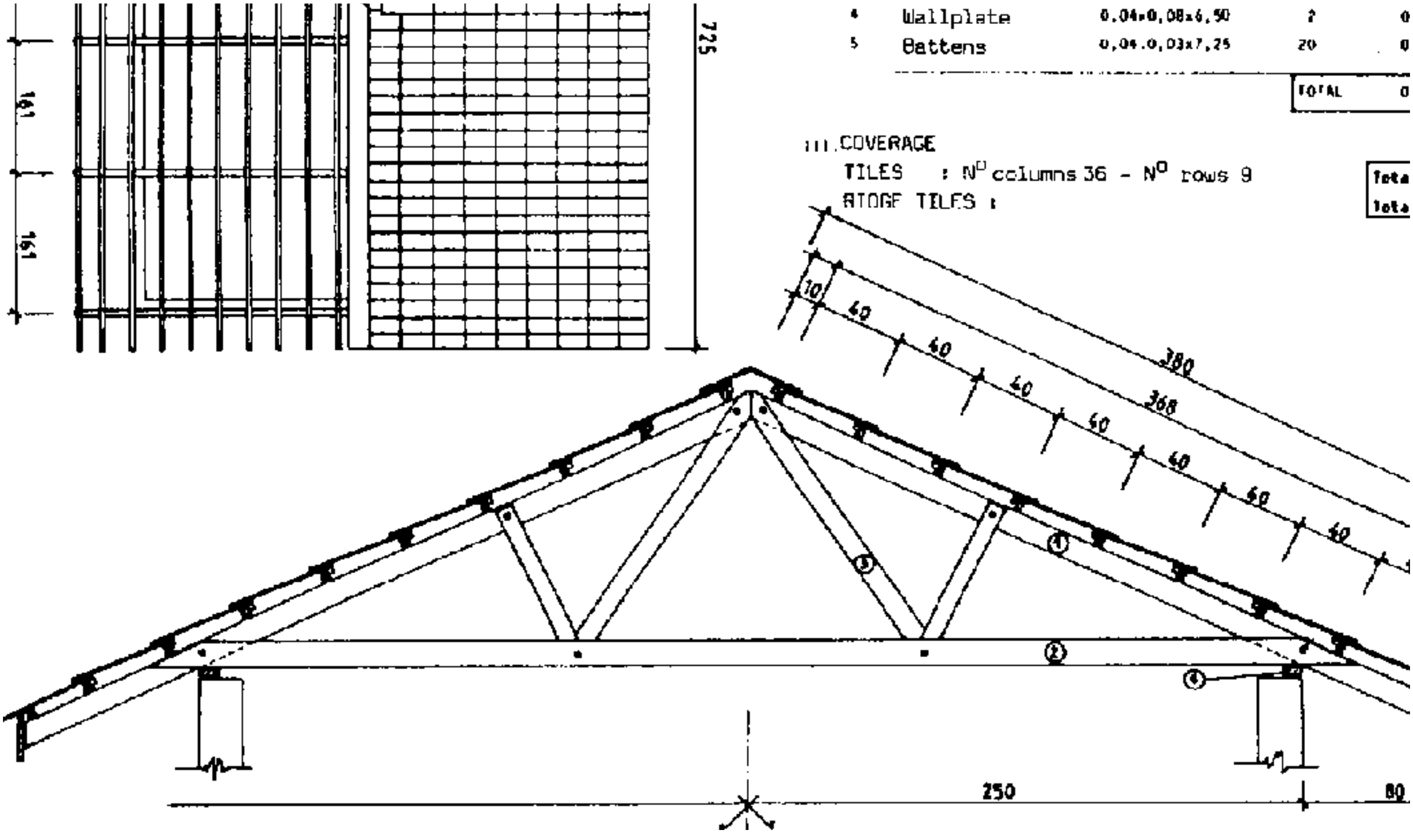


Figure 87. Costing of materials for fibre or micro-concrete covering (short span) (type I) Intervals between trusses (centre): 1.61 m

VII.4 Roofing material for fibre or micro-concrete roof (large span) (type II) (figure 88)

1. This roof is intended for a larger building: 7.50 m × 7 m.
The span is also larger: 7 m.
The structure is composed of three triangular trusses with a 7 m span.
Intervals between trusses (centre) is 3.55 m.
A lattice of rafters and purlins is necessary.

2. Timber sections:

Purlins of 10 cm thickness can span the intervals between trusses.
The distance between the ridge purlin and the wall-plate is 3.90 m.
An intermediate purlin reduces the spacings between rafters to 1.95 m.
A section of 0.04 m × 0.06 m is sufficient for these rafters. The intervals between rafters (centre) is 1.42 m. Laths of 0.04 m × 0.03 m are suitable for such intervals.

3. The dimensions of the building are given. The dimensions of the slope are such that the length and the width of the roof may be divided by an exact number of tiles (see section VI.2.3 in this chapter).

4. Tile consumption:

Down slope: (4.40 m + 0.2 m) equivalent to 11 tiles + ridge
Across slope: 7.85 m equivalent to 39 tiles
Surface of slopes: 7.85 m × 4.60 m = 72.2 m^2

Surface to be covered with pantiles:	Subtract ridge coverage area
	: 7.85m × 0.2m × 2 = 3.14m^2
	: 72.2 m^2 - 3.14 m^2 = 69.06 m^2

Theoretical number of tiles per m^2: 12.5

Theoretical number of tiles: 69.06 m^2 × 12.5 = 862 tiles
Actual number of tiles: 39 × 11 × 2 = 858 tiles
Number of tiles to be ordered (+5% breakage): 858 + 5% = 900 tiles.

5. Real cost of tiles: 900 × CFA francs 80 = CFA francs 72,000.

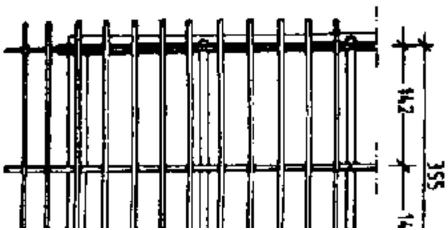
6. Ridge tiles are 30 cm wide:

Number of ridge tiles: 7.85 m : 26 = 31 units
Number of ridge tiles (+5% breakage) = 33 units
Cost of ridge tiles: 33 × CFA francs 105 = CFA francs 3,465.

7. The cost of 1 m^3 of structural timber is calculated as follows:

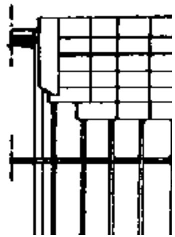
Timber consumption: see diagram below.
Price of timber per m^3: CFA francs 38,000/m^3
1.1407 m^3 × CFA francs 38,000 = CFA francs 43,346.

8. The total cost of the roof is indicated in the summary table in section VIII of this chapter.



II. TIMBER CONSUMPTION

No.	Designation	Dimension m x m x m	Quantity U	Volume m^3
1	Main rafter	0,07x0,15x3,80	6	0,2394
2	Tie beam	0,07x0,15x7,10	3	0,22365
3	Strut	0,07x0,12x1,95	6	0,09828
4	King post	0,07x0,12x1,60	3	0,0432
5	Ridge purlin	0,06x0,10x7,40	1	0,0444



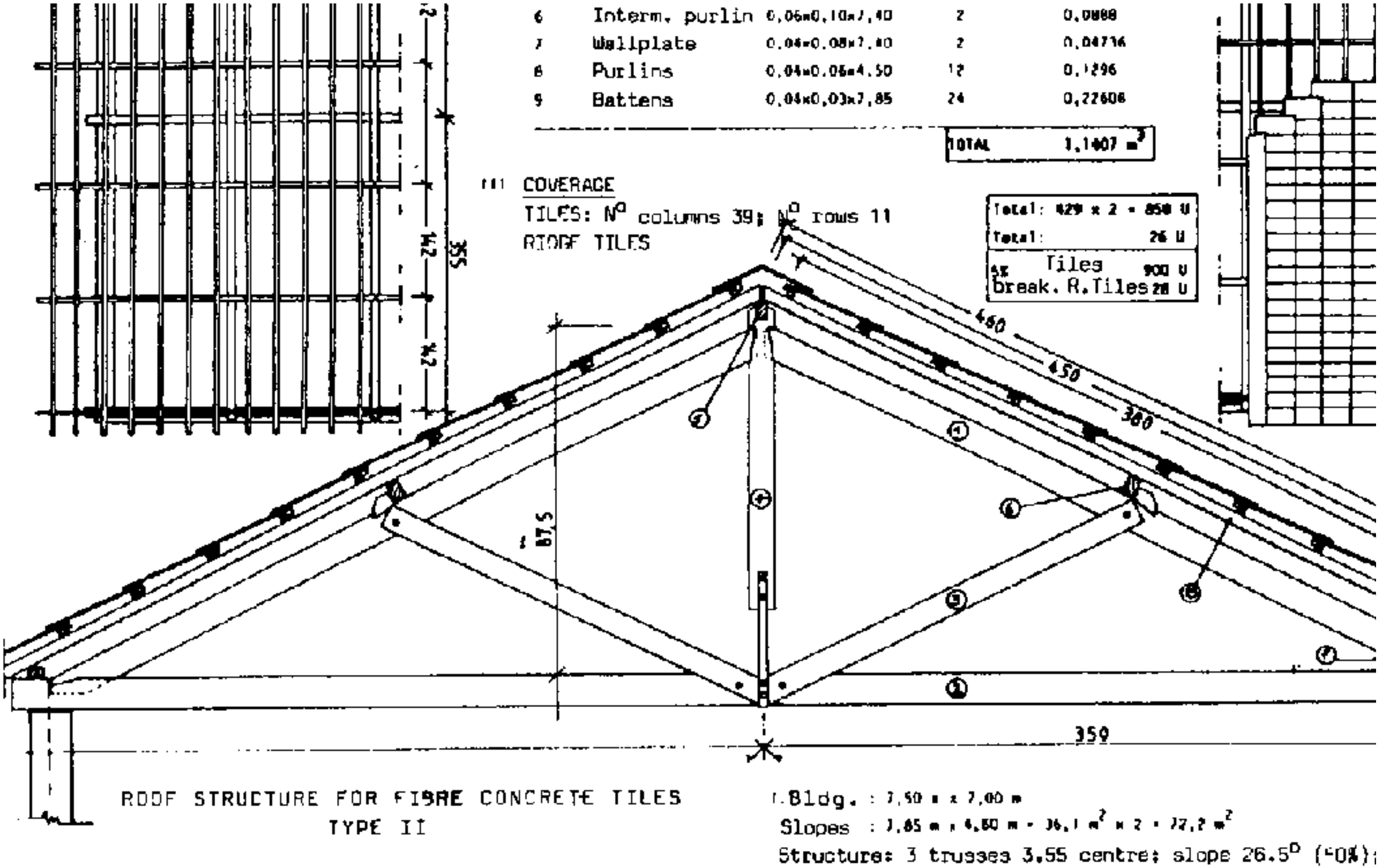


Figure 88. Costing of materials for fibre or micro-concrete covering (large span) (type 11) Trusses + purlins and rafters

VIII. COMPARATIVE COSTING OF CORRUGATED IRON AND FIBRE OR MICRO-CONCRETE ROOF COVERINGS

Table 25 provides a comparative costing of raw materials. It shows the raw materials consumption and production costs for the three types of roofs analysed above: corrugated iron sheet, fibre or micro-concrete (short span), fibre or micro-concrete (large span).

Note

Please refer to the note at the beginning of section VII. This costing analysis does not include transport costs, labour and profits. Such a comprehensive estimate was carried out in April 1988 in Cte d'Ivoire and confirms that the overall cost of a fibre or micro-concrete roof is 30 per cent tower than that of a similar corrugated iron roof.

Table 25. Comparative table of costs for corrugated iron and fibre or micro-concrete roofing (San Pdro. Cte d'Ivoire)

DESIGNATION	UNIT	CORRUGATED SHEET			FIBRE OR MICRO CONCRETE					
					TYPE A (price CFA F)			TYPE B (price CFA F)		
		Unit. Price	Qty.	Total Price	Unit. Price	Qty.	Total Price	Unit. Price	Qty.	Total Price
Structural Timber	m^3	38.000	0,6641	75.236	38,000	0,818	31,084	38,000	1,1407	43,346
Cladding	m^2		53			55,1			72,2	
(Sheet/tiles)	unit	1.880	40	75.200	80	680	54,400	80	900	72,000
Ridge	ml		7,28			7,25			7,85	
(Sheet/Tiles)	unit	3.830	4	15.320	105	26	2.730	105	28	2,940
Total cost			53 m^2	115.756		55,1	88,214		72,2	118,286

Total cost			53 m^2	[illegible]		[illegible] m^2	[illegible]		[illegible] m^2	[illegible]
Unit cost			m^2	2.184		m^2	1,601		m^2	1,638

TOTAL SAVINGS WITH FIBRE OR MICRO-CONCRETE: 35%

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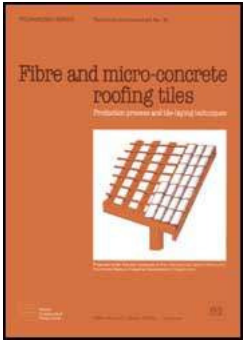


Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

V.2 Double nib tiles
V.3 Fixing ridge tiles

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

CHAPTER VIII LAYING THE TILES

This chapter is intended for the skilled workmen who will lay the tiles on the roof structure. A pro-condition for proper installation is to look into the means of ensuring watertightness, especially for the most exposed areas: the sides and wall-plates. The battens supporting the tiles should be fixed by a skilled roofer. This is a delicate job requiring great precision. Before laying the tiles, the roofer should make sure that he has the correct quantity of tiles for the area to be covered. The final section of this chapter deals with the various criteria to be observed when laying tiles and fixing them on the roof frame.

I. WATERTIGHTKESS

I.1 Edges

In regions exposed to violent winds, special attention should be given to the edges. Two assembly systems are available to fasten the edge tiles securely and prevent wind penetration and uplift on this exposed section of the roof (see chapter VII, section III). The first solution is extremely simple: a small scantling is nailed at the end of the purlin (driving the nails upwards). This small block of wood will support the edge of the end tile and keep it level with the other tiles (figure 89).

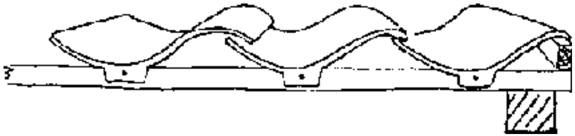


Figure 89. Laying the last tile across a scantling

The second system ensures better watertightness. The principle is the same: the edge of the tile rests on a scantling. The side of the roof is closed with boards to prevent the wind from penetrating under the tiles (figure 90).

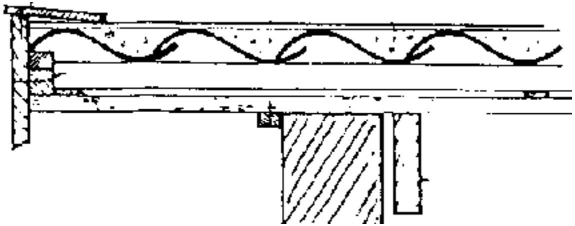


Figure 90. Watertight closing of sides

I.2 Wall-plates

If a board is laid at the bottom end of the slope, the top part of the board should be at least as high as the battens (figure 91). This presents the twofold advantage of closing the void between the covering and the frame and supporting the last row of tiles so as to keep the roof slope level. If no board is placed at the bottom end of the roof, the last batten should be placed at a distance of a few centimetres from the lower edge of the rafters.

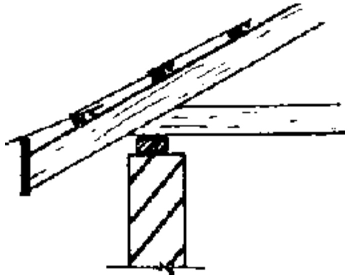


Figure 91. End border

I.3 Waterproof polythene sheet

In hurricane climates it is advisable to place a waterproof sheet under the tiles. It offers protection against dust and water infiltration when the roof is subjected to strong gusts of wind. A polythene sheet is inserted between the rafters and the purlin. The polythene strips are placed horizontally starting from the bottom of the slope and should be left slack. Minimum overlap of strips is 15 cm.

II. LAYING THE BATTENS (OR LATHS)

Placing the battens requires precision. They should be strictly parallel. Battens have small sections (0.03 m × 0.04 m or 0.025 m × 0.05 m). If the roof is likely to be subjected to exceptional loads and pressures, the batten section should be increased.

Spacing of the battens depends on tile length and overlap. Pantiles measuring 25 cm × 50 cm should be laid on battens placed at precise 40 cm intervals. For correct spacing, a template may be used (figure 92).

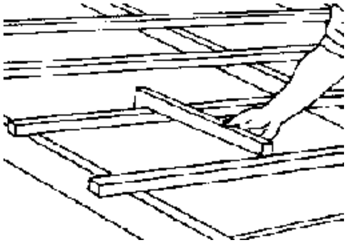


Figure 92. Carpenter's template for correct spacing of purlins

When the length of the roof slope is a multiple of 40 cm, an exact number of tiles may be used ("n"): all the visible parts of the tiles are identical. If the roof slope is not a multiple of 40 cm, the last two battens (close to the ridge) should be placed closer: the second row of tiles will be narrower than the rest.

Before laying the tiles, the roof structure should be checked for alignment. A sighting should be taken from an angle of the building to check that the upper and lower extremities of trusses and rafters are correctly aligned. Along the roof slope, battens should be absolutely level. To check this, a perfectly straight control batten should be placed along the roof slope, perpendicular to the battens. All the battens should be in contact with the control rod (figure 93).

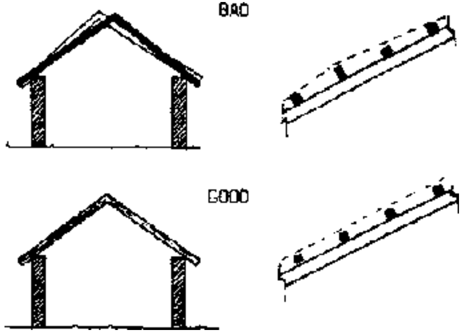


Figure 93. Structural checks before laying the tiles

III. CALCULATION OF RAW MATERIALS CONSUMPTION

The outside dimension of pantiles is 24 cm × 49 cm. The size of screeding frames is 26.5 cm × 49 cm (the 2.5 extra centimetres are taken up by the curve of the tile).

Pantiles are curved. They fit laterally under the rib and lengthwise by simple overlap. Overlap should be 9 cm down the slope and 4 cm across.

The effective coverage area of the tile (or "bare") is 40 cm × 20 cm (two-thirds of total tile coverage area). Theoretically, 12.5 pantiles are required to cover one square metre of roof surface. For Roman pantiles, an average of 11.5 tiles are required to cover one square metre of roof surface.

In practice, the quantity of tiles required to cover a given roof surface will depend on:

- the pitch of the roof;

- the measurements of the slopes: the length and width of the slope should be

multiples of the tile dimension;

- regular placing of tiles;

- loss through breakage.

Remark

Several parameters may affect the outside tile measurements, such as:

- measurements of screeding frame (24, 24.5 or 25 cm);
- shape of the tile (pantile, roman tile, other).

III.1 Estimate

1. Laving the tiles horizontally (across)

Theoretically, 5 well-laid tiles cover an average width of 1 metre. Inaccuracies in tile laying will result in the same number of tiles ("n" tiles) covering varying widths of roof.

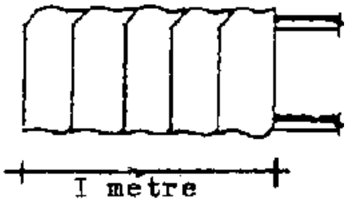


Figure 94. Accurate placing of tiles: 5 tiles/metre

Table 26. Comparison of widths covered with accurate and inaccurate placing of tiles

Number of tiles	Accurate placing	Inaccurate placing

20	4 m	3.6 m
30	6 m	5.4 m
40	8 m	7.2 m
50	10 m	9.0 m
60	12 m	10.8 m

2. Laying the tiles vertically (down)

Theoretically, five tiles cover 2 metres lengthwise. Overlap is 10 cm.

