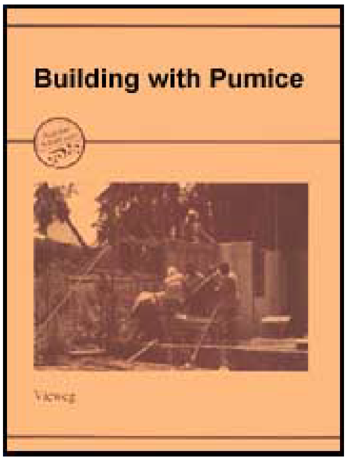

Building with Pumice

by Klaus Grasser / Gernot Minke

A Publication of Deutsches Zentrum für Entwicklungstechnologien -GATE
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Content

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Preface

This book represents a first-ever attempt to explain and illustrate how the volcanic material pumice can be processed using simple technologies suitable for developing countries.

In Germany, the first wall-building brick made of pumice and a slow-hardening binder (milk of lime) dates back to the year 1845. That marked the starting point of a local pumice-based building industry in volcanic regions of the Eifel Mountains, where pumice deposits were abundant. As time passed, the material's market area expanded steadily. Today's pumice industry in the Rhineland operates large production facilities and has enough raw material reserves to last beyond the turn of the century at the present rate of production.

Pumice, an extremely light, porous raw material of volcanic origin, can be found in many parts of the world, including various developing countries with areas of past or present volcanic activity. In some countries, volcanic ash (with a particle size of less than 2 mm), pumice (with particle sizes ranging from 2 to 64 mm) and consolidated ash (tuff) are traditionally used, on a local scale, as versatile building materials. However, the large number of inquiries received in the past few years indicate a lack of useful information on the subject of elementary pumice processing techniques for producing building backs and blocks, slabs and panels. This handbook therefore represents an attempt by its author, Klaus Grasser, to fill that gap by translating into a straightforward, easy-to-learn set of instructions and practical suggestions some of the experiences he has gathered in El Salvador, Guatemala, Ecuador and Rwanda in connection with the use of pumice as a building material.

The wall construction advisory services offered by GTZ/GATE as part of its "Building Advisory Service and Information Network (BASIN)" would be happy to provide additional information upon request.

Hannah Schreckenbach
Planning Officer, GTZ, Division 434

1. Introduction

1.1 House Construction and Related Problems

The HABITAT statistics pertaining to the International Year of Shelter for the Homeless, 1987 show that:

- more than 1 billion people, or roughly 1/4 of the world's total population, have no permanent homes, but instead live in primitive' unhygienic dwellings. Some 100 million people, most of them in developing countries, have no roof over their heads at all;

- about one-half of all city dwellers in developing countries (up to 80% in some cities) live in slums or so-called squatter settlements;

- the population of the urban centers in developing countries is increasing by roughly 3.5% annually, equating to a yearly global gain of approximately 49 million people;

- by the year 2000, those cities will be experiencing a yearly population increase of about 78 Million people -or more than 214,000 each and every day;

- just to keep up with such developments, the presently available living quarters (of all descriptions) and the available infrastructure would have to be more than doubled;

- the population explosion in the slums and squatter settlements of major cities is even more dramatic: the rate of increase there is twice that of the cities themselves and four times as high as that of the global population;

- the situation in the rural areas of most developing countries is complicated by the fact that only 41% of the rural population has access to clean drinking water (compared to 71% of the urban population); only 12% of the rural population has access to sanitary facilities (compared to 59% of the urban population).

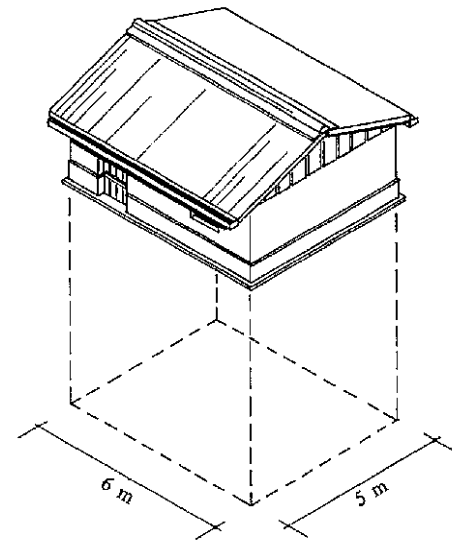


Fig. 2: Sketch of a 30 m^2 house

Fig. 2

Everyone would like to live in his own home. Many people in industrialized countries occupy apartments in multistory buildings.

This situation involves lots of problems for which there is no immediate solution. This book is intended to stimulate interest in a line of approach to such problems by describing how to build simple, inexpensive houses out of a very commonplace raw material, namely pumice, i.e. volcanic glass or hardened volcanic froth. Such homes can be constructed on a self-help basis by individual builders, as cooperative efforts, or on an industrial scale. Which building components can be made of pumice and how those components can be put together to make a house is described in the following chapters.

We will be referring throughout to a basic model with roughly 30 m² floor space, for which the requisite building material costs approximately US $1500. Such houses could serve well and be affordable as a minimum size dwelling for a family of 6 or less (Fig. 2). The described home-construction systems can be enlarged, built onto and/or modified at will, depending on the prevailing architectural style, the family's space requirement and their given financial situation. The building materials for the house do not have to be bought or made all at once, but can be accumulated or put together little by little. With a bit of handicraft skill, it is relatively easy to make most of the building material-assuming, of course, that the builder has access to and knows how to handle pumice (or volcanic ash), cement, water and a few elementary tools.

The best way to tackle the job is for several prospective homebuilders to team up with each other to jointly plan, organize and implement their own building projects.

The main purpose of this book is to give practical information on the use of pumice as a building material and on organizing one's own homebuilding project. Naturally, no individual solutions can be offered for problems concerning the purchase of property or the financing, obtaining a building permit or actual construction of the house.

Building material for a house can be made from any number of raw materials, e.g. straw, reed, rocks, soil, wood, metal, etc., depending on what is available within a reasonable distance, for which climate the house is being built, and which culture-dependent conceptions it will have to incorporate. Pumice, too, is a good raw material for use in making building members. Pumice is not found everywhere, but only in the vicinity of extinct or still-active volcanoes, e.g. in Central America, East Africa, East Asia and Europe (Fig. 3).

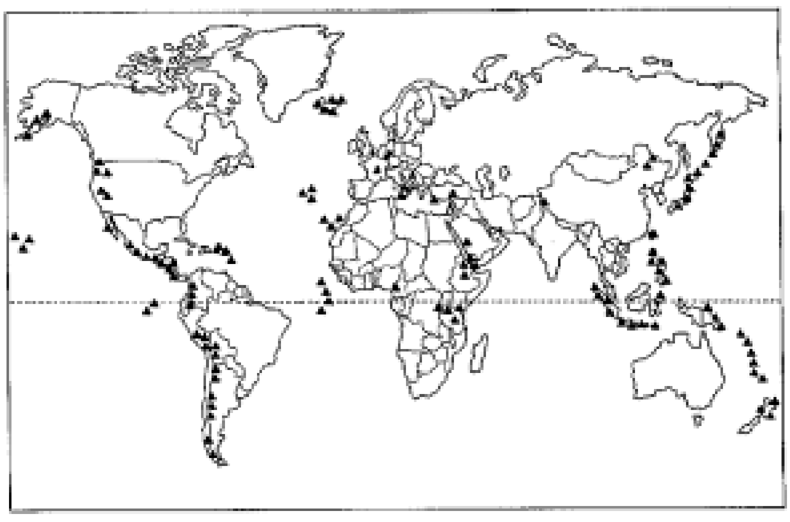


Fig. 3: Countries with extinct, dormant or active volcanoes (▲: volcanoes)

Fig. 3

Europeans have always used pumice in residential buildings and industrial structures and continue to do so. As a building material in general it is very popular, particularly in the near vicinity of the deposits.

The dissemination of knowledge and the transfer of technology concerning the production of pumice building materials should help developing countries establish their own indigenous production of inexpensive, versatile building materials. This book hopes to stimulate the utilization of existing resources in the form of volcanic ash/pumice deposits while also providing practical guidance for the production of building members for low. cost homes.

1.2 Turning Pumice into Building Material

All pumice building members can be made using simple craft skills. No complicated (and therefore expensive) machinery is needed.

What are needed most are a wood or metal formwork, a wheelbarrow, a shovel, a trowel and a level area for shaping and drying the pumice building members. Cement or lime, sand and water must also be available.

Producing one's own pumice building members can always be recommended, where the raw material is sufficiently inexpensive or, even better,.available free of charge -and the building is to be put up on its own, where there is solid foundation soil, and the builder/owner has some skill and prior experience in handling building materials.

It is important to know that pumice building members are very durable if made properly and that they are particularly suitable for dry climates.

As mentioned above, the materials needed to build a pumice home with 30 m² floor space cost roughly US $ 1500. Add to that, of course, the cost of the property and any wages paid to helpers or contractors. For making one's own wall members from pumice, the raw material should be available within a radius of 30 km (Fig. 4).

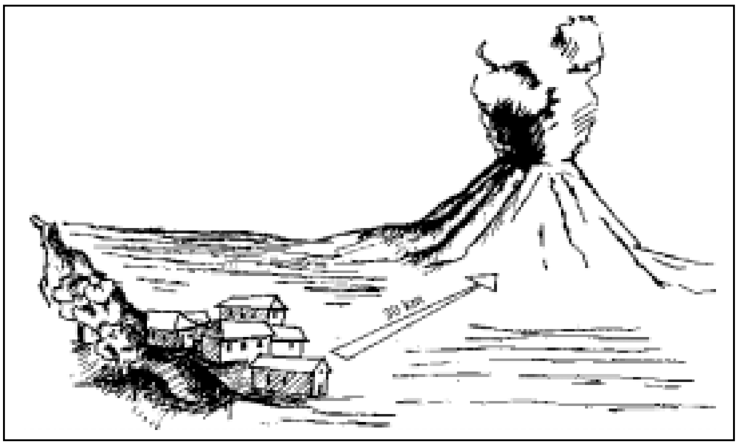


Fig. 4: Maximum distance between deposit and building site.

Further information on rules and regulations governing home construction can be obtained from:

- cooperative building societies,
- building authorities,
- credit institutions,
- architects,
- missions.

2. General Information on Pumice

This chapter outlines the options available for making building members from pumice. It provides information on where to find pumice and how to process it in a self-help situation.

2.1 What is Pumice?

Pumice is a very porous form of vitrified volcanic rock, usually of very light colon Its true density, i.e. the density of the powdered material, amounts to between 2 and 3 kg/ dm^3 and its bulk density, i.e. the density of the loosely piled material, amounts to between 0.3 and 0.8 kg/dm3. In other words, pumice is very light. It has roughly the consistency of a mixture of gravel and sand, with light, porous individual granules that normally either float on water or sink only slowly. Pumice particles are either round or angular and measure up to 65 mm in diameter. Only particles in the 1 -16-mm size range should be used to obtain good building material.

Fig. 5: A volcanic eruption

In addition to light-colored pumice, there are also various dark-colored forms referred to as lava, tuff, etc. They, too, can be used as building material, but the light-colored pumice processes better, as described in Chapter 2.4.

Pumice has the following chemical composition:

silica	SiO_2	approx. 55%
alumina	Al_2O_3	approx. 22%
alkalies	K_2O+Na_2O	approx. 12%
ferric oxide	Fe_2O_3	approx. 3%
lime	CaO	approx. 2%
magnesia	MgO	approx. 1%
titania	TiO_2	approx. 0.5%

Pumice originates during volcanic eruptions, when molten endogenous rock is mixed with gases before being spewed out (Fig. 5). The light, spongy particles are hurled up and carried off by the wind. As they cool and fall back to earth, the particles accumulate to form pumice rock or boulders. Sometimes the molten rock is too heavy to be ejected, in which case it flows out and collects at the foot of the volcano as a compact, fairly homogeneous, usually somewhat less porous rock formation. Most such lava deposits can be cut up into natural stone blocks for direct use in construction work.

2.2 Where is Pumice Found?

Most pumice is found on the downwind side of volcanoes (Fig.6).

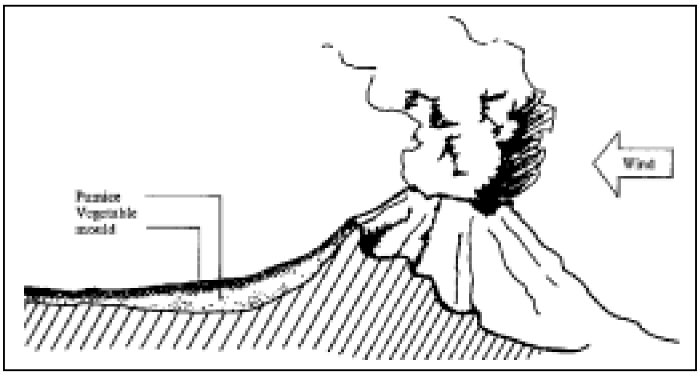


Fig. 6: Pumice deposits on the downwind side of a volcano

The average deposit is loose, with a layer thickness ranging from 50 to 300 cm. Pumice should always be extracted under expert supervision and not haphazardly; otherwise, the results will look like Figure 7. The thickness of the pumice strata decreases with increasing distance from the center of the eruption.

The size of pumice particles ranges from superfine powder (0-2 mm) to sand (2-8 mm) to gravel (8-65 mm). The particle porosity can reach 85%, meaning that 85% of the total volume consists of "air" and only 15% of solid material. Its high porosity gives pumice good thermal insulating properties and makes it very light.

Old pumice deposits in areas with once-active volcanoes are covered with a 0.2-1 mthick layer of humus. When quarrying it, care must be taken to ensure that no humus is mixed into the pumice. If a large area is being mined, e.g. for a housing project, the humus should be replaced afterwards to prevent erosion and consequent ecological damage.

Additional site-specific information on pumice deposits is available from the various national geological institutes and/or soil research offices.

2.3 What Properties Does Pumice Have?

Pumice has excellent properties. As a building material it is

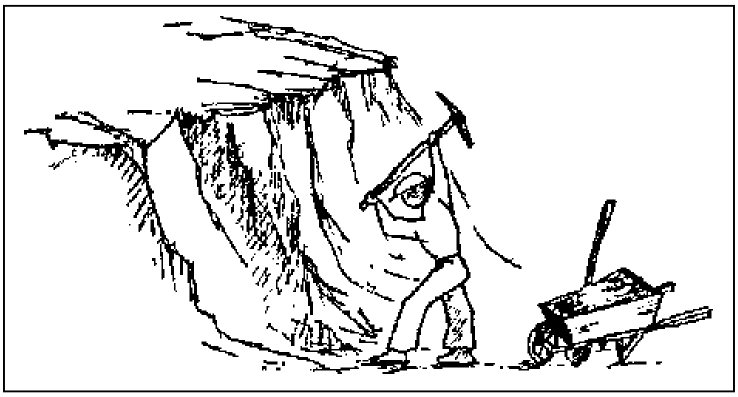


Fig. 8: Pumice extraction

- very light,

- inexpensive,
- refractory,
- resistant to pests,
- easy to work with,
- sound-absorbent,
- heat-insulating,
- temperature-balancing (Figs. 9, 10 and 11).

But then, it also has some negative properties like:

- the lower compressive strength of pumice concrete, as compared to concrete containing other, heavier aggregates;
- the tendency of its edges and corners to break off more easily than those of heavy concrete'
- its lack of frost resistance when wet.

Consequently, pumice building material should not be used for:

- foundations,
- components with constant exposure to water, e.g. in showers,
- components subject to heavy traffic, e.g. stair treads and floor tiles.

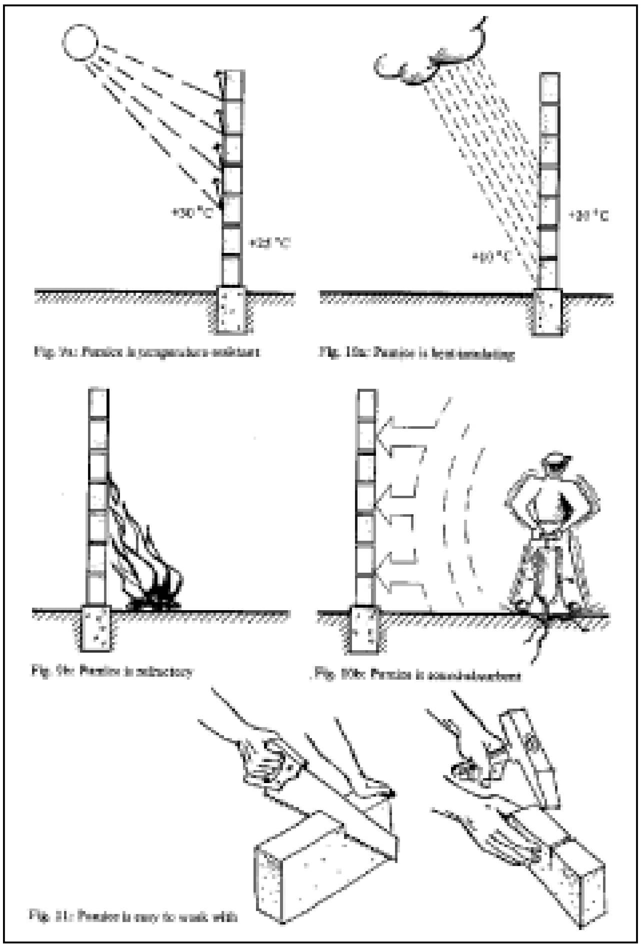


Fig. 9, 10, 11

2.4 How Can Pumice Be Made into Building Members?

A few expedients that facilitate working with pumice are required for turning it into building members, e.g.:

- some means of hauling the pumice from the deposit to the building site (Fig. 12);

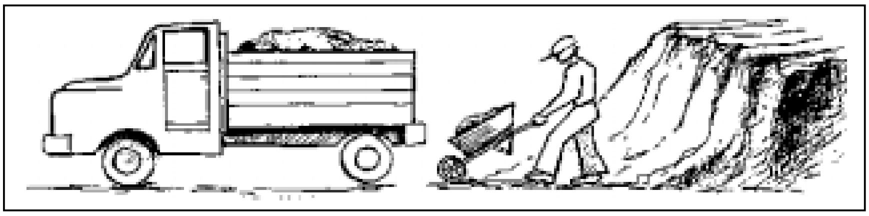


Fig. 12: Various means of transportation

- various tools like a wheelbarrow, shovel, buckets, saw, hammer, nails, spirit level, a folding rule, trowel, plumb bob, set square, plastic sheeting, etc. (Fig. 13).

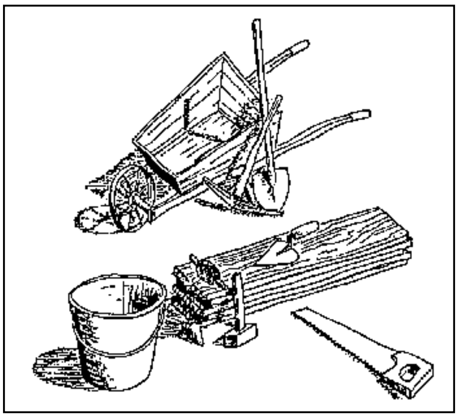


Fig. 13: Various tools

- an adequate supply of natural pumice (amounting to, for example, about 5600 kg, or 7 m³ for a house with 30 m_ floor space). A wheelbarrow holds about 0.15 m³, meaning that about 45 wheelbarrow loads would be needed to build the house;

- wooden molds for bricks, molds, etc. and/ or a press for making cavity blocks (Fig. 14: cf. Figure 34, p. 31).

In addition, a roofed-over, level work area is needed. The pumice being processed should have a particle-size distribution of 1 - 16 mm. The requisite cement should be Portland cement with normal compressive strength, to which lime or pozzolana can be added. Pumice building members can also be made exclusively with lime, as described in Chapter 3. The cement and lime must be kept dry, and there should be enough on hand to last for a full week of work. The gauging water should be clean; unpolluted rainwater is well-suited. How to make the molds is described in Chapter 3.

In general, pumice building members are classified as lightweight concrete, since they are produced and processed in a similar manner, the main difference being that the aggregate -namely the natural pumice -is very light, porous and water-absorbent, so that such material has to be worked somewhat differently than normal-weight concrete.

As a rule, natural pumice is first saturated with water and then mixed with cement or lime, poured into the prepared molds, compacted (either manually or by mechanical means), removed from the mold and stored to set and cure.

What sets pumic material apart from normal-weight concrete is that pumice concrete is usually soil-moist, i.e. used with relatively little gauging water and only small amounts of fine-grain aggregate - enough to cover the pumice particles with cement paste, but not enough to fill the cavities between the particles of aggregate. Consequently, pumice building components normally have a porous not quite smooth surface like that of nor mar-weight concrete. If so desired or necessary, e.g. for facade tiles, fine aggregate like sand can be added to obtain a smooth surface.

2.5 What Kind of Buildings Can Be Made of Pumice?

Pumice-based material can be used for building various kinds of structures:

- single-story homes,
- apartment buildings (up to four stories),
- workshops and storehouses,
- schools.

This book deals with the construction ofsingle-story homes, for which pumice building materiel can be made into (cf. Fig. 15):

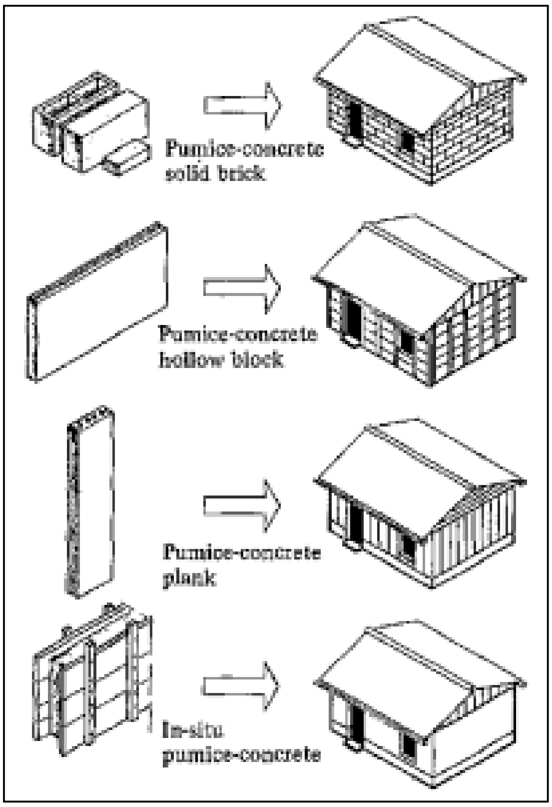


Fig. 15: What kind of buildings can be made?

