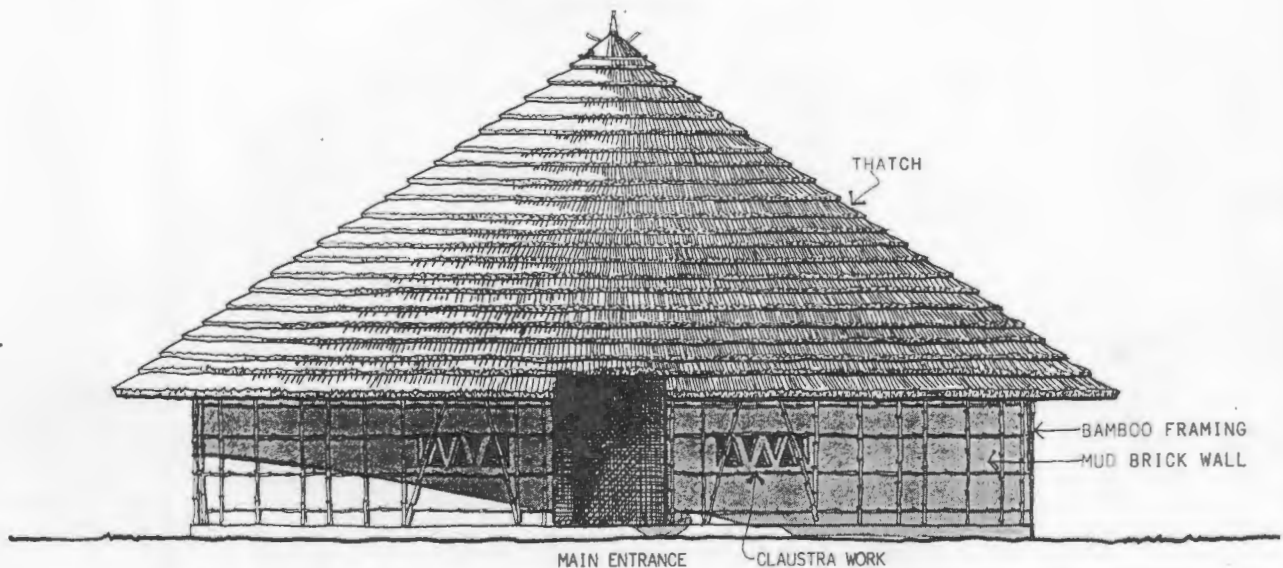


**The Introduction of
earthquake resistant building techniques
in Koumbia,
North West Guinea**

Final Report

**John Norton
Development Workshop**

September 1985



for

**the USAID Project of technical, financial and material assistance to
the Government of Guinea**

***The Introduction of
earthquake resistant building techniques
in Koumbia,
North West Guinea***

Final Report

***Text & Drawings: John Norton
Development Workshop, BP 13, 82100, Lauzerte, France***

for USAID Conakry, Guinea

***the USAID Project of technical, financial and material assistance to
the Government of Guinea;
Project No 675-1214.01***

**INTRODUCTION OF
EARTHQUAKE RESISTANT
BUILDING TECHNIQUES
IN THE KOUMBIA AREA,
N.W. GUINEA (1985)**

CHAP. 2

A QUOI SERT LA CONSTRUCTION PARASIMILIQUE ?

Dans la communauté, ce sont les bâtiments publics qui sont les plus importants. Par exemple:

- les écoles
- les cliniques
- les bureaux...

Peu de personnes seront atteints par l'effondrement d'une maison.

Beaucoup de personnes peuvent être blessées quand une école s'effondre.

A la suite d'un tremblement de terre, un bâtiment public pourra servir.....

- d'hôpital de secours
- de cantine

.... ce sont les bâtiments publics qui servent d'abri provisoire.

Quand les maisons se sont effondrées....

5

Development Workshop

This case-study is based on a USAID project of technical, financial and material assistance to the government of Guinea, for which the author was the chief consultant.

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1. BACKGROUND

1.1 THE EARTHQUAKE

An earthquake with a magnitude of 6.3 on the Richter scale took place on the 22nd December, 1983, in the area of Koumbia, north-west Guinea. There were a number of after-shocks continuing well into January, 1984, of which the largest had a magnitude of 4.5 and killed one person. The earthquake caused extensive damage in the administrative area of Gaoual, with its epicentre near Koumbia. The official figures put the damage at 276 dead, 1441 injured, 430 houses of durable construction damaged, and 4919 houses of local materials damaged, in addition to a large number of public facilities damaged.*

The Government of Guinea (GOG) ordered people not to occupy any buildings until advice had been given on how to make them safe, and in the immediate post-earthquake period tents were supplied from a number of sources.