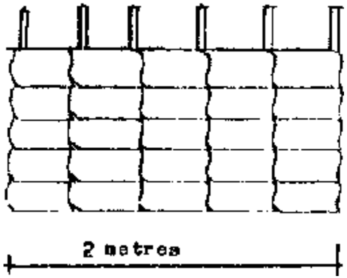


Figure 95. Accurate placing of tiles: 5 tiles/2 metres

3. Variation of number of tiles with roof slope

A relationship may be established between the width of a construction (roof span), the pitch and length of roof slopes (table 27). These parameters have a bearing on materials consumption; the designer may define roof measurements which are even multiples of the tile dimensions.

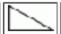
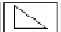
The length of the slope may be calculated on three different assumptions:

- <u>the length of the slope</u> is pre-established ("n" number of tiles): if the span increases (width of building), the pitch is less steep;

- <u>the span</u> is pre-established: if the pitch becomes steeper, the number of tiles increases (length of slopes);

- <u>the pitch</u> is pre-established (degrees): if the span increases, the number of tiles increases (length of slopes).

<u>Table 27. Relationship between the three factors which determine tile consumption: span. pitch, length of slopes</u>

Pitch	22º	25º	30º	35º
	Span (metres)			
Length of slopes (number of tiles)				
10	3.7	3.6	3.5	3.3
11	4.1	4.0	3.8	3.6
12	4.4	4.4	4.2	3.9
13	4.8	4.7	4.5	4.3
14	5.2	5.1	4.8	4.6
15	5.6	5.5	5.2	4.9
17	6.3	6.2	5.9	5.6
18	6.7	6.5	6.2	5.9
19	7.0	6.9	6.6	6.2
20	7.4	7.3	6.9	6.6

Three different situations are possible:

- <u>measurement is not predefined:</u> the builder may select one or two criteria;

- <u>one criterion is predefined:</u> the choice of the other two criteria should be made in view of the possibilities;

- <u>two criteria are pre-established;</u> only one third criterion is possible.

III.2 Example of calculation

The measurements of a building are as follows:

- Span : 6.70 metres
- Width of roof : 7.50 metres (including eaves)
- Roof pitch : 22º

A span of 6.70 metres with a 22º pitch means that 18 tiles should be used. Across the roof, the number of tiles used varies between 38 and 41 depending on the skill of the workmen. A safety margin of 5 per cent should be added to cover breakage during unloading and handling.

<u>Table 28. Tile consumption</u>

	Net tile consumption	Gross tile consumption
Accurate worksmanship	18 × 38 = 684 units	684 + 5% = 718 units
Inaccurate workmanship	18 × 41 = 738 units	738 + 5% = 774 units

IV. LAYING THE TILES

Tiles are laid according to a well-defined progression. The first tile should be laid in the lower left-hand corner of the slope. The following tiles are placed in an upwards and left to right progression. Frequent checks should be made as the work progresses.

Before laying the tiles marks are made at one metre intervals on the battens at the bottom and top of the slope. A rope is stretched between the first two marks. Five columns of tiles should fit within this area (figure 96).

Each tile is laid and adjusted carefully. All the tiles in a given column should be accurately aligned. A straight batten placed flush against the column may be used as a template (figure 97). Faulty alignment should be corrected immediately. The nib should adhere closely to the batten.

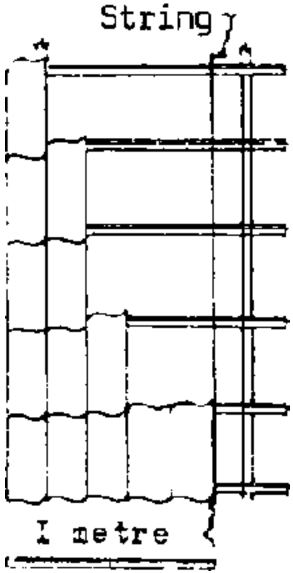


Figure 96. Marker for alignment of 5 columns of tiles

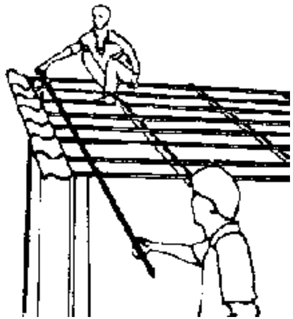


Figure 97. Checking tile alignment

When the first slope is completed, the second slope is covered in an identical manner. The ridge tiles should be installed gradually as soon as enough columns are completed on the second slope. This avoids the need of climbing on the finished part of the roof.

A simple V-shape is a good design for ridge tiles. The angle of the open "V" depends on the roof pitch (see chapter III, section V.2). Depending on local custom or design preference, ridge tiles may be placed:

- butt to butt with mortar joints (figure 98 a);
- with single overlap (figure 98 b);
- with double overlap (figure 98 c);
- with special fit (specially moulded tile) (see chapter IV, section III.2).

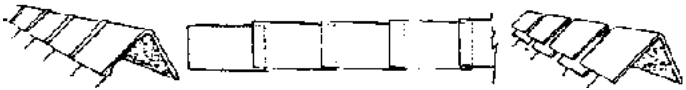


Figure 98. Three methods of laying ridge tiles

If the first row of tiles is not closed with a bar, openings will remain between the lower edge of the ridge tile and the channels of the first row of roof tiles. These openings may be closed with mortar. Another solution consists in laying special tiles for the first row under the ridge (see chapter IV, section IV).

When roof repairs are necessary, a ladder may be placed in the direction of the slope, with the two uprights resting in the tile channels. The workman's weight will thus be spread over the whole slope.

V. FIXING THE TILES TO THE BATTENS

V.1 Pantiles

Pantiles may be placed without any special fixing device. For increased security in wind-prone areas, tiles should be fixed to the structure. Three methods are possible, although systems 2 and 3 are recommended.

1. Wailing or pegging through the nib (figure 99)

Although this is the simplest method, it is also the riskiest: the hammer may skid on the nailhead and break part of the nib, the whole nib or even the tile. Driving a peg through the nib is not advisable since the nib might break up under the pressure.

2. Galvanized wire loop (figure 100)

The galvanized wire loop is cast in the fresh mortar when the tile is moulded (see chapter IV, section 11.4, step 12). The tile may be fixed by nailing the wire loop to the purlins or by tying it down through the loop around the batten. The fixing wire should be taut. If there is too much play, wind suction might cause the tiles to clatter. This produces an unpleasant noise and, if the uplift is very severe, may result in the tiles cracking.

3. Plastic cord (figure 101)

A length of plastic cord is slipped through the nib hole. The cord is tied around the purlins.

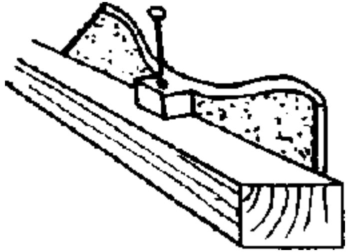


Figure 99. Nailing the tile on the batten

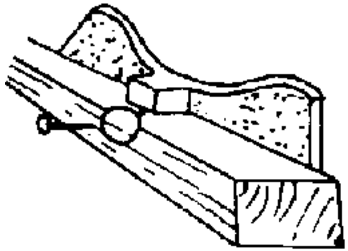


Figure 100. Nailing through galvanized wire loop

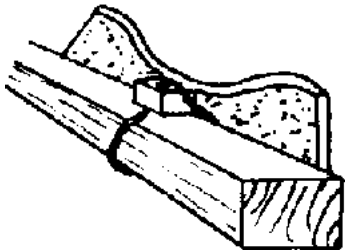


Figure 101. Tying down with cord

V.2 Double nib tiles

In hurricane areas, special tiles are required: they are thicker (8 mm to 10 nun) and fitted with two nibs (see chapter IV, section 11.4, step 8-b).

Both the upper and lower nib are tied down with galvanized wire or plastic cord. When laying the tiles, the second nib of the upper tile and the main nib of the lower tile should be fixed to the same batten (figure 102). The tiles are thus fixed at their upper and lower end and cannot be lifted by rough winds.

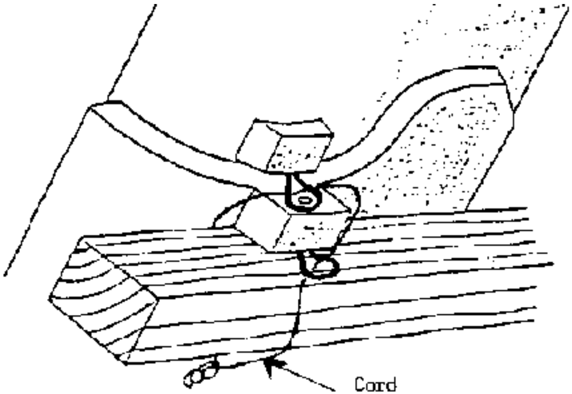


Figure 102. Upper and lower fixing around batten

V.3 Fixing ridge tiles

Grouting is not sufficient to fix ridge tiles (with or without special fit) on the ridge. When moulding the tiles, galvanized wire loops should be cast in the inner angle of the tile (see chapter IV, section III).

The tile is placed on the ridge. It is fixed to the roof frame with G.I. wire or a plastic cord. The wire or cord are either slipped under the purlins (figure 103), or looped around the

ridge purlin (figure 104).

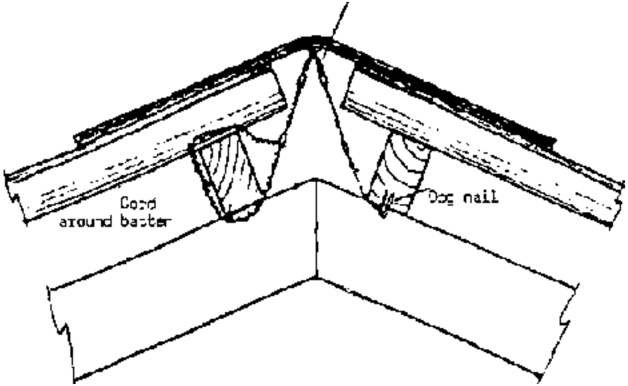


Figure 103. Tying ridge tile around purlins

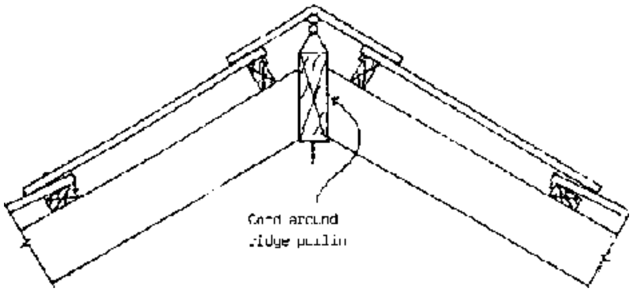


Figure 104. Tying ridge tile around ridge purlin

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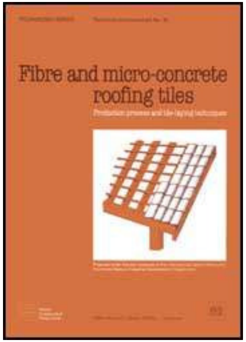

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

CHAPTER IX FEASIBILITY STUDY

The information presented in this chapter is meant to help contractors, financial institutions and government agencies in charge of housing programmes to estimate the cost of concrete tile production. In the first section a list of questions highlights the main factors which must be analysed prior to any in-depth study. A standard method for estimating production costs is suggested. This initial estimate of costs per square metre of roofing may be compared with the cost of other materials on the market.

I. PRELIMINARY STUDY

This preliminary investigation aims at assessing the potential demand for concrete tiles without going into a detailed analysis. The methodology of this section is based essentially on estimates rather than on detailed studies.

The list of questions below should help to form an initial opinion. If the results of the preliminary study are positive, a more elaborate survey of market and financial conditions may be conducted.

1. Background data

Information should be collected on the following items:

a) Exchange rate for imported equipment: US$ 1 = ?
Import regulations applying to equipment.

b) Interest rates: commercial loans, loans to small industries, housing credit.

c)

Salaries:	- Salaries in the formal sector (including fringe benefits).
	- Salaries in the informal sector (self-employed).

d) Weather conditions: temperature, humidity, wind, rain, etc.

2. Supply of roofing materials

a) List of the roofing materials available and in use.

b) Place of production of these materials (local or imported).

c) Cost per square metre of roofing (one actual square metre, including overlap).

d) Breakdown of materials per type of housing (middle class, lower middle class, informal, etc.).

e) Who sells roofing materials (retailers, wholesalers, manufacturers, contractors)?

3. Demand potential: market

a) Estimated volume of unsatisfied demand (in square metres of roofing per year or number of dwellings).

b) Expectations and preferences of potential customers with regard to roofing materials: insulation, durability, ease of assembly, prestige, strength characteristics.

c) Form of payment for building materials (delivery delays, retail prices, wholesale prices)?

4. Technology

a) Is it possible and necessary to import a vibrating table?

b) Could the vibrating table be manufactured in a local workshop?

c) Are the raw materials available locally (sand, fibre, cement, pigment, etc.)?

d) What is the unit cost of these materials (including transport and delivery)?

e) Can the moulds be produced locally? If so, how and at what cost?

f) Is there a local tile-roof tradition? If not, what is the quality and availability of local labour?

5. Management

a) Human resources: is local labour available? Would it be socially acceptable for women to utilize this technology?

b) Institutional support: what type of help may a contractor expect from national or local agencies in terms of financing, training and information?

c) Education level of contractors: training and follow-up of trained labour.

d) Availability or credit? If yes, under what terms?

e) Administrative regulations applying to the setting up of small businesses.

II. VARIATIONS IN PRODUCTION COSTS

Each production unit may be subjected to different financial arrangements. Some units may be launched with private capital only. Others may be subsidised wholly or in part, for Instance in terms of land, buildings, working capital and equipment.

It should be noted that production costs vary with the country or region considered. Unit production costs vary according to local circumstances and a number of factors such as:

- **price of cement: locally produced or imported;**
- **price of sand: distance of extraction site from production unit (transport costs);**
- **price of aggregate: availability of aggregate from quarry or extraction site (including transport costs);**
- **price of vegetable fibre: availability of processed fibre or in-plant defibration of**

stalks (if fibre is used);

- **production environment: urban, rural, building site;**
- **salary levels,**
- **ongoing interest rates for capital investments and working capital.**

The calculations made in the following sections offer examples which must be adapted to the specific features of each case study and current prices and salaries in the country or place of production.

III. METHODOLOGY FOR THE ESTIMATION OF PRODUCTION COSTS

The methodology includes three sections:

- **calculation of amounts of inputs in the production process (steps 1 to 5);**
- **estimation of total annual cost (steps 6 to 12);**
- **unit production costs and retail or wholesale price (steps 13 and 15).**

STEP 1: Annual production

The number of tiles produced yearly (gross annual output) varies with demand (market), amount of capital available and equipment capacity. The estimated output is generally calculated in the preliminary survey.

The net yearly output is the gross annual output minus an estimated percentage for breakage and rejects (2 to 5 per cent on average).

STEP 2: Raw materials

Raw materials consumption is calculated on the basis of production capacity and range of products (pantiles or Roman tiles (6 mm, 8 mm or 10 mm), ridge tiles). Estimates of these amounts may be calculated as explained in chapter II, section IV.

STEP 3: Equipment

A list of equipment and supplies, including spare parts and tools, should be made. Imported equipment and locally produced equipment should be included in this section. The list of equipment and tools may be drawn up on the basis of the expected rate of annual production and explanations given in chapter III, section XII.

STEP 4: Labour

Calculate manpower requirements. The skilled manpower/unskilled manpower ratio depends on the number of machines in operation. The total workforce will depend on output levels, number of shifts per day and the information given in chapter VI, section IV.

STEP 5: Infrastructure

Infrastructure includes:

- **land;**
- **building(s);**
- **curing tanks;**
- **covered sheds.**

This infrastructure should meet the requirements spelled out in chapter VI, section II. Dimensions for curing tanks are given in chapter III, section IX.

STEP 6: Working capital

In addition to land and equipment, a production unit must have enough working capital at its disposal to cover the purchase of raw materials, payment of salaries and the constitution of a stock of finished products. The working capital should be sufficient to cover raw materials for one month and finished products for one month (salaries plus other inputs, i.e. production costs).

STEP 7: Depreciation of equipment and buildings

Any equipment, whatever its characteristics, has a limited lifespan. Separate estimates should therefore be made for each type of equipment. This also applies to buildings.

Depreciation costs of equipment and buildings are function of purchase price, lifespan and interest rate. Table 30 may be used to calculate depreciation. It gives a depreciation factor "F" for interest rates ranging from 5 to 40 per cent lifespans ranging from 1 to 25 years.

This table should be used as follows: if "Z" is the purchase price of the equipment or building, the total annual depreciation cost is Z/F, where factor "F" corresponds to a given interest rate and given lifespan. The longer the lifespan, the lower the annual depreciation. The higher the interest rate, the higher the yearly depreciation.

STEP 8: Land

The lifespan of a plot of land is unlimited. If the land is purchased, the annual cost price is equal to its rental value. If the land belongs to the plant owner an amount (rental price) may be determined for covering the added value of the land while it is used.

STEP 9: Cost of raw materials

The annual cost of raw materials is calculated on the basis of estimated consumption (step 2) and unit cost for each material, including transport and delivery.

STEP 10: Cost of labour

Labour costs are calculated on the basis of local salaries. Workforce requirements are defined in step 4.

STEP 11: Interest on working capital

If a loan has been taken out to put up the working capital (step 6) interest payments on the loan should also be added as a cost item.

STEP 12: Power - water

Energy costs depend on the type of equipment used: manual or electric vibrating table. The power-driven table may be connected to the public mains system (a.c.) or a car battery. The 12 volt motor does not use much energy: the batteries should be recharged every other day. Lighting in the workshop should also be included, particularly if the unit runs two shifts a day.

Water costs are a function of total output.

For water and power consumption, a quick calculation should be worked out and a flat amount adopted as a first estimate.

STEP 13: Total annual production costs (steps 7 to 12)

Total annual costs = Cost of depreciation of equipment and buildings

+ annual rental cost of land

+ annual cost of raw materials
+ annual cost of manpower
+ annual interest on working capital
+ annual cost of energy and water

STEP 14: Unit production cost

The unit production cost is equal to total annual production costs divided by net annual output.

STEP 15: Retail or wholesale price

Unit production cost plus profit margin, plus any sales tax or value added tax.

IV. APPLICATION OF THE CONSTANT METHODOLOGY

The methodology is applied to the case of a production unit established in Antananarivo (Madagascar) in April 1987. The exchange rate applicable in April 1987 to calculate the cost of imported equipment was US$ 1 = MG.F 730.

IV.1 DETERMINATION OF THE OUTPUT AND INPUTS

1. Types of tiles

The methodology is applied to two types of tiles and two types of mixes of raw materials.

- two types of tiles:	• standard	:6 mm thickness, 1 nib
	• hurricane-resistant	:10 mm thickness, 2 nibs

- two types of mixes: see table 29

Table 29. Mixes of raw materials

	Raw materials	Ratio	Percentage
Mix 1	Cement : sand	1 : 3	25 : 75
Mix 2	Cement + ash : sand	(4/5 +1/5) : 3	20+5 : 75

- Mix 1 is the standard 1 : 3 ratio mix.

- Mix 2 is a special mix resulting from strength trials. Replacing 20 per cent of the amount of cement with rice husk ash does not impair tile resistance. This mortar composition results in a 10 per cent saving on the cost of raw materials.

2. Production capacity

The output of the production unit is 2,000 tiles per week (this requires two vibrating tables). The unit will run one shift a day. The unit is scheduled to operate 5 days a week throughout the year, i.e. 52 weeks.

3. Cost of raw materials

Sand:	The sand is extracted in Moramanga and is free of charge. Loading and transport costs amount to MG.F 20,000 per ton. Average sieving losses amount to 10 per cent of total supplies. The cost price of sand is calculated at MG.F 22,000 per ton.
Cement:	Average market price is MG.F 7,500 per 50 kg. bag.
Fibre:	Average market price is MG.F 1,500 per kg.
Rice husk:	Rice husk is free. Transport costs are low (indicative price: MG.F 10,000 per ton) in view of the closeness of the rice paddies.

Galvanized 10/10 or 12/10 at MG.F 6,000/kg (approximately 200 m) i.e. MG.F 32.5/m.

wire:

4. Labour

For a unit of this size (2,000 tiles/week and 2 tables), three workmen and one foreman are required (see table 20).