- pumice concrete solid blocks (solid pumice bricks),
- pumice concrete cavity blocks,

- pumice tiles,
- pumice panels/planks,
- in-situ pumice concrete,
- special-purpose pumice building members (cf. Chapters 4.6 and 5).

Chapter 3 describes how prefabricated pumice wall members can be used for building houses.

Pumice-plank and pumice-panel homes are houses made of prefabricated members. After laying the foundation, the individual members (mainly the wall members) are prepared and used to erect the house on the foundation slab. This mode of construction is expecially well-suited for collective self-help measures in which several families wish to build the same kind of house, because erection of the plank or panel walls requires the work of several people at once (Fig. 16). One of the main advantages is the comparatively short erection time.

Pumice-concrete brick houses are built in a similar manner to heavy-clay brick houses, i.e. the masonry consisting of relatively small pumice bricks is built up on a solid foundation in the traditional manner. This method yields very individual homes and serves well for renovating or expanding existing homes.

3. Precast Pumice-Concrete Building Members

This chapter offers some practical self-help information on how to make and use simple pumice building components and members.

The following activities are explained:

- making simple pumice-concrete solid bricks,
- making simple pumice-concrete cavity blocks,
- making simple pumice-concrete wall panels,
- making wall-length reinforced pumice concrete hollow-core planks.

Such building members can be made using elementary do-it-yourself techniques without complicated tools and implements -and may then be used for building a simple home.

The essential raw material is, of course, pumice. Consequently, the first step should be to find out where the raw material can be obtained, either by quarrying it or buying it from an inexpensive source. Then comes the decision as to how well the Chapter 2.3 conditions are met, and whether or not one's own handicraft skills and available time will suffice for making the pumice concrete needed for the prefabrication work (solid or cavity bricks, planks or panels).

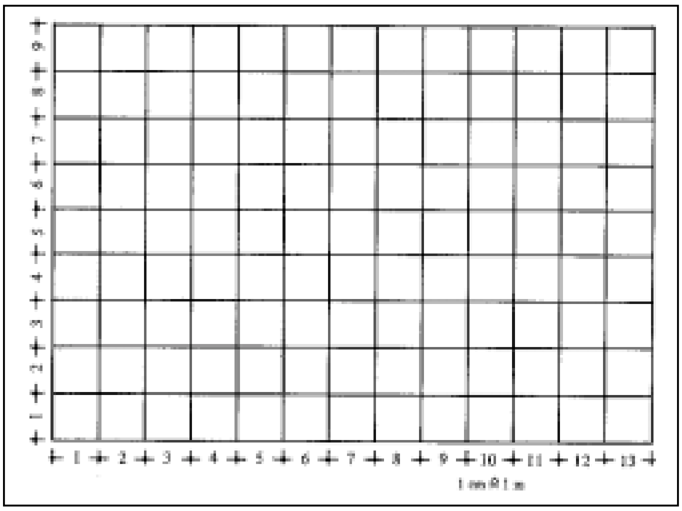


Fig. 17: Pattern for sketching out a self-help builder's home.

In preparing one's own pumice-concrete homebuilding project, the following checklist could be valuable:

My property has an area of ... m².

Pumice is available within a radius of ... km. I have the means to buy and haul cement and lime! 1 bag costs US $ ...
There is an adequate supply of water located ... km away.

I either own or can borrow the following tools:

- shovel
- pick
- hammer
- bucket(s)

- wheelbarrow
- trowel
- nails
- boards
- saw

I have either made concrete before or know a mason and one or two friends who would be willing to help me make the building members and erect my house.

Enter your own ideas for a house in Figure 17. There are many ways to design a floor plan, depending mainly on the nature of the property upon which the house is to be built. Figure 18 shows several examples of common floor plans as a guideline. Fill in the following list as a basis for calculating the cost of construction:

The house I am planning to build has :
. . . m² floor space,
. . . m² wall area,
. . . windows measuring . . . cm by . . . cm,
. . . doors measuring. . . cm by . . . cm, a floor made of ..... .
. . m² roof made of . . ... other important characteristics:
The property for the house will cost an estimated US $.

In order to calculate the quantities of building material needed for the house as planned, the following technical data must be known:

-1 m³ pumice concrete contains:
3 bags of cement (= 150 kg)
600 kg pumice material,
250 litres of water.

- The same cubic meter of pumice concrete will yield:
approx. 500 solid bricks (24 x 11.5 x 7 cm), approx. 120 cavity blocks (40 x 15 x 20 cm with 2 cavities),
approx. 25 pumice panels (100 x 50 x 7 cm), 12 wall planks (200 x 50 x 10 cm, with cavities),

or, in other words:

- One bag of cement (50 kg), 200 kg pumice and 80 litres of water are needed to make 0.33 m³ pumice concrete.

- Thus, 1 bag of cement is enough for making:
165 solid bricks (24 x 11.5 x 7 cm),
40 cavity blocks (40 x 15 x 20 cm with 2cavities),
8 pumice panels (100 x 50 x 7 cm?,
4 wall planks (200 x 50 x 10 cm with cavities).

For a house with 30 m³ floor space, the following quantities are needed:

2500 solid bricks (24 x 11.5 x 7 cm) or
500 hollow blocks (40 x 15 x 20 cm with 2 cavities) or
64 pumice panels (100 x 50 x 7 cm) or
36 wall planks (200 x 50 x 10 cm with cavities).

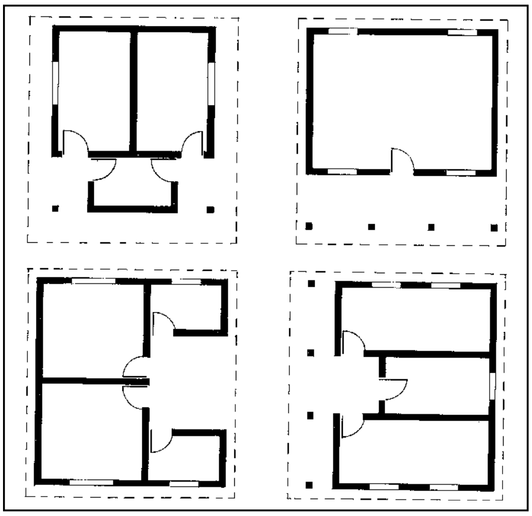


Fig. 18: Selection of four 30 m² plans

3.1 How is Pumice Processed?

3.1.1 Making building blocks from pumice and lime

The pumice gravel is screened to separate the coarse and fine fractions and remove soil contamination. Then, the pumice is mixed with carefully measured amounts of cement and water to produce a batch of lightweight concrete. Careful mixing is very important for ensuring that the pumice concrete will be of uniform quality.

The mixture is filled into molds (the dimensions of which vary, of course, depending on what kind of building member is being made) and then compacted by shaking and tamping. Then, the molds are carefully removed, and the block (or plank, panel, brick, etc.) is laid out to dry. After four or five days, the individual pieces can be stacked and left to cure and dry for at least another four days. After another 20 days, they are sufficiently transportable and can be used any time after that. Walls made of pumice members should be rendered/stuccoed to obtain a smooth finish and keep water out of the masonry. (The processing of pumice building members is shown schematically in Figures 19 and 20.)

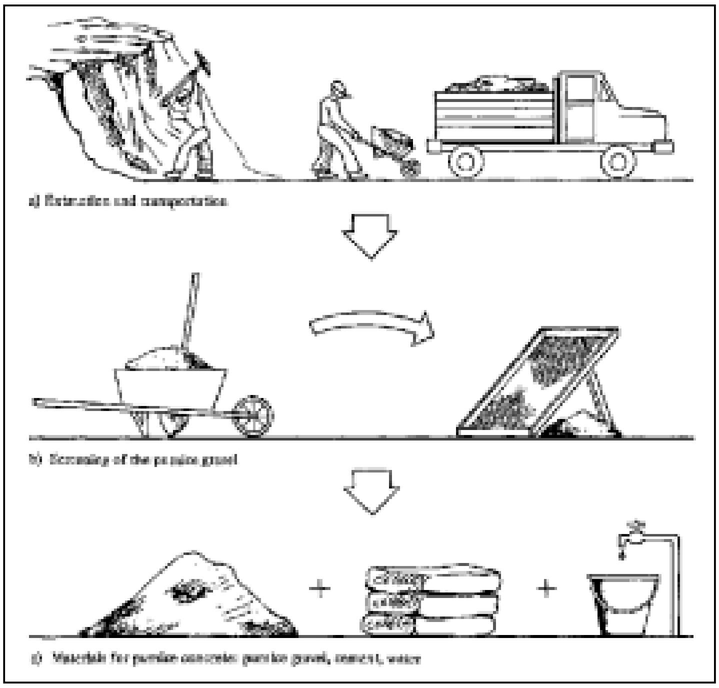


Figure 19: Production process for pumice building members (part1)

The proper mixing ratio is achieved as follows: first, put together a suitable particle. size blend. The heavier the end product should be, the more fine material and cement you will need.

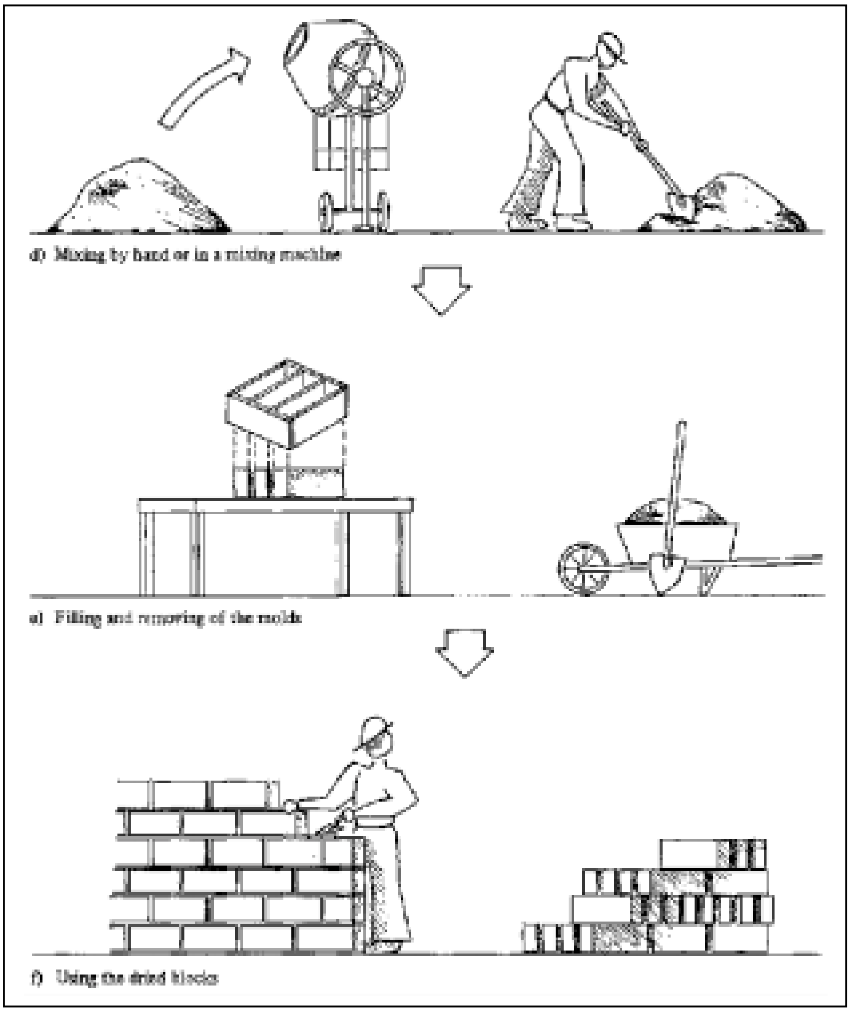


Fig. 20: Production process for pumice building members (part 2)

The consistency of the mixture should always be such that the large particles touch each other, providing mutual support, while the fine aggregate materials more or less fill in the spaces in between. Good pumice cement usually consists of four parts mixed pumice, one part Portland cement and one part clean water. Mix the parts by hand or in a mixing machine until the material takes on the appearance of soil-moist light weight concrete of uniform colon

Use the mixture as quickly as possible (within 30 minutes at the most) and do not let it even begin to dry out beforehand. In most cases, the described mixing ratio will be just right. If, however, the pumice is already moist and/or has a less-than-optimal particle-size composition, add more pumice, sand, cement or water as necessary (cf. Fig. 21).

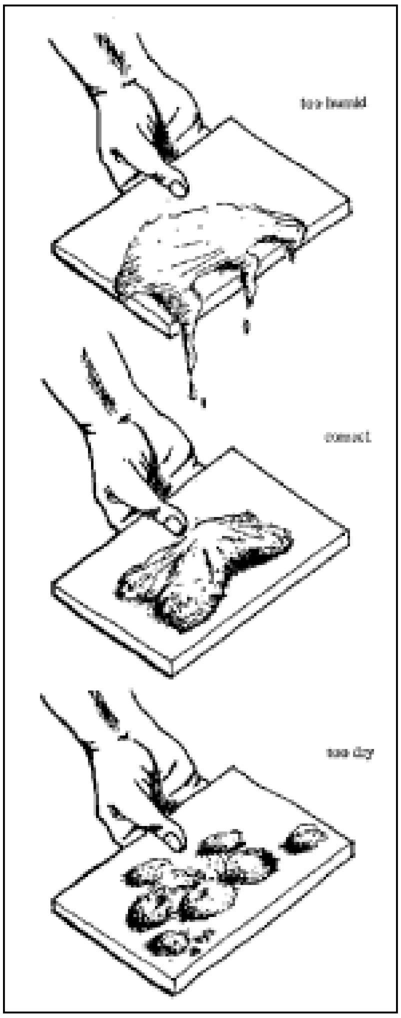


Fig. 21: Proper moisture content of pumice-concrete

Heed the following points in preparing your pumice concrete:

- Use only clean pumice.
- Saturate the pumice with water prior to mixing.
- Use only new cement.
- First mix the presaturated (soil-moist) pumice with cement; then add water and mix thoroughly to obtain a moldable mix.
- Compact the mixture well, but not excessively.
- Keep precast building members out of the sun and cover them with, say, wet cement bags to keep them from cracking.
- Keep building members out of the rain.
- Let pumice bricks, blocks, planks and panels dry for at least 28 days, or one month, prior to use.
- Stack building members on a level base.
- Handle them carefully to avoid breaking off their edges.
- Remember that pumice building materials can also be made with lime instead of cement.

3.1.1 Making building blocks from pumice and lime

Building blocks can be made of natural pumice and lime. Indeed, such blocks used to be quite common. However, careful consideration must be given to the characteristics of the lime.
In the first place, use only hydraulic -or better -eminently hydraulic lime. Dolomitic or magnesium lime, i.e. lime with a somewhat grey color, is preferable to fat lime, i.e. chalk-colored lime, for

making good pumice. lime blocks, thanks mainly to the fact that the grey types, as the name implies, contain more magnesium, which reacts with the silica fraction to give the finished product superior strength properties. On the other hand, whatever lime is used should contain as little salt as possible, particularly in the form of sulfuric acid, because salt causes efflorescence and detracts from the blocks' mechanical strength.

To obtain pumice-lime blocks with strength values exceeding 20 kg/cm²:

- the exact chemical composition of the lime and all pumice materials under consideration should be ascertained by way of careful chemical analysis, and

- sample blocks and compression strength test specimens should be prepared.

In general, the following mixing ratios are recommended:

1 m³ pumice (slightly moist, but not dripping wet)
150 kg hydraulic lime gauging water as necessary or
3 m³ pumice (slightly moist, but not drip. ping wet)
250 kg hydraulic lime
100 kg Portland cement gauging water as necessary

The latter batch should yield about 1000 pumice-concrete solid bricks measuring 25 x 12 x 10 cm and displaying a compression strength of roughly 25 kg/cm² after approximately 3 months' curing time.

It is extremely important to realize and act on the fact that pumice-lime bricks need a much longer curing time than do pumice-cement bricks. They should be allowed to cure a good three to six months to develop adequate stability and compressive strength prior to transportation and use.

Accordingly, it is better to make solid bricks than cavity blocks out of pumice-lime mixes, since the thin walls of the latter are much more susceptible to breaking and therefore require more caution in their manufacture and use.

3.2 What Can You Make with Pumice?

3.2.1 Pumice concrete
3.2.2 Pumice concrete solid bricks/blocks
3.2.3 Pumice concrete cavity blocks
3.2.4 Pumice wall panels
3.2.5 Reinforced pumice-concrete hollow-core planks
3.2.6 Special-purpose pumice-concrete building members and their applications.

Once the pumice-concrete mixture consisting of pumice, cement and water has been properly prepared, it can be poured into various molds to produce different kinds of wall members, e.g. pumice-concrete tiles/ panels and reinforced pumice-concrete hollow-core planks (cf. Fig. 22).

Pumice concrete should not be used for making building members that will be exposed to heavy wear and tear, e.g. stairs, nor is it suitable for building members that are liable to have constant contact with moisture.

3.2.1 Pumice concrete

Lightweight pumice concrete is made in the same manner as normal-weight concrete, except that natural pumice takes the place of sand and gravel. To make pumice concrete from the basic materials pumice, cement and water, follow these steps;

- The first step after the raw pumice is delivered to the intended production site is to remove any humus and other impurities by screening or desilting as necessary.

- The second step is to establish the particle-size spectrum of the pumice material. To obtain a good pumice concrete, the particle -size distribution should be about 1-16 mm, i.e. the pumice should have roughly 40% particles measuring 1 - 3 mm in diameter, 25% particles measuring 3 -7 mm in diameter, and 35% particles measuring 7-16 mm in diameter.

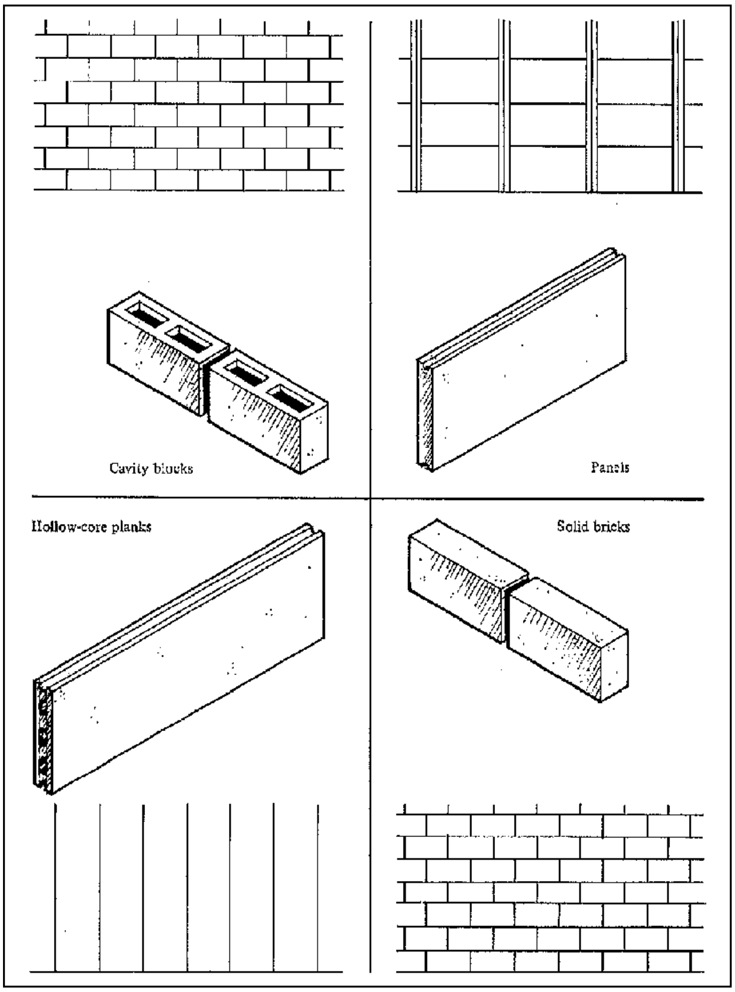


Fig. 22: Four pumice-concrete building members

If the particle-size distribution of the raw material does not approximately correspond to the above, it will have to be screened as shown in Figure 23.

Frequently, it will suffice to screen off the particles that are larger than 16 mm, perhaps replacing them with sand.

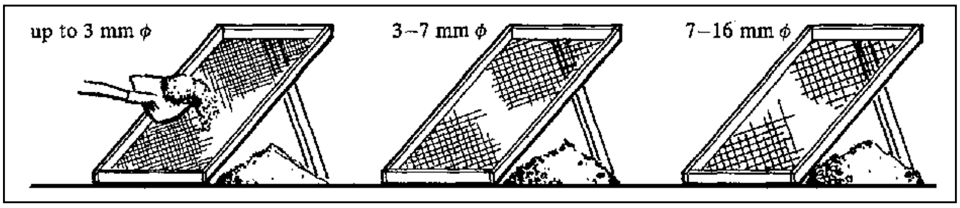


Fig. 23: Screening the raw material

- The third step is to add cement and water to the pumice gravel to produce pumice concrete, preferably with the aid of an electric or diesel-powered mixer. If none is available, the concrete can be mixed just as well with a shovel on a clean base or in some kind of big tub (Fig. 24).

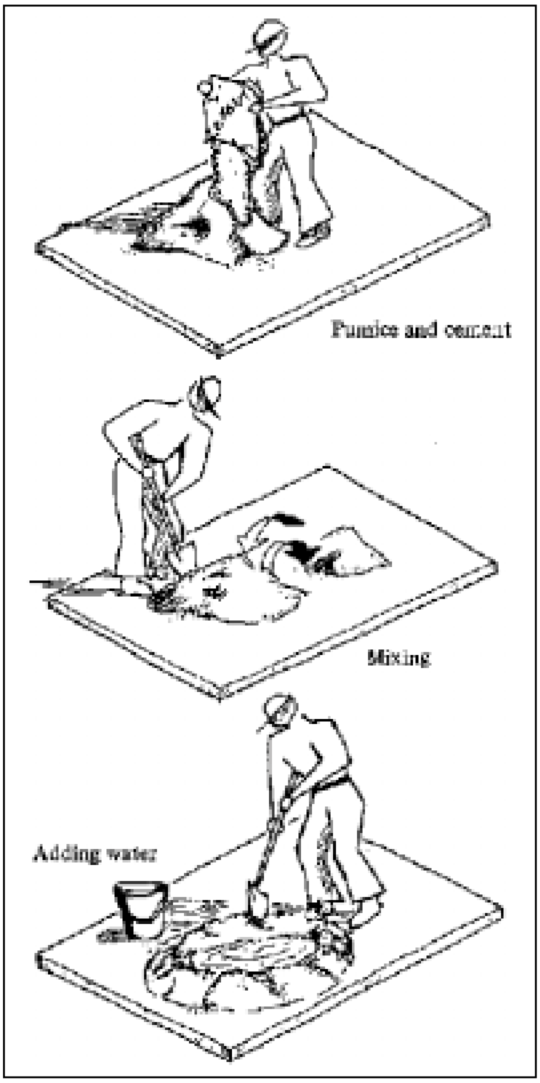


Fig. 24: Hand-mixing system

How much cement and water are needed depends greatly on the physical condition of the pumice material, especially its inherent moisture and particle-size distribution. As a rule of thumb though, four parts pumice to one part cement and one part water is about right (Fig. 25).