1.2 IMMEDIATE RESPONSE

Immediate aid was provided by the United States Government in the form of fuel and food, and two seismologists and an engineer visited the area in early January to assess the damage and the likelihood of future quakes. Scott Johnson, the engineer from RHUDO Abidjan, proposed that the immediate shelter needs of the people should be met by using bamboo matting to make walls for small round thatched huts. This temporary shelter has been the main form of housing, for the following 18 months, pending the introduction of alternative and more durable building techniques.

1.3 THE USAID PROJECT

In addition to the immediate response, USAID Conakry and RHUDO Abidjan submitted a proposal to set up a project to help in the longer-term rehabilitation of the earthquake area, and requested \$90,000 from the AID Office of Foreign Disaster Relief in Washington. This was granted in early 1984.

* The discrepancy between the damage to durable construction and the high figure for damage to local materials buildings is largely accounted for by the fact that there were relatively few buildings of durable materials in the area. The survey showed that all building types were damaged, and that certain traditional building - Gabion construction, with mud on a bamboo lattice frame - actually withstood the earthquake relatively well.

The USAID project has concentrated on the problem of housing in the earthquake damaged area. Both numerically and in terms of the effect on the local population, the greatest difficulty will have been the reconstruction of houses, and of their ancillary buildings, such as animal shelters and grain stores. In the long term, domestic construction will certainly be the most important part of construction activity in the area. Even if a Government run house-building programme had been possible, the local population would have been left to build for themselves with the resources available to them after the initial period of post-disaster relief had finished.

The aim of the USAID programme has been to develop and introduce earthquake resistant building techniques, which as far as possible use locally available resources, and which can be adopted by the local population with the minimum of difficulty, both technical and financial. The programme has aimed both to meet the short-term needs for housing in the area, and to equip people with the ability to build in the future in a more earthquake resistant way than in the past. The significant feature of the programme has been to approach the problem of rehousing through training and demonstration, thus making maximum use of a small budget.

Often, the more conventional action following earthquakes has been to attempt to provide replacement homes for the people whose homes were either damaged or destroyed. The shortcomings of this approach are that it is expensive, it provides housing which - whilst being more earthquake resistant - frequently fails to meet the needs of the occupants, and most importantly it does not equip the population with the ability to build more safely. As a result in the long term people build extensions or new homes which are just as unsafe as the housing which they occupied before the earthquake.

The USAID programme also recognised that in the longer term resources for building will be limited unless one uses what is available locally and reliably in the region.

The first part of the programme assessed the vulnerability of the existing building techniques in the Koumbia area to earthquake damage, to see what damage had taken place and why. At the same time a list of locally and nationally available materials was drawn up.

The outline of the practical phase of the programme was then worked out in consultation with the GOG Ministry of Social Affairs, who have been responsible for coordinating all relief and reconstruction work. It was agreed that the introduction of improved earthquake resistant building

techniques should be done through working with the local builders in the Koumbia area, training them in the new techniques, and building a number of demonstration houses. These demonstration houses would use existing house forms of the area, but would incorporate earthquake resistant techniques. The houses would be distributed amongst the earthquake-damaged villages of the area, so that as many people as possible would come into contact with the new ideas. (Subsequently the houses were to be used as school-teachers' homes.)

Given existing housing preferences in the area, and the acknowledged trend toward rectangular housing - in durable materials when these can be afforded - three demonstration house types were chosen: a traditional round house using local materials; a rectangular house using local materials; and a rectangular house using reinforced concrete framing and fired brick walls; which is the form that most people favour, but which very few can afford at present. All three types were to be repeated in four centres.*

To complement the practical part of the programme in the Koumbia area, a Manual on earthquake resistant building design and construction in Guinea would be prepared, with the particular intention that official buildings could be constructed in the same manner as the domestic construction being done by the inhabitants of the Koumbia area, to avoid setting a dual standard.

1.4 TIMING OF THE PROJECT

The programme was run in two main periods. The first - the assessment of local conditions and resources - took place between the 1st and 24th June, 1984. There were delays in starting due to the change of Government in April 1984, and the dissolution of the GOG agency which had been handling post-earthquake operations, a rôle which then became the responsibility of the Ministry of Social Affairs.

The timing of the second part of the project - practical work in the Koumbia area - was determined by the need to have the active participation of the local population. No building work normally takes place in the rainy season, between May and October. Following the rainy season, almost everyone in the area is engaged in agriculture until the harvest, in mid- or late December. Locals would therefore not have been free to work on the training and building

* The four centres chosen were Woupirdé, Madina Guiledji, Kamélé and N'Djourieh.

programme before the beginning of January 1985. In addition, time was needed by the Guinean members of the project, (Projet de Reconstruction de Koumbia) , to repair some of the roads leading to the more remote villages and to gather local materials, such as thatching grass, bamboo, and bricks. In fact the logistics of getting materials, local currency, and food and shelter for the project team resulted in practical work starting only in early March, 1985. This period of technical assistance ended on 24th April.