5. Equipment

5.1 Vibrating table: two portable vibrating tables.

5.2 Number of moulds = 400.

The cost of moulds depends on their origin (imported or local). The most cost-effective solution should be chosen. Moulds produced at the Sosimabi plant (Malagasy plastic factory) with an average lifespan of four years, are more economical. They are made of 3 mm thick fibre-glass material. There is a risk, however, of delivery times being fairly long. If delivery time is too long, imported moulds should be used during the initial start-up period.

5.3 Interfaces: Number of sheets: 1,200

The yearly sheet consumption depends on the quality of the polythene material. A 200 micron film lasts four months on average. Yearly sheet consumption is three times the number of moulds used.

5.4 Tools

Tools include one wheelbarrow, one sieve, a few trowels and shovels, one scale and buckets. A flat amount is calculated for this item of expenditure.

6. Infrastructure

The cost of infrastructure is based on the estimate for a small 6.50 m × 5 m shed covered with a timber and fibre or micro-concrete tile roof. A locked storage area of 2 m × 5 m should be fitted within the shed. Five 3 m^2 tanks should be built above ground at a short distance from the shed.

7. Land

The price of rental for the land is estimated at MG.F 20,000 a year.

8. Interest rate

The rate used in this calculation for Antananarivo is the average interest rate charged in April 1987 by the Central Bank of Madagascar to local craftsmen, i.e. 12 per cent.

9. Profits

This item may be omitted from the calculation of production costs. It may be worth including in the computation if the plant owner wishes to have an idea of his potential profit.

The profit margin is equal to that applied by building and metalworks cooperatives, i.e. 20 per cent.

IV.2 ESTIMATION OF UNIT PRODUCTION COST

STEP 1: Annual production

Gross: 400 tiles × 22 days × 12 months = 105.600 tiles

Net: 105,600 - 5% breakage = 100,320 rounded off to <u>100.000 tiles</u>

<u>STEP 2: Yearly consumption of raw materials</u>

Mix 1: Cement : sand ratio = 1:3

Materials	Standard tile: 6 mm		Hurricane tile: 10 mm	
	Qty/tile	Annual Qty 105,600 tiles	Qty/tile	Annual Qty 105,600 tiles
Sand (+ 10% losses)	1.2 kg	128 tons	2 kg	211 tons
Cement	0.4 kg	42,240 kg	0.66 kg	69,700 kg
Fibre	0.011 kg	1,161 kg	0.019 kg	2,006 kg
Galvanized wire	0.15 m	15,840 m	0.3 m	31,680 m

Mix 2: (Cement + ash): sand ratio = (4/5 + 1/5 i.e. 20 per cent cement + 5 per cent ash) : 3

Materials	Standard tile: 6 mm		Hurricane tile: 10 mm	
	Qty/tile	Annual Qty 105,600 tiles	Qty/tile	Annual Qty 105,600 tiles
Sand (+ 10% losses)	1.2 kg	128 tons	2 kg	211 tons
Cement	0.32 kg	33,790 kg	0.53 kg	55,970 kg
Fibre	0.011 kg	1,161 kg	0.019 kg	2,006 kg
Rice husk ash	0.08 kg	8,450 kg	0.13 kg	13,730 kg
Galvanized wire	0.15 m	15,840 m	0.3 m	31,680 m

STEP 3: Equipment

Description	Quantity		Unit cost
Vibrating table + accessories	2	MG.F	1,058,500 1/
Transport: 20% equipment		MG.F	219,000 2/
Moulds	400	MG.F	17,250 + LT 3/
Transfer sheets/year	1,200	MG.F	53 + LT
Tools: 1 wheelbarrow, 2 shovels			
4 trowels, 1 cutter		MG.F	16,500 + LT
Spare parts Motor	3	MG.F	20,000 + LT
Vibrator	2	MG.F	20,000 + LT
Miscellaneous		MG.F	10,000 + LT

1/ Unit cost based on an import price of US$ 1,450 (US$ 1 = MG.F 730).
2/ Transport cost is equal to 20 per cent of FOB price.
3/ LT: local tax 15 per cent.

STEP 4: Manpower

- Manager and foreman 1
- Workmen 3

STEP 5: Infrastructure

- Land (15 m × 15 m) 225 m^2

- including: shed 30 to 35 m^2

5 tanks (3m^2 each)	15 m^2

STEP 6: Operating capital

One month's supply of raw materials + one month of finished products = Two months of raw materials + one month of salaries + energy (see step 2).

To calculate the working capital required, the quantity of materials used in mixes 1 and 2 are based on an average production of 6 mm and 10 mm tiles.

Inputs	Unit	Unit price MG.F	Mix 1		Mix 2	
			Qty	Total cost MG.F	Qty	Total cost MG.F
Sand (2 months)	T	22,000	28	616,000	28	616,000
Cement (")	kg	150	9,328	1,399,200	76,480	1,122,000
Fibre (")	kg	1,500	264	396,000	264	396,000
Galv. wire (")	m	32.50	3,960	128,700	3,960	128,700
Ash (")	kg	10	-	-	1,848	18,480
Manager	month	82,600	1	82,600	1	82,600
Workmen	month	23,600	3	70,800	3	70,800
Energy + water	month	15,000		15,000		15,000
TOTAL				2,708,300		2,449,580

STEP 7: Depreciation (interest rate 12 per cent)

Description	Initial cost	Lifespan	F factor	Annual depreciation

		(years)	(see table 30)	
2 vibrating tables	2,540,000	5	3.605	704,687
400 moulds	7,935,000	4	3.037	2,612,775
1,200 interfaces	73,140	1	0.893	81,903
Tools	19,800	5	3.605	5,492
Spare parts	126,500	5	3.605	35,090
Infrastructure	3,000,000	25	7.843	382,506
TOTAL				3,822,453

STEP 8: Land

- Annual cost for rental of land: MG.F 20,000

STEP 9: Annual cost of raw materials

Mix 1: Cement: sand ratio = 1:3

Materials	Unit	Unit price MG.F	Standard 6 mm		Hurricane-resistant 10 mm	
			Qty	Total cost MG.F	Qty	Total cost MG.F
Sand	T	22,000	128	2,816,000	211	4,642,000
Cement	kg	150	42,240	6,336,000	69,700	10,455,000
Fibre	kg	1,500	1,161	1,741,000	2,006	3,009,000
Galvanized wire	m	32.5	15,840	514,800	31,680	1,029,600
TOTAL				11,408,300		19,135,600

Mix 2: **(Cement + ash): sand ratio = (4/5 + 1/5) : 3**

Materials	Unit	Unit price MG.F	Standard 6 mm		Hurricane-resistant 10 mm	
			Qty	Total cost MG.F	Qty	Total cost MG.F
Sand	T	22,000	128	2,816,000	211	4,642,000
Cement	kg	150	33,790	5,068,500	55,970	8,395,500
Fibre	kg	1,500	1,161	1,741,000	2,006	3,009,000
Ash	kg	10	8,450	84,500	13,730	137,300
Galvanized wire	m	32.5	15,840	514,800	31,680	1,029,600
TOTAL				10,225,300		17,213,400

STEP 10: Annual manpower costs

1 manager/foreman at MG.F 70,000/month =	840,000
3 workmen at MG.F 20,000/month =	720,000
	1,560,000
Social benefits 18%	280,000
TOTAL	1,840,800

STEP 11: Interest on working capital

- Annual interest rates stand at 12 per cent.

- The cost of working capital depends on the type of mix used (step 6).

	Mix 1	Mix 2

Working capital	2,708,300	2,449,580
Annual interest 12%	324,996	293,949

STEP 12: Energy and water

Estimated flat amount of MG.F 15,000 per month, i.e. MG.F 180,000 per year.

STEP 13: Total annual production costs

Total annual production costs = fixed costs + variable costs.

Fixed costs = Steps 7+8

Step	Description	
7	Depreciation	3,822,453
8	Cost of land	20,000
TOTAL fixed costs		3,842,453

Variable costs = steps 9 + 10 + 11 + 12 depending on composition of mix:

	Mix 1		Mix 2	
	6 mm	10 mm	6 mm	10 mm
Step 9 (raw materials)	11,408,300	19,135,600	10,225,300	17,213,400
Step 10 (manpower)	1,840,800	1,840,800	1,840,800	1,840,800
Step 11 (interest)	324,996	324,996	293,949	293,949
Step 12 (energy + water)	180,000	180,000	180,000	180,000
TOTAL VARIABLE COSTS	13,754,096	21,481,396	12,540,049	19,528,149

Total yearly production costs = fixed costs + variable costs

	Mix 1		Mix 2	
	6 mm	10 mm	6 mm	10 mm
Fixed costs	3,842,453	3,842,453	3,842,453	3,842,453
Variable costs	13,754,096	21,481,396	12,540,049	19,528,149
TOTAL	17,596,549	25,323,849	16,382,502	23,370,602

STEP 14: Unit production cost (cost price)

Unit production cost is equal to the total yearly production costs divided by the yearly net quantity produced (100,000 tiles).

	Mix 1		Mix 2	
	6 mm	10 mm	6 mm	10 mm
Unit production cost MG.F	176	253	164	234
Cost price per m^2 (12.5 tiles/m^2) MG.F	2,200	3,163	2,050	2,925

STEP 15: Retail price

Assuming a profit margin of 20 per cent:

	Mix 1		Mix 2	
	6 mm	10 mm	6 mm	10 mm
Unit production cost	176	253	164	234
Profit margin 20%	35	51	33	47

Unit retail price	211	304	197	281
Cost per m^2	2,637	3,800	2,463	3,512

IV.3 COST COMPARISONS FOR DIFFERENT MATERIALS

1.	CLADDING MATERIAL	Price per m^2 (in MG.F)
	Galvanized corrugated iron sheet (1)	7,000 to 12,000 (9,500 on average)
	Flat clay tiles (2)	2,600 to 3,700 (3,150 on average)
	Industrial tiles (2)	3,250
	Fibre or micro-concrete tiles 6 mm (3)	2,463 to 2,637 (2,550 on average)
	Fibre or micro-concrete 10 mm(hurricane resistant) (3)	3,512 to 3,800 (3,656 on average)

(1) The price of galvanized corrugated iron sheet varies from one city to another.

(2) The prices of flat clay tiles are detailed in ref. 18 and 19.

(3) The variation in F.C. or micro-concrete tile prices results from the use of different mixes (see section IV.1 in this chapter).

2	ROOF STRUCTURE (4)	MG.F
	Galvanized corrugaged iron sheet	1,241
	Flat clay tiles	3,940
	Industrial tiles	2,976
	Fibre or micro-concrete tiles	2,072

(4) Cost of roof structure per one square metre is quoted from ref. 5.

3	COST COMPARISONS FOR COMPLETED ROOF	MG.F
	Galvanized corrugated iron sheet	10,741
	Flat clay tiles	7,090
	Industrial tiles	6,496
	Fibre or micro-concrete tiles 6 mm	4,535 to 4,709 (4,622 on average)
	Fibre or micro-concrete tiles 10 mm (hurricane-resistant)	5,584 to 5,871 (5,728 on average)

4. CONCLUSION

The cost of one square metre of fibre or micro-concrete tile roofing is globally more economical than the cost of using other materials.

A cost comparison of one square metre of total roofing (frame + fibre or micro-concrete tiles) with other types of roofs shows that the following savings may be made:

		Savings
- Fibre or micro-concrete tiles 6 mm:	Galvanized corrugated iron	57%
	Flat clay tiles	35%
	Industrial tiles	29%
- Fibre or micro-concrete tiles 10 mm:	Galvanized corrugated iron	47%
	Flat clay tiles	21%
	Industrial tiles	12%

Table 30. Value of factor "F" for calculation of depreciation costs

	INTEREST RATE														
YEAR	5%	6%	8%	10%	12%	14%	15%	16»<	18%	20%	22%	24%	25%	26%	28%
1	0.952	0.943	0.926	0.909	0.893	0.877	0.870	0.862	0.847	0.833	0.820	0.806	0.800	0.794	0.78
2	1.859	1.833	1.783	1.736	1.690	1.647	1.626	1.605	1.566	1.528	1.492	1.457	1.440	1.424	1.39
5	2.723	2.673	2.577	2.487	2.402	2.322	2.283	2.246	2.174	2.106	2.042	1.981	1.952	1.923	1.86
4	3.546	3.465	3.312	3.170	3.037	2.914	2.855	2.798	2.690	2.589	2.494	2.404	2.362	2.320	2.24
5	4.330	4.212	3.993	3.791	3.605	3.433	3.352	3.274	3.127	2.991	2.864	2.745	2.689	2.635	2.53
6	5.076	4.917	4.623	4.355	4.111	3.889	3.784	5.685	3.498	3.326	3.167	3.020	2.951	2.885	2.75
7	5.786	5.582	5.206	4.868	4.564	4.288	4.160	4.039	3.812	3.605	3.416	3.242	3.161	3.083	2.93
8	6.463	6.210	5.747	5.335	4.968	4.639	4.487	4.344	4.078	3.837	3.619	3.421	3.529	3.241	3.07
9	7.108	6.802	6.247	5.759	5.328	4.946	4.772	4.607	4.303	4.031	3.786	3.566	3.463	3.366	3.18
10	7.722	7.360	6.710	6.145	5.650	5.216	5.019	4.833	4.494	4.192	3.923	3.682	3.571	3.465	3.26
11	8.306	7.887	7.139	6.495	5.938	5.453	5.234	5.029	4.656	4.327	4.035	3.776	3.656	3.544	3.33
12	8.863	8.384	7.536	6.814	6.194	5.660	5.421	5.197	4.793	4.439	4.127	3.851	3.725	3.606	3.38
13	9.394	8.853	7.904	7.103	6.424	5.842	5.583	5.342	4.910	4.533	4.203	3.912	3.780	3.656	3.42
14	9.899	9.295	8.244	7.367	6.628	6.002	5.724	5.468	5.008	4.611	4.265	3.962	3.824	3.695	3.45
15	10.380	9.712	8.559	7.606	6.811	6.142	5.847	5.575	5.092	4.675	4.315	4.001	3.859	3.726	3.48
16	10.858	10.106	8.851	7.824	6.974	6.265	5.954	5.669	5.162	4.730	4.357	4.033	3.887	3.751	3.50
17	11.274	10.477	9.122	8.022	7.120	6.373	6.047	5.749	5.222	4.775	4.391	4.059	3.910	3.771	3.51

18	11.690	10.828	9.372	8.201	7.250	6.467	6.128	5.818	5.273	4.812	4.419	4.080	3.928	3.786	3.52
19	12.085	11.158	9.604	8.365	7.366	6.550	6.198	5.877	5.316	4.844	4.442	4.097	3.942	3.799	3.53
20	12.462	11.470	9.818	8.514	7.469	6.623	6.259	5.929	5.353	4.870	4.460	4.110	3.954	3.808	3.54
21	12.821	11.764	10.017	8.649	7.562	6.687	6.312	5.973	5.384	4.891	4.476	4.121	3.963	3.816	3.55
22	15.163	12.042	10.201	8.772	7.645	6.743	6.359	6.011	5.410	4.909	4.488	4.130	3.970	3.822	3.55
23	13.489	12.303	10.371	8.883	7.718	6.792	6.399	6.044	5.432	4.925	4.499	4.137	3.976	3.827	3.55
24	13.799	12.550	10.529	8.985	7.784	6.835	6.434	6.073	5.451	4.937	4.507	4.143	3.981	3.831	3.56
25	14.094	12.783	10.675	9.077	7.843	6.873	6.464	6.097	5.467	4.948	4.514	4.147	3.985	3.834	3.56

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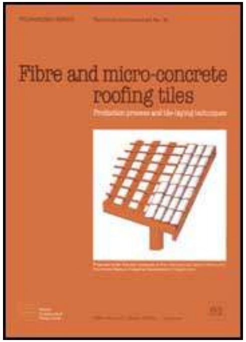

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

CHAPTER X SOCIO-ECONOMIC CONSIDERATIONS

The foregoing chapters deal with the technical and economic aspects of fibre or micro-concrete tiles. They are intended for small-scale entrepreneurs, construction engineers and members of agencies concerned with economic housing. However, a number of socio-economic constraints may slow down the adoption of the technology, particularly in economic housing programmes. The aim of this chapter is to describe the various socio-economic benefits which may result from widespread use of fibre or micro-concrete tiles and to suggest various policies and measures to encourage fibre or micro-concrete tile production.

This chapter is of particular interest to members of planning agencies, housing authorities and development agencies who are in a position to initiate legislation and programmes in order to promote the production of appropriate building materials.

I. DECENTRALISATION OF INDUSTRY

The setting up of small industries in rural areas and medium-sized urban centres (towns and large villages) helps to slow down the alarming process of unchecked urban growth. Small industries generate local employment, halt rural exodus and are conducive to the emergence of regional poles of economic development. In order to fit in with their local environment, these small rural industries should be of an appropriate size and geared to meet potential demand and the socio-economic needs of the population. Another consideration is that the higher the degree of mechanization of an industry, the greater the need for skilled manpower. The choice of a technology should therefore be based on the availability of skilled manpower to ensure the upkeep and repair of equipment. Fibre or micro-concrete technology fits in ideally with these criteria. The requirements set out

above can all be met when starting up production units in towns and villages.

It should also be borne in mind that small production units should be flexible enough to adjust their output to market demand. They can also operate on a seasonal basis and leave the farmers free for field work during the planting or harvesting season. Large-scale capital intensive production units cannot adjust to these many requirements.

II. USE OF LOCALLY AVAILABLE MATERIALS

The inputs required for fibre or micro-concrete tile production are the following:

- sand: 74 per cent; (or mix of sand and aggregate)
- cement: 25 per cent;
- vegetable fibre: under 1 per cent.

Other inputs improve the quality of the product:

- galvanized iron wire: under 1 per cent;
- rice husk ash: 5 per cent + 20 per cent cement;
- pigment: e.g. iron oxide.

In most production units, mortar accounts for 98 per cent of inputs. In most regions, sand and aggregate are available within a range of 50 km. However good quality sand may be lacking in countries where alluvial material is rich in clay and quartz site deposits are rare. If the sand is to be brought in by rail and/or trucks, this will have an impact on production costs. Generally speaking, it is assumed that the cost of sand reflects mainly extraction costs and transport costs. These activities are useful for the local economy since they generate employment.

The second input is cement. In certain cases cement represents the major obstacle to a widespread use of the technology. Where cement is not produced domestically, import costs must be calculated and included in the overall costing analysis. If a local brand of cement is available, care should be taken that its quality and characteristics are suitable for the technology. In either case, however, it is important to recall that the low proportion of cement used (25 per cent) makes it possible to produce 2,500 tiles per ton of cement, i.e. 200 m^2 of roofing for 20 bags of cement.

Aggregates are generally available around the production area. They may be extracted from a natural site, as a river: cost will then be essentially the transportation. They may be extracted from a quarry: cost will be Increased by the quarry process and will influence the production cost of the tiles.

Fibre is always produced locally. Although it only accounts for 1 per cent of total input weight, it is extremely bulky. Defibration of plants or fruits (e.g. sisal or coir) may be done manually or with simple mechanical equipment. The use of these fibres is also an asset for the local economy, since production of fibre generates a great deal of employment.

Aggregates are usually available close to the production unit. When they are quarried from natural sites, their cost is essentially that of transport. When they are produced in industrial rock crushing plants, the additional expenditure should be worked into the cost price.

The energy bill is low: each vibrating table runs on a small 12 volt motor powered either by a car battery or 220 volt AC current and a transformer. Compared with other types of production (e.g. tile firing or sheetmaking which are both energy consuming), the quantity of energy going into fibre or micro-concrete is almost negligible.

These two factors - use of locally available materials and low energy consumption - are

decisive arguments in favour of this technology.

III. PROMOTION OF EMPLOYMENT

Promotion of employment is a priority in the developing world. Technologies which require more labour per unit of production should be encouraged, provided this labour is used efficiently.

It can be shown easily that concrete tile production units generate more employment than industries processing imported roofing materials (galvanized corrugated iron or asbestos cement). A survey made in Kenya in 1985 (ref. 7) shows that fibre or micro-concrete tile manufacturing generates five times more jobs in the country than sheet production and seven times more than the handling of imported sheet material.