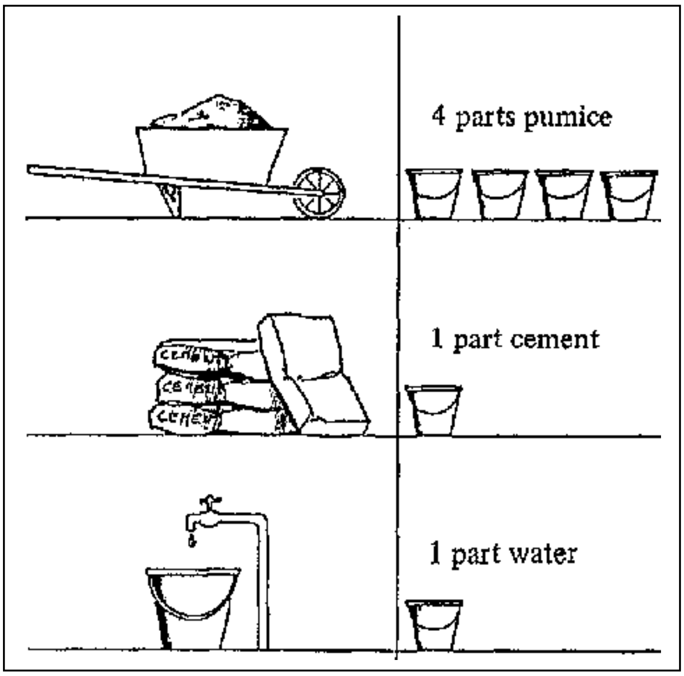


Fig. 25: Volume indication of quantities

Pumice concrete should be soil-moist, i.e. it should have no excess water. The moisture level is right if the mold surrounding the concrete can be removed immediately after compacting without having the shaped piece fall apart (Fig. 26).

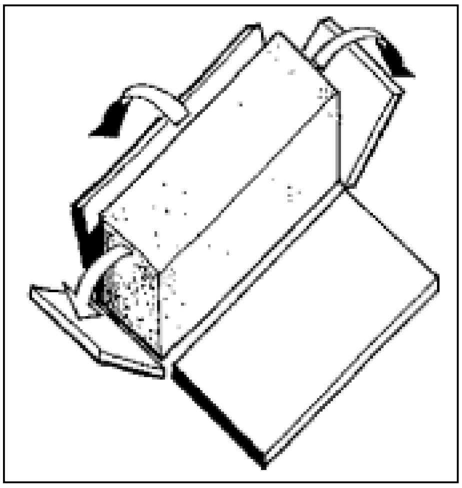


Fig. 26: Immediate removal of forms possible

3.2.2 Pumice concrete solid bricks/blocks

The least complicated kind of wall member for dolt-your-self production by people with little or no handicraft experience is the simple solid pumice brick (Fig. 27). The dimensions can be chosen at will, but adhering to a standard commercial brick format is recommended. If the bricks are to be used for repairing existing walls, they naturally should be of the same size as the bricks or blocks in the old masonry.

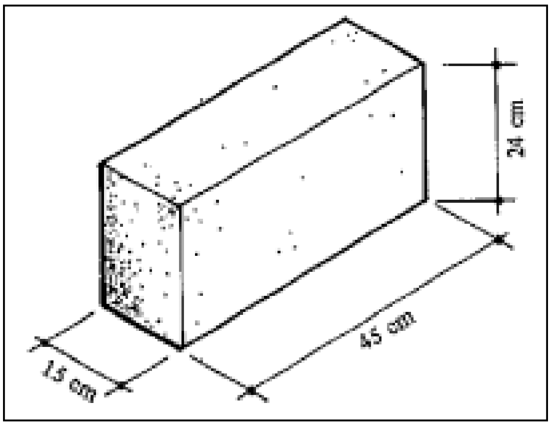


Fig. 27: Pumice-concrete solid brick.

Elementary-type pumice-concrete bricks are best suited for use in filling out concrete skeleton structures, but are also good for putting up self-supporting walls. Particularly in areas where no loam or clay is found, pumice bricks serve well as alternative wall-building members -assuming, of course, that natural pumice is available (Fig. 28).

The production of pumice concrete solid blocks measuring 49 x 24 x 15 cm is described below. Such blocks are easy to make in a self-help situation.

First, make a simple wooden mold with inside dimensions corresponding to the desired block format (Fig. 29). Normal, smoothly planed boards or square timbers make good box-mold building material. In making the box mold, be sure that it will be easy to remove from the freshly compacted block, i.e. that it is either easy to take apart and put back together or has such smooth inside faces that the block slips out easily.

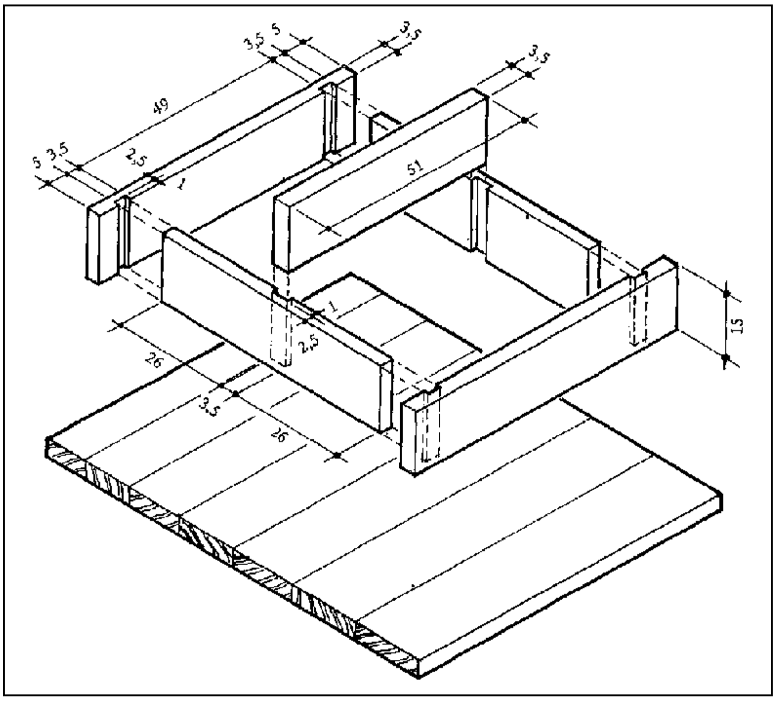
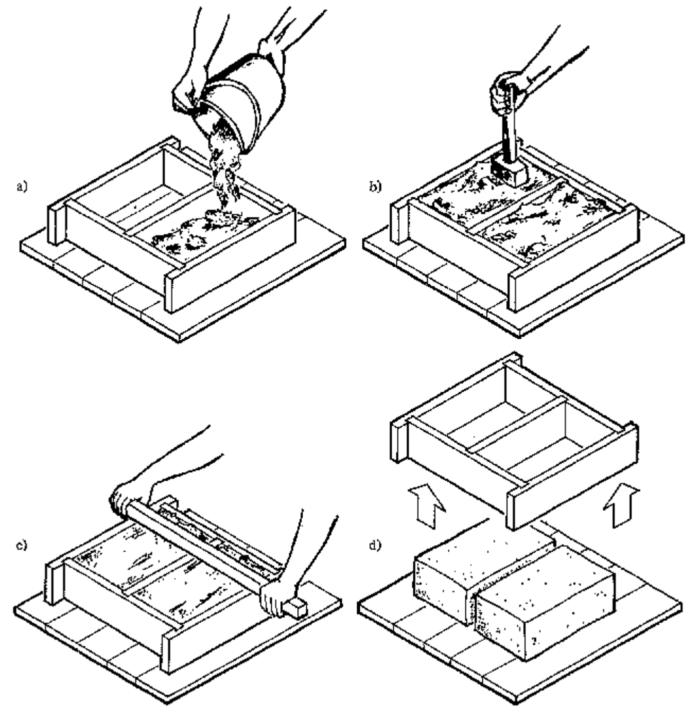


Fig. 29: Wooden mold for pumice-concrete solid brick, including board

Place the box mold on a smooth, level base, or better yet on a smooth backing board. Try to have a large number of such boards on hand, depending on how many blocks are to be produced in a certain length of time.

Pour the pumice concrete into the mold(s) and compact it by tamping with a wooden or iron compactor (Figs. 30a and 30b). Smooth off the top with a lath (strike board). If the concrete is soil-moist, the box mold can be removed immediately after the concrete has been compacted (Figs. 30c and 30d). Clean it with water for immediate reuse. If the pumice concrete mixture is right, the freshly compacted block -the so-called "green compact" will not lose its shape, i.e. crumble or sag.



a)–c): Manual compaction of pumice-concrete in the mold
d) Removing the mold

Fig. 30: Forming pumice-concrete solid bricks

Give the green blocks four or five days to harden before stacking or otherwise handling them. Subsequently, they will require another four days of hardening before they can be transported. All in all, a curing time of 28 days, i.e. one month, is required before they can be placed.

The dimensions 50 x 25 x 12 cm and 30 x 24 x 11.5 cm make a good choice for commercial-scale production of handstruck blocks/bricks, because one and the same kind of block/brick can be used for putting up a 30 cm thick wall, a 24 cm thick wall or an 11.5 cm thick wall.

3.2.3 Pumice concrete cavity blocks

With a little practice and skill, pumice concrete cavity blocks are also easy to make in small quantities. The size of the wooden mold is more or less a question of personal preference, but a 49 x 24 x 15 cm format with two cavities is recommended (Fig. 31). With a view to facilitating placement of the blocks, it is advisable to leave the cavities open at one end only. That way, the mortar is easier to distribute around the supporting surface without having it fall into the cavities (Fig. 32). Since the blocks are supposed to be removed from the molds immediately after they are compacted (so that the wooden molds are immediately available for reuse), the inside of the molds should be made as smooth as possible. Some sort of sheet metal lining serves exceptionally well. Considering the hand-made nature of the finished blocks, either round plastic tubing or blocks of wood would be the best choice for use as cores for forming the cavities, since both are easy to twist out of the green product without damaging the cavities.

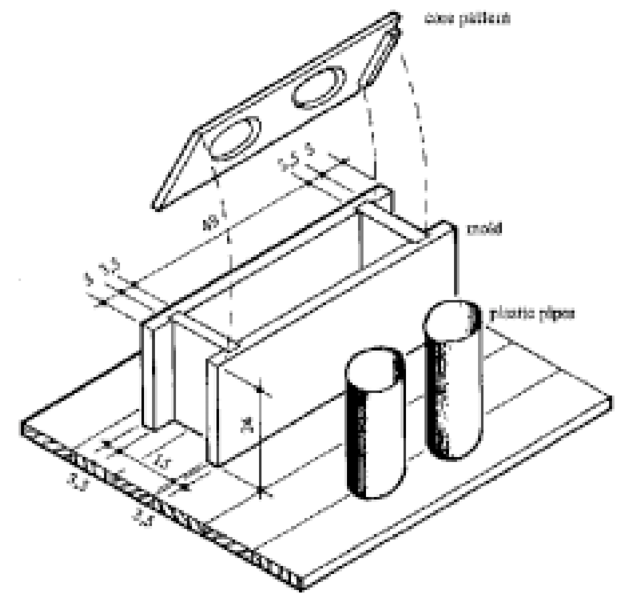


Fig. 31: Wooden mold for two-cavity blocks

The production of concrete cavity blocks requires careful work to avoid damaging the corners and edges of the blocks when the molds are removed. The main things to watch for are that the pumice concrete is neither too dry nor too wet and that it is carefully compacted.

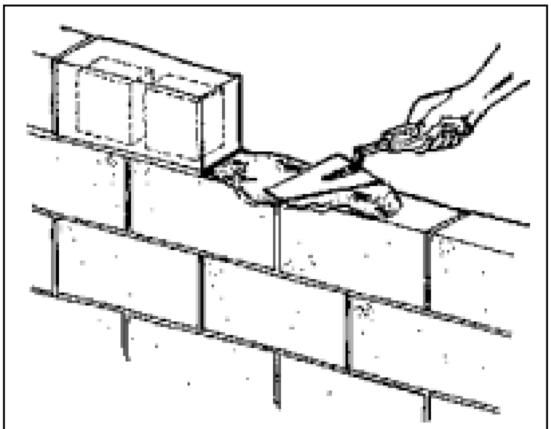


Fig. 32: Spreading mortar on a cavity block

Follow this procedure for making two -cavity pumice-concrete blocks:

- Place the wooden mold on a support (wooden board).
- Cover the bottom of the mold with about 2 cm of pumice concrete (Fig. 33a).
- Put the core pattern (for plastic tubes or wooden blocks) on the mold (Fig. 33b).
- Insert the tubes or blocks for the cavities.
- Remove the pattern.
- Fill the remainder of the mold with pumice concrete and compact it well (Figs. 33c and 33d).
- Then, slowly and carefully pull the plastic tubes or wooden blocks out of the mold and remove the mold itself (Fig. 33e).

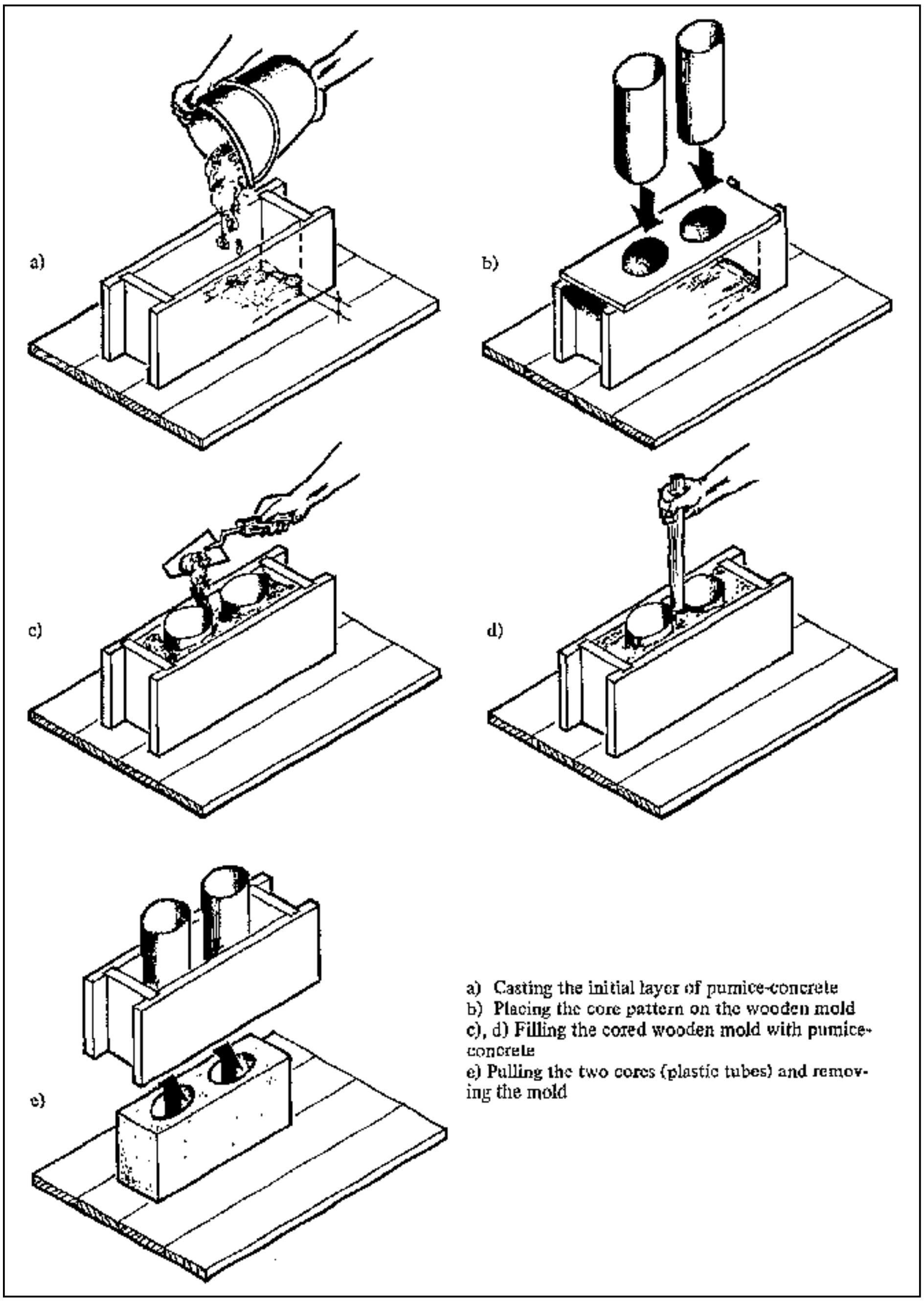


Fig. 33: Forming pumice-concrete two-cavity blocks

Leave the block on the board to dry for 4 -5 days. Then stack the blocks to harden for another 4 days. After a total of 28 days, the blocks will have cured sufficiently for trans. portation and use. Handle the blocks with care, because they break more easily than solid blocks.

If you wish to produce large numbers of cavity blocks, use either steel molds instead of wooden molds or, better, a simple hand -operated mechanical press that compacts the blocks and ejects them from the molds.

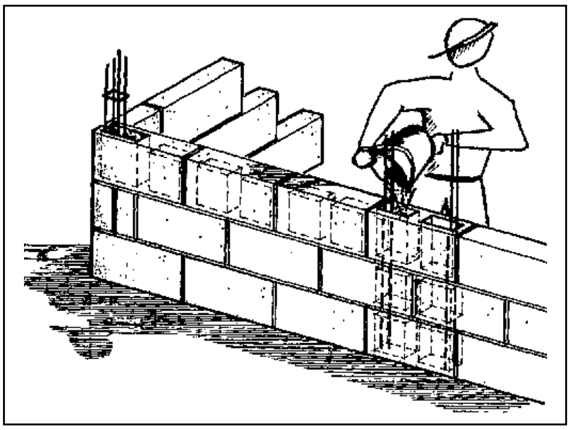


Fig. 36: Filling the corners with concrete and reinforcing bars

Since cavity blocks have relatively thin walls (approx. 2 - 3 cm), the pumice concrete should have a maximum particle size of about 10 mm, i.e. any fraction above 10 mm will have to be screened out of the pumice gravel prior to mixing the concrete. Screening can be accomplished using simple wire screens with mesh sizes of 10 mm (approx. 3/8") and 7 mm (approx. 1/4"). The recommended mixing ratio reads:

2 parts pumice, 1-6 mm in diameter
2 parts pumice, 6 -10 mm in diameter 1 part (Portland) cement.

The advantage of cavity blocks is that they weigh less than solid blocks/bricks, which also means that less pumice concrete (and, hence, less cement) is consumed in making enough blocks for a wall of a given size. An additional advantage is that the cavities situated at the corners of the house can be filled with concrete and reinforcing bars to yield a strong framework' which can be very important in areas subject to earthquakes (Fig. 36). To do so, ram the reinforcing bar (or some other round tool) through the block bottoms to get wall-length cavities at the corners (Fig. 37).

Pumice concrete cavity blocks are useful above all else for filling out skeleton structures, but they are also suitable for making load-bearing walls. Different house-building systems based on cavity blocks are discussed in Chapter 4.3.

3.2.4 Pumice wall panels

How self-help builders with little or no training can use pumice to make simple wall panels measuring 100 x 50 x 5 cm or 100 x 50 x 7 cm is described below. Such panels can be used in any of several time-tested special-purpose house-building systems.

The main merit of the relatively small format is that it makes the panels relatively light and accordingly easy to produce, haul and handle -just right for do-it-yourselfers. A panel width of 50 cm and length of 100 cm combine well for a 2.00-m wall height, and openings for doors and windows can be made by simply leaving out a number of panels at the appropriate places.

To make such pumice-concrete panels, proceed as follows:

Make a simple wooden box mold out of 5-8 cm thick boards. If a large number of panels are needed, it would be a good idea to make several identical molds. That way, the panels can be stacked to save space. The long sides of the panels are supposed to be grooved. To make the grooves, use strips of wooden trim or plastic tubing (Fig. 38a). Later on, when the panels are being placed, the grooves must be filled with mortar to obtain strong joints. For details on wall construction with pumice-concrete panels, refer to Chapter 4.4.

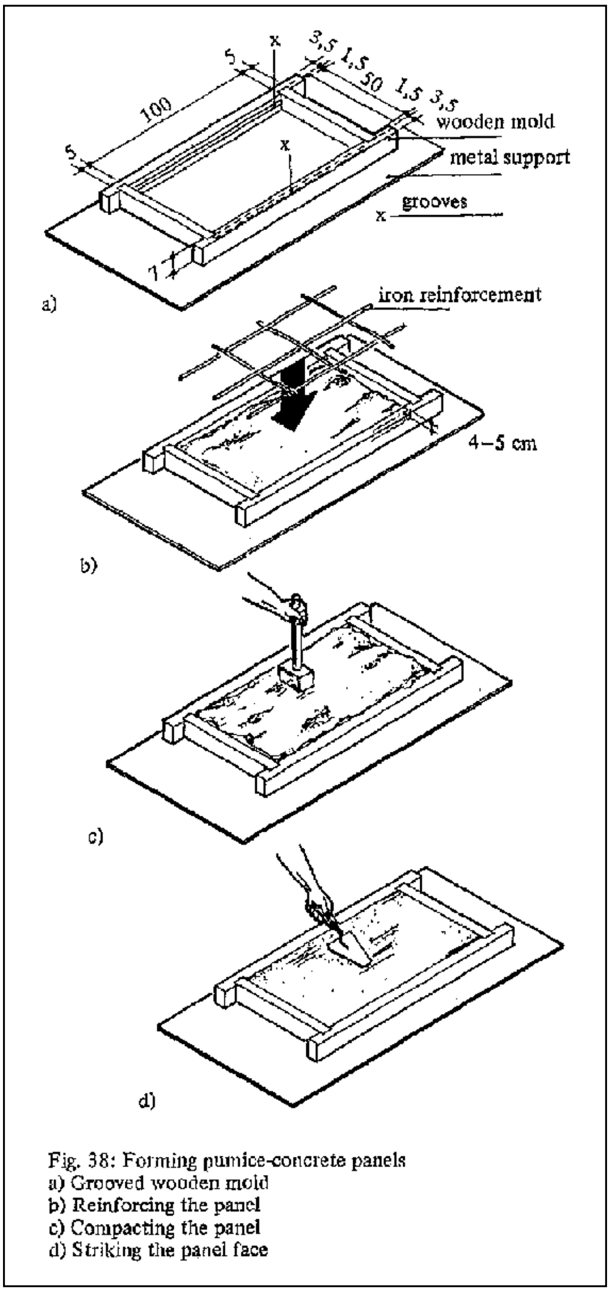


Fig. 38: Forming pumice-concrete panels

The panel-making area must be absolutely level. Each panel should have its own support made of smooth sheet-metal or wood. If nothing else is available, smooth paper or plastic sheeting can be laid out under each mold/panel, as long as the ground is perfectly level.