The manual on earthquake resistant building design and construction was prepared following the period of technical assistance, and was completed in July, 1985.

1.5 TECHNICAL ASSISTANCE AND GUINEAN COUNTERPARTS

The detail of the programme was worked out by John Norton,* who provided the main technical assistance for the project. This included the assessment of vulnerability and resources of the first stage, working out the technical solutions to make the various types of building methods more earthquake resistant, producing plans and lists of materials and equipment required, setting up and running the first part of the builders' training and construction of prototypes, and laying out all the buildings.

Because of delays in starting work on site, the period of technical assistance was extended, and Peter Tunley was brought in by John Norton to oversee the work on the four building sites for the month of April, 1985.

John Norton designed and produced the manual.

The overall coordination of all construction activities in the Koumbia area was directed by Souleymane N'Diaye, a Guinean engineer seconded to the Ministry of Social Affairs for the programme. He assured continuity in between periods of technical assistance, and arranged for all transport, the purchase of materials, the hiring of labour, and the provision of lodging and food for the project team in Koumbia. N'Diaye was supported by a very small team of Guineans who looked after the control and security of materials.

All the skilled and unskilled labour for the project was hired locally from the villages of the Koumbia area.

* John Norton, architect, Development Workshop, Toronto, Canada, consultant to USAID.

2. ACHIEVEMENT OF THE PROGRAMME

2.1 BUILDING WITH LOCAL MATERIALS

By the end of the period of technical assistance on the 24th April 1985, the main aims of the project had been achieved.

(i) Round house: Two demonstration round houses, at Woupirdé and Madina Guiledji, displayed all the techniques for making the buildings more earthquake resistant and safer, notably the use of bamboo framing on each side of the mud block walls to restrain them in the event of movement. The round houses at Kamélé and N'Djourieh had both been started.

(ii) Rectangular house: The rectangular house at Woupirdé was in the process of being roofed and had all the bamboo framing in place. Enough progress had been made to show all the framing details, particularly where they differed from the details of the round house, at the external corners. At both Kamélé and N'Djourieh the rectangular houses had been begun.

2.2 BUILDING WITH DURABLE MATERIALS

There were many difficulties in getting the materials for this house type up to Koumbia, and the start of work was badly delayed. Enough progress was made, however, to show the correct preparation of the reinforcement, and particularly the reinforcement of the ring beam, and thus to correct some of the errors previously made in this type of construction.

By the end of the period of technical assistance, at Woupirdé all the reinforcement had been prepared and the foundation trenches finished, ready for the concrete to be poured; at Madina Guiledji the foundation concrete had been poured; at N'Djourieh the brick walls had been started - which in turn fixed the positions of the doorways and columns - and the reinforcement for the ring beam was ready; and at Kamélé all the reinforcement was ready on site and the foundation trenches were ready for the concrete.

Unlike the buildings of local materials which need to be roofed before the rains begin, this house type can continue to be built after the rains have started. N'Diaye, the Guinean engineer in charge of the programme, is now able to supervise and complete the work to the earthquake resistant specifications.

2.3 NUMBER OF PARTICIPANTS

The people from Koumbia, Woupirdé, Madina Guiledji, and those living south of Madina Guiledji going up to Koumbia had all had the opportunity to see the



COMPLETED DEMONSTRATION ROUND HOUSE AT WOUPIRDE

DEMONSTRATION RECTANGULAR HOUSE (LOCAL MATERIALS) READY FOR ROOFING.



3. ACCEPTABILITY

3.1 LOCAL SHORT-TERM RESPONSE

One of the most important achievements of the programme has been to restore confidence in the use of local materials and to show that there are ways of building safely with them. This is particularly important because, although confidence in traditional building methods was weak in the immediate post-earthquake period, as the impact of the disaster and the memory of it fades, people will inevitably revert to traditional building methods. Without a demonstration of how to build safely, these would repeat the weaknesses of the past.

This has been achieved by working within the context of the local building tradition, correcting and altering those techniques and elements which made the buildings unsafe during the earthquake, and confirming the techniques which need no change. The people had correctly observed that the wood and bamboo-framed buildings with mud plastered onto the outside surface of the frame had withstood the earthquake well. The shortcoming of this building system, however, is that termites destroy the frame without the damage being apparent. The project has sought to overcome this by showing how the frame can be placed on the outside of the wall, thus allowing damaged frames to be both seen and replaced. Buildings with walls built of mud bricks have a cleaner and neater finish which is regarded favourably, and the project has also shown how to give this type of construction a greater degree of rigidity.

The local reaction to the demonstration houses using local materials was positive. At Madina Guiledji, where the walls were finished off with mud plaster before the bamboo framing was put into place, they were most acceptable to the villagers and attracted much positive comment, notably that the buildings looked strong and attractive.