The same study shows that if Kenya were to replace half its current production of corrugated iron with tile production (clay or fibre or micro-concrete), over 3,000 jobs would be generated directly, whilst 200 to 300 at most would be lost in the corrugated iron sheet industry, resulting in a net increase of 2,700 jobs.

The ratio of direct job creation to total output depends on the type of equipment used, organization of production and structure of the production unit (see chapter VI, section IV).

Concrete tile production technology also has multiplier effects on the national economy, which vary with the production scale, the origin of the equipment and raw materials used. The technology has more multiplier effects upstream and downstream than technologies which rely heavily on imported materials. Part of the equipment and tools may be produced locally, another source of job creation. The use of locally available raw materials also promotes the maintenance or creation of new jobs. Finally, the sale and transport of tiles produced in small decentralized units is also likely to create more jobs than the

dissemination of "centralized" materials such as corrugated iron.

IV. INVESTMENTS - FOREIGN EXCHANGE SAVINGS

The local production of construction materials requiring a high ratio of imported products (equipment and/or raw materials) contributes to increasing the external debt of developing countries. The substitution of galvanized corrugated iron or asbestos cement sheets for traditional materials is very extensive in many countries. Importing these materials results in a sizeable currency outflow and a direct increase of the foreign debt.

Concrete tile production is based on the optimal use of locally available materials. It minimizes the need for imported roofing materials, thereby reducing the trade deficit. A survey carried out in Kenya (ref. 7) shows that the share of hard currency costs in the retail price is:

- **66 to 75 per cent for corrugated iron;**
- **17 per cent for fibre or micro-concrete tiles.**

Finally, unlike other building materials, fibre and micro-concrete tiles do not require energy for drying and curing. This removes the need to consume imported fuels or to contribute to deforestation by burning firewood to fire clay tiles.

In developing countries, start-up capital is usually conceded at very high interest rates. Starting up a concrete tile unit does not require a large amount of initial capital. A tile production unit may thus be started by entrepreneurs with very little start-up capital requiring low interest payments.

The equipment required for tile production is relatively light and simple. Several types of vibrating tables are available in a price range of US$ 400 to 1,000. The screeding moulds account for a large share of initial investment. Depending on the material used for the

moulds and place of production, their price ranges between US$ 8 to US$ 15 (the material used is critical to mould durability). Small equipment and tools are not costly. With regard to infrastructure, the area required is less than for corrugated iron or clay tile production. For on-site production, the cost of land is nil. The curing tanks, cement shed, sand boxes are simple constructions. The working capital accounts for a large share of start-up capital. It should cover two months' supplies of raw materials and one month's output of finished products.

In summary, be it in terms of currency savings or start-up capital, fibre or micro-concrete tile production offers obvious advantages over other roofing materials such as corrugated iron and asbestos cement sheets or indeed clay tiles.

V. TILE PRODUCTION COSTS AND HOUSING CONSTRUCTION COSTS

In developing countries, building materials account for the largest share of overall construction costs. In the case of economic housing or informal dwellings, the cost of materials may represent up to 80 per cent of total construction costs. As a consequence, the cost of building materials is the only major financial item which the builder must take into consideration. It is therefore vital to promote the production of economic materials, in order to make it possible for low income groups to build their own houses, and to keep down to a minimum investments by housing agencies.

Compared with other roofing materials, the retail or wholesale price of one square metre of fibre or micro-concrete tile cladding is extremely competitive. Table 31 shows the relative cost of different roofing materials for three African countries:

Table 31. Comparative cost of roofing materials

	Kenya[1] (Kenyan	Madagascar[2] (MG	Cte d'Ivoire[3] (CFA

	Kenya[1] (Kenyan shillings/m2)	Madagascar[2] (MG. F/m2)	Cte d'Ivoire[3] (CFA F/m2)
Clay tile	73	3,200	-
Asbestos	161	-	-
Corrugated iron 28 g	72	9,500	1,450.60
Corrugated iron 84 g	84	-	-
Fibre or microconcrete 6 mm	50	2,550	1,000

[1] ref. 7, 1985.

[2] Average prices in Antananarivo, ref. 5, March 1987.

[3] Average prices in Abidjan, ref. 6, September 1987.

The amount of savings made depends on the economic conditions of the country and availability of competitive materials. The savings made by using fibre or micro-concrete tiles may be estimated at:

- 30 to 70 per cent in Kenya;
- 20 to 75 per cent in Madagascar;
- 45 per cent in Cte d'Ivoire.

To counter these relatively high figures, it is often claimed erroneously that a roof frame for fibre or micro-concrete tiles is more expensive than for corrugated iron, since the cladding material is heavier. The argument goes on to claim that the savings made on roofing materials only are offset by higher structural costs. This argument is refuted from a technical standpoint in section VI, chapter VII. In addition, economic surveys show that, in most cases, the cost per square metre of roofing (frame plus cladding) is lower when

concrete tiles are used. Table 32 sums up the situation for three African countries.

Table 32. Comparative cost per m^2 of roofing (frame + cladding)

	Kenya[1] (Kenyan shillings/m^2)	Kenya[2] (Kenyan shillings/m^2)	Madagascar[3] (MG. F/m^2)	Cte d'Ivoire[4] (CFA. F/m^m)
Clay tile	-	-	-	-
Flat tile	-	-	7,090	-
Industrial tile	119	166.35	6,496	-
Asbestos cement	188	248.15	-	-
Corrugated iron 28 f	109	118.64	10,741	2,184
Corrugated iron 26 g	96.25	-	-	-
Fibre or microconcrete 6 mm	96.50	138.55	4,622	1,609

[1] ref. 7, 1985

[2] ref. 16.

[3] ref. 5, 1987.

[4] ref. 6, 1987

The amount saved depends on the economic circumstances of the country, the price of timber and manpower and the production site. This amount may be estimated as follows:

- 0 to 49 per cent in Kenya;
- 29 to 57 per cent in Madagascar;
- 30 to 35 per cent in Cte d'Ivoire.

VI. CONCLUSIONS

The foregoing sections in this chapter show that there is a good case for promoting fibre, or micro-concrete tiles as roofing material, particularly for countries suffering from under-employment and a housing shortage. Fibre or micro-concrete roofing offers increased comfort (heat and noise insulation) for economic dwellings and public buildings. Lover construction bills are an incentive to private ownership. An added advantage is the possibility of on-site production: since the equipment can be moved easily, it may be rented out or lent for informal constructions. Appropriate training of labour is essential to promote the widespread use of this material on a commercial basis. In order to further the use of fibre or micro-concrete tiles, institutions concerned with housing and construction should promote the adoption of the following measures:

- preparation of standard specifications on fibre or micro-concrete tiles;

- provision of various incentives when fibre or micro-concrete tiles are used, e.g. lower cost of building permits; publicity for fibre or micro-concrete tiles through advertisements, demonstrations and model buildings;

- promotion of fibre or micro-concrete tiles for the construction of public buildings, e.g. schools, health centres, etc.;

- augmentation of taxes on imported materials, thereby making locally produced materials more attractive;

- promotion of research and development relating to this material, particularly to

assess its quality and durability;

- organization of training programmes.

The measures described above could usefully encourage the production of fibre or micro-concrete tiles rather than other building materials (particularly galvanized corrugated iron) in terms of cost, local availability and comfort.

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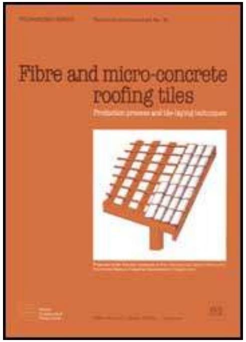

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

ANNEXES

ANNEX I GLOSSARY OF TECHNICAL TERMS

Additive: A product which, added to mortar, alters its qualities or improves performance

Additive:	A product which, added to mortar, alters its qualities or improves performance.
Aggregate:	Inert materials used to make mortar (sand, gravel, etc.).
Alkaline:	Having the properties of a base (chemistry) (see pH).
Bare (or margin):	Part of tile which remains visible after laying.
Batten (or lath):	A thin, long strip of wood placed on the rafters and supporting the tiles.
Bulking:	The quality of a material to increase in volume, in particular by trapping air between its particles.
Channel (of tile):	The concave part of the tile serving as a gutter for run-off water.
Clay:	A soil composed mainly of hydrated aluminium silicates in combination with other substances derived from the decay of water-absorbing, impermeable and soft feldspaths. Particle size under 0.002 mm.
Clinker:	Vitrous material collecting the impurities from the gangue which forms at the surface of molten ore.
Cohesion:	The capacity of the components of a material to hold together.
Compacting:	Packing densely the components of a material.
Curing:	Period during which optimal environment conditions (temperature and moisture) are maintained in order to enable a process to. reach its final stage. In this technical memorandum this refers to the mortar setting process, which should take place in an environment devoid of excess moisture.
Defibration:	Removing the fibres from a plant, essentially by stripping the pulp.
Fibre concrete:	A composite of mortar (sand + cement) and reinforcing fibres. The fibre acts as a reinforcement, particularly when the mortar is subjected to differential strains during setting.
Filler:	Micro-particles (in the order of 1 micron).

Granulometry:	Measurement of particle or grain size and shape. A method for grading particles according to size.
Hip rafter (tile):	A piece of timber forming the edge of a roof. A tile covering the edge of a roof.
Interface:	A flexible polethylene sheet used as a support for the mortar and as a separation between the mortar and the vibrating table or frame.
Lean-to:	A single-pitch roof resting on or against a wall and supported by pillars or posts.
Lime:	There are 2 types of lime: Calcium oxide (CaO) resulting from limestone calcination, and calcium hydroxide [$Ca(OH)_2$] obtained by adding water to quicklime.
Main rafter:	Pieces of timber forming the angle of a truss. The 2 main rafters support the roof sides.
Margin:	Edge of a roof. A margin overhang is the extension of roof sides beyond the gable.
Micro-concrete:	A composite of mortar (sand + cement) and reinforcing aggregates.
Milk (of cement):	A cement highly diluted in water.
Mortar:	A mixture composed of a binder, aggregate and water. This technology uses sand (0.06-2) and ordinary Portland cement (OPC).
Mould:	A solid object on which a pliable substance is applied in order to take its shape; a solid hollowed-out object in which a mouldable or liquid substance is poured in order to acquire the shape of the cavity.
Nib:	A small protruding part at the lower edge of the tile with which the tile is fixed to the roof battens.
Ordinary Portland cement (OPC):	A hydraulic binder composed of lime, silica, aluminium and iron oxide. Portland cement is made by heating limestone and clay.
Overlap:	That part of the tile which is covered by a neighbouring tile.

Overhang:	A roof part, generally lean-to, jutting out over an open-air area in front of an opening, facade, etc.
Permeability:	The quality of being penetrated or soaked through by a liquid.
pH:	A symbol signifying the hydrogen ion concentration of a solution. If the pH is over 7, the solution is alkaline. Under 7, the solution is acid.
Pitch (or slope):	Angle of roof sides measured in degrees or percentage.
Plasticity workability:	The quality of a material to change its shape - pliant, flexible, malleable, workable.
Porosity:	The quality of a material to absorb a liquid. (A material which is full of pores, or small holes.)
Pozzolana:	A volcanic soil formed of loose slag.
Purlin:	Cross-piece of timber resting on main rafter and supporting the rafters. Intermediate purlin, ridge purlin, wall-plate.
Rafter:	A piece of timber placed at the same angle as the truss, resting on the purlin and supporting the covering material. Rafters usually rest on the ridge and wall-plate.
Ratio:	The relation between two dimensions, two quantities of raw materials.
Rejects:	When grading an aggregate, that part of the material which does not pass through the mesh.
Ridge beam:	A horizontally placed piece of timber forming the tip of a roof structure.
Rim (of tile):	Curved (convex) part of the tile overlapping with the next tile.
Sand:	Small grains resulting from the breaking down of sedimentary rocks (quartz, silica). (Particle size 0.02-6 mm, British Standard.)
Screeding frame:	A metal frame of varying depth (6, 8 or 10 cm) used for screeding and vibrating the mortar. The shape of the vibrated mortar screed follows the shape of the screeding

	frame.
Screen (or sieve):	Round or square-meshed grid used to grade aggregates.
Setting (of cement):	A chemical process (hydraulic binding) inducing the hardening of mortar.
Settling:	Sinking of matter suspended or dissolved in a liquid to the bottom of a vessel.
Shrinkage:	Contraction, reduction of mortar volume.
Sisal:	A fibre obtained from agaves.
Slag:	Non-metallic waste matter obtained when ore is smelted (clinker). Volcanic clinker-like substance resulting from the cooling down of lava.
Slope(s):	The side(s) of a roof.
Span:	The distance between the two resting points of a piece of timber supporting a load or a pressure.
Truss:	An assembly of wood (or metal) beams supporting the ridge, purlins and rafters in a roof structure. Trusses are usually assembled in triangular shape. They are placed in a vertical plane across the roof length. Triangulation consists in spreading the load by dividing the total span.
Valley:	A concave angle formed by the intersection of two roof slopes.
Valley tile:	A concave tile or lead flashing used as gutter for rain-water.
Volumic mass:	Weight of one volume unit of raw material.
Wall-plate:	A horizontal piece of timber placed on top of the front supporting wall of a roof slope. The roof wall-plates are placed perpendicular to the trusses and support them.
Water content:	Quantity of water contained in a substance.

ANNEX II AGENCIES TO BE CONTACTED FOR INFORMATION ON FIBRE CONCRETE

TECHNOLOGY

International Labour Office (ILO)
Technology and Employment Division,
CH-1211 Geneva 22, Switzerland

United Nations Industrial Development Organisation (UNIDO)
Vienna International Centre,
P.O. Box 300,
A-1400 Vienna, Austria

<u>Bangladesh</u>

Housing and Building Research Institute,
Darus-Salam Mirpur,
P.O. Box 2953
Dhaka 18

Bangladesh Cottage and Small Enterprises Corporation (BSCIC)
Malek Mansion
128 Motijheel Com. Area
Dhaka 1000

<u>Belgium</u>

Centre de dveloppement industriel (CDI)
26-28, rue de l'Industrie,
1040 - Bruxelles

UNATA

131, Gvd Heuvelstraat,
3140 - Ramsel

APPRO - TECHNO
Rue de la Rieze, 24
B 5660 Couvin

Burkina Faso

Cellule de Technologie Approprie (CTA)
Office National de la Promotion de l'emploi (ONPE)
01 BP 4575 Ouagadougou 01

Chad

Centre de Matriaux de Construction
BP 906
N'Djamena

Cte d'Ivoire

Centre d'assistance aux petites enterprises (CAPEN)
Immeuble La Pyramide,
Abidjan

Dominican Republic

CII-Viviendas/Cetavip,
Ciudad Ganadera,
Apartado Postal No. 20328,

Santo Domingo
Comunidad Los Boncos,
Barrio La Libertad,
San Juan de la Maguova

Germany

GTZ
Section 434
P.O. Box 5180
6236 - Eschborn 1

German Appropriate Technology Exchange (GATE)
Dag Hammarskjoldweg 1,
6236 - Eschborn 1

Ghana

Department of Rural Housing and Cottage Industry (DRHCI)
P.O. Box 55
Accra

Technology Consultancy Center (TCC)
University of Science and Technology - (UST)
Kumasi

Guatemala

Centre de Tecnologa Apropiada,
"Manuel Guaran",

Apartado 1779,
Ciudad de Guatemala

Haiti

Appui Technologique a la Production Artisanale
PNUD
BP 657
Port au Prince

India

Development Alternatives
B32 Institutional Area
New Mehranli Road, Hanz Khas
New Delhi 110 016

A.M.G. Leprosy Relief Project,
P.O. Box 18,
Titlagarh 767033,
Bolangir Dt., Orissa

Indonesia

Proyek Act Swiss,
Jalan Diponegoro,
Praya, Lombok-NRB

Kenya

Actionaid-Kenya,
P.O. Box 42814
Nairobi

Housing Research Development Unit (HRDU)
P.O. Box 30197,
Nairobi

I.T. Workshops
4th Ngong Avenue,
P.O. Box 45156,
Nairobi

Kenyatta University College,
P.O. Box 43844,
Nairobi

ONDUGU Society Kenya
P.O. Box 40417
Nairobi - Telephone: 540187

Madagascar

Centre national de l'artisanat malgache (CENAM)
Immeuble Somacodis,
Antananarivo

CENAM

67 Hectares,

Antananarivo

Malawi

Rural Housing Project
P.O. Box 30135 or P.O. Box 30548
Lilongwe

ECOSYSTEM
P.O. Box 938
Blantyre - Telephone: 620167

Mozambique

Projecto Telhas de Fibro Cimento,
C.P. 292,
Pemba, Cabo Delgado

Nepal

Development and Consulting Services
P.O. Box 8,
Butwal - Telephone: 073.20391

Nicaragua

Empresa Regional de Fibralix,
Gobierno Regional,
Granada

Sofonias,

Apartado 88,
Jinotepe,
Carazo

Peru

Meteco
Schell 319, Officina 906
Miraflores,
Lima

Philippines

Illigan Institute of Technology,
Mindanao State University,
P.O. Box 5644
9200 Illigan City

Regional Network in Asia and Pacific
for Low-cost building materials
Housing and Urban Development Coordinating Council,
10th floor, Allied Bank Center, Ayala Avenue,
Makati

Pagtambayayong Foundation, Inc.
102 P. del Rosario Extension
Cebu City

Antonia Cbro Grobenciong
Labrador

Dwu, Tacloban City

Solomon Islands

St. Dominics R.T.C.
P.O. Box 22,
Gizo

Sri Lanka

Institute for Construction Training and Development (ICTAD)
"Savsiripaya"
123 Wijjerama Mawatha
P.O. Box 1973
Colombo 7

Swaziland

Ministry of Natural Resources,
Land Utilisation and Energy, Housing Branch,
P.O. Box 1173
Mbabane

Sweden

Swedish Agency for Research Cooperation (SAREC),
Birger Jarlsgatan 61,
10525 Stockholm

Swedish Cement and Concrete Research Institute (CBI),

Drottning Kristinasvaeg, 26
100-44 Stockholm

<u>Switzerland</u>

Building Advisory Service and Information Network (BASIN) (see SKAT)

Swiss Centre for Appropriate Technology (SKAT),
Basin (Building Advisory Service and Information Network)
2 Tigerbergstrasse
CH-9000 St. Gallen

<u>United Kingdom</u>

Building Research Establishment
(Overseas Division),
Bucknalls Lane, Garston,
Watford WD2 7JR

Intermediate Technology Development Group (ITDG),
Myson House, Railway Terrace,
Rugby CV21 3HT

Intermediate Technology Workshops,
J.P.M. Parry and Associates Ltd.,
Over end Road,
Cradley Heath B64 7DD

<u>United Republic of Tanzania</u>

Building and Research Unit,
P.O. Box 1964,
Dar es-Salaam

United States

A.T. International
1331 'H' Street N.W.,
Washington DC 20005

Zambia

Steffen Knak-Nielson,
P.O. Box 30500, Lusaka

Zimbabwe

Department of Appropriate Technology,
Hlekwewi Friends Rural Service Centre,
P.O. Box 708, Bulawayo

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PHOTOGRAPH (p. 21)

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Members of DINKA tribe cutting sisal leaves (Tonj district, Sudan, April 1963)

QUESTIONNAIRE

1. Name ....

2. Address ....

3. Profession (Please check appropriate box)

Manager of tile-production unit ..../_/
If so, please specify production capacity ....

Official of State agency ..../_/
If so, specify your position ....

Official of financial institution ..../_/
If so, specify your position ....

Member of university or research centre ..../_/
If so, specify name of university or centre ....

Employee in technological institution ..../_/
If so, specify name of institution ....

Employee in training institute ..../_/
If so, specify ....

Other (Specify)
...
...

4. How did you obtain a copy of this technical memorandum?
Specify whether purchased or obtained free ....

5. Was this memorandum helpful in (please check):

Learning about the technology of fibre or micro-concrete tile production
...

Estimating unit production costs for various production capacities
...

Ordering the equipment required for local production
.../_/

Improving your current production technology
../_/

Reducing your production costs

../_/

Improving tile quality

.../_/

Deciding on the appropriate plant capacity for a fibre concrete tile production unit

..

Drawing up recommendations for the construction industry

.../_/

Estimating credit lines for the setting up of a fibre concrete production unit

..