Considering the size of the panel, it would be a good idea, but not absolutely necessary, to include some form of iron reinforcement consisting of, say, a lattice arrangement of 10 mm (3/8") reinforcing bars sized to match the panels' dimensions. Any panel that will be subject to bending stress (sag), though, should have at least two such bars running lengthwise with several bends/curves (Fig. 38b).

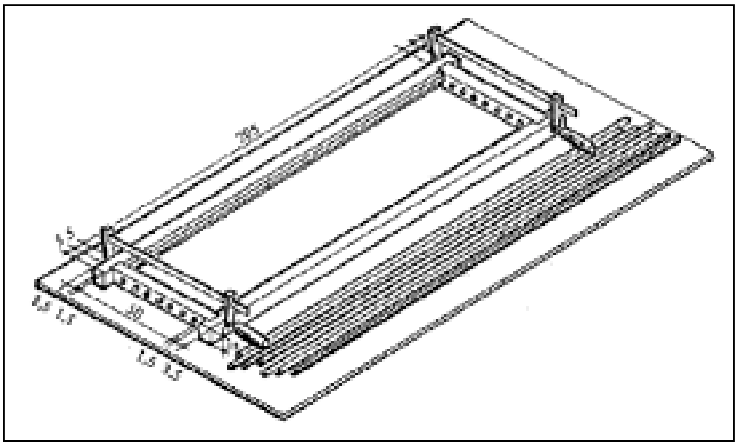


Fig. 39: Mold for hollow-core planks

For poring the panels, prepare a soil-moist pumice-gravel concrete, consisting of four parts pumice gravel to one part cement, and fill the wooden frame with it as described in Chapter 3.2.1. Place the reinforcing lattice such that it "floats" at the center of the panel; smooth the surface of the panel with a strike board or trowel (Figs. 38c and 38d). Leave the panels on the ground to set and harden for about five days, after which they can be handle and stacked. Then give them 25 days to cure prior to transportation and placement. In loading the panels for transportation, be sure to protect them against impact and bending, i.e. it is better to arrange them in an upright position instead of laying them flat.

If the floor in question will not be subject to heavy loads, reinforced pumice-concrete cavity planks can be used in place of the reinforced hollow girders (cf. Fig. 40, Chp. 3.2.5). Planks up to 10 cm thick, however, can only be used to span not more than than 3.0 m. In homes of simple construction, however, such reinforced planks can serve well, as long as careful attention is given to reinforcement, installation and handling, in addition to clarification of the acceptable span width with the aid of a stress analyst (structural engineer).

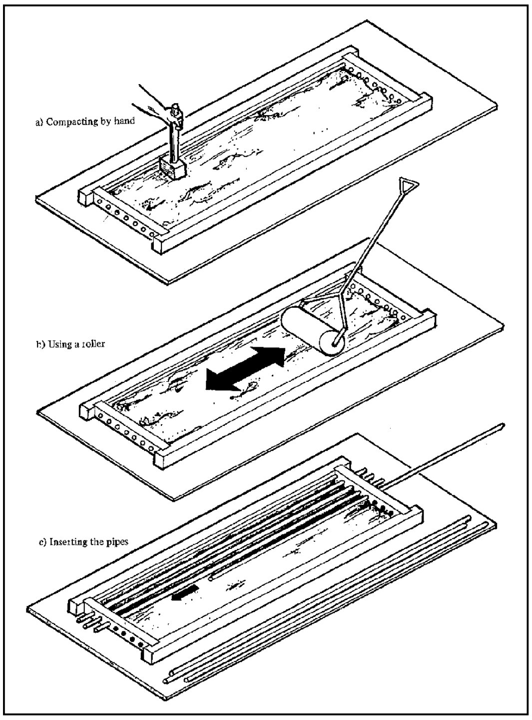


Fig. 40: Forming pumice-concrete hollow-core planks

The prime use for such simple building panels is for filling in skeleton structures, although they can just as well be used for repairing existing walls and building new houses. Consider for example the house described in Chapter 4.4. It consists of a skeleton made of channel-section steel into which the panels are inserted. An alternative example consists of a load-bearing wooden framework and inserted panels.

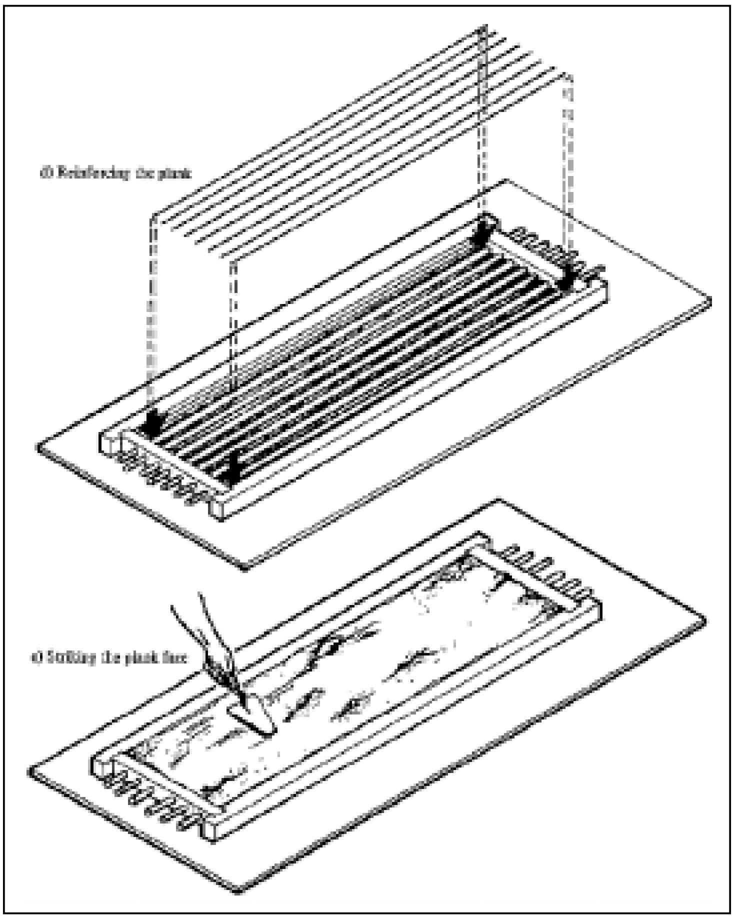


Fig- 40 (2)

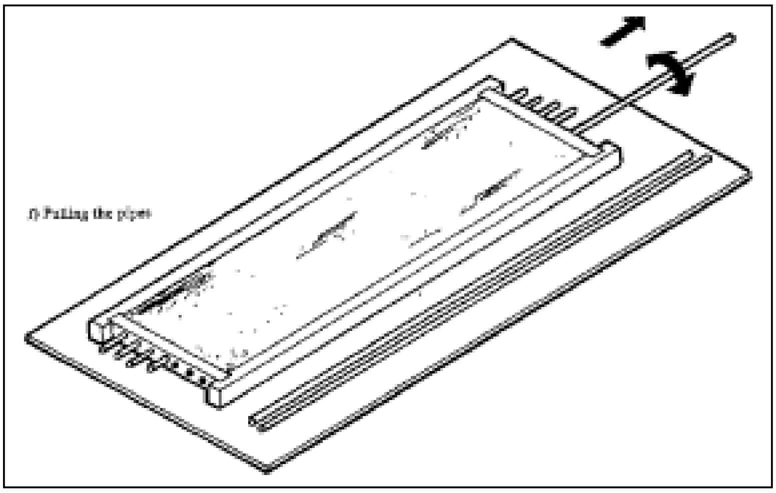


Fig. 40 (3)

3.2.5 Reinforced pumice-concrete hollow -core planks

Compared to the simple type of panel de scribed in the preceding Chapter, it takes somewhat more skill, tools and technical equipment to produce reinforced pumice -concrete hollow-core planks. Consequently, this approach is more suitable for collective self-help building projects than for individual homes. Since easy handling of building members is an important criterion in connection with self-help building projects, care should be taken to avoid making excessively large planks that could not be carried by hand. A maximum length of 250 cm and a maximum width of 50 cm are recommended. The planks used in the model homes discussed in Chapter 4.5 measure 220 x 50 x 10 cm. Planks of that size are just small enough to be carried and placed by four workers.

A relatively large area is needed for producing hollow-core planks. Especially the casting area has to be absolutely level, hard-wearing and easy to clean. The plank molds should be made of solid wood, because they will have to be used repeatedly (Fig. 39). Longitudinal cavities are necessary to save weight. To make them, place plastic tubes or steel pipes in the molds and pull them out after the planks have been compacted. To cast the planks, place the fully assembled wooden molds on a perfectly smooth and level floor panel or on ground covered with plastic sheeting. Alternatively, the floor panel can be coated with used oil before the molds are filled. Soil-moist pumice concrete prepared as described in Chapter 3.2.1 should be used for making the planks.

First, pour a 2 or 3 cm thick layer of pumice concrete into the properly prepared mold and carefully tamp it with a broad hand-held compactor. Even better results can be achieved with a roller, e.g. a steel pipe filled with concrete (Figs., 40a and 40b). Try to get the surface as level as possible. Next, insert the pipes or tubing through the holes in the short ends of the molds (Fig. 40 c). Place thin reinforcing rods (do not forget to have them ready) between the core tubes/ pipes (Fig. 40d). Now, fill out the interspaces with a second layer of pumice concrete that just barely covers the pipes/tubes. Again, carefully tamp the concrete with a broad compactor (or use a roller). Then, pour the third and last layer of pumice concrete, compact it, and strike off the surface with a straightedge lath, subsequently smoothing it over with a trowel (Figs. 40e and 40f). Now, carefully twist the pipes/ tubes out of the mold and remove the mold from the green plank. Leave the planks on their bases to set and harden for about seven days. After that, they will be durable enough for lifting and carrying. They must be transported in an upright position (as opposed to Lying flat) and will require a total of 28 days curing prior to use (Fig. 41). With a view to achieving uniform quality, the planks should, if possible, be prepared in series in a small production installation. That, in turn' will require the availability of several identical molds and pumice concrete of uniform quality.

Reinforced pumice-concrete hollow-core planks serve well as filler members in various types of frame construction. A simple model house made of load-bearing hollow-core planks is described in Chapter 4.5.

3.2.6 Special-purpose pumice-concrete building members and their applications

Channel blocks can be very useful (Fig. 42) as form blocks for peripheral tie beams, as lintels for doors and windows, and as filler blocks for anchoring steel door hinges, wall ties, etc. (Fig. 43).

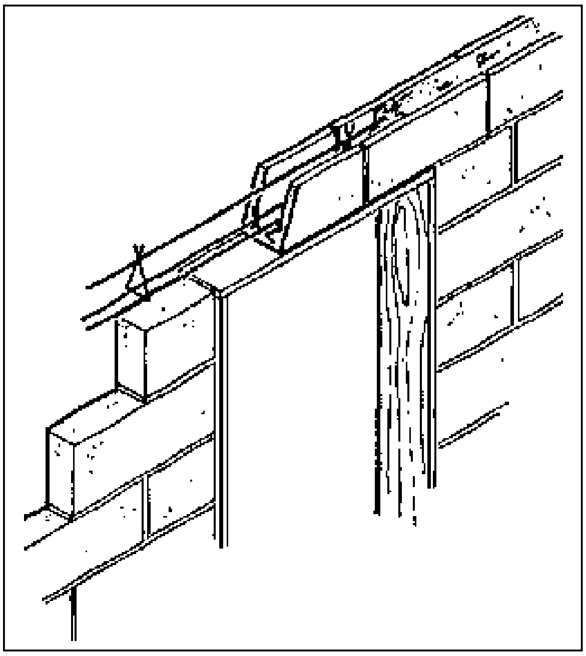


Figure 43: Channel form block in a tie-beam configuration

Channel blocks are made in much the same manner as cavity blocks, except that the core (block of wood) is not placed at the center, but flush with one side of the mold. The walls of channel blocks should be at least 3 or 4 cm thick to make them strong enough to cope with the pressures that arise in connection with pouring and compacting the pumice concrete.

Closed, square hollow blocks serve primarily as form blocks for columns and as chimney blocks (Fig. 44). The blocks must be carefully aligned during placement, or there will be danger that the concrete could push them out of line, resulting in a crooked column. Such blocks serve well as chimney blocks if the clear cross section measures at least 10 x 10 cm and the walls are at least 5 cm thick.

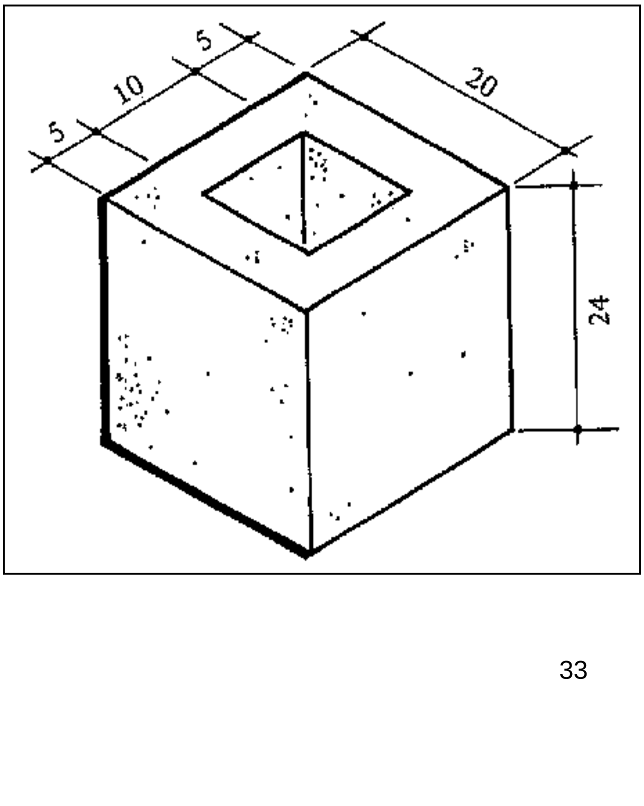


Fig. 44: Chimmey block

Naturally, attention should be paid to dimensional accuracy in fabricating the blocks in order to obtain straight, well -functioning chimneys.

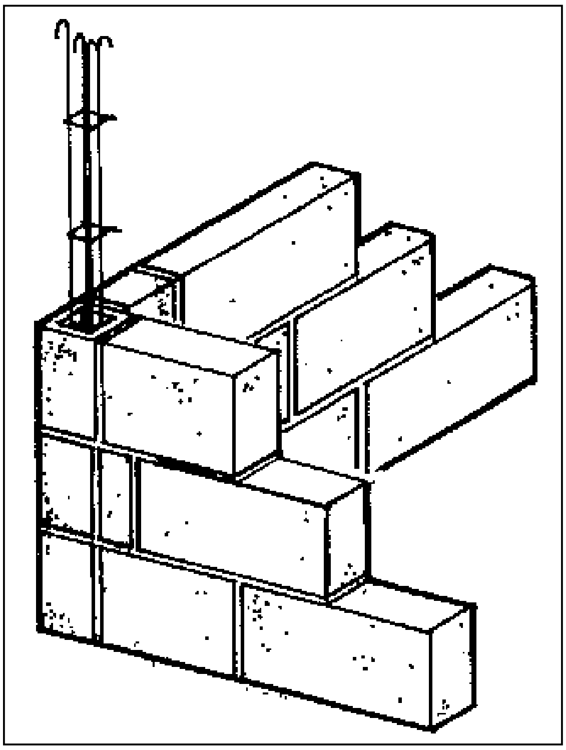


Fig. 45: Masonry corner with channel block serving as support fromwork

Fine-grained pumice concrete can also be used to make diverse kinds of vent blocks that provide through-wall ventilation without letting in sizable vemin or other uninvited guests (Fig. 46). Such blocks also serve as ornaments and in the construction of ventilated store-rooms. They are made in a manner similar to that used for producing cavity blocks, as described in Chapter 3.2.3. However, we recommend not trying to make blocks of very complicated shape, because pumice blocks are never as smooth as those made of normal-weight concrete.

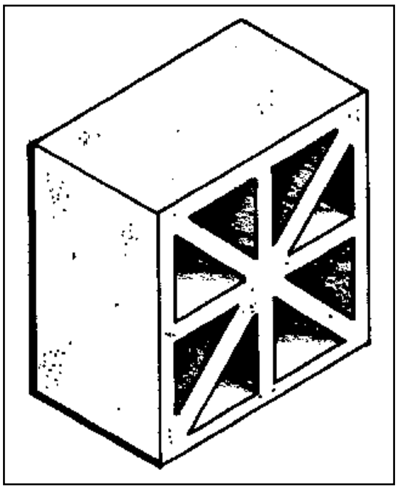


Fig. 46: Vent block

Yet another application for pumice-concrete blocks are intermediate floors. So-called pumice-concrete "hollow floor fillers" can be used in constructing ribbed floors (Fig. 47), e.g. when there is a shortage of form - work material, since such floors consist exclusively of prefabricated members.

The load-bearing beams, i.e. "lattice girders with concrete flanges" are suspended between the walls in a carefully aligned arrangement, with spacing to accommodate the hollow floor fillers. Then the fillers are placed side by side on the concrete flanges of the lattice girders. Check the visible under -face, the seating, the end blocks, etc. and install any supplementary reinforcement that may be considered necessary. After that, place a 5 cm-thick layer of pumice concrete over the fillers. The main function of the pumice in such floors is to minimize concrete consumption and reduce the weight burden in the tensioned zones of the floor.

With the requisite accuracy of static analysis, orderly installation and a small-scale industrial production mode, self-help groups can manufacture so-called "beam floors with pumice-concrete hollow-core plank fillers". The precast hollow planks should measure about 30 x 30 cm, with a length of 3-4 m, and have structural-iron reinforcement in their tension zone. They are placed side by side and then filled with concrete. This yields a very sturdy floor that will carry relatively heavy loads, depending on the span width, reinforcement, and the thick-ness of the pumice-concrete hollow girders.

4. Instructions for Building Pumice-Concrete Houses

This chapter tells how to build several different kinds of houses using building members of the kind described. Typical, practical models that have already been successfully built in various countries were selected.

They include: one in-situ pumice-concrete house, three pumice-brick/block houses, two simple panel-wall houses and two houses made of wall-height hollow-core planks. All of them have approximately 5 x 6 m (= 30 m_) floor space and are suitable for self-help construction.

4.1 House with In-situ Pumice-concrete Walls

Technical description:

This house has load-bearing walls made of in-situ cast pumice concrete. It rests on a reinforced concrete strip footing (normal -weight concrete, not pumice concrete) or on a natural-stone masonry foundation. The in-situ pumice-concrete walls are erected directly on the foundation. They are 15 to 25 cm thick and, to the extent necessary, reinforced with steel to provide protection against earthquakes. The massive walls can be rendered/plastered or smoothed with several coats of paint. The door and window openings are simply left free, and the door -and window cases are embedded in the concrete. In-situ concrete walls have the advantage of not requiring prefabrication (like bricks or panels). On the other hand, they do require the installation of wooden form work to contain the concrete - which in turn involves extra expense, work and prior knowledge (Fig. 50). The roof substructure consists of lattice steel or wooden beams. The roof skin can be made of galvanized corrugated sheeting screwed down on wooden laths, although any other kind of roofing would also be suitable, e.g. clay roofing tiles, straw and reed, etc. The solid walls are strong enough to accommodate a ceiling for the possible subsequent addition of a second story. The floor is made of thin concrete screed on a layer of sand and gravel. Wooden or steel frames hinged to the concrete -embedded cases are recommended for the windows and doors.

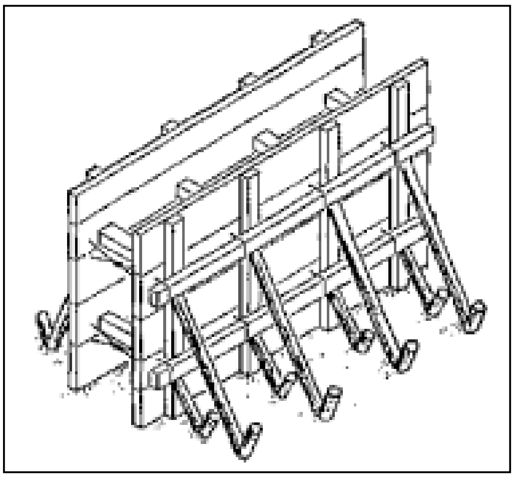


Fig. 50: Wooden formwork for in-situ pumice-concrete walls

This type of construction is most suitable for building new homes. Since it requires a substantial amount of formwork, it is appropriate for countries with adequate supplies of wood. Putting up formwork is no job for beginners, so the aid of specialists should be enlisted.

This type of house lends itself well to the construction of sizable housing developments by self-help cooperatives. The use of prefabricated forms that can be used repeatedly, together with the aid of trained specialists, can help maximize the effectiveness of the building effort.

The following list is a rough bill of quantities for the subject type of house. Local prices can be entered in the "price" column, thus allowing comparison with other house -building systems.

Bill of quantities

Quantities	4.1 House with pumice concrete walls	Walls	Prices
ca. 50 m² wall area	walls comprising 7.5 m³ pumice concrete for a wall thickness of 15 cm. A concrete mixing ratio of 1:4 will yield about 7.5 m³ pumice concrete for 1000 kg cement (20 bags weighing 50 kg each). The same walls with a thickness of 25 cm require 12.5 m³ pumice concrete. For a mixing ratio of 1:4, about 1750 kg cement (35 bags weighting 50 kg each) are needed for 12.5 m³ pumice concrete.		…
70 m	reinforcing rods (approx. 10 mm diameter) for a peripheral tie beam, if the house is located in an earthquake area.		
30 m	reinforcing rods for around the doors, windows and corners.		
ca. 50 m²	wooden formwork, at least 2 cm thick for casting the walls. Suggestion: prepare forms with height of roughly 1.10 m and cast the formwork and pour the upper part. Wood for forms can often be borrowed, not necessarily bought.		