In the case of construction using durable materials the project has aimed to correct a number of faults which were common building practice in the area. However, it must be recognized that - whilst it is much favoured - the greatest problem will remain the difficulty in getting sufficient and correct materials for this type of construction. As a result construction work will often be skimpy and of poor quality, although the training to remedy this was well received.

3.2 FACTORS AFFECTING LONG-TERM ACCEPTABILITY

The degree to which the new ideas will be adopted in the long-term will depend on many factors, including cost, availability of materials, skill

available, and resistance to change. For example, materials which are regarded as local are not necessarily available close by every village: in some cases bamboos have to be brought some distance by vehicle; water and soil suitable for making mud bricks are not always adjacent to where people want to build. This means that there are variations in what can realistically be expected.

The acceptability of the programme is above all susceptible to what people's expectations are. The project has demonstrated ideas which meet different needs taking account of what people can afford or obtain in the context of building their own homes. Immediately following the earthquake, however, the people in the Koumbia area were given to understand that GOG and aid agencies were going to build new homes for everyone. This belief - at least after the change in government in April 1984 - was groundless, but it resulted in people being less concerned in getting advice on how they themselves are to build their own homes safely. It is an example of how important it is not to raise people's expectations where there is little or no hope of fulfilling them.

4. HOUSE FORM AND CONSTRUCTION BEFORE THE EARTHQUAKE

4.1 THE EXTENDED FAMILY CLUSTER

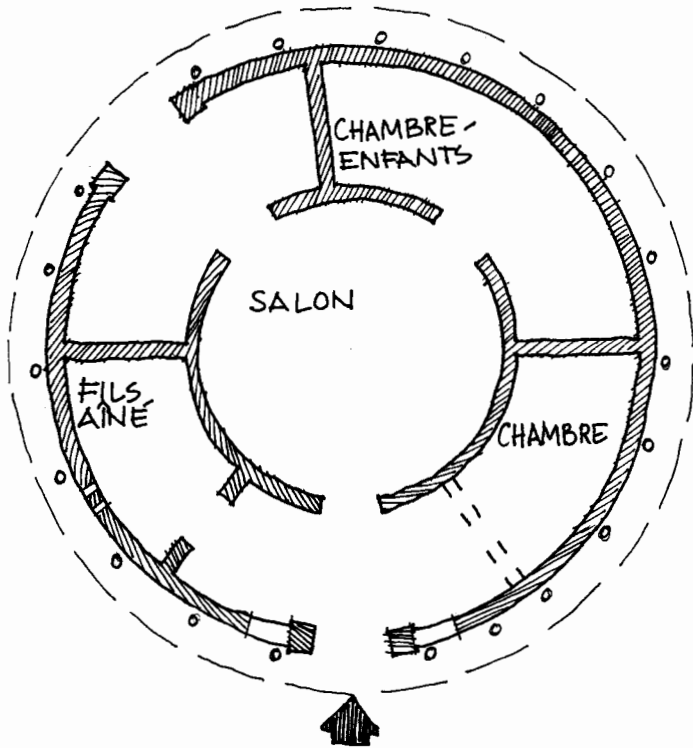
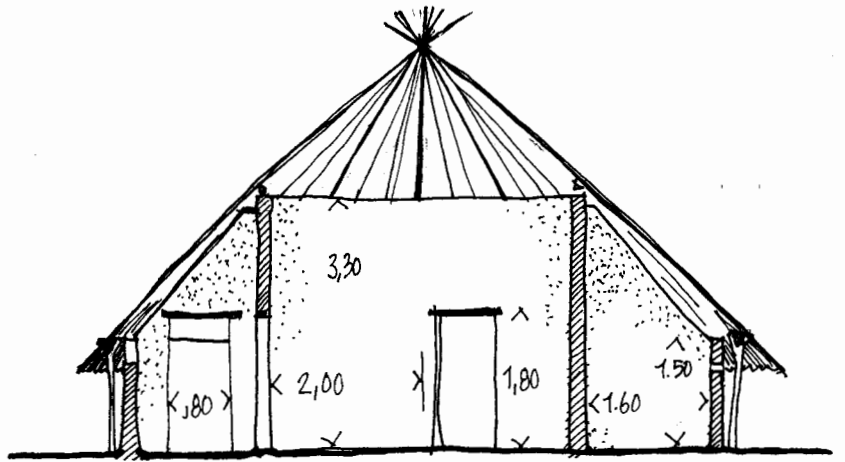
Before the earthquake there were two main forms of housing in the area. The traditional round house or 'case', which in the case of the extended family cluster included both large and small houses, and the rectangular house, which was more common in Koumbia than in the outlying villages, but which in most cases was still one of a cluster of dwellings making up the family compound. The round houses with a few exceptions were built with mud, wood, bamboo and thatch, whilst the majority of rectangular houses were built with fired bricks and corrugated roof sheeting, and in some cases with reinforced concrete columns.