Ensuring training requirements

../_/

Improving advice to counterparts on fibre concrete tile technology

..

6. Is this memorandum sufficiently detailed as regards:

- Description of technology	(Yes) /_/	(No) /_/
- Information concerning costs	/_/	/_/
- Assessment of socio-economic impact	/_/	/_/
- Bibliography	/_/	/_/

If you have given any negative answers, please explain why below or on a separate sheet:

...

7. What improvements would you suggest for a second printing of this memorandum?

....

8. Please complete and send this questionnaire to:

Entrepreneurship and Management Development Branch
International Labour Office
CH-1211 Geneva 22
Switzerland

9. Should you require additional information on any of the issues dealt with in this memorandum, the ILO and UNIDO will do their best to forward it to you.

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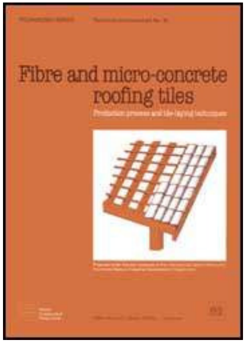

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

Other ILO publications

Safety and health In construction. An ILO code of practice

Changes in working practices and conditions in the construction industry over the past decade have meant that competent authorities, health and safety committees, management or employers' and workers' organisations, in particular, should take a fresh look at such aspects as the safety of workplaces, health hazards, and construction equipment and machinery. This code of practice takes account of new areas in the sector which require improved health and safety practices and other protective measures.

ISBN 92-2-107104-9 20 Swiss francs

Training contractors for results, by Tor Hernes. A guide for trainers and training managers. Edited by Derek Miles Construction is a precarious and demanding industry, relying on the successful deployment of a multitude of disparate materials and skills. It is therefore hard to manage, and the performance of contractors who run small and medium-scale enterprises, especially in developing countries, is frequently criticised. At the same time, there is a growing appreciation that the industry offers scope for dramatic improvement. Training programmes alone will not achieve this, but they can make an

important contribution, provided that they are well designed and well delivered.

This guide gives practical advice on preparing and running a successful training programme for building contractors. It is the outcome of a new and remarkably effective approach pioneered by the ILO: Interactive Contractor Training (ICT). In ICT sessions participants are encouraged to focus on the *results* of learning, measurable in terms of improved performance in quality, time and cost on the construction site.

For Hernes developed the Interactive Contractor Training methodology during a four-year ILO assignment, and is now an independent consultant in the field of construction management training.

Derek Miles is Director of Construction Management Programmes in the Management Development Branch of the ILO. "This is a particularly worthwhile acquisition for trainers and policy-makers alike. It is not the type of book that, once bought, remains untouched on the shelf." (*New Zealand Journal of Industrial Relations,* University of Otago, Dunedin)

ISBN 92-2-106253-8 20 Swiss francs

Technology Series

The object of the technical memoranda in this series is to help to disseminate, among small-scale producers, extension officers and project evaluators, information on small-scale processing technologies that are appropriate to the socio-economic conditions of developing countries.

ISSN 0252-2004

Small-scale brickmaking. Technology Series, Technical Memorandum No. 6
Provides detailed technical information on different brickmaking techniques and covers all

processing stages, including quarrying, clay preparation, moulding, drying, firing and the testing of produced bricks. The techniques described are mostly of interest to small-scale producers in both rural and urban areas. The processes and equipment are described in great detail, including drawings of equipment and tools which may be produced locally, floor plans, labour and skill requirements, materials and fuel inputs per unit of output. A list of equipment suppliers from both developing and developed countries is also supplied with a view to assisting the would-be brickmaker to import the required equipment. A chapter of interest to public planners compares, from a socio-economic point of view, the various brickmaking techniques described in this memorandum.

ISBN 92-2-103567-0 27.50 Swiss francs

Small-scale paper-making. Technology Series, Technical Memorandum No. 8

Provides technical and economic information on alternative paper-making technologies, describes the characteristics of various types and grades of paper products and gives guidance in the choice of paper machines. The information relates mostly to small-scale paper mills with a capacity of 30 tonnes of paper per day or less. The raw materials suggested for such mills include straw, bagasse, waste paper, rags and cotton waste, as well as other agricultural residues and imported wood pulp. Unlike other memoranda in the series, this memorandum is not a technical introduction to paper-making in general, nor is it a basic textbook on the subject. Instead, it provides people already in possession of the necessary background knowledge with criteria for choosing amongst different methods of paper-making.

ISBN 92-2-103971-4 22.50 Swiss francs

Small-scale manufacture of stabilised soil blocks. Technology Series, Technical Memorandum No. 12

This memorandum provides technical and economic information on alternative technologies for the production of stabilised soil blocks. The information provided relates mostly to small-scale units producing up to 400 blocks per day. It covers all aspects of block making: the quarrying and testing of raw materials; the choice of soil stabilisers; pre-processing operations (grinding, sieving, proportioning and mixing); block-forming methods, including a detailed description of machines currently available for making soil blocks; the curing and testing of produced blocks; and the use of mortars and renderings in wall construction.

The first and last chapters, which are on the technical and economic efficiency of stabilised soil blocks in comparison with other building materials, will mostly be of interest to public planners and housing authorities. The subjects covered include production costs, employment generation, foreign exchange savings and housing maintenance costs. The last chapter also gives some guidelines for government action in support of the use of earth as a building material.

ISBN 92-2-105838-7 20 Swiss francs

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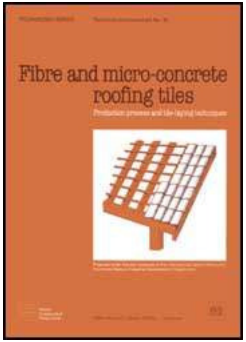


Back Cover

This technical memorandum, which has been prepared jointly by the ILO and UNIDO, is part of a series on manufacturing technologies. The object of the series is to acquaint small-scale producers with alternative production techniques for specific products and processes that are specially adapted to socio-economic conditions in developing countries.

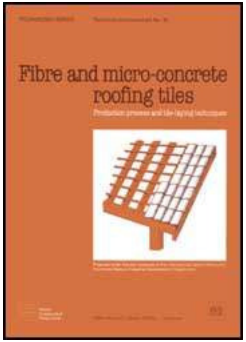
Housing is one of the crucial problems of our time; one-quarter of the world population lives in some form of precarious dwelling, while nearly 100 million human beings have no dwelling at all. Given the limited resources available for low-cost housing programmes, it is important that building costs be kept to a minimum by the use of appropriate materials and techniques. The fibre or micro-concrete tile is just one such material.

It is also a technology that should contribute to attaining several development objectives: employment creation, the improvement of the balance of payments and the creation of

rural industries.

This technical report meets two specific needs. First, it provides governments and institutions concerned with housing with socio-economic information enabling them to determine to what extent it is in the interest of their countries to promote the use of fibre or micro-concrete tiles and the means to be adopted to that end. Second, it provides building contractors and building material firms with all the technical and economic information that they will need for setting up fibre or micro-concrete tile production units. The production scales considered range from 500 to 5,000 tiles a week (equivalent to a roofing surface of 40 m^2 to 400m^2).

The technical chapters provide detailed information on the raw materials, equipment and production methods used. These are followed by a chapter describing a simplified method of estimating production costs of tiles on a given scale of production and of predetermining the profitability of such a unit. The final chapter examines the effects at national scale of the adoption of fibre or micro-concrete tiles, and more especially the impact on employment, balance of payments, rural industrialization and building costs.



FOREWORD

This technical report is the sixteenth of a series of reports prepared and distributed jointly by the International Labour Office (ILO) and the United Nations Industrial Development Organisation (UNIDO). It is the third of a collection dealing specifically with building materials for low-cost housing.

Housing is one of the crucial problems of our time; one-quarter of the world population lives in some form of precarious dwelling and nearly 100 million humain beings have no dwelling at all. The situation in some countries is especially dramatic - towns are expanding out of control and can no longer absorb the massive influx of people from the rural areas who settle in shanty-towns on the outskirts of the cities while, at the same time, dwelling conditions in the rural areas continue to deteriorate.

Given the housing situation in developing countries, the United Nations General Assembly

decided to proclaim 1987 "International Housing for the Homeless Year". The purpose of that decision was twofold - to make the international community aware of the problems facing the homeless and to promote specific activities to increase the amount of low-cost housing available. The ILO undertook to contribute to some of those activities especially as the promotion of appropriate policies for the building sector should help also create productive employment. It is to be hoped that the preparation and distribution of this technical memorandum will encourage the adoption of such policies by the governments of developing countries.

Given the limited resources available for low-cost housing programmes, and the limited means of the families who require such housing, it is important that building costs be kept to a minimum by the use of the appropriate techniques and materials. The use of appropriate materials - and especially materials which can be produced from raw materials found locally and requiring little or no imported equipment - should contribute to attaining many of the development goals, especially the generation of creative employment, the improvement of the balance of payments and the development of rural industries.

The fibre or micro-concrete tile is just one such material. That tile is produced from a mixture of about 20 per cent cement to 80 per cent sand. Fibre or aggregate are added as reinforcement. The production of this type of tile has the following advantages: it uses locally available raw materials (only the cement will have to be imported by certain countries); low equipment costs as the plant can be produced locally with but few imported inputs (such as the motor); relatively low total investment such as can be put up by local contractors; low-cost creation of productive jobs; very little or no imported inputs; thermal and acoustic comfort; improved appearance of dwellings.

Even though the advantages of the fibre or micro-concrete tile are currently recognised by specialists in that area and this type of tile has proved its worth in very many countries

since 1976, its use on a large scale requires three sorts of measures which are the responsibility of the governments of developing countries.

First of all, research and development has to be encouraged in connection with this type of material. Such efforts could, for example, be devoted to trying to replace cement by some local, less costly material, to identifying new fibres, to effecting market studies to discover what obstacles exist to the widespread use of fibre or micro-concrete tiles, etc. Then certain legal or fiscal measures will have to be reviewed which might otherwise hinder the adoption of such materials. Finally, it will be important thoroughly to disseminate information on this technology and to ensure the proper training both of the users and the potential producers of such materials. Indeed, in many developing countries, it will be necessary to overcome an unjustified obsession with corrugated iron, which obsession constitutes a serious hindrance to the adoption of other materials more appropriate for roofing. This technical memorandum is meant to serve as an instrument - among others - leading to a better understanding of fibre or micro-concrete tiles for roofing.

The preparation and distribution of this technical report meets two specific needs. Firstly, it will provide governments and persons in charge of the institutions concerned with housing with socio-economic information which will enable them to determine to what extent it is in the interest of their countries to promote the use of fibre or micro-concrete tiles and the means to be adopted to that end. Secondly, it will provide building contractors and the heads of building material firms with all the technical and economic information that they will need for setting up fibre or micro-concrete tile production units. The production scales considered range from 500 to 5000 tiles a week (equivalent to a roofing surface of 40 m2 to 400 m2). Production units on this scale should not exceed the size of a small firm.

The technical chapters, which are addressed to the producers and potential users of fibre or micro-concrete tiles (chapters II to VIII) provide fairly detailed information on the raw

materials, equipment and production methods used and should require no further comment other than the information provided by equipment manufacturers. Contractors lacking the necessary technical knowledge would be able to avail themselves of the training organised by various institutions such as the ILO (see Annex II). In other words, this technical report should not be considered a training manual but rather a solid basis for such a manual or for training sessions.

Any contractor who may be considering investing in a fibre or micro-concrete tile production unit could resort to a simplified method enabling him to estimate production costs of tiles on a given scale of production and to predetermine the profitability of such a unit (chapter IX). The final chapter, addressed to planners and funding institutions, sets forth information of a socio-economic nature on the effects at national scale of the adoption of fibre or micro-concrete tiles, and more especially the effects this will have on employment, balance of payments, rural industrialisation and building costs.

A questionnaire has been included with this technical report so that anyone wishing to send the ILO or the UNIDO their comments and observations on the content and usefulness of this publication may do so. Replies will be taken into account in the preparation of future reports.

This technical report was prepared by Mr. G. Brys, member of the ILO Entrepreneurship and Management Development Branch. Mr. Brys is responsible, in that service, for the technology and employment programme for the building sector.

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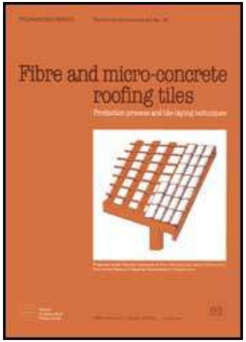

ACKNOWLEDGEMENTS

The publication of this report was made possible thanks to the assistance of the Belgian Government and the Belgian General Administration for Co-operation and Development which financed the author's services.

A considerable amount of information was obtained from SKAT - Swiss Centre for Appropriate Technology.

The International Labour Organisation and the United Nations Industrial Development

Organisation wish here to express their appreciation of this generous assistance.

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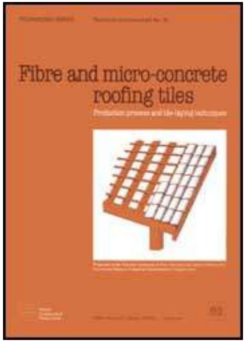

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

CHAPTER I INTRODUCTION

I. OBJECTIVE

Shelter is a basic need of the human species. It is one of the basic rights which any human being may claim. However, housing remains one of the crucial problems of our time: one-quarter of the world population (i.e. 1 billion people) live in non-durable and insalubrious dwellings, whilst some 100 million human beings go without a roof over their heads. Some countries experience particularly dramatic situations: urban populations grow unchecked, essentially in suburban slum areas; simultaneously, housing conditions in rural areas are constantly deteriorating. The overall situation of housing in the developing world represents a major challenge requiring innovative policies and technology.

The satisfaction of this essential need is complicated by the fact that other problems affecting housing directly or indirectly must be resolved first: land use policy, infrastructures, employment, sanitation, loans and interest rates, etc.

The fact must be faced that governments and people do not have the capital resources to construct conventional dwellings. It should be a principal objective to find new ways of reducing overall construction costs. In developing countries, materials represent 50 to 80 per cent of total building costs. These are often difficult to obtain and their high cost is the result either of total or partial import dependency or the use of production technologies unsuited to local conditions. The development, dissemination and use of building techniques that are consistent with low-cost housing result in appreciable socio-economic benefits such as:

- **generation of productive employment: unlike conventional building techniques, appropriate technologies do not require costly industrial materials and equipment; as a consequence, they contribute to job creation both directly when implementing low-cost housing programmes and indirectly at the input manufacturing stage (particularly construction materials);**

- improvement of the balance of payments: appropriate technologies make optimal use of local raw materials;

- development of rural industries; which help to maintain the workforce in rural areas and check the population drain towards urban areas.

For all of these reasons it seems essential to give priority to the production of building materials with a high percentage of locally available inputs.

Of all the components which make up a house, roofing plays an especially critical role. Roofing performs several essential functions:

- insulation from heat and cold;
- provision of shaded shelters;
- protection of dwellings from dust and sand;
- protection from rain.

A few traditional materials are still used in certain regions: thatch, clay tiles and more rarely, wood and bamboo. Corrugated sheet, whether galvanized or not, is a universal and poor substitute for all locally produced roofing materials. Its drawbacks are as follows:

- traditional architecture is gradually replaced by non-descript styles;

- living conditions in the dwellings deteriorate. Corrugated sheet roofing does not provide heat insulation. On the contrary, solar radiation on the sheet is transmitted by conduction to the air within, thereby causing overheating. During heavy rainfall, the impact of raindrops on the sheets overhead often produces a deafening noise;

- negative impact on the trade balance since most of the sheet material must be imported.

For these various reasons, there is a greater need for research and development to generate innovative technologies for roofing materials than for other building materials.

This volume presents one of the solutions meeting the two priority requirements (locally available materials and roof characteristics). The goal of this technical memorandum is to give a detailed presentation of the technical and economic features of concrete tiles reinforced with vegetable fibre or aggregates. It proposes to assist urban and rural constructors to set up their own production units. There is also a hope that the information presented in this report may induce governments to promote the use of fibre concrete or micro-concrete tiles, both for individual dwellings and community buildings.

II. BRIEF DESCRIPTION OF TECHNOLOGY

The production of fibre or micro-concrete tiles is based on a simple step by step process. Materials are usually available in a majority of countries: sand of average particle size, ordinary Portland cement (OPC 45), aggregate, vegetable fibre (sisal or coir), pigments. A cement mortar is prepared with OPC 45 and sand and aggregate. The cement: sand/aggregate ratio ranges from 1:3 to 1:2. When producing fibre concrete, vegetable fibres are chopped in segments 10 to 20 mm in length. The fibre is weighed in a ratio of 0.5 to 1 percent of dry mortar weight and added to the mortar. Once the sand-cement-fibre mix is completed, water is added to a suitable homogeneous and plastic consistency. One scoop of mix containing the correct measure for one tile is placed in the screeding frame on a vibrating table.

The vibrating table is made of a metal plate mounted on springs and powered by a small 12 volt electric motor (car battery or a.c. + transformer). A screeding frame of the size of the expanded (flat) tile is fixed on the table. The mortar is trowelled into the screeding frame, and the power is switched on for approximately 45 seconds. Once the layer is vibrated, a small cube of mortar is moulded on the right hand side of the tile to form a nib.

Once vibration is completed, the vibrated layer of mortar is transferred to a polyester or glass fibre mould. The mould is a standard pantile form. Once in the mould, the screed takes the shape of the pattern. At this stage, a tile-fixing device is moulded on the tile: this is usually a galvanized iron wire loop embedded in the fresh mortar of the nib. This loop will later fasten the tile on the roof battens (laths). After allowing to dry for 24 hours, the tile is hard enough for demoulding but needs additional curing. An additional curing period of 5 days through total immersion in a water tank guarantees good tensile strength. Finally, tiles must be kept in storage under a shed for 15 to 20 days before they can be sold and placed on the roof.

III. COMPARATIVE REVIEW OF MAJOR ROOFING MATERIALS

III.1 Wood

Wood, a particularly versatile material, may be put to many uses in construction. However, as the technical and physical characteristics of wood differ widely from one species to another, no universal rule may be laid down. In hot and humid climates in particular, special preservatives against insects, fungi and dampness are necessary. Such chemical treatments often increase production costs. A number of traditional methods are also effective, such as: liming, painting with used engine oil, smoking.

However the intensive use of wood as roofing material contributes to one of the major problems of tropical countries: deforestation. We therefore recommend extreme caution in assessing the consequences of using wood as roofing material.

The main characteristics of wood shingles are:

- **length = variable (330 mm, 470 mm, 510 mm);**
- **width = variable (80 to 200 mm);**
- **thickness = thin end (upper) 3 to 6 mm;**

- thickness = thick end (lower) 12 to 16 mm;
- weight = 35kg/m2.

Shingles may be laid on scantlings or boards and panels. The number of shingles per square metre depends on the roof slope. The main advantages of wood shingle are:

- heat insulation;
- moderate weight;
- good rot resistance (for certain species);
- durability (up to one century with good maintenance);
- noise insulation;
- attractive aspect.

III.2 Bamboo

Bamboo is the generic name for some 550 plant species growing in tropical and temperate regions. It grows easily and in abundance. With an extremely high fibre content, bamboo offers good bending and tensile characteristics.

Bamboo presents three major drawbacks: it is highly flammable; it splits easily as a result of variations in air moisture; it has a short life-span.

As in the case of wood, preventive treatment is possible but has the drawback of increasing the cost price. Making bamboo tiles and shingles is extremely simple. Laying techniques are not difficult. Moreover, bamboo can be used as roof structure material.

There are essentially two techniques. Bamboo tile roofing consists of successive rows of half-stems covering the whole length from the ridge to the gutter. A first layer is laid, with the concave side facing up. A second layer is laid on the first, with the convex side facing up (as for Roman tiles).

Bamboo shingles are segments of 3 to 4 cm in width and maximum length between knots. They are fixed on battens made of half-stems laid concave side up.

III.3 Grass - Straw - Thatch - Reed - Papyrus

These materials have been in use for centuries. They are economical and easy to use. The major drawbacks Involved in using organic materials result from damage caused by insects and natural decay.

Laying processes are critical to durability. A correctly laid thatched roof may last up to 10 years. Unfortunately know-how is becoming scarce and nowadays grass roofs need to be changed every 2 or 3 years.