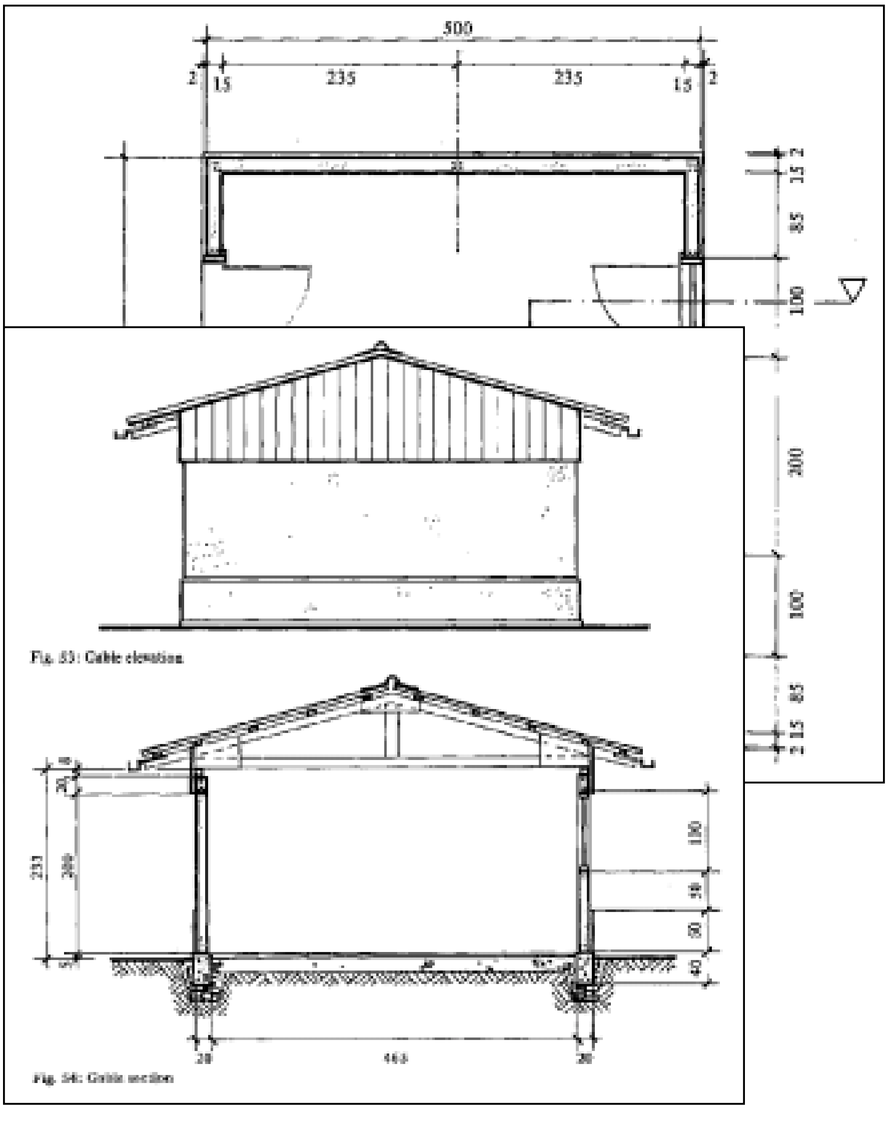


Fig. 51 and 52

Fig. 53 and 54

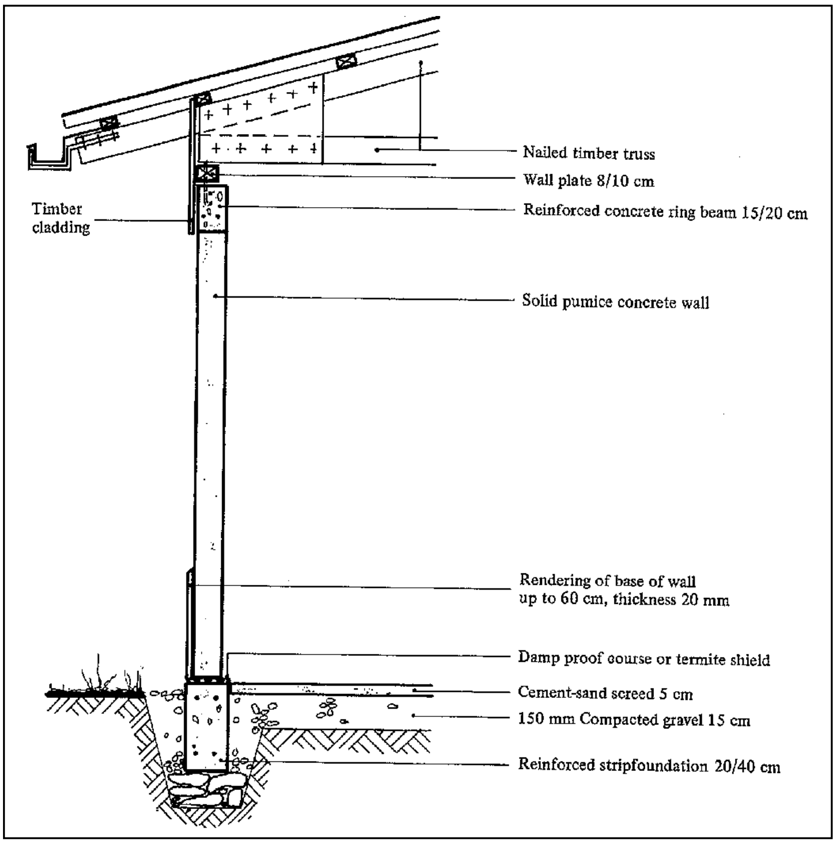


Fig. 55: Section

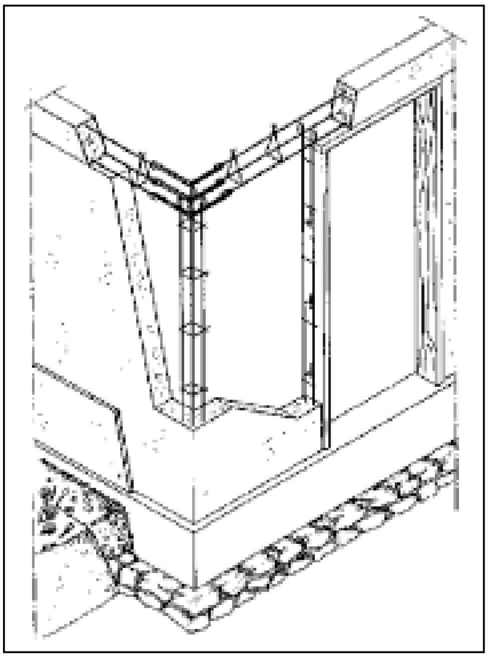


Fig. 56: Isometric view

4.2 House with Pumice-concrete Solid-block/brick Walls

Technical description:

In this case, the walls are made of masonry consisting of prefabricated pumice-concrete solid blocks/bricks. They can range in thickness between 10 and 25 cm, depending on the size of the blocks/bricks.

The strip footing can be made of in-situ normal-weight concrete or of natural stone masonry, as long as it is strong enough to carry the weight of the walls. First of all, the blocks/bricks for the walls have to be made. Fifty bricks measuring 25 x 11.5 x 7 cm will produce one square meter of wall with a thickness of 11.5 cm. Only 7 blocks measuring 49 x 30 x 11.5 cm are needed per square meter wall area with a thickness of 11.5 cm. The pumice-concrete bricks are very light and therefore quick and easy to place. Care must be taken to ensure that the walls have the proper masonry bond and are exactly vertical (Fig. 57). It is important to remember that pumice bricks have to be dipped in water prior to use to keep them from absorbing the gauging water and setting too quickly, which would result in very unstable joints. The walls of the house can be rendered/plastered, and plinth rendering to a height of 30 -50 cm is recommended in any case.

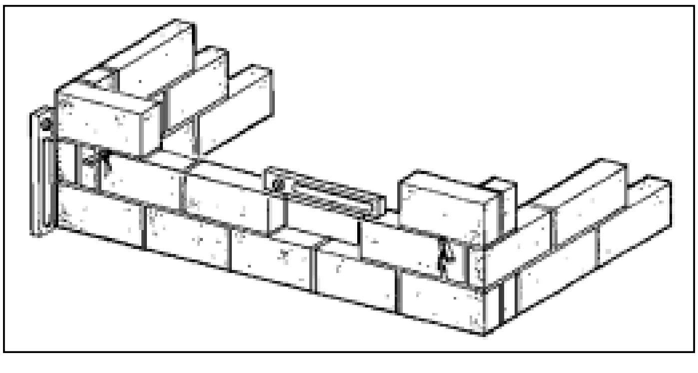


Fig. 57: Setting up brick walls

The top row of bricks should carry a peripheral tie beam of reinforced concrete or wood, so that a second story can be added to the house at will. Walls with a thickness of about 15 cm will suffice for a single-story house, but the wall thickness should be increased to approx. 25 cm for the first floor of a two -story house (10 - 15 cm for the upper story). The roof can be made of clay roofing tiles, corrugated asbestos, corrugated metal, wood, reed or palm fronds. The walls are sturdy enough to carry heavy roofing. The doors and windows can be made of wood or metal, and their cases should be . tied into the masonry.

The house is very well-suited for self-help construction. One person alone can easily make the bricks/blocks, since all that is needed is a wooden mold, pumice, cement and water. After making just a "few" bricks, the same person can build the walls little by little. This type of construction involves no heavy work at all, since more bricks can be made and placed whenever the builder has a few extra hours or days.

Quantities	4.2 Pumice-brick/block house	Walls	Prices
ca. 50 m² wall area	for bricks measuring 24 x 7 cm and a wall thickness of 11.5 cm, 2500 bricks and about 700 kg cement (14 bags) will be needed to put up the walls.		…
ca. 2 m³	masonry mortar, i.e. approx. 6 bags of lime/cement and approx. 2 m³ sand (For a wall thickness of 24 cm and blocks measuring 49 x 24 x 11.5 cm, 800 blocks, 1400 kg cement (28 bags) and 2.4 m³ mortar consisting of approx. 7 bags of lime/cement and approx. 2.4 m³ sand will be needed for the walls.)		…

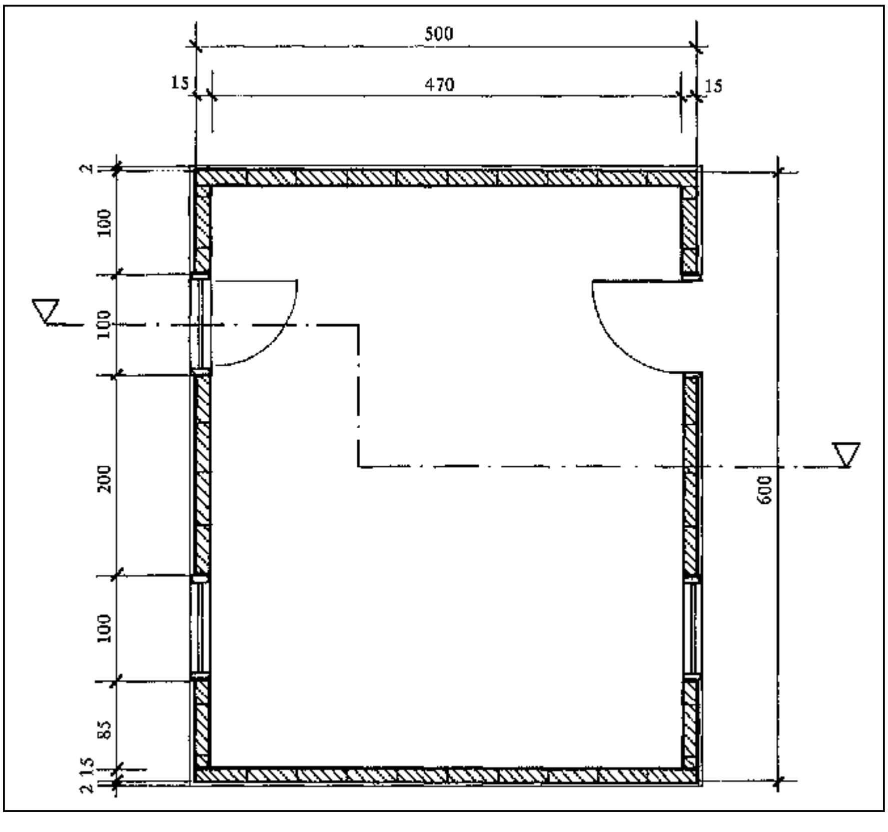


Fig. 58: Plan

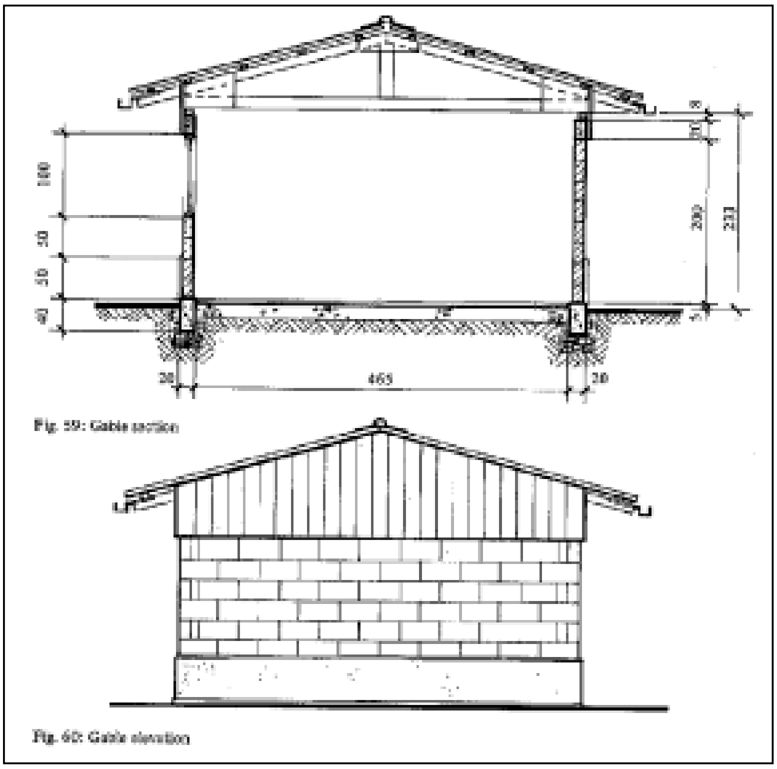


Fig. 59 and 60

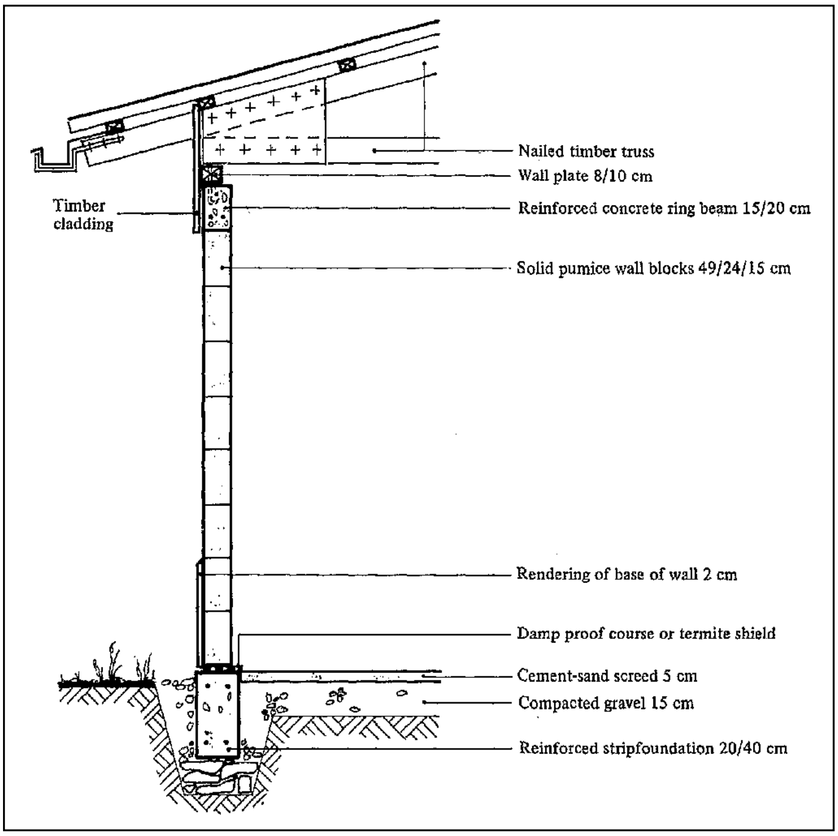


Fig. 61: Section

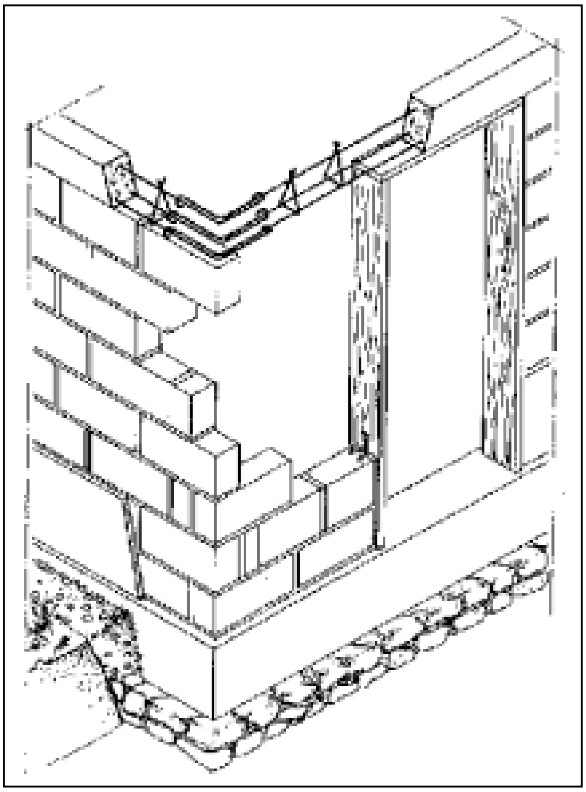


Fig. 62: Isometric view

4.3 House with Pumice-concrete Cavity-block Walls

4.3.1 Masonry construction
4.3.2 Fair-faced concrete-column skeleton structure

4.3.1 Masonry construction

Technical description:

The walls of this house are made of so-called two-cavity pumice-concrete blocks, which have the advantage of forming a strong and sturdy wall with less material than would be needed for a wall made of solid blocks. Additionally, the cavities have a good insulating effect in both cold and hot climates.

The foundation should be made of in-situ concrete or natural stone masonry and be 5 to 10 cm wider than the walls.

The first step in putting up the walls, of course, is to prefabricate the cavity blocks as described in section 3.2.3. The blocks are placed with the closed end up, i.e. such that the cavity openings are pointing downward. That way, it is easier to spread the mortar around the edges of the last course before setting the blocks of the next row (Fig 32; cf. Chap. 3.2.3).

In earthquake areas, it is a good idea to fill the corner cavities with reinforced concrete.

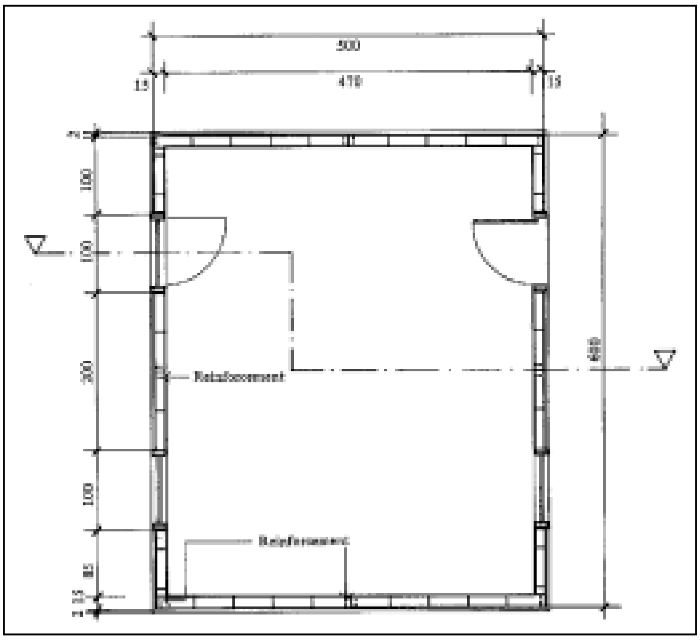


Figure 63: Plan

The reinforcing bars should be embedded in the foundation at the corners. Then only the "tops" of the cavity blocks have to be neatly opened (Fig. 37, cf. Chap. 3.2.3), the blocks threaded onto the rods, and the cavities filled with (well-compacted) pumice concrete all the way up to the top of the wall. There, the reinforcing rods should be attached to a peripheral tie beam, which can be placed in special pumice channel blocks that are subsequently filled with pumice concrete (Fig. 43; cf. Chap. 3.2.6).

The door and window cases should preferably be prefabricated and built in as the walls sistance and can accept a second story.

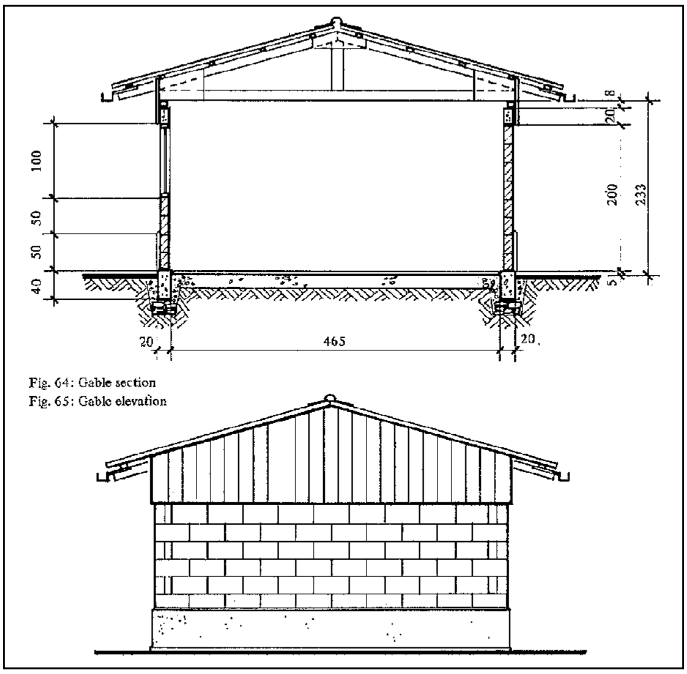


Fig. 64 and 65

The roof can be covered with clay roofing tiles, corrugated asbestos, corrugated metal, reed or palm fronds.