The extended family cluster was and remains an important influence on the size and type of housing required in the Koumbia area. Because of its evolutionary nature it affects to some extent the choice of materials used for a house. A family lives in a compound, enclosed by a fence, within which are a cluster of buildings. The process may begin with the construction of a large 'case', provided the owner can afford it, which contains several rooms. This 'case' is occupied by the male head of the family, his wife and probably several children. (Fig.1) An evolution of this as the family grows is the construction of a second large 'case' for the first wife and her children. The husband remains on his own in the original 'case', and some of the space is used for storage. (Fig.2) When the husband takes a second wife, she too will have her own 'case', where she will live with her children. This means that at this stage there will be three dwellings in the compound in a loose cluster. (Fig.3) The process continues with each additional wife.

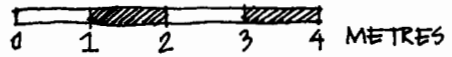
Land is divided equally between wives, regardless of the number of children each one may have. Inheritance, however, is through the sons. Daughters remain with their mothers until they get married and go to live in their husband's home. Young men remain in their mother's 'case' until they are aged 17 or 18, at which point they move out and build a small, one-roomed house relatively close to their mother's. (Fig.4) The son goes on living in this house when he gets married and has a child. If there is a second child, the first may be moved over to live in its grandmother's house. This process continues until the son is rich enough to afford his own large 'case', perhaps on a new plot of land, and the cycle begins again. Small one-roomed houses which were previously occupied by a son are then sometimes used as

FIG. 5.

COUPE
SECTION



PLAN: 'CASE' À MADINA GULEDJI



ELEVATION

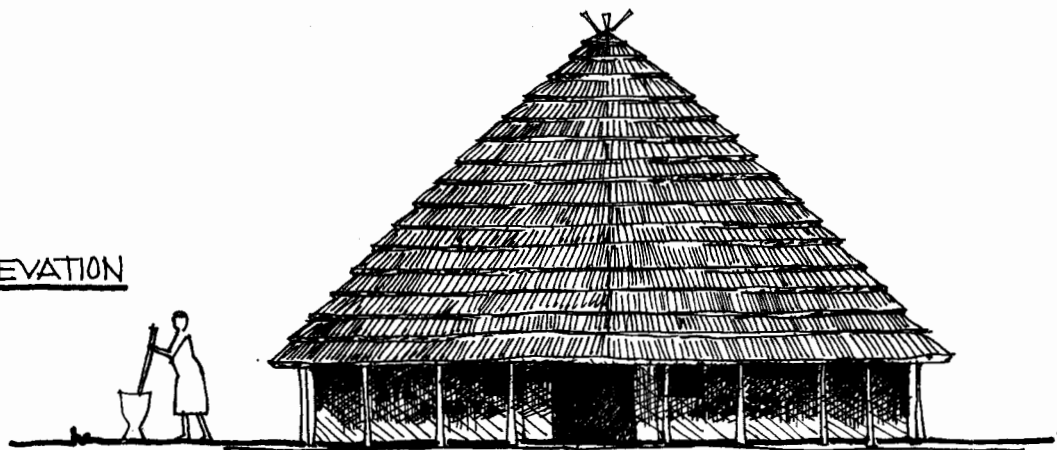




FIG.6. TRADITIONAL WALL WITH WOOD AND BAMBOO FRAME
COVERED BY MUD PLASTER

FIG.7. ROOF FRAME READY FOR THATCHING ON TEMPORARY HOUSE
NEAR KAMELE





SINGLE ROOM ROUND HOUSE, TYPICAL OF "SON'S" HOUSE



LARGE FAMILY "CASE" - NOTE CLAUSTRA OPENINGS IN WALLS

to be 45 years old. The main problem with this system is that termites eat the organic material in the framework, making the building potentially unsafe. More commonly in recent construction the walls were built with mud blocks about 16 to 20 centimetres wide. Although these walls did support some of the weight of the roof, in many instances the roof was supported by wooden forked posts placed just outside the outer circle wall. The survey showed, however, that quite a lot of people had dispensed altogether with the forked posts and were now placing the roof framework directly onto the mud block walls.

The roof structure was entirely of bamboo, circular in shape with bamboo poles radiating down from the top of the cone. On average, there was one pole every 10 centimetres at the perimeter. (Fig.7) The bamboos were held together by rings of split bamboo attached to the inside and to the outside of the main bamboos, one ring every 35 centimetres up the slope of the roof. The whole framework was tied together with bark strips. This framework was assembled up-side-down on the ground and then lifted into place over the building. Thatching grass in bundles was attached over the framework with a bamboo batten to hold it down. The thatch was normally laid with a 40 centimetre gap between each ring of grass. The grass bundles were usually about 1 metre long. A cheaper, but less durable system was to lay the grass loose on the roof and to hold it down with battens. Because the grass was not bunched and laid tightly this gave a poorer final result.