Preparation of the materials is quite simple. Sound plants with hard, dry and long stems are collected. The stalks are tied in bunches of 10 to 15 cm diameter. The bunches are tied to the battens with ropes and piled in staggered layers up to a thickness of 25 to 30 cm.

Population growth and drought have a negative impact on the continued use of thatch as roofing material. This natural resource is becoming increasingly scarce.

III.4 Corrugated sheet

Corrugated sheet is a universal substitute for traditional materials. It is often perceived as a symbol of higher social status.

Corrugated sheet comes in several grades. Quality depends on the metal used (aluminium, iron, steel), sheet thickness and the thickness of the protective coating (galvanisation). Sheet thickness ranges between 0.15 mm (39 gauge) and 1.22 mm (18 gauge). The thickness of the galvanizing material (zinc) varies in the range of 60 microns.

Galvanized steel sheet is attacked by corrosion as the protective coating decays. Aluminium sheet is naturally protected by its self-preserving oxide layer. Over time, it acquires a greyish colour and loses its reflective properties. The durability of corrugated roofing sheets depends on these parameters.

The widespread use of corrugated sheet as roof cladding material is essentially due to the fact that its qualities are consistent with the circumstances of developing countries:

- **lightweight (lighter roof structure);**
- **readily transportable;**
- **simple laying procedures.**

In the long run, serious defects appear, amongst which:

- **poor heat insulation;**
- **poor noise insulation;**
- **deterioration of false ceilings as a result of condensation;**
- **need to import the material (foreign currency);**
- **poor quality of galvanization (corrosion);**
- **unattractive external aspect.**

For all of the above reasons, more appropriate solutions must be found, offering all the benefits of sheet roofing but none of its defects. Fibre concrete tiles are the perfect solution.

III.5 Clay tiles

Another traditional roofing material is fired clay tile. The technology involves local raw materials and relatively unskilled manpower. With good quality tiles, a roof will present good physical characteristics (strength, heat and noise insulation, etc). Clay tiles come in

many shapes: Roman (or Spanish) tiles, flat tiles, pantiles, industrial tiles.

The use of clay as a raw material is highly dependent on several parameters:

- quality of the clay: the presence of impurities results in a brittle end-product;

- firing method: the type of kiln used and the firing method strongly affect tile quality;

- wood consumption: firing requires a large quantity of fuel and contributes to deforestation. The firing of 5,000 tiles (65 to 200m2 of roofing depending on the type of tile used) requires 2 to 4 cords of firewood depending on the type of kiln used;

- heavy weight: the weight per square metre of roofing varies from 35 to 80 kg. This requires a much larger section of timber, as compared with lightweight traditional materials or sheets, and therefore an increase in the cost of substructures.

III.6 Brick and stone: arches

Arch roofs are very widespread in certain regions and practically unknown in others. They can span large surfaces with materials which hold together by compression only. Such materials are usually available locally (brick, stone, earth). The more expensive elements required to provide bending strength (wood, metal, reinforced concrete) can thus be dispensed with.

Although this type of roofing presents all the benefits of appropriate technology for developing countries (local materials, labour intensive, good heat and noise insulation, durability), a major obstacle hinders widespread application: know-how.

In regions where this technique is used, there is no need to seek and suggest alternative methods. Where it does not exist, the training of skilled manpower requires long training hours and persuasion: numerous fears and deterrents linked with innovation, especially in building techniques, need to be overcome.

III.7 Fibre or micro-concrete

Fibre or micro-concrete technology has been in existence for a long time. It presents many technical and economic benefits but has also been criticized for its many drawbacks. Most of the time, such drawbacks are due to inappropriate management of the technology and insufficient know-how. This last point cannot be over-emphasised. Although the manufacturing process is simple, strict observance of all the manufacturing instructions is critical in order to obtain a quality product that will be readily accepted and disseminated. The end product must compete in terms of economics, strength and durability with the better-known materials. In other words, poor know-how hinders the dissemination of this technology: the product cannot gain widespread acceptance on the market without good technology transfer.

Compared with the other technologies as briefly described above, fibre concrete tiles present numerous advantages:

- most of the materials used are found locally. Extracting them is a source of employment;

- investments required for starting up production units are moderate. Equipment accounts for only a small share of initial investments and can be made locally. The largest portion of start-up capital goes into a revolving fund for raw materials, infrastructure and labour;

- the technology generates employment;

- the use of fibre or micro-concrete tiles results in hard currency savings through a reduction of Imports;

- the life expectancy of the material is at least 10 to 15 years: the oldest fibre concrete tile roofs are found in Kenya (10 years);

- heat and noise insulation;

- attractive appearance.

IV. PRODUCTION SCALE

The production capacity of fibre or micro-concrete tile-making units depends essentially on two factors:

- type of equipment;
- number of workstations.

A small production unit can produce 500 tiles a week, or the equivalent of 38m2 of roof. With a more sophisticated plant, production capacity may be increased to 1,000 tiles per week, or 80m2 of roof. With more work stations, production may be raised to 5,000 tiles a week or 400m2 of roof cover.

Table 1 gives examples of production capacity for three types of plant: small, medium and large.

Table 1. Production capacity for three plant sizes

Production Scale	Tiles per week	Type of machine	Number of workers	Type of market
Small	500	Small mobile screeding	2	Local and rural

Small	500	Small mobile screening machine	2	Local and rural
Medium	2,000	Electric plant	3	District
		Hand powered plant	4	
Large	5,000	Complete work station	7	Urban Industrialized

Small- and medium-scale production units

A small-scale production unit produces enough tiles in a week to cover a house. Capital investment is low and within reach of small communities. Portable plants can be used to produce tiles close to building sites, thereby reducing transport costs. Sand being the largest input, production units should be located as close as possible to a quarry in order to reduce transport costs.

Large-scale production units

By increasing the number of work stations and purchasing more sophisticated equipment, production can be increased to keep up with increasing demand. Although the capital outlay is larger, this is offset by a lower manpower ratio. In addition, infrastructures for this type of production units require larger workshops and more expensive storage areas.

This technical memorandum applies to all production scales: output can be easily adjusted to the capacity of individual producers. There is little technical difference between the various types of plant.

V. CONTENTS OF TECHNICAL MEMORANDUM

Chapter II describes the various raw materials involved in the technology. It deals with physical and chemical characteristics, quality and quantity control. One section deals with

additives. Another section discusses suggestions for improved performance.

Chapter III describes the equipment and tools required for a production unit.

Chapter IV gives a step by step description of the tile-making process. For each step, possible mistakes are identified together with their consequences on tile quality.

Chapter V describes the various tests for quality control of the end product. All the tests are described. Where tests are failed, reasons for failure are identified. A separate section in this chapter presents problems, causes and solutions in table form.

Chapter VI deals with the organization of production. The last section in this chapter presents two typical plant layouts. Chapter VII is intended for carpenters. It discusses the basic principles of roof frame construction. It also offers a comparative analysis of different types of structures for different types of roofing.

Chapter VIII is intended for roofers or tile layers. It presents basic rules for calculating the number of tiles required for a given roof surface as well as several methods for fixing the various types of tiles on the frame.

Chapter IX defines a methodology for the assessment of production costs and the sales price of tiles. One section applies the methodology to a specific case study. A second section provides basic information on costing methods.

Chapter × presents a point by point discussion of the various criteria and socio-economic factors resulting from the dissemination of this technology.

Annexes I, II and III contains respectively a glossary of technical terms, a list of major institutions which can provide information on fibre concrete or micro-concrete technology and a bibliography.

VI. TARGET AUDIENCE

The aim of this technical memorandum is to provide information for various professional categories (architects, contractors, building technicians etc.) or institutions interested in construction materials and, more specifically, economic housing in developing countries, i.e.:

- authorities concerned with low-cost housing;
- construction research institutions;
- government agencies in charge of housing and public construction;
- financial institutions, banks, loan agencies;
- local craftsmen and small-scale entrepreneurs wishing to set up their own production units;
- building cooperatives;
- volunteer organizations, technical assistance workers, etc.;
- members of the various crafts involved in roof-making.

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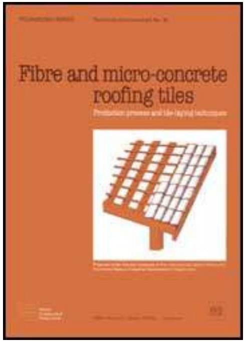

Fibre and micro-concrete roofing tiles

Fibre and Micro-Concrete Roofing Tiles - Production Process and Tile-Laying Techniques (ILO, 1992, 172 p.)

CHAPTER II RAW MATERIALS AND MORTAR

The quality of a mortar depends on the quality of its components, mix proportions and the mixing environment. Many variables can thus affect the end quality of the tiles.

The following chapter gives a description of components and a presentation of the major characteristics required for a good quality mix. Sand, aggregates, cement and fibre are analysed in detail as basic components. Mortar quality is also highly dependent on mix ratios. Another section discusses the main additives. Finally, several suggestions for improving the end-product are given at the end of the chapter.

I. SAND

The quality of sand is highly dependent on its origin (petrology-mineralogy) and its physical properties (shape, texture, porosity etc). The type of sand used has a direct influence on the strength of fibre concrete products. It is difficult to choose the right type of sand without prior trials. The choice of sand and its adequacy to the technology depend

on several factors:

- **- appropriate grading (particle size distribution in aggregates);**
- **- particle shape;**
- **- clay content (sand equivalent);**
- **- presence of organic matter.**

I.1 Granulometry

The size distribution of sand particles has a direct influence on the strain and stress strength of concrete products. If the sand contains a majority of identical size particles, natural bonding cannot occur. A "well graded" sand contains a wide range of particle sizes. Different grain sizes are necessary for appropriate bonding, inter alia for the following reasons:

- a diversity of grain sizes reduces the prevalence of voids;

- a high number of contact points in the aggregate allow the cement to bond the particles together;

- the absence of voids (density) prevents excessive shrinkage (development of micro-cracks) during setting;

- fine and medium-size particles fill the voids and prevent the cement milk from seeping during the vibration phase;

- an excessive ratio of "fines" will require additional water to achieve good workability; this reduces the overall strength of the mortar.

Sands are graded according to particle size.

Table 2: Grading of soil by size of constituent

Size of particles (in mm)	Name
60.0 - 20.0	Coarse gravels
20.0 - 6.0	Medium gravels
6.0 - 2.0	Fine gravels
2.0 - 0.6	Coarse sand
0.6 - 0.2	Medium sand
0.2 - 0.06	Fine sand
0.06 - 0.02	Coarse silt
0.02 - 0.006	Medium silt
0.006 - 0.002	Fine silt
< 0.002	Clay

Source: British Standards Institution B.S. 1377, 1975.

Particle size analysis (granulometry) ensures the adequacy of a given sand to the technology. A dried sand sample is sieved through square or round mesh screens. In many countries, public works laboratories have the testing equipment and can offer this service.

The successive rejects collected on the sieves are weighed. The granulometric curve of an aggregate is constructed by plotting the mesh size on the horizontal axis and the percentage of successive rejects on the vertical axis.

The shape of the granulometric curve is significant. It gives a direct insight of grain size distribution of the aggregate in a given sand sample. Three typical examples are given on

the following page (figures 1 to 3).

Reinforced concrete aggregates (mortar) are often defined by two letters: d/D, "d" being the smallest dimension and "D" the largest dimension.

The mix used in fibre and micro-concrete technology requires a fairly well-balanced sand with particle size ranging from 0.06 to 2 mm. It should be graded on a 2 mm to 2.5 mm mesh size sieve. With this type of sand, the granulometric curve will be suitably distributed, thereby guaranteeing good stress and strain strength.

The presence of 0.06 mm. size particles is an advantage in low cement ratio mortars, provided the components are clean and adequate from a mineralogic standpoint. However, the percentage of micro-particles must remain very low (1 to 5 per cent) otherwise they hamper mix workability.

The granulometric curve given in figure 4 is that of a very clean sand used in Madagascar during preliminary testing prior to the installation of the tile production unit.

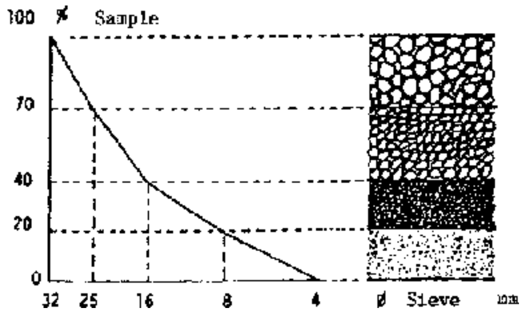


Figure 1. Granulometric curve of homogenous soil composed of granulates of various sizes (ref. 14)

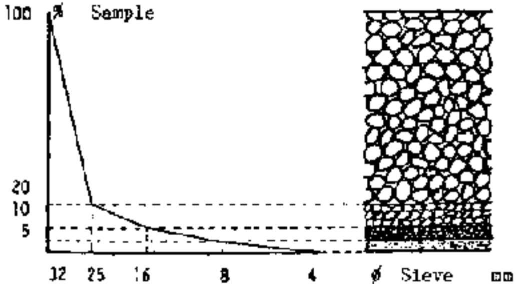


Figure 2. Granulometric curve of soil composed essentially of large granulates (ref. 14)

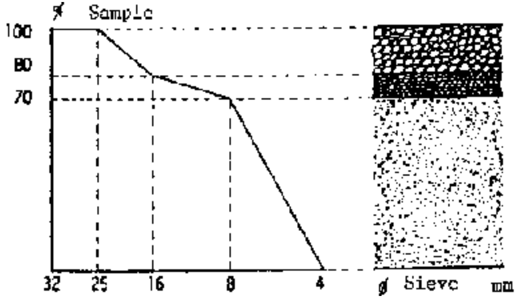
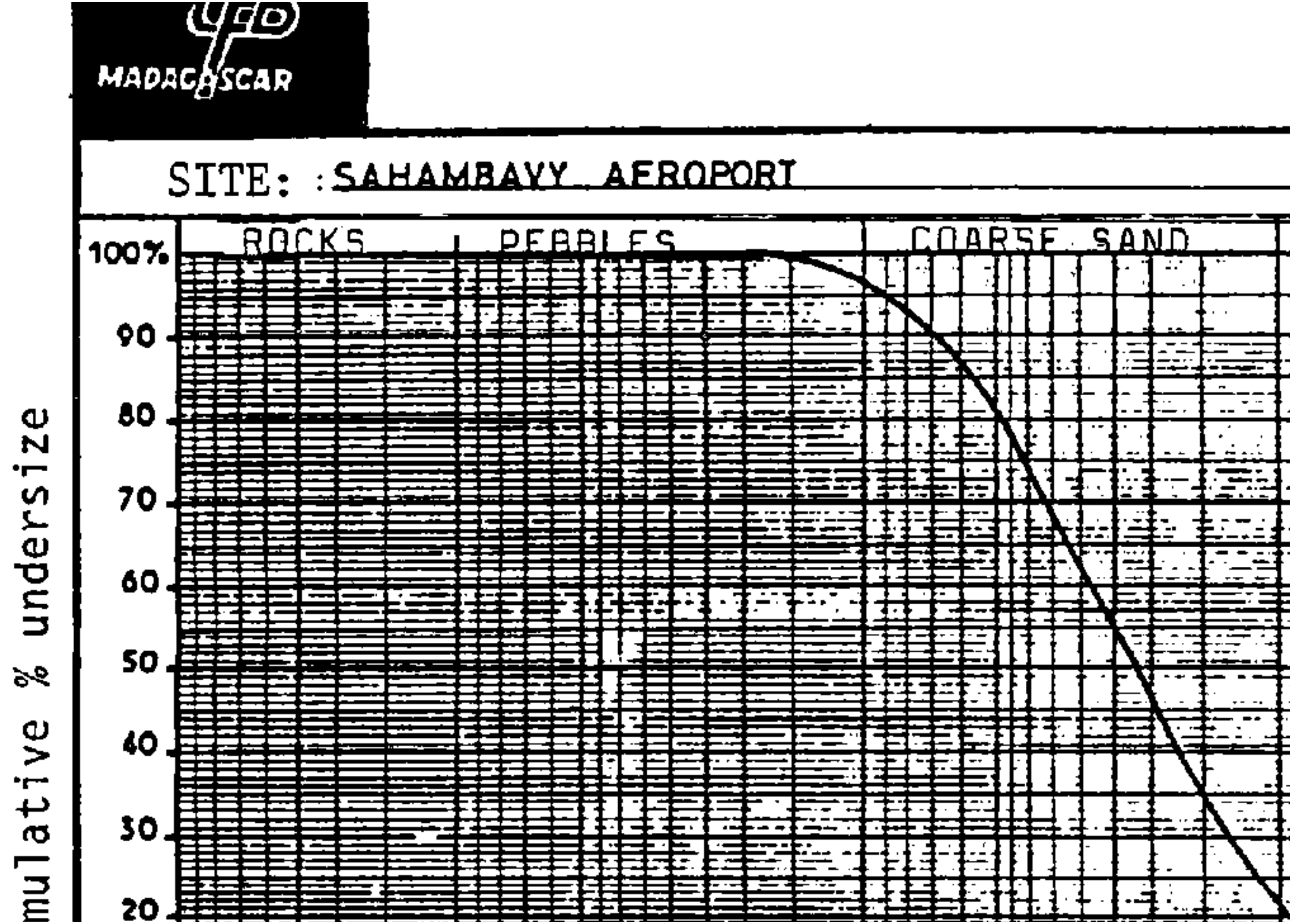


Figure 3. Granulometric curve of soil composed essentially of fine particles (ref. 9)

SOIL GRANULOMETRIC ANAI



MADAGASCAR
SITE: SAHAMBAVY AEROPORT
ROCKS
PEBBLES
COARSE SAND
100%
90
80
70
60
50
40
30
20
mulative % undersize

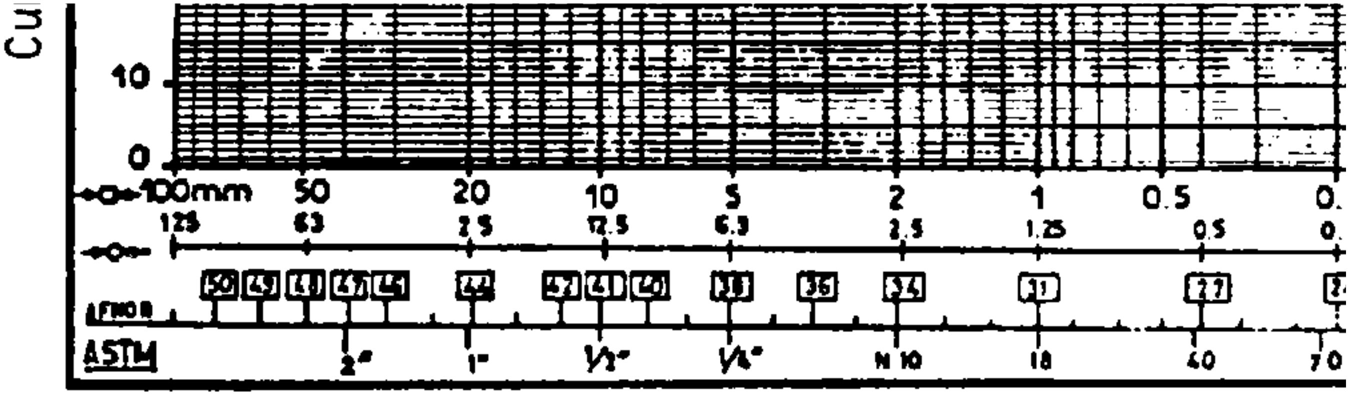


Figure 4. Granulometric analysis of a sand sample from Madagascar

I.2 Grain shape

Grain shape affects the amount of water required for the mix. Angular particles impair the workability of the material. Smooth, round-shaped particles will require less mixing water. The water ratio of a mortar will directly affect the strength of the finished product (see section IV.3 in this chapter).

In addition, a high proportion of particles with flat and smooth surfaces (e.g. mica) is detrimental to mortar quality. Mica presents a double disadvantage: microparticles cannot adhere to its smooth surface; the cleavage of mica particles induces the development of cracks.

I.3 Clay content: sand equivalent

Clay is composed of microscopic particles. When mixed with sand, the microparticles

deposit on the grain surface and form a coating which prevents the chemical binder (cement) reaction from operating. A high clay content reduces the strength of the finished product.