The door and window cases should preferably be prefabricated and built in as the walls go up in order to achieve a more stable connection between them and the masonry. If that is not possible, a few pieces of wood, screws or the like can be embedded in the masonry joints at strategic locations to provide anchorage for the subsequently placed door and window frames. The floor can be executed in any desired fashion, although the installation of a layer of gravel covered by a thin layer of concrete screed or a bed of sand followed by ceramic floor tiles is recommended.

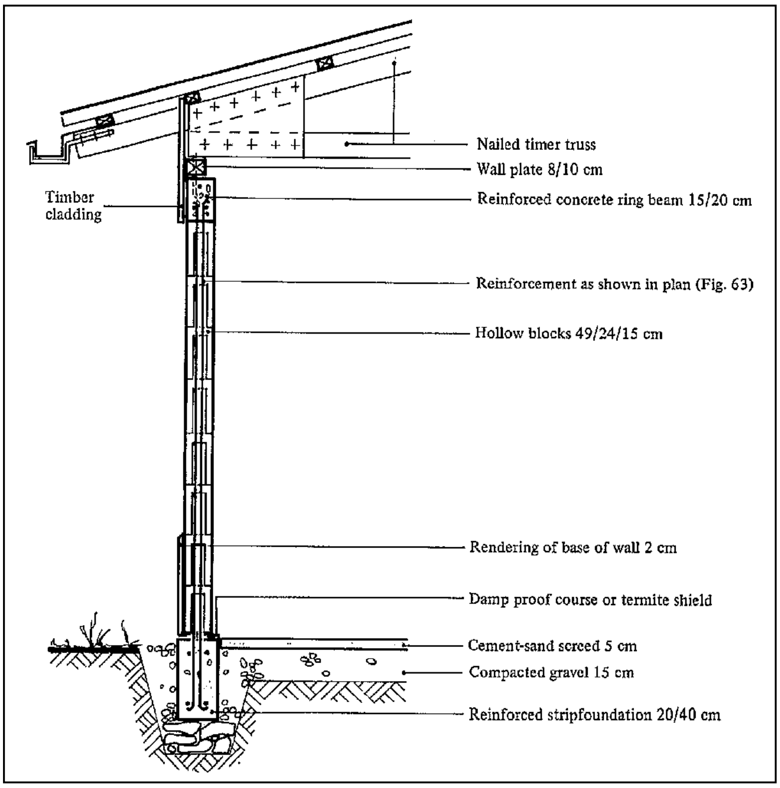


Fig. 66: Section

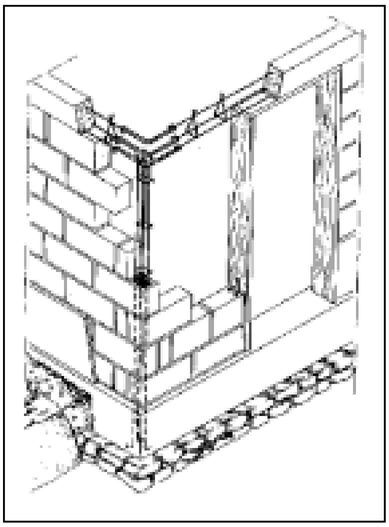


Fig. 67: Isometric view

4.3.2 Fair-faced concrete-column skeleton structure

Technical description:

This type of structure consists of a load-bearing concrete-column skeleton filled out with pumice-concrete cavity blocks.

The house rests on reinforced-concrete isolated or strip foundations with encastre concrete columns. The pumice-concrete cavity blocks fill out the spaces between the columns. The floor of the model house consists of a layer of sand and gravel topped with a thin layer of concrete screed. The roof substructure is made of lattice steel or wooden beams. The covering may consist of roofing tiles' sheet zinc or corrugated asbestos sheet on wooden laths. The window and door openings have built-in cases made of square timbers or steel. The door leafs and window sashes are hinged to the case frames.

This model house is of very sturdy, durable design and can be added onto or altered at will, since any infill wall can be torn down and moved with no special effort. It is relatively complicated to build, however, and therefore less appropriate for individual doit-yourself builders than for joint-effort projects of rural communities or building cooperatives.

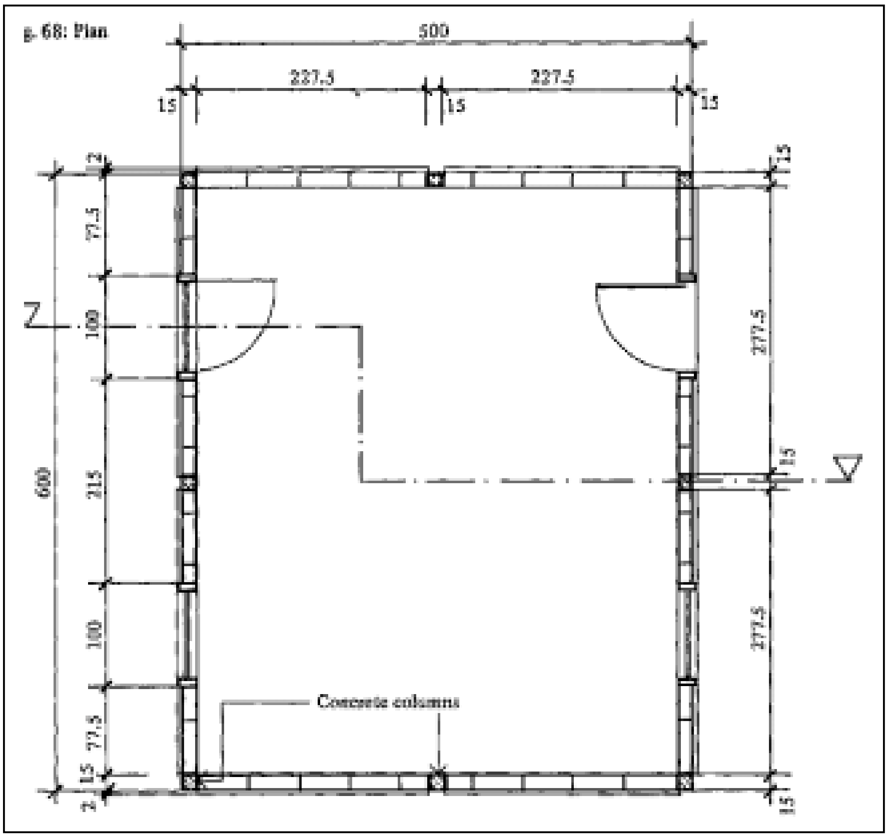


Fig. 68: Plan

GATE has already sponsored the construction of such model houses in El Salvador and Nicaragua. This type of pumice-concrete block house is nearly identical to GATE's "concrete column house", for which detailed self-help instructions are available.

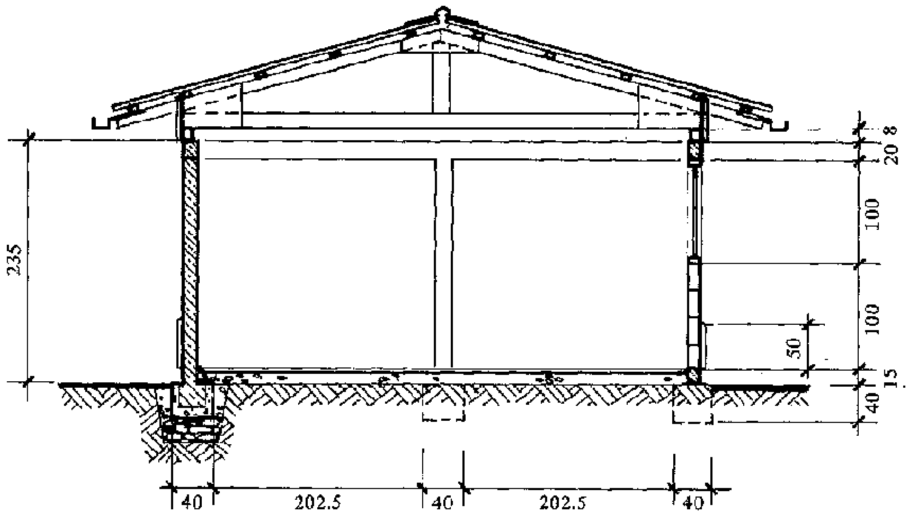


Fig. 69: Gable section

Fig. 70: Gable elevation

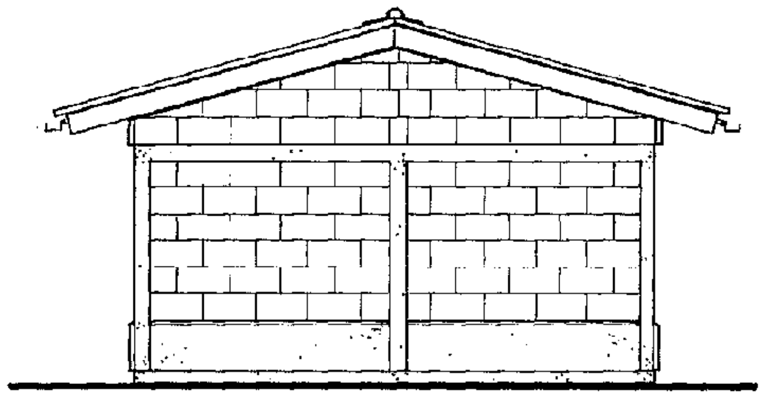


Fig. 69 and 70

Quantities	4.3 b) House with pumice-concrete cavity-block walls; fair-faced concrete-column skeleton	Walls	Prices
ca. 2 m³	reinforced concrete for the concrete skeleton with 15 x 15 cm columns		…
ca. 50 m²	pumice-concrete block walls consisting of approx. 400 pumice-concrete cavity blocks measuring 49 x 24 x 15 cm (wall thickness: 15 cm)		…
ca. 1 m³	masonry mortar for the joints, consisting of approx. 3 bags of lime/cement and 1 m³ sand		

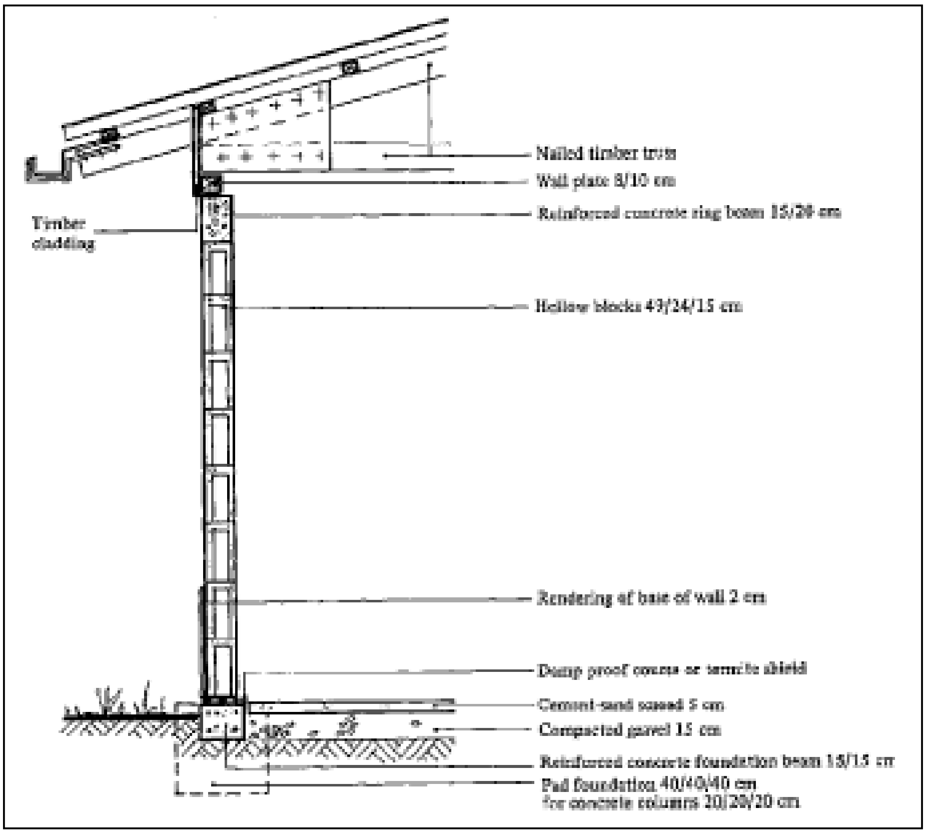


Fig. 71: Section

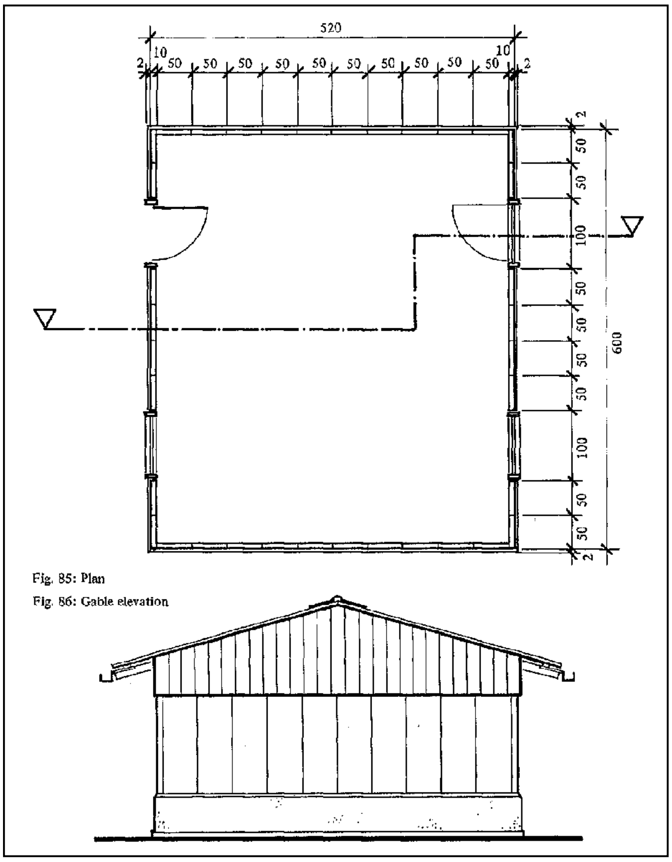


Fig. 85: Plan

Fig. 86: Gable elevation

Fig. 72: Isometric view

4.4 House with Pumice-panel Walls

4.4.1 Sectional steel load-bearing system
4.4.2 Wooden post and beam system

4.4.1 Sectional steel load-bearing system

Technical description:

This structure essentially consists of steel channel sections with pumice panels in between.

The house rests on a reinforced-concrete strip foundation with cutouts for the steel channel sections (or profiles made of galvanized sheeting). The cutouts are filled with concrete after" the walls are properly squared.

Four wall panels of the kind described in Chapter 3.2.4 are stacked on edge between each two uprights, producing a rigid wall element measuring 2 m in height and 1 m in width (cf. relevant isometric drawing).

The wall structure gets its stability from the strip foundation at the bottom and a continuous tie beam in the form of a steel channel track at the top (cf. details in the relevant technical drawings).

The steel tracks are joined at the corners by riveting or welding (cf. 1:10 details in the relevant technical drawings).

Openings for windows and doors can be placed as desired simply by leaving out the appropriate pumice-concrete panels. The window and door cases are made of simple square timbers of the same thickness as the panels set in the channel sections.

The floor comprises a layer of coarse gravel, a layer of sand, and a layer of smooth concrete screed.

The roof consists of zinc sheeting nailed onto a wooden substructure, although any other suitable material could also be used.

GATE has also published instructions for building this house (under the name "concrete panel house"); the instructions are available from GATE on request.

Bill of quantities:

Quantities	4.4 a) House with pumice-panel walls; sectional steel load-bearing system	Walls	Prices
ca. 3 m³	concrete for strip foundations		
ca. 4	reinforcing cages appropriate to the foundation		
ca. 44	steel channel sections with a length of about 2.40 m and a profile thickness of about 3 mm for wall construction		
ca. 76	lattice-reinforced pumice-concrete panels (100 x 50 5 cm) as wall elements		
ca. 4	wooden, concrete or steel tie beams with cutouts for steel channel sections		
ca. 30 m	boards for gable formwork		
ca. 0.4 m³	wood for the roof substructure and lathing		
ca. 30 m²	corrugated metal sheet roofing or equivalent material		