Roofs on larger houses projected out from the perimeter wall by about 50 centimetres.

On average a roof can last up to 8 or more years if it has been well done, and notably if the thatch has been tightly packed, but termites and penetrating rainwater can reduce the life of a roof enormously. People in the Koumbia area said that they sometimes used caustic soda and lime to try and combat termite attack, but the resulting improvement would in fact be limited.

The floor of the traditional round house was made with animal dung and mud, heavily compacted, which gave a good and tidy finish. Some of the walls had a whitewash coating over the mud-plaster finish, but the main protection of the walls from rain was provided by the large overhang of the roof. Openings were either in the form of brick lattices in the perimeter wall, or very small rectangles. There were no window openings in the inner room, enough light coming through the doors.

4.3 THE RECTANGULAR HOUSE

(i) Form: The form of the rectangular house was less consistent than that of the round house. The plan form varied widely in the Koumbia area, but

the most common appeared to be a central hall with openings to the outside at either end, and rooms along both sides. Fig.8 shows an example of this. The use of the rooms was the same as for a round house: general use in the central hall, and children and storage areas in the side rooms.

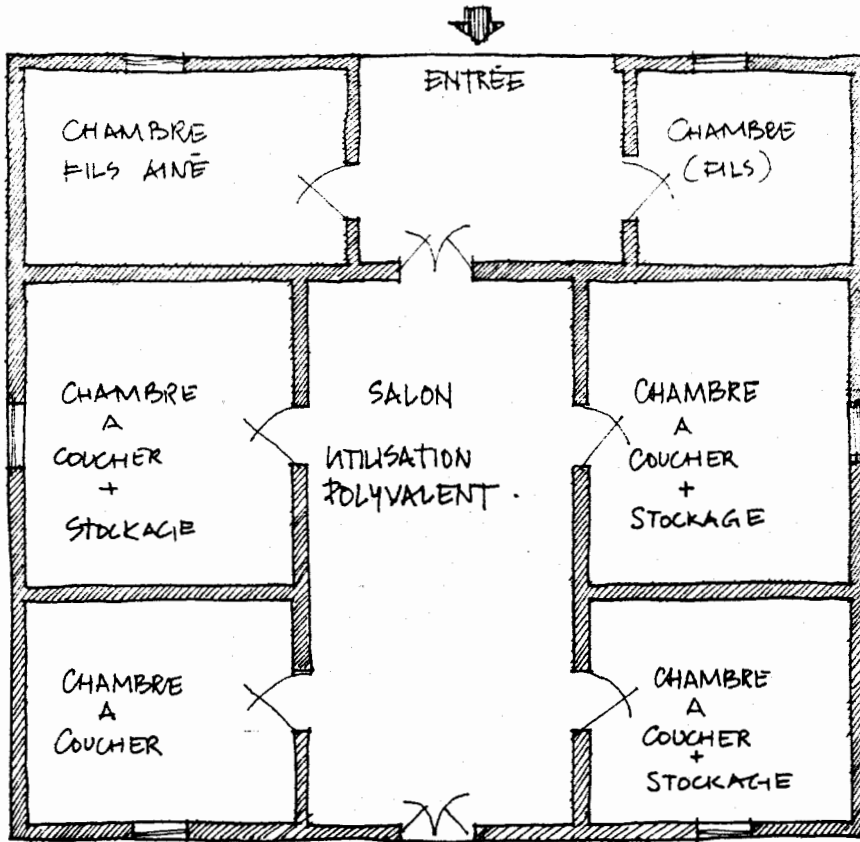
(ii) Construction: There were some examples of rectangular houses built with local materials: mud walls, forked posts supporting the perimeter of the roof, and a substantial roof framework made of wood, (not bamboo), with bamboo battens laid over it. The roofs were either hipped (Fig.9) or actually round, almost as on a round house, but with the eaves trimmed to fit the different house plan. Where local materials were used, the roof covering was thatch. A number of people said that this house shape was more practical than the round house.

Especially in Koumbia itself, there were rectangular houses built with concrete floors and footings, reinforced concrete columns, and walls built with locally produced fired bricks, or - less commonly because of the expense - cement blocks. Before the earthquake nobody used ring beams at the top of the walls. Openings had lintels of reinforced concrete or more commonly of wood, and in all cases the lintel was much too short. The roof framework was made of sawn timber, and covered with corrugated iron sheeting of various sizes and quality depending on where it had been obtained.