The lowest sand equivalent acceptable for this technology is in the range of 75 percent to 85 percent. This is a "clean" to "very clean" sand, with a low percentage of clay fines.

It should also be noted that a total absence of fine particles negatively affect mortar workability. Although additional water can be used for the mix, this is detrimental to the quality of the final product (see section IV. 3 in this chapter).

The clay content of a sand sample may be established by a very simple test. This test must be carried out regularly, particularly if the sand comes from different sites.

Clay content or sand equivalent test (figure 5)

Materials

- **One test-tube graduated in millilitres;**
- **Salt water solution.**

Method

- **Pour a small amount of salt water in test-tube;**
- **Add sand up to 100 ml graduation mark;**
- **Add salt water up to 150 ml mark;**
- **Cover tube; shake energetically;**
- **Place tube on flat surface; level sand surface by tapping on test tube;**
- **Allow to decant and settle for 3 hours.**

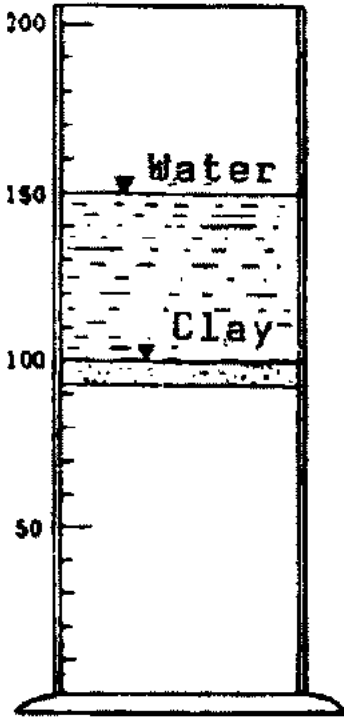


Figure 5. measuring sand equivalent.

<u>Reading and results</u>

- **Total height of sand plus clay = H2**
- **Height of sand only .... = H1**

- Sand equivalent is equal to:

$$S.E = \frac{H1 \times 100}{H2}$$

I.4 Impurities

Organic impurities may impair the setting properties of concrete. A simple test gives the content of organic matter in the sand. This test should be performed regularly, particularly if the extraction site is changed during a production run.

Test for organic impurities

Materials

- One 350 ml jar graduated at 130 ml and 200 ml;
- One 3 per cent NaOH or CaOH distilled water solution.

Method

- Fill jar with sand up to 130 ml mark;
- Pour water solution up to 200 ml mark;
- Shake mixture energetically;
- Allow to decant and settle for 24 hours.

Reading and results

The colour of the solution indicates the organic matter content:

- transparent to light yellow:	low organic matter content: the sand is appropriate;
- dark yellow:	presence of organic impurities: final strength of concrete will be reduced by

- dark yellow: presence of organic impurities: final strength of concrete will be reduced by 10 to 20 per cent;
- reddish-yellow: sand should be rejected: final strength of concrete will be reduced by 50 to 80 per cent.

II. AGGREGATE - GRAVEL

II.1 Rationale

Numerous experts in many countries now recognise that natural vegetable fibre may be replaced with small-sized gravel - aggregate - when preparing the mix. Although the many advantages of fibre concrete have been amply demonstrated, substituting aggregate for the fibre produces other benefits, such as:

- the mechanical strength of the tile will remain constant over time; it will not be impaired by the decay of fibres caused mainly by the influence of alkali in the cement;

- tiles which are not reinforced with vegetable fibre should be made thicker (approximately 30 per cent more). Although this means increasing the raw materials required, costs will not be higher. Fibre is an expensive material in some countries and in any event the adjunction of fibre in the mortar is extremely labour intensive. Substituting aggregate for the fibre increases the overall productivity of a tile-making production unit;

- by increasing tile thickness to 8mm, micro-concrete tiles offer excellent strength qualities, advantageous during long distance hauls.

II.2 Characteristics and selection

Aggregates should have the same characteristics and properties as sand. Most sands

already contain the required quantity of coarser grains. The following points should be observed:

- **maximum particle size depends on tile thickness; in no case should it exceed two-thirds of the tile thickness: for an 8mm tile, maximum grain size should be 6mm;**

- **aggregates should be as clean and free from clay as the sand (see sections 1.3 and 1.4 in this chapter);**

- **natural rounded aggregates should be preferred to crushed quarry materials. For one reason, if they are silica based, they will be less porous and the amount of water required to bring the mix to the appropriate consistency need not be increased (adding extra water impairs mortar strength). Another reason is that quarry material is more angular and therefore reduces mortar workability;**

- **aggregate porosity, as mentioned above, is an essential factor which must be borne in mind when selecting samples;**

- **a granulometric curve for the aggregate giving the percentage distribution of different sized particles is not as vital as it is for sand. The main point to be observed for gravel is that the maximum gravel size should be less than two-thirds of the overall tile thickness.**

If a granulometric curve is planned, it should preferably be made from the sand plus gravel mixture. The general outlook of the curve should be similar to that shown in figure 4, the main difference being a shift of the curve to the gravel side.

III. CEMENT

Cement is a material with adhesive and cohesive properties. It is an hydraulic binder

composed of lime, silica, alumina and iron oxide. Several basic components enter into the production of cement. As a result, cement comes in several varieties: Ordinary Portland cement, pozzolanic cement, aluminous cement, metallurgical cement etc. Portland cement is made from limestone and silica. When fired at 1500ºC, this mixture produces clinker. The clinker is crushed into a fine powder and mixed with a small quantity of gypsum. Metallurgical cements are made from slag, a by-product of iron production. Pozzolanic cements are a mixture of Portland cement and pozzolana (volcanic ash).

Ordinary Portland cement is also suitable[1], although its quality can vary widely depending on its origin. Cement setting depends essentially on the water/cement ratio, water evaporation, ambient temperature and relative humidity. Setting of the cement will begin as soon as hydratation starts: the process gives off heat. Setting time decreases with higher temperatures. After 24 hours, setting is effective. The cement will continue to harden and will reach optimal strength after 28 days.

> **[1] Ordinary Portland cement. See British Standards Institution B.S. 12, 1971.**

Pozzolanic cements are the result of adding pozzolana to OPC. Pozzolana is a natural or artificial component which contains silica in its reactive phase. Pozzolanic cements are slow-setting. If the production cycle (demoulding, mixing new mortar, moulding and setting) can be kept down to 24 hours, all the moulds may be reused each day. With a slow-setting cement, the tiles cannot be demoulded before 48 hours, and a larger number of moulds is necessary to maintain daily production. This means a higher investment.

Cement storage conditions are critical to the quality of a mortar mix. Even in normal storage conditions, the properties of cement deteriorate over time. The chemical reaction starts as soon as the cement is in the presence of humidity: the air moisture seeps through the bags and produces lumps. It is unadvisable to store cement for a long time: it loses 20 per cent of its strength after 3 months, 30 per cent after 6 months and 40 per

cent after one year (figure 6).

Cement must therefore always be stored away from dampness and wind. Bags should not be in contact with the ground, but rather placed on pallets. They should not be stacked against an outer wall. In order to avoid air circulation, they should be stacked very tight. In draughty storage sites, cement bags should be covered with a plastic sheet.

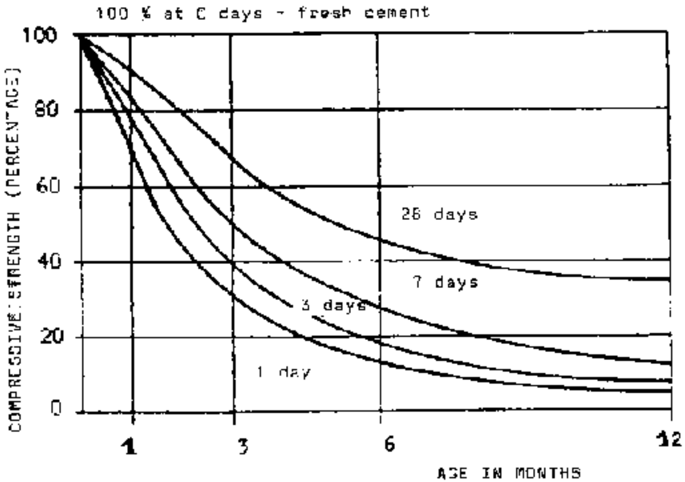


Figure 6. Decrease in strength of OPC kept in paper bags at different stages of curing (ref. 29)

IV. FIBRE

Fibre concrete tile production is fairly widespread throughout the world. The use of vegetal fibre for reinforcement has become routine technology. However, experts in several countries have now come to question the value of adding fibre in the mix.

Although the adjunction of fibre is no longer viewed as a must, it does remain a worthwhile and indeed valuable technology.

This section describes the major characteristics required of fibres for fibre concrete production. Fibre size and quantities are described in section IV.2 of this chapter.

IV.1 Rationale

Adding fibre to concrete serves the following purposes:

- **to prevent cracks due to shrinkage during the cement hardening period. Shrinkage occurs when the water trapped in the voids evaporates. The end volume of the dry product is smaller than the total volume of its components;**

- **to produce thinner tiles. Concrete tile-making has been known for many years. However, in order to prevent the development of cracks, it was necessary to produce thick tiles (12 mm minimum). This resulted in an increase of the load per square metre of roof (50 to 60 kg/m2). The adjunction of fibre to the mix makes it possible to reduce tile thickness to 6 mm: the load is thus brought down to 21 kg/m2. The gain is twofold: less cement is needed to produce the same number of tiles and wood structures can be kept lighter;**

- **to improve impact strength. In the course of handling tiles are often subjected to various shocks and constraints. Careless transport and handling are the main causes of breakage. Adding fibre to the mix improves the tile's resistance to these hazards.**

Concrete tiles may also be produced WITHOUT FIBRE. Fibres are replaced by aggregates.

A simple test measures the benefits of reinforcing tiles with fibre. A mortar is prepared

and divided into two samples. The first sample is moulded without fibre. The second sample receives additional fibre before moulding. Drying and curing of both tiles are carried out in the same conditions (21 day cycle). The two tiles are held vertically with the small edge resting on the ground, and released at the same time. The reinforced tile does not break. If the impact is not strong enough, it may crack; the non-reinforced tile will always break (figures 7 and 8).

IV.2 Modification of the physical properties of tiles due to fibre adjunction

The mechanical properties of a mortar reinforced with vegetable fibre are modified. The tensile strength required to develop the first crack is slightly lower for fibre concrete: fibre has a negative effect on cement setting (presence of chemicals). Conversely, when subjected to impact, a non-reinforced tile will break more readily. A fibre reinforced tile will present a higher distortion capacity.

Tile porosity is not affected by the incorporation of fibre, provided the quantities used are in keeping with the standards defined in section V.2 of this chapter. There is an indirect relationship between fibre content and porosity: with a higher proportion of fibre, more water goes into the mix, thereby reducing its strength (mechanical strength and permeability).

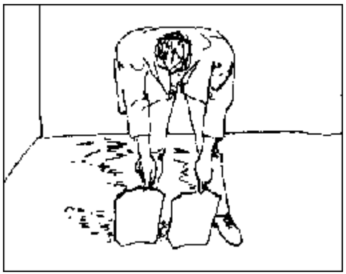


Figure 7. The tiles are held at a short distance from the ground with the small side resting on the ground

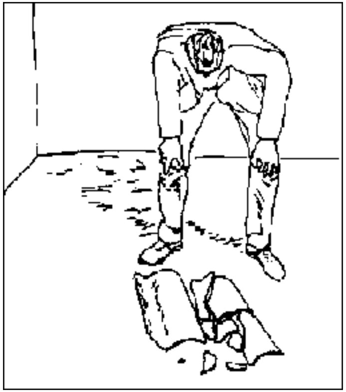


Figure 8. The tiles are dropped. The left-hand tile (reinforced with fibre) does not break. The right-hand tile breaks in several pieces.

The following physical properties of a tile are not affected nor modified by a small proportion of fibre in the mix:

- **thermal conductivity;**
- **noise transmission;**
- **water absorption;**
- **elasticity in relation to dampness;**
- **elasticity in relation to temperature.**

IV.3 Types of fibres

Rather than industrial products (glass fibre, iron filings) and man-made materials

(polymer fibre), the fibres best suited to the socio-economic circumstances of developing countries are natural fibres. This study deals essentially with sisal fibre and, to a lesser extent, coir fibre.

The adequacy of other fibres for fibre concrete production should not be rejected a priori. However, this should be confirmed by a specific study before mass production is started.

Table 3 shows the major physical properties of the most commonly used fibres. Appropriate fibres present the following features:

- **flexibility (non brittle);**
- **rough surface texture;**
- **non-oily to the touch;**
- **free from chemicals (e.g. sugar) affecting cement setting;**
- **dimensional stability even in the presence of moisture.**

IV.4 Sisal (figure 9)

Sisal is grown in many countries of the world. It grows easily in warm climates. Its lifespan is 10 to 14 years. The first leaves are collected after 3 or 4 years and are 1.2 m to 2 m long. Each leaf contains on average 1000 fibres of 1 to 1.5 m in length, arranged longitudinally. Fibre diameter ranges from 0.2 mm to 0.5 mm. Sisal leaves contain 85 per cent water, 4 per cent fibre and 11 per cent of various residues. During its lifespan, each plant produces 5 to 7 kg of fibre. The physical properties of fibres are shown in the table above. Most sisal farms extract the fibre automatically. However, in rural areas, certain families still cultivate and process sisal leaves by hand. This simple operation consists in scraping the leaf until the pulp is completely removed.

Where sisal is not available locally (in the shape of "long strands"), information may be sought from the different industries which are likely to use this product (figure 10). These

industries will indicate their source of supply in the country or abroad.

Table 3. Physical properties of fibres

Fibre type	Length mm	Diameter mm	Density kg/m3	Youngs Modulus GPa	Tensile Strength MPa	Elongation at break %	Water absorption %
Kenaf	30-750	0.04-0.09	NA	22	295	NA	NA
Coir	50-350	0.1-0.4	1440	0.9	200	29	130-180
Sisal	1000-1300	0.2-0.3	1450	26	570	3	60-70
Bagasse	NA	0.2-0.4	1250	17	290	NA	70-75
Bamboo	NA	0.1-0.4	1500	27	575	3	40-45
Jute	1800-3000	0.1-0.2	1500	32	350	1.7	NA
Flax	500	NA	1540	100	1000	2.0	NA
Elephant	NA	NA	NA	5	178	3.6	NA
Grass							
Water-reed	NA	NA	NA	5	70	1.2	NA
Plantain	NA	NA	NA	1.4	92	5.9	NA
Musamba	NA	NA	NA	0.9	83	9.7	NA
Piassava	NA	NA	NA	6	143	6.0	110
Polypropylene	NA	NA	910	6.8	586	210	2
Glass	NA	NA	2700	76	1240	3.5	4
Steel	5-200	0.1-0.4	7860	207	700-2100	3.5	NA
Asbestos	<15	<0.2	2550	159	210-2000	2.5	7-18

Concrete	NA	NA	2300	32	5	0.02	NA

(1) Mpa: Megapascal: 1 Mpa = 10 bars = 10.2 kgf/cm2.
(2) Elongation of fibre up to breaking point, expressed as percentage of initial fibre length.
(3) Water absorption capacity of fibre as a percentage of its initial water content.

Source: ref. 11

IV.5 Coir

Coconut husk (figure 11) is composed of a layer of fibrous tissue (mesocarp) wedged between an outer hull (exocarp) and the hard shell surrounding the kernel (endocarp). The husk accounts for 35 per cent of the total weight of the nut. There are three main types of coconut fibres:

- long, fine and white, used for making mats and ropes;
- coarse and rigid (bristle), used for brushmaking;
- short and flexible.

Only the first type of fibres are suitable for reinforcing concrete. They are collected when the nut is gathered before it is completely ripe for the kernel to be sold. The fibre of coconuts grown for palm oil production cannot be used, since the nut must reach full maturity before harvesting. The short and flexible fibres derived from mature copra nuts are therefore not suitable. Rigid fibres (bristle) are not adequate for this technology.

SISAL FIBRE

Upholstering	Ropes	Tow	Sacking	Mats	Reinforced	Handicrafts
	Twine	Packing		Rugs	Plastic	

	Nets					

Figure 10. Use of sisal in various industries

Figure 9. Sisal plant (ref. 33)

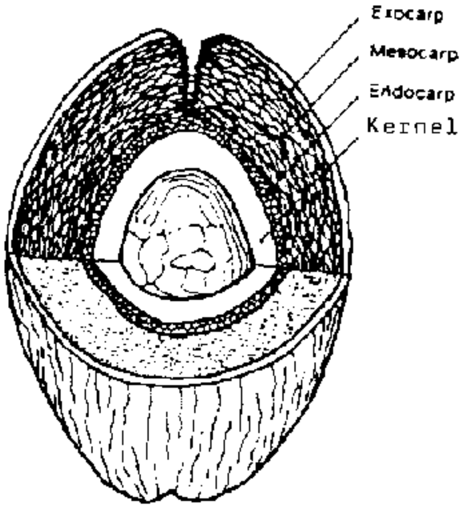


Figure 11. Coconut husk

The average length of coir fibres ranges from 5 cm to 35 cm, their diameter being 0.1 mm to 0.5 mm. The physical properties of fibres are shown in table 3 in this chapter. Coir fibre presents good elongation at break properties.

V. MORTAR

For the production of vibrated mortar (without fibres), a mixture of sand and aggregate should be prepared. The sand:aggregate ratio depends on several factors such as grain distribution in the samples, mineralogical origin, grain shape, costs, etc. The appropriate sand:aggregate ratio should be worked out on a case by case basis with practical trials and strength tests. The sand:aggregate ratio is usually 1:1 to 1:2.

V.1 Cement: sand/aggregate ratio

The composition of a mortar mix is defined by a ratio giving the amount of cement to be added to a mix of sand and aggregate. The percentage of cement is critical to tile strength. The accuracy of the cement:sand/aggregate ratio is important with regard to both the cost of materials and tile strength.

Proportioning can be done by weight or volume. Both methods have their drawbacks:

By weight:	- variations in the mineralogical composition of sand and aggregate (bulk);
	- variation in the water content of sand and aggregate depending on its origin and/or place of storage.
By volume:	- bulking (compacting) of sand/aggregate and/or cement.

The ideal ratio of the mortar mix required for this technology is given by the weight of DRY MATERIALS, i.e. a cement:sand ratio of 1:3. A 6 mm tile weighs 1.6 kg.

Table 4. Ideal ratio of dry materials

	Per tile	10 tiles

Sand/aggregate	1.2 kg	12 kg
Cement	0.4 kg	4 kg

In practice, the sand and aggregate used are never dry; it is often stocked in the open air and its water content varies. It is therefore necessary to find a method of measurement which approximates the ideal theoretical ratio as closely as possible. For this purpose, the equipment delivered with the vibrating table generally includes scoops to be used for batching sand and cement (see chapter III, section VII).

Proportioning of the mix components must be adjusted to a number of parameters determined by the quantity of raw materials (see above) and local climatic conditions. Where climatic conditions are harsh, or if roofs are exposed to hurricanes, impact of fruits falling from trees, or rock-throwing, two measures may be taken separately or simultaneously:

- **increasing tile thickness while maintaining the basic cement:sand/ aggregate ratio;**
- **increasing the proportion of cement to improve strength characteristics.**

As an example, the three tables below (5, 6 and 7) show the weight of components per tile for various cement: sand/aggregate ratios and different tile thicknesses (theoretical weight of dry materials consistent with average bulk).

a) <u>Good quality raw materials;</u>

Table 5 gives reference figures for standard tiles made with high quality raw materials. The particle size of the sand and aggregate are appropriate, and the cement used is OPC 45. The tiles are intended for hurricane-free areas. If violent storms are expected to occur, tile thickness should be increased.

Table 5. Weight of cement and sand for a 1:3 ratio

RATIO 1 : 2		CEMENT	SAND/AGGREGATE
Percentage of total weight		25%	75%
Thickness:	6 mm	0.40 kg	1.20 kg
	8 mm	0.53 kg	1.60 kg
	10 nun	0.66 kg	2.00 kg

b) Mediocre raw materials or harsh climate;

Table 6 gives reference figures for tiles intended to be used in two fairly frequent situations. If the raw materials do not meet the criteria described above, the amount of cement used must be increased. In countries prone to violent windstorms and hurricanes, both the amount of cement and tile thickness should be increased.