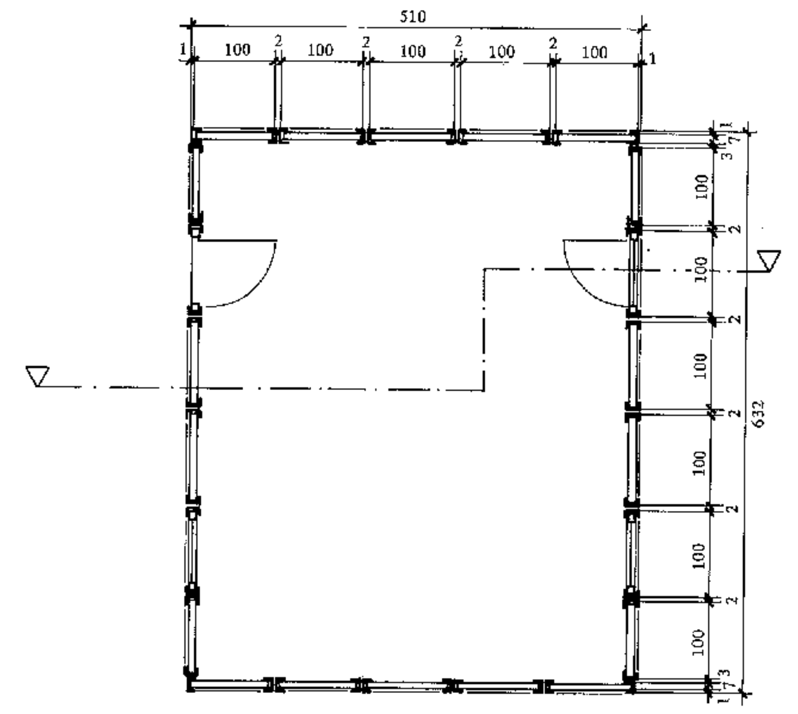


Fig. 73: Plan

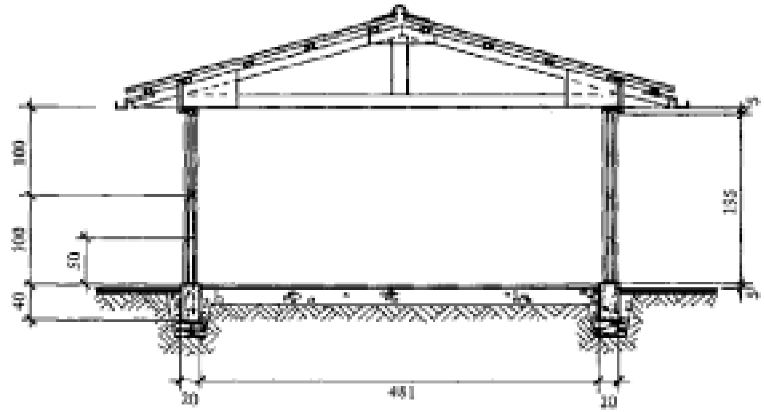


Fig. 74: Gable section

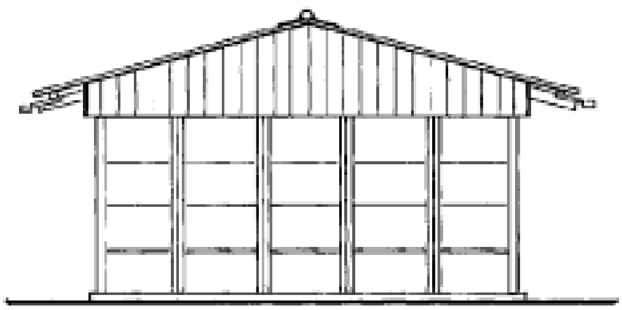


Fig. 75: Gable elevation

Fig. 74 and 75

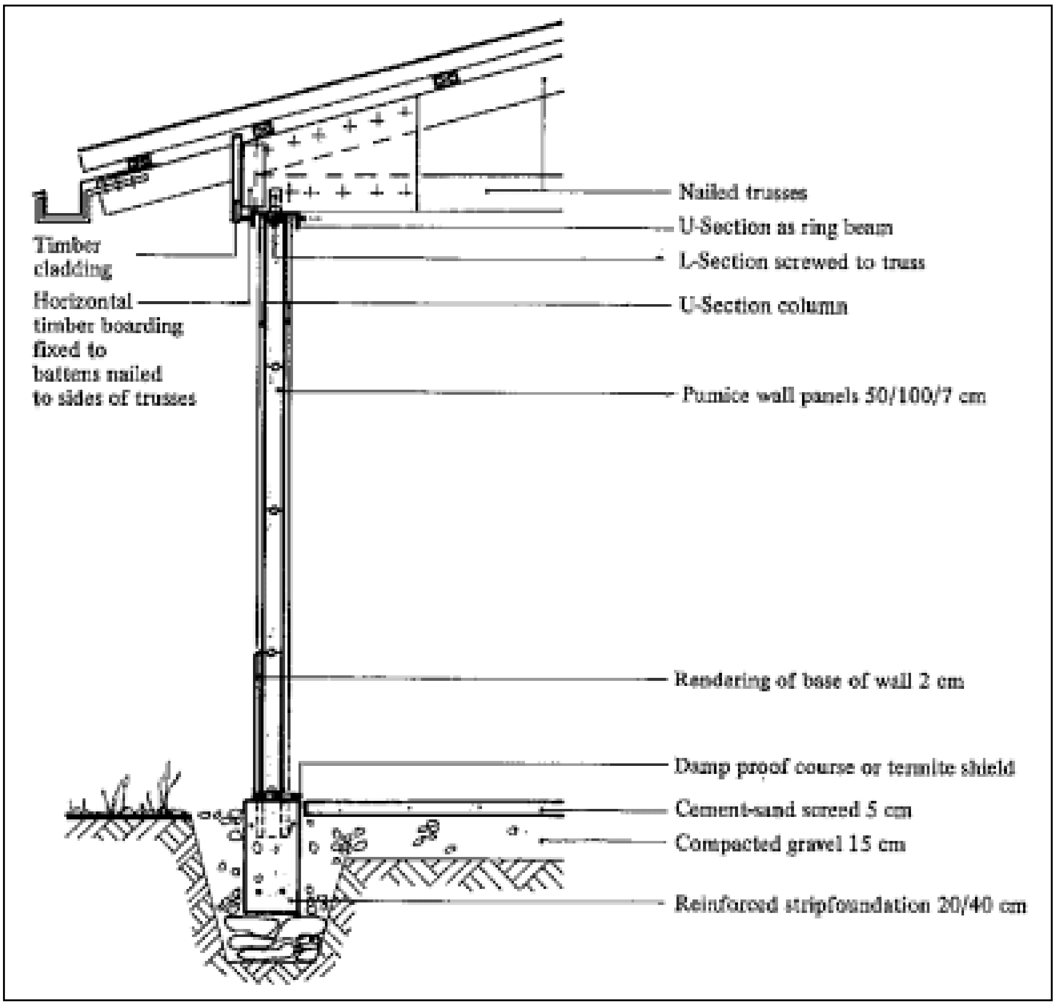


Fig. 76: Section

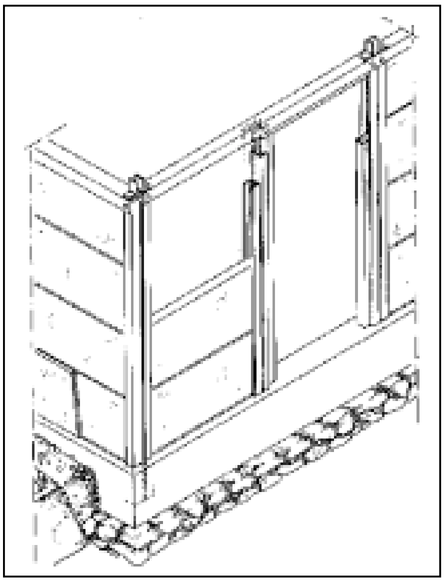


Fig. 77: Isometric view

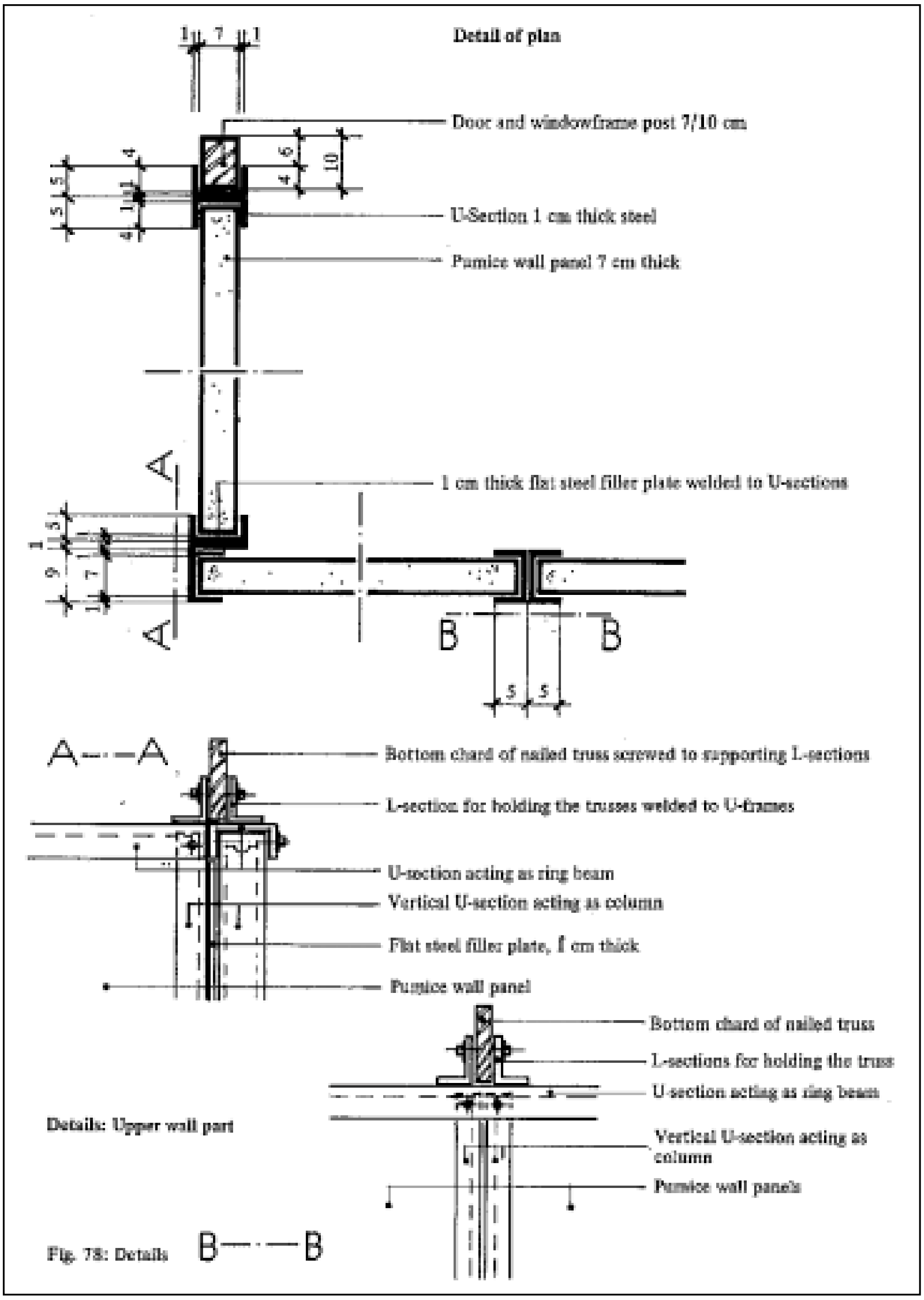


Fig. 78: Details

4.4.2 Wooden post and beam system

Technical description:

This house is built according to the same basic system as the preceding house, except that the frequently very expensive steel channel sections are replaced by relatively inexpensive wooden posts and beams. While the model house has corner posts measuring 10 x 10 cm and intermediate/interior posts and tie beams measuring 7 x 10 cm, the wooden-post cross sections ultimately depend on the thickness of the pumice-concrete panels. The posts should consist of sawn wood that has been treated against pests with chemical agents, tar, used oil, lime, saltwater, etc.

Cutouts of adequate size are left for the wooden posts in the natural-stone or concrete strip foundations. The posts are inserted into the cutouts and wedged in place. Later, the cutouts are filled with concrete. Thin laths nailed onto the wooden posts hold the panels in place. One lath can be left out at first to allow easier stacking of the panels. Only when all of the panels are in place and properly aligned should the last lath be nailed on. The horizontal joints between the panels can be closed with mortar (= grout).

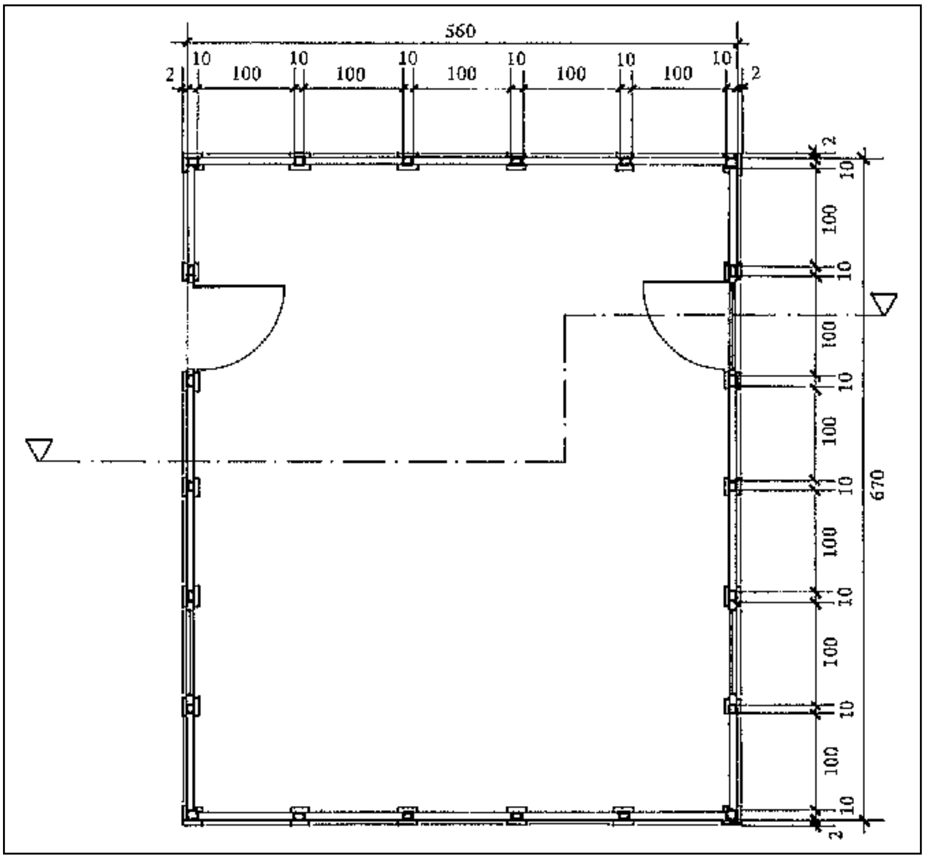


Fig. 79: Plan

This structural system is particularly well-suited for use in areas with easy access to cheap wood. The wood in question does not have to be straight lumber. If the wood is a little crooked, the pumice-concrete panels can be made to conform, and any residual openings can be sealed off with pumice mortar.

It is important that the wooden posts be rigidly anchored at top and bottom.

Since pumice-concrete panels are very easy to make, and since the wood and pumice-concrete are both easy to work with and mutually adaptable, the house can be built as a family-scale self-help project.

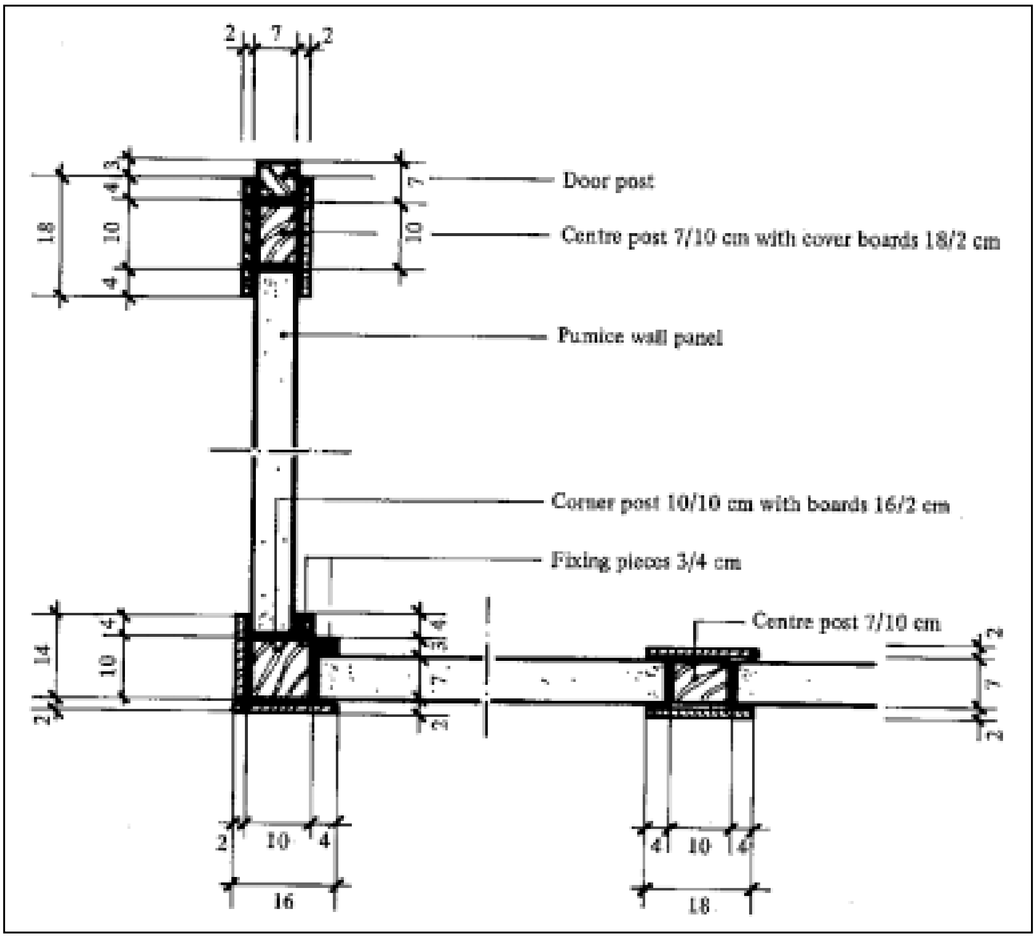


Fig. 80: Detail of plan

Quantities	4.4 b) House with pumice-panel walls; wooden	Walls	Prices
ca. 22	wooden posts, approx. 10 x 10 cm, 7 x 10 cm		
180 m	wooden laths, approx. 2 x 3 cm or 2 x 4 cm, as "guide rails"		
ca. 64	pumice-concrete wall panels, 100 x 50 x 5-8 cm, requiring: 2.50 m³ pumice concrete, i.e. 350 kg or 7 bags of cement		
ca. 0.20 m³	mortar for horizontal joints between the panels		
ca. 26 m	wood for the continuous tie beam, approx. 7 x 10 cm or 12 x 12 cm		

Fig. 81: Gable section

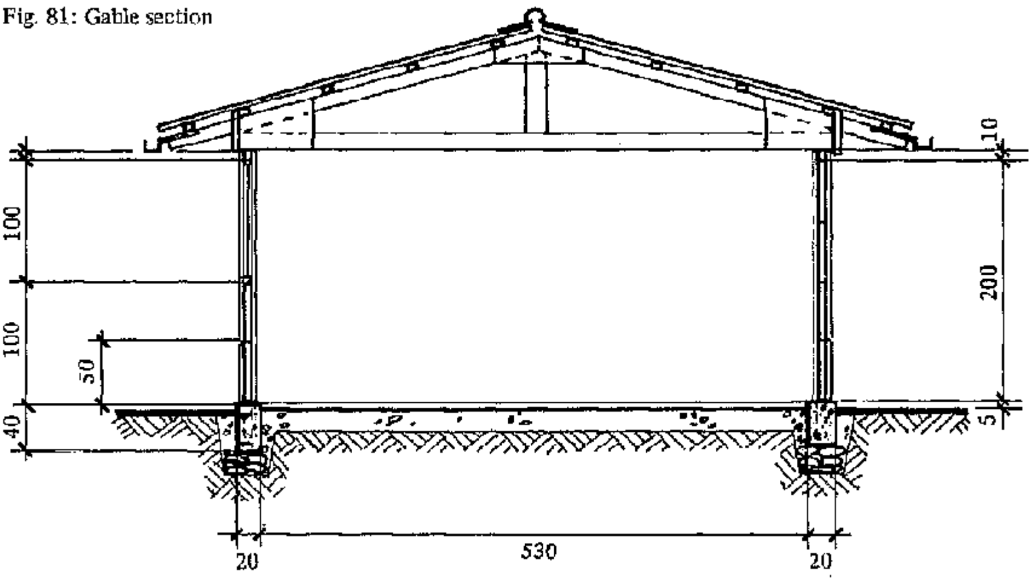
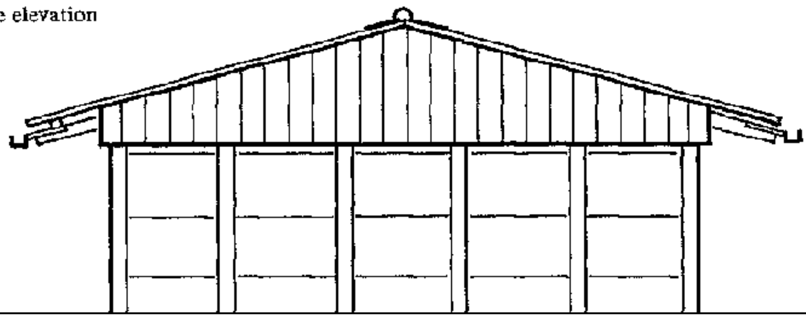


Fig. 82: Gable elevation



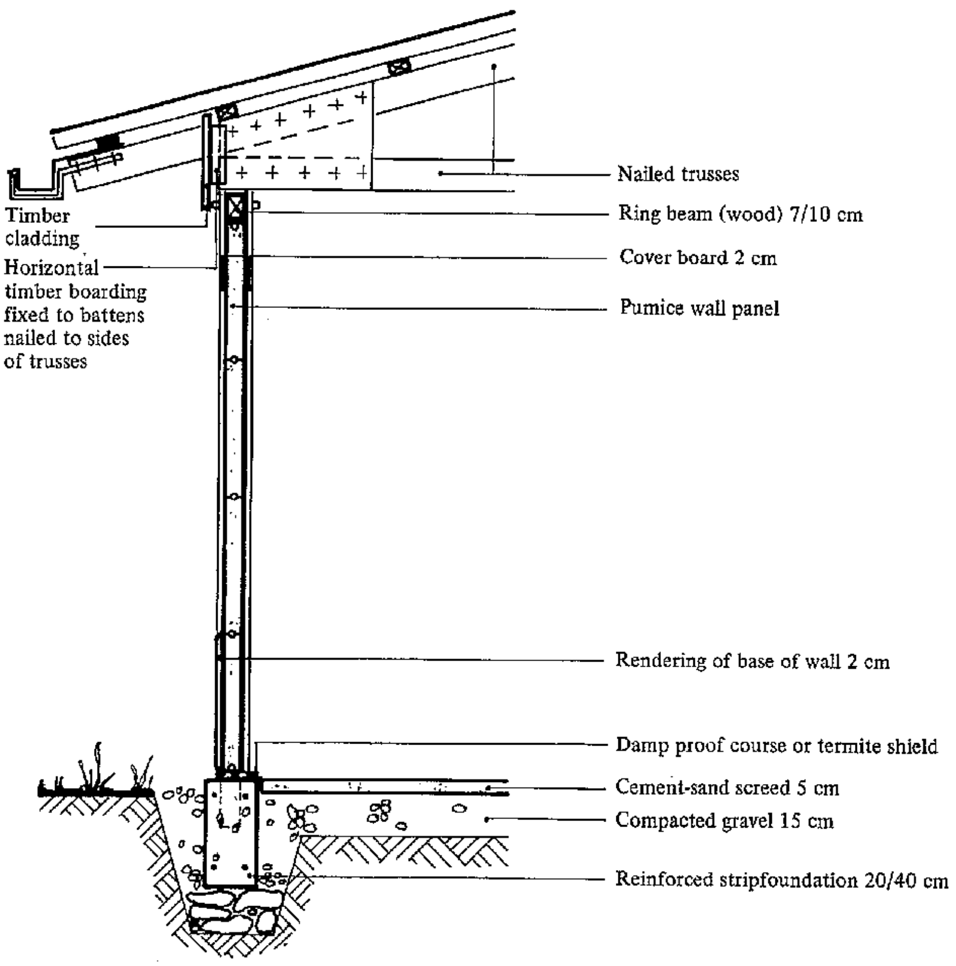


Fig. 81 and 82

Fig. 83: Section

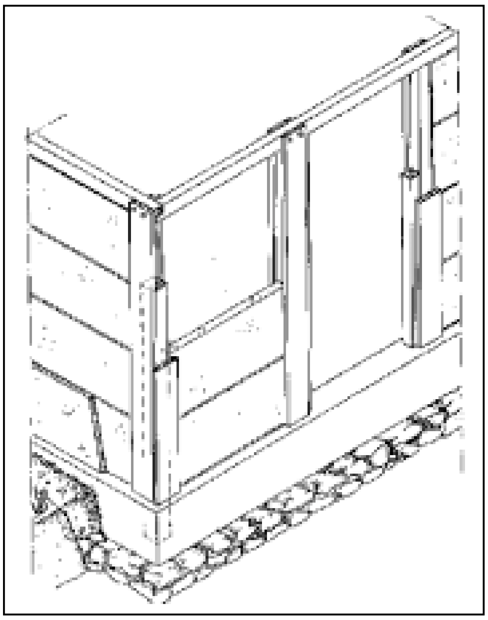


Fig. 84: Isometric view

4.5 House with Wall-length Reinforced Pumice-concrete Hollow-core Planks as Self-supporting Wall Members

4.5.1 Hollow-core planks 50 x 205 x 10 cm
4.5.2 Hollow-core planks 30 x 205 x 12 cm

Technical description:

This house has no load-bearing skeleton structure. The thick, wall-length self-supporting, hollow-core planks suffice to yield a stable house (as long as the planks are at least 7-15 cm thick). Such planks are rather heavy, requiring several people or special-purpose tools for handling and placing them. Consequently, this house is most suitable for housing projects involving several appropriately equipped professionals.

The house needs a solid natural-stone or reinforced-concrete foundation. The planks are easy to make, once a good set of molds has been prepared (cf. Chap. 3.2.5). It is important that the planks be cast properly and true-to-size, otherwise they may not fit together. Placing consists of erecting one plank after another, beginning at a corner of the house and propping each plank with wooden stays. As soon as one side of the house and its two corners are standing, the joints be-tween the planks can be grouted with thin pumice-concrete containing only very small aggregates. Care must be taken to ensure that the entire joint is properly filled and compacted from top to bottom. A continuous tie beam made of normal-weightconcrete must always be installed around the top of the walls to help hold the planks together. The roofing can consist of any preferred material.

If all planks are. properly joined and plumb, and if the foundation is strong enough, this type of construction can accommodate a second story.

Bill of quantities:

Quantities	4.5 House with wall-length reinforced pumice-concrete holow-core planks as self-supporting wall members	Walls	Prices
ca. 50 m²	hollow-core plank walls, 10 cm thick, i.e. 38 hollow-core planks measuring 220 x 50 x 10 cm and comprising 3.42 m³ pumice concrete (approx. 500 kg or ten 50-kg bags of cement)		…
ca. 1 m³	fine-grain pumice concrete for grouting the joints and casting the continuous tie beam		…
ca. 150 m	reinforcing rods, 3/8" diameter for tie beam and joints		…

4.5.1 Hollow-core planks 50 x 205 x 10 cm

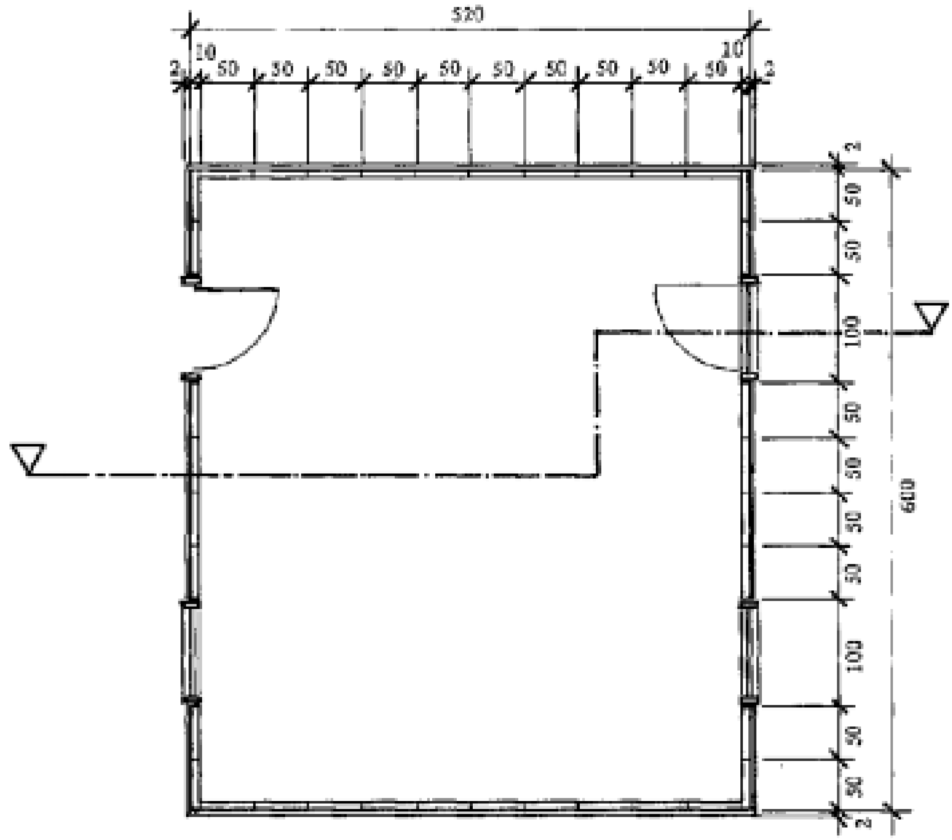


Fig. 85: Plan

Fig. 86: Gable elevation

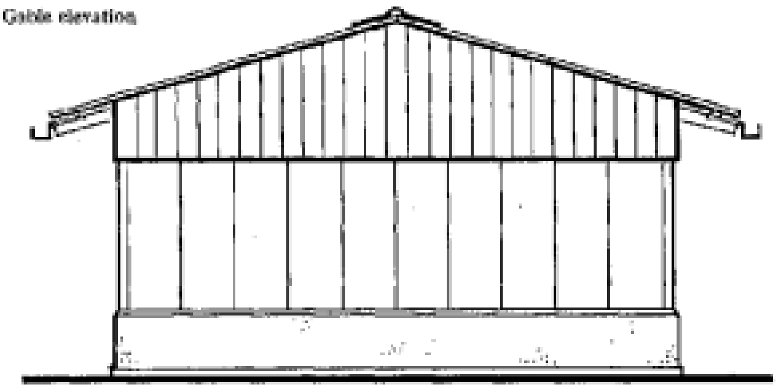


Fig. 85 and 86

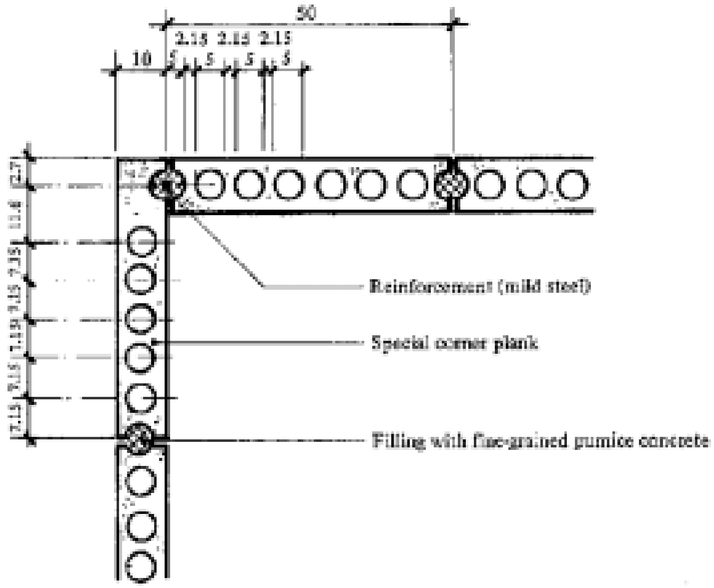
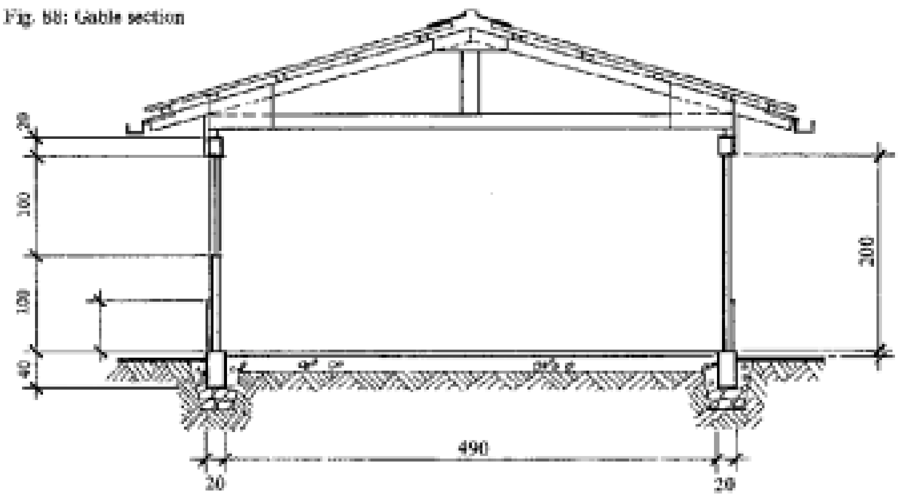


Fig. 87: Detail of plan

Fig. 88: Gable section



Figures 87 and 88

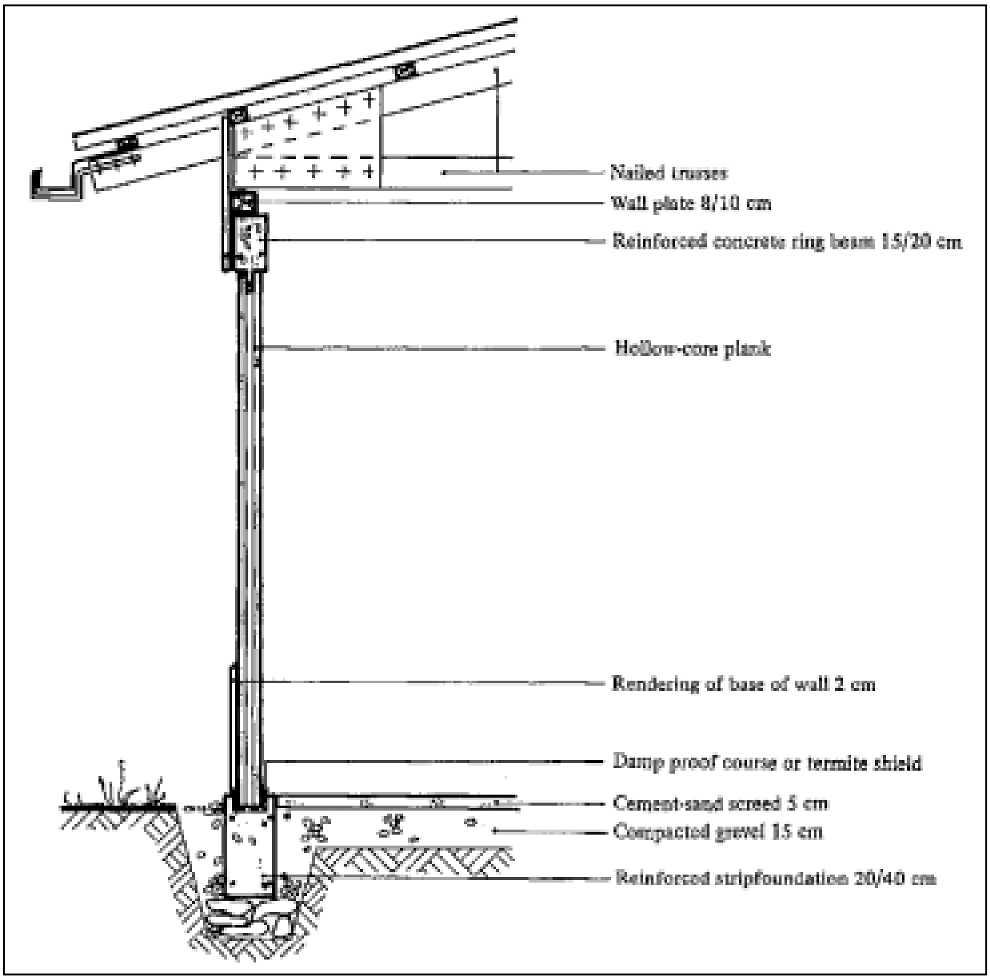


Fig. 89: Section

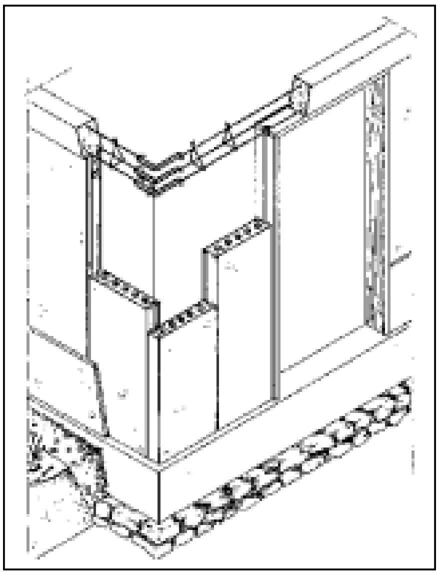


Fig. 90: Isometric view

4.5.2 Hollow-core planks 30 x 205 x 12 cm

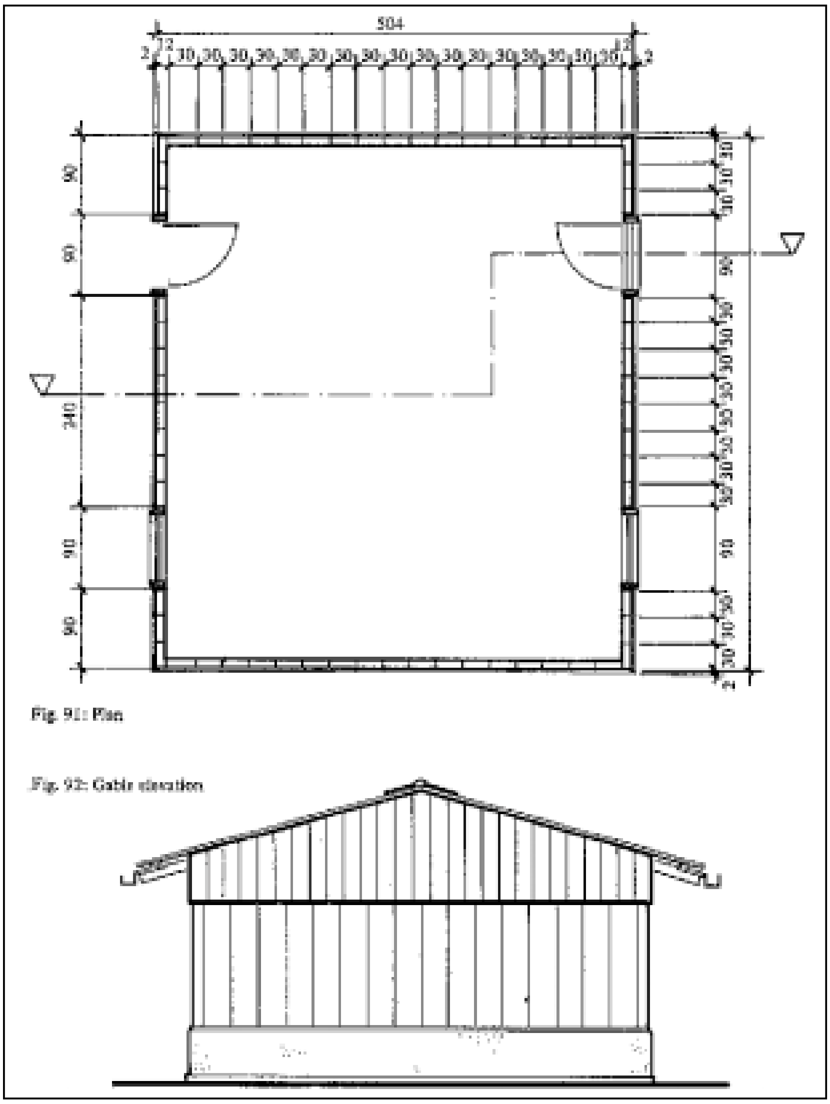


Fig. 91 and 92

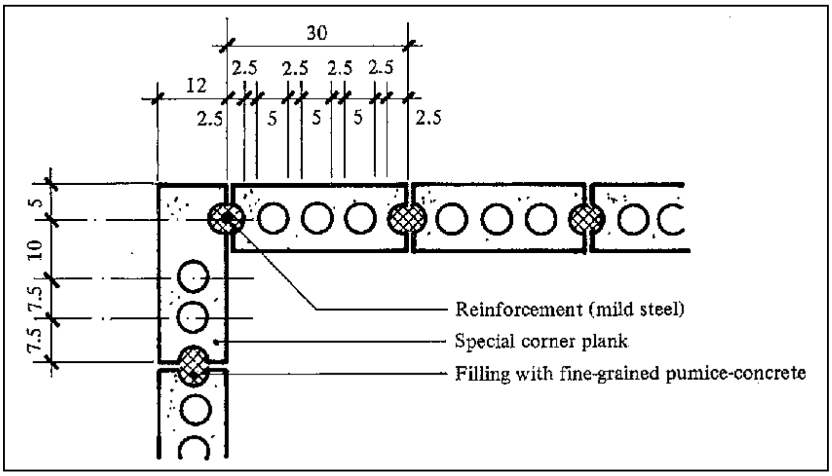


Fig. 93 and 94

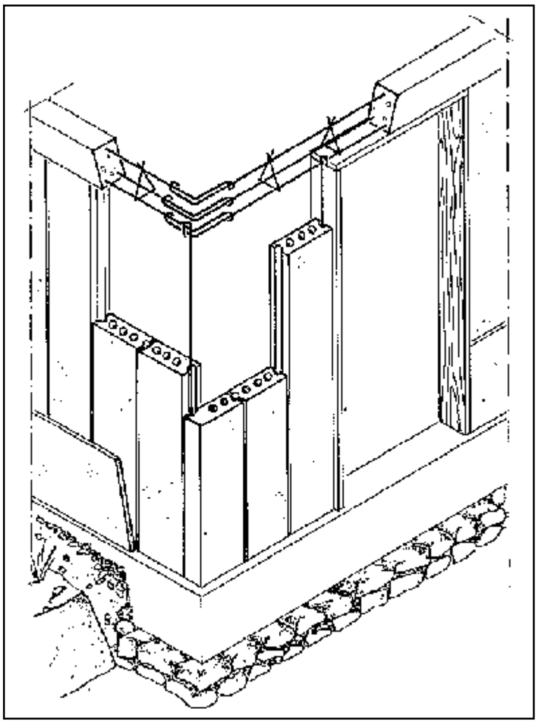


Fig. 95: Isometric view

5. Building with Unbonded Pumice

In many Third World countries, bonding agents like cement and lime are disproportionately expensive. In the late 1970s a mason in the Federal Republic of Germany had to work about 20 minutes to earn enough to pay for a bag of cement. At the same time, a mason in Guatemala, India or Bangladesh had to work three days to earm the "same" bag of cement. In terms of wages, cement was roughly seventy times as expensive there as it was in the Federal Republic of Germany.

That fact prompted the Research Laboratory for Experimental Building at Kassel Polytechnic College to investigate the question of how natural building materials like sand and gravel could be used for building houses without the necessity of using such binders. The use of fabric-packed bulk material was found to be the most cost-effcient approach. In that connection, various ways of producing and applying such materials had to be developed and tested. Pumice proved to be an exceptionally good bulk material for such applications, because it weighs less and has better thermal insulating properties than ordinary sand and gravel.

The first trials were conducted in 1976. Figure 96 shows a 2.20 m high column with a frustum-shaped shell made of PVC-coated polyester. Open at the top, the column is rendered stable by the bulk filler and its conical shape. The internal pressure generated by the filling stretches the jacket tight and keeps it from collapsing. The column's load-bearing capacity depends on the tensile strength of the jacket. The column shown in the photo is capable of accepting a load of more than 10 kN (1000 kg). As shown in Figure 97, a load-bearing arch can be made by filling an arch-shaped fabric tube with sand -the only trouble being that filling the tube is very time-consuming.

In 1977 a dome-shaped experimental structure made of fabric-packed bulk material was erected on the research laboratory's test grounds

The structure is 3.20 m high, has an outside diameter of 4 m and consists of 220 m of thin polyester hoses. The hoses are filled with the aid of a vacuum cleaner-driven bag filler of in-house de. sign (Fig. 98). A pair of vacuum cleaners draw the bulk material into an elevated funnel (up to 3 m high). The bags are attached to the bottom end of the funnel. When the vaccum cleaners are turned off, a gate at the bottom of the funnel opens automatically, letting the bulk material fall into the hose.

The empty hoses have a diameter of 20 cm; after filling, they take on a elliptical shape, i.e. about 11 cm high and 25 cm wide. The structure is erected by placing the hoses on top of each other in concentric rings of de. creasing radius. The dome-shaped structure has a cross section that roughly corresponds to the shape of an inverted catenary. The desired shape is obtained with the aid of a rotating vertical template mounted at the center of the structure.

The round opening at the top is reinforced with a supplementary steel-pipe compression ring and covered with a mushroom-shaped member that can be raised for venting. Filling the hoses takes about 7.5 man-days, and the erection work, including manufacture of the compression ring and cover, takes approximately 12 man-days.

Based on experience gathered during that project' the research laboratory designed and tested an earthquake-proof stacked-bag type of construction in Kassel in early 1978 (Fig. 100 and 101). The basic element consisted of 2.5 m long bags made of 0:5 m wide strips of burlap and filled with pumice gravel. The hose-like bags were knotted at the ends, bent double and stacked to yield 1.2 m wide wall members. Thin bamboo poles were pounded through the bags and fastened to a continuous tie beam (made of -slender pine poles) at the top to make the stack stable. Several coats of whitewash were applied to keep the fabric from rotting and the wall from soaking up precipitation. Subsequent trials showed that it is a good idea to immerse the bags in lime slurry prior to use.

In connection with a joint research project conducted by the Research Laboratory for Experimental

Buildings' the Francisco Marroquin University in Guatemala, and the Centro de Estudios Mesoamericano Sobre Tecnologia Apropiada (CEMAT), a 55 m_ house made of stacked bags filled with pumice sand was erected in Guatemala in 1978 (Fig. 102 -105). This type of construction draws on prior experience with the aforementioned stacked-bag type of construction and was modifed as necessary to satisfy local requirements in Guatemala.

The basic structural member for this system was a hose-like bag made of cotton fabric with a diameter of about 10 cm and a length of anywhere from 1.70 to 2.80 m. The bags were filled with pumice sand and gravel, then stacked and pressed together so that the originally round bags took on a rectangular cross section measuring roughly 8 x 10 cm with round edges. The bags were first dunked in whitewash and then stacked directly on a 0.1 m-wide and 0.8-1.0 m-high strip foundation/plinth made of natural stone masonry. Immersing the bags in whitewash prior to use ensures that the cotton fabric is saturated with lime as protection against rotting.

Vertical bamboo poles placed at intervals of 0.45 m on both sides of the bags and interconnected with wire loops gave the stacked bags the necessary stability. The bamboo rods were fixed to the foundation and to the horizontal tie beam at the top.

Additional stability was provided by thick, round or square timbers (6 -8 cm diameter) that were rammed 0.3-0.5 m into the ground at the end of each stack of bags (ca. 2.25 m). This wall-building system is flexible enough to accommodate the motion induced by an earthquake. The continuous tie beam at the top keeps individual wall members and the entire system from falling over. After the walls were finished, they were given two coats of whitewash inside and out to keep rain from soaking into the bags. Table salt and alum were added to the whitewash to improve the vapor diffusion capability of the finished coating and to protect it against the digestive attack of microorganisms (1 bag of lime to 4 kg table salt, 2 kg alum, and approx. 30 lifers water).

With reference to seismic stability, the purlin roof structure was separated from the wall structure. It Tests on six roundwood columns, with interconnection provided by wooden struts.

The building materials for the 55 m² house cost US $ 630.78, or US $ 11.46 per m².

It took 6 -8 workers about three weeks to build the house -meaning that labor only accounted for some 20 -25% of the total cost of construction.

Compared to a similar house built according to customary methods using cement-bonded cavity blocks, this house took about the same amount of time to build, but cut the cost of building materials by 48%.

A different earthquake-proof mode of construction for fabric-packed bulk materials was developed by the research laboratory in 1977 and tested on an experimental structure in Kassel (Fig. 106). This type of fabric-packed bulk-material wall comprises two rows of roundwood poles that are tilted toward each other and separated by two strips of fabric that are either sewn together at the bottom or nailed onto a lath and then filled with pumice gravel. The lateral pressure exerted by the bulk material is contained by driving the wooden poles into the ground and tying the top ends together. The 4 -8 cm-thick poles are 2.10 m long and spaced at 0.45 m intervals.

The walls are 0.45 m thick at the bottom and 0.20 m at the top. As protection against ground moisture and splashing water, the walls were built on a cat 0.3 m-high plinth. The fact that the vertical poles are fastened to a flexible round-wood or bamboo-pole tie beam at the top and inclined toward each other on all sides ensures adequate stability to cope with vertical and horizontal seismic ground motion.

As shown in Figure 107, such wall members can be prefabricated. Rolled together, the poles and fabric making up a 10 m long section of wall turn into a single roll measuring 2.5 m in length and 0.5 m in diameter. This "shell" is easy to handle and haul, e.g. in a pickup, can be erected in a short time by two people, and then just has to be filled with loose pumice and sand.