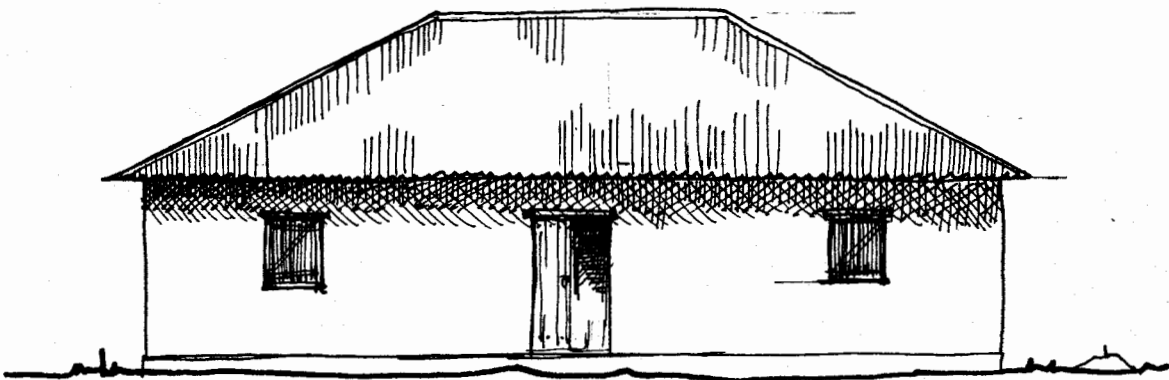
The walls of these houses were very thin, at most 16 centimetres thick, when the bricks were laid with the widest side down, but very often even thinner, when the bricks were laid on edge, giving a thickness of 10 to 12 centimetres only. The difficulty that people experienced with this type of construction was evident in the extremely poor quality of work, often due to the inability to get sufficient correct materials. Thus there were a large number of examples of the wall having been built, but no columns having been poured, either because the builder could not get cement, and/or because he could not get reinforcing bars. This left walls which were not connected at all at corners and at junctions.

4.4 THE CONSTRUCTION PROCESS

For all types of house construction the house owner was responsible for providing materials. He then had the choice of doing the building work himself with the help of family and friends, or he could contract the work out to a specialist wall- or roof-builder. He could also contribute his own labour, and work in this way with a mason or carpenter, in order to reduce the cost. More commonly a mason would be contracted to build all the walls, the floor,



PLAN.



ELEVATION

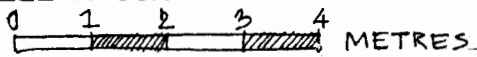
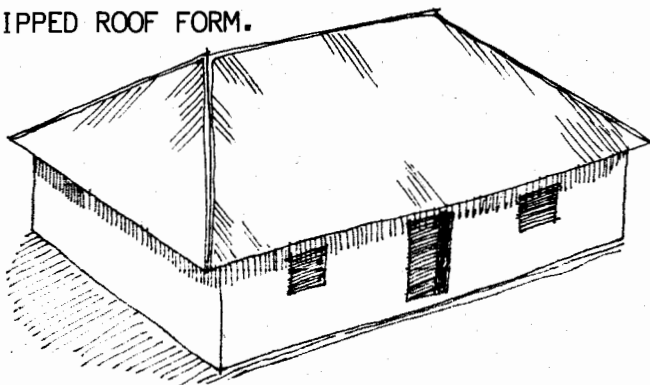


FIG.8 HOUSE BUILT WITH DURABLE MATERIALS AT KOUMBIA.

FIG.9. HIPPED ROOF FORM.



and to do the plastering. He would bring his own apprentices and labour. The house-owner was expected to provide two meals a day for the whole team. On average it took 10 days to do all the masonry work on a traditional round house. A carpenter would then do all the roof, as well as putting in the forked roof support posts, and again he would bring in his own team. To do the carpentry work on a traditional round house took about 5 days.

A similar division of work existed for houses built with durable materials such as corrugated roof sheeting and fired bricks, but in this case the owner had to hire an additional team to dig the foundations. A five-room house took 10 to 15 days for the masonry etc., and 7 days for the carpentry. Work could be paid by the day, but more often a contract would be made and payment would be on completion of the job.

People worked a 6-day week, normally from 7 a.m. to 4 p.m., but this tended to vary.

5. DAMAGE TO HOUSING CAUSED BY THE EARTHQUAKE

5.1 CONSTRUCTION WITH LOCAL MATERIALS

(i) The traditional round house: In traditional round houses, constructed from mud, bamboo, timber, and thatch, most injury and loss of life occurred because of the collapse of mud block walls. Rescue operations were made more difficult by roofs that had also collapsed. Although almost all the buildings in the earthquake area were damaged, a good number in fact remained standing. The thinness of the mud-block walls was blamed for the failure in most traditional round houses, but in fact the most common cause of failure was the collapse of lintels over openings in the circular wall of the inner room. This resulted from the lintel being too short and not projecting far enough into the wall on either side of the opening. The concentration of stress at openings and the general shaking during an earthquake lead to the collapse of the lintel and the subsequent collapse of the wall above it. This had several effects: the continuity of the circular inner wall was removed, leaving tall, thin, unstable segments of wall which could easily fall (Fig.10); the collapse of the lintel allowed the roof structure to sag at that point, (Fig 11) thus applying an outward thrust on the remaining wall on either side of the opening, and on the lower perimeter wall, both of which were pushed over by this thrust. Supporting forked posts were also pushed over by this effect.

Additional failure occurred through the complete absence of bonding between walls, such as between the inner and outer circle walls and the partition walls which linked them and which divided the outer circle into rooms.

Nearly all perimeter walls fell outwards. Collapse of walls also occurred as a direct result of the shaking and flexing movement caused by the earthquake. Crack lines showed two clear forces: diagonal cracking caused by stress, particularly near openings and wall junctions; and horizontal cracking and the horizontal displacement of bricks.

Some of the older buildings with walls built using an internal wood and bamboo lattice frame, with a thick mud coating on both sides, remained standing, although damage and collapse occurred when the roof exerted more thrust than the wall could resist, and also where the framework was rotten. The mud coating on this type of wall fell off in many cases, leaving the framework exposed.

Newly erected roof frameworks are structurally rigid, and rest principally on their perimeter supports. With age, however, the framework tends to sag



FIG.10. TALL SEGMENT OF WALL REMAINING ON ROUND HOUSE INNER WALL, AFTER COLLAPSE OF LINTEL AND MOST OF INNER WALL.

FIG.11. COLLAPSED ROOF, KOUMBIA. RELIEF TENTS IN BACKGROUND



as a result of termite attacks to the binding and the horizontal rings which hold the roof together. During the earthquake, the degree to which roofs exerted downward and outward pressure depended to a large extent on their age and condition.

In general, the round form of the traditional building is a good shape for earthquake resistant building. Stress normally concentrates at corners and junctions, where two walls may move against each other. The continuity of the round wall lessens the places where such conflict can occur.

(ii) The traditional rectangular house: In Koumbia, a few examples of rectangular houses with mud block walls were noted, and in all cases they had collapsed completely, leaving the roof framework resting on rubble on the ground. (Fig.12) In Kamélé, one building of this type was found only partially destroyed, but all its corners had collapsed. (Fig.13)

(iii) Ancillary buildings: Buildings such as animal shelters and stores, which were usually supported on wooden posts, suffered damage as a result of loosening soil and especially where the structure was top-heavy the result was that the building leant over or collapsed.

5.2 CONSTRUCTION WITH 'DURABLE' MATERIALS

In Guinea, the term 'construction en dur' refers to building with cement blocks, usually with reinforced concrete columns, and with a corrugated roof covering. Fired bricks are regarded as being less durable, but are far more commonly used because of the difficulty in getting the ingredients for cement blocks, and should therefore be included in this category.

Buildings of this type were mainly rectangular and mostly found in Koumbia town itself. There were very few examples of round houses using durable materials.

Almost every building of durable materials was damaged in the earthquake. Most remained standing, but the damage was invariably beyond realistic repair. People have plastered over the cracks, but the structures have been weakened.

Despite the popular faith in the value of durable materials, the quality of workmanship and of the materials used was extremely poor, with the result that many buildings were much weaker than they should have been, particularly taking account of their cost. A general observation can be made, that traditional construction in the area is of good quality, whilst modern durable construction is bad. Despite the widespread desire to have a building using reinforced concrete and blocks or bricks for walls, the necessary building



FIG. 12. RECTANGULAR HOUSE ROOF FRAME RESTING ON RUBBLE OF COLLAPSED WALLS. KOUMBIA

FIG. 13. COLLAPSED CORNERS ON SMALL RECTANGULAR HOUSE.



skill has not been available, and this has significantly increased the vulnerability of this type of building.

Three main causes of failure were observed: collapse of walls; failure of reinforced concrete; and collapse of lintels. In addition, serious cracking occurred. Some roofs collapsed following the collapse of their supporting structure.

The major failure was the collapse of walls, which were too thin in relation to their length, and not rigid enough. There was an extremely bad practice of laying fired bricks on edge, which meant that they could not withstand the slightest movement.

The concrete on some reinforced beams shattered and left the bars exposed and unable to carry the structure they supported. Similar failure occurred in columns. Poor technique contributed to this. The concrete in columns was usually poured in several stages, so that there were joints at intervals up the column. Local builders said that this was done because the wood for shuttering was too short, so they poured the lower part, waited for it to dry, and then moved the shuttering up for the next stage. This happened in nearly all private construction. Concrete was also never vibrated when being poured, leaving gaps and holes and bars often exposed, well before any earthquake damage. Bars