Table 6. Weight of cement and sand for a 1:2 ratio

RATIO 1 : 2		CEMENT	SAND/AGGREGATE
Percentage of total weight		33%	66%
Thickness:	6 mm	0.53 kg	1.06 kg
	8 mm	0.71 kg	1.42 kg
	10 nun	0.88 kg	1.77 kg

c) Replacing cement with silicous ash

Table 7 gives reference figures for tiles produced with the adjunction of vegetal ash with a high silica content (see section VI.3 in this chapter). Tests must be made to assess the

feasibility of substituting silicous ash for part of the cement. In the example shown in table 7, the suggested ratio makes it possible to replace 20 percent of total cement weight with silicous ash. The ratio will then be:

(4/5 + 1/5) cement + ash: 3 sand/aggregate.

Table 7. Amounts of cement, ash and sand for a (4/5 +1/5): 3 ratio

RATIO (4/5 +1/5) : 3		(CEMENT + ASH)		SAND/AGGREGATE
Percentage of total weight		20%	5%	75%
Thickness:	6 mm	0.32 kg	0.08 kg	1.20 kg
	8 mm	0.43 kg	0.10 kg	1.60 kg
	10 mm	0.53 kg	0.13 kg	2.00 kg

V.2 Fibres

When producing fibre concrete tiles, the length and quantity of fibres added to the mortar directly affect the plasticity (workability) of the mix.

1. Fibre length

There is a relationship between the quantity of fibres used, their length and "balling". If the density of long fibres is excessive they will tend to bunch up together and form small bundles (figure 12).

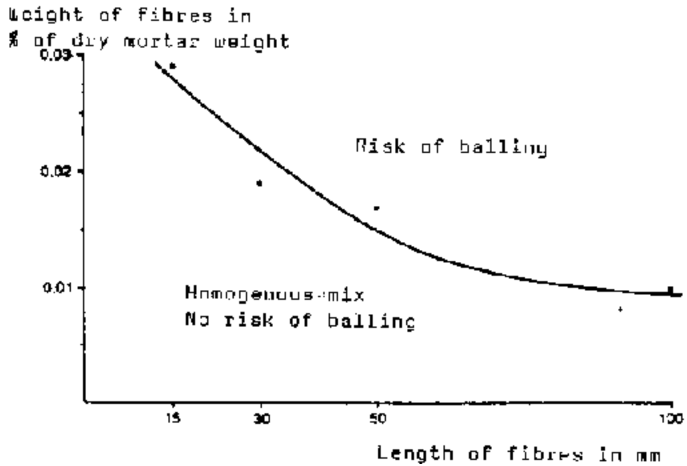


Figure 12. Relationship between length/quantity of fibre and balling (ref. 10)

Opinions vary as to optimal fibre length. Experience shows that fibres are not effective if they are too short. Where there is a risk of cracking, the fibres should be long enough to bond with the mortar. If they are too short, they cannot act as a reinforcing bonding agent. On the other hand, excessively long fibres have a negative effect on mortar plasticity.

A suitable compromise must therefore be found. Reports on several experiments on fibre length quote the following extremes: 6 mm (ref. 22) and 50 mm (ref. 10). An average fibre length of 15 mm to 20 mm gave excellent results in trials carried out in Madagascar and Cte d'Ivoire.

2. Proportion of Fibre

The major role of fibre is to prevent cracks due to shrinkage during setting and give

enough strength to the tile to avoid breakage during handling and transport. Once these major risks no longer exist, reinforcing fibres are less necessary. After a few months' weathering, the sisal fibre is attacked chemically by the alkaline water of the concrete. The space initially occupied by the decomposing fibres becomes vacant; as a consequence, the tile will be more liable to crack or break than a non-reinforced concrete tile, since the latter remains compact over time. If the gaps left by the decomposed fibres are too numerous, the tile will become porous. Thus, the lifespan of a fibre is a critical factor: despite their reinforcing properties, fibre additives should be used sparingly. Between 0.5 to 1 per cent on average of the total sand + cement weight provides good reinforcement performance without subsequent deterioration.

3. Water absorption: mortar workability

The adjunction of fibre to the mortar causes a demand for additional water. This has a negative effect on tile strength (see section V.3.2 in this chapter). There is a relationship between the amount of fibre and the amount of water necessary to ensure good mortar workability. The graph below (fig. 13) shows that as the quantity of fibre increases (expressed as a percentage of total mortar weight), there is a demand for additional water in order to keep workability constant.

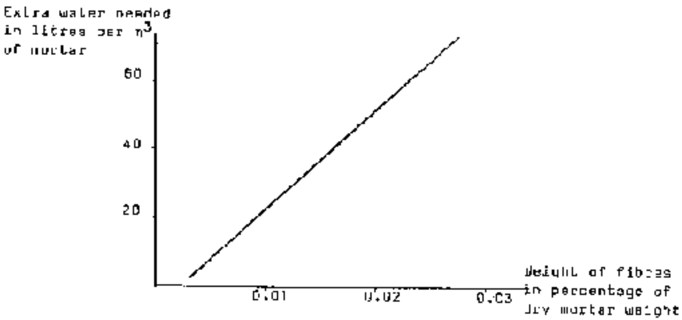


Figure 13. Extra water required in relation to fibre volume to keep workability constant (ref. 10)

4. Recommended fibre length and ratio

Recommended standards for tiles of 6 mm to 10 mm thickness:

- **length: 15mm to 20 mm (max. 25 mm);**
- **quantity expressed as percentage of total weight: 0.5 to 1 per cent of dry mortar weight.**

V.3 Water

1. Quality

Drinking water may naturally be used without restriction. However, in many developing countries, the water supply cannot be taken for granted.

Tests made in Botswana in 1978 (ref. 24) on the use of brackish water (as compared to drinking water) showed no difference in the behaviour of fibre concrete tiles. Brackish water should, however, be avoided: in the presence of salt, the wire loops cast in the tile nib are likely to corrode more quickly. Whenever the sand or water used for mixing contains salt, the use of galvanized wire or plastic fixtures is recommended for the fastening loops.

Roof rainwater may be used, except immediately after a dry spell when it will be contaminated by debris.

2. Quantity

Several factors have an effect on the amount of water to be used for the mix. The

appropriate amount is determined by trial and error (see Chapter IV step 5). The proportion of water in the mix affects the quality of the mortar.

The setting reaction (hardening of the mortar through the action of the hydraulic binder on aggregates) is triggered by the adjunction of water to the dry mix. The water fills in the voids. During setting, the water evaporates, thereby producing shrinkage. The setting speed and extent of shrinkage depend on three main factors:

- quantity of water used for the wet mix;
- air temperature;
- air-moisture.

The amount of water used for the mix is expressed by the water: cement ratio. It can be altered to obtain the desired consistency (plasticity) (table 8).

Table 8. Water:cement ratio as a function of concrete consistency

Consistency of concrete	Quantity of water (litres per C kg. cement)	Observation
Dry	C × 0.5	Aggregates should be
Plastic	C × 0.6 to 0.7	slightly moist (1 to
Fluid	C × 0.75 to 0.8	2 percent humidity)

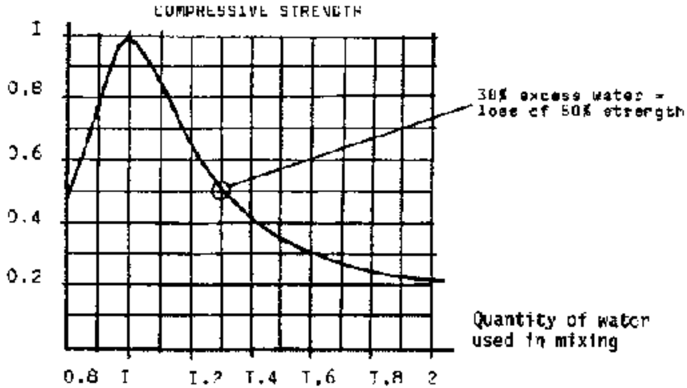
Source: ref. 8

The quantity of water used in the mortar mix has a major effect on tile strength and porosity.

a) Strength

If shrinkage is excessive during setting, microcracks will develop. As a consequence, this will reduce the ability of the tile to withstand the various strains and stresses.

The strength of hardened concrete reaches a maximum for a precise quantity of water and decreases with excessive or insufficient amounts of water (fig. 14). In the example shown in the graph, 30 per cent of water in excess (as opposed to the exact amount conferring maximum strength) results in a loss of 50 percent of maximum strength.



<u>Figure 14. Relationship between tile strength and water/cement ratio</u>

- For compressive strength, unit is maximum strength
- For water , unit is quantity producing maximum strength

b) <u>Porosity</u>

Too much water in the mix also results in increased tile porosity. Porosity is due to the presence of gaps created by the withdrawal of the water filling in the gaps between the aggregate and the cement.

Tile porosity (permeability) is in an inverse ratio to the quantity of water used for the mix (figure 15).

V.4 Summary of ratios and quantities of raw materials

Table 9. Summary of quantities of raw materials required for given ratios and tile thicknesses

Ratio	Tile Thickness mm	Cement kg	Sand Aggreg. kg	(Fibre) gr	Water litres	Total Weight kg	Number of tiles /m2	Weight of tiles kg/m2
1 : 3	6	.4	1.2	11-16	.26	1.616	12.5	20.2
1 : 2	10	.88	1.77	18-26	.577	2.675	12.5	33.5

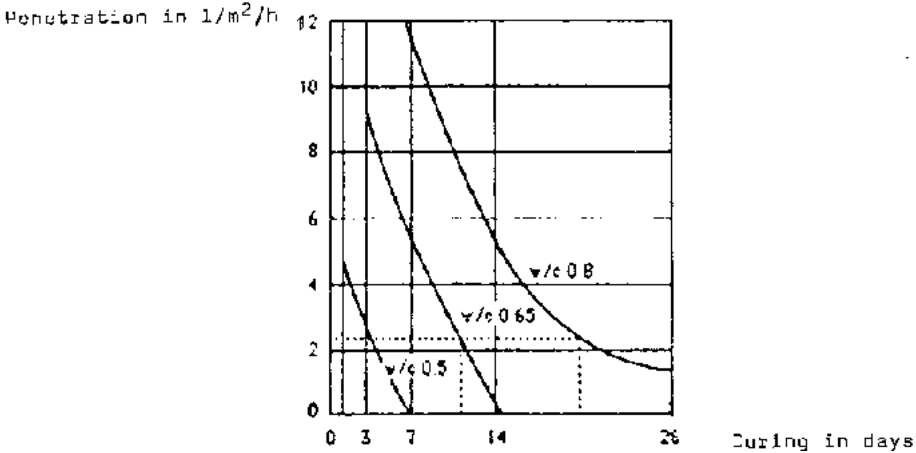


Figure 15. Relationship between water/cement ratio (w/c) and permeability (penetration

in 1/m2/h) at several stages of curing (ref. 29)

VI. ADDITIVES

A wide range of additives may be included in the mix. Incorporated in small amounts (usually less than 5 per cent of cement weight), they confer special qualities to the mortar or improve its specifications.

VI.1 Setting accelerators

Accelerators reduce setting time and speed up the hardening process.

VI.2 Setting retarders

Retarders slow down the setting process. They are used when the mortar is likely to dry too quickly and develop cracks.

VI.3 Waterproofing agents

Waterproofers reduce porosity. A standard sand/cement mix presents a certain degree of porosity. The quality and grading of the sand used are the principal factors affecting the degree of permeability of concrete. After lengthy exposure to rainfall, the undersurface of the tile becomes darker: the water has seeped through. If the damp stain is limited (less than one-third of the total surface), there is no need to change the proportioning of the mix. If it is larger and the grading of the sand cannot be improved, a waterproofing agent should be added.

In regions exposed to heavy rainfall or long rainy seasons, the waterproofer may be in the form of an additive. Additive concentration depends on the characteristics of local waterproofing products.

Waterproofing agents come in several forms: powder, paste, liquid. They can be used as admixtures or primers.

a) Waterproofing admixtures

Very fine particles fill in the gaps between the coarser aggregates. They are chemically inactive (lime, talc), or chemically active (calcium and aluminium chloride, zinc and aluminium sulphate).

Other additives act in a different way. They emit an electrostatic charge which repels the water molecules. There is, however, some doubt as to whether their effect is lasting over the long term (calcium stearate, soda, potassium, resins, fats).

The technique used in Malawi (ref. 29) combines the pore-blocking effect and the water-repellent effect. Slaked lime is added to the dry mix (2 per cent of dry mortar weight). The lime acts as a micro-filler inside the material (pore-blocking effect). Externally, it conveys water-repellent properties to the surface of the concrete (water-repellent effect). Lime also improves the plasticity of the mix. This characteristic makes it possible to reduce the water:cement ratio and therefore increase the strength of the finished product.

b) Surface waterproofing

These substances act as surface pore-fillers or protective coatings. If the roof runoff water is collected for consumption, it is essential to make sure that the gradual decay of the protective coating will not contaminate the water. The application of surface waterproofers implies an additional production step, thereby resulting in increased production costs.

c) Natural waterproofing agents

A third type of waterproofers are the result of natural processes (weathering). The gradual accumulation of fine particles of dust slowly blocks the surface pores which water, previously permeated. In certain countries, second-hand tiles fetch a higher price than new ones.

VI.4 Pigments (colouring agents)

The colour of fibre concrete tiles depends on the colour of the sand and cement used. They usually come in lighter or darker shades of grey. A simple method of making fibre concrete products more attractive is to incorporate a pigment (colour) in the mix. Pigments can be of mineral or synthetic origin. They are available commercially in the form of very finely ground powders (microparticles or fillers).

Depending on the grade of the sand, the adjunction of a filler may have a positive or negative effect on concrete quality. If the adjunction of pigment produces a sticky mix, this means that the quantity of fines is too high. The mortar cannot be correctly vibrated. After demoulding, the tile surface will show pock marks. These are air bubbles which have been prevented from rising up to the surface during vibrating because the wet mix is too compact.

The most common pigment is iron oxide. The adjunction of iron oxide produces a red colour tile, very similar to a natural clay tile (fired clay).

One point which must be stressed is that dark colours increase the capacity to absorb radiated heat and this should be viewed as a drawback in hot climates.

The additional cost resulting from colouring depends on local market conditions. This can be easily calculated and incorporated in the sale price.

The use of artificial pigments does not affect the quality of run off rain-water.

There are two methods of colouring tiles:

(a) In the wet mix:

The pigment is incorporated into the mortar at the mixing stage. The quantity required depends on the shade desired and the additional cost. On average, 5 to 10 per cent by weight of cement gives a good result. With higher quality pigments, this amount may be reduced to 3 per cent of cement weight. This method produces a permanent and fade-resistant colour.

(b) Surface coating:

The pigment is added to a fluid composed of cement and water paste. The mixture is applied on the dried tiles with a brush. The high cement content of this paste guarantees good surface adherence, although run off water will eventually destroy this primer.

VI.5 Fluidifiers

If the workability of the mortar is not satisfactory, a substance may be added to increase its plasticity. The simplest product is dish-washing detergent which, added in small quantities, makes moulding easier.

VII. IMPROVING PERFORMANCE

Laboratory research (ref. 10 and 12) shows that the highly alkaline environment of cement (pH above 13) induces brittleness in the vegetable fibres[1]. In the test, the tiles are placed in a weathering machine and subjected to artificial and cyclical changes in temperature and humidity.

[1] The pH value of a solution defines its acid or basic characteristics, For a pH under

7, the solution is acid; above 7, the solution is alkaline.

The chemical decomposition of fibres is induced by the dissolution of lignin and hemicellulose. The fibre is discoloured yellow. The destruction of the interstitial material bonding the vegetable cells causes the fibre to lose its reinforcing properties (figures 16 and 17).

Fibre deterioration may be inhibited by reducing the alkalinity of the cement. Several methods may be used:

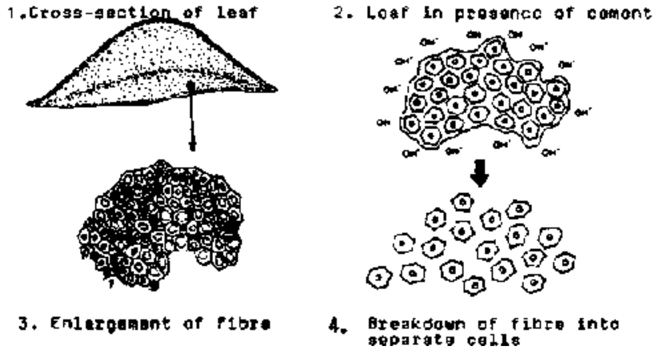


Figure 16. Schematic representation of the breaking down of a sisal fibre into separate cells (ref. 10)

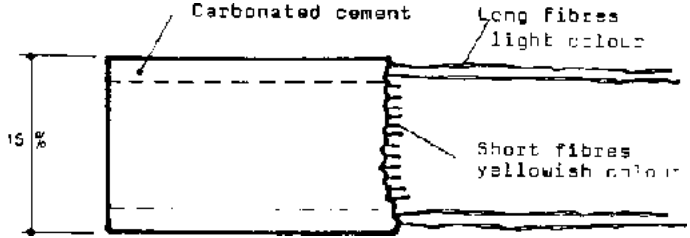


Figure 17. Result of fibre decay after 10 months (ref. 10)

VII.1 Carbonation of the cement

Carbonated cements have a pH value under 9. Cement carbonation depends essentially on the capacity of the mortar to diffuse the carbon dioxide (C02) it contains.

Tests of concrete behaviour (ref. 4) show that carbonation can occur neither at 100 per cent nor at 25 per cent relative humidity. When air moisture stands at 100 per cent, the voids in the aggregate fill up with water and C02 diffusion within the concrete is slow. At 25 per cent relative humidity, there is not enough water in the gaps for the dioxide to break down into carbon monoxide which, by reacting with the by-products of cement hydration (particularly Ca(OH)2), will produce the carbonation reaction. It seems therefore that carbonation is closely related to the percentage of air moisture (research underway). Other factors also have an influence on carbonation, such as the type of cement used and the thickness of the moulded products.

VII.2 Furnace slag and pozzolana

The alkalinity of mortar can be drastically reduced by substituting slag or pozzolana for part of the ordinary Portland cement. Depending on the proportions used, the mortar pH value may drop to approximately 11.

Slag is the smelting refuse resulting from the separation of residual impurities from the ore. Slag and clinker are interchangeable (see Chapter 2, section 2). Eighty per cent of the clinker may be replaced with slag (ref. 28). The strength properties of slag concrete develop more slowly than when ordinary Portland cement (OPC) is used.

Pozzolana is a binder consisting of lime and a large percentage of silica and/or alumina. Fifteen per cent of the OPC may be replaced with pozzolana without impairing the physical characteristics of the concrete.

VII.3 Vegetable ash

The combustion of rice husks produces silica rich ashes, which display the same properties as pozzolanic additives. When added in large quantities, rice husk ash:

- **reduces cement alkalinity;**
- **accelerates the carbonation process; improves the protective effect of fibre in the concrete.**

Substituting vegetable ash with a high silica content for part of the OPC improves the breaking strength of the finished product. The first cracks will develop later, and as a result of stronger strains and stresses than with Portland cement only. In other words, the performance (mechanical strength) of fibre concrete products is enhanced by the adjunction of silicous ash, thereby increasing the lifespan of the finished product.

Vegetable combustion ash cannot be used unprocessed. It must be crushed to a very fine powder before use, for instance in a tube crusher.

Other plants also contain a high proportion of silica. Table 10 gives a list of plants suitable for silica extraction after combustion and crushing of the ashes.

Table 10: Plants containing a high proportion of silica

Table 10

Plant	Part of plant	Ashes % of plant	Silicium % of ash
Rice	Husk	22,1	93,0
Wheat	Leaf sheath	10,5	90,5
Sorghum	Leaf sheath	12,5	88,7
Rice	Straw	14,6	82,0
Breadfruit tree	Stem	8,6	81,8
Bagasse		14,7	73,0
Corn	Leaf blade	12,1	64,3
Bamboo	Nodes (inner portion)	1,5	57,4
Sunflower	Leaf and stem	11,5	25,3
Lantana	Leaf and stem	11,2	23,3

Source: Ref. 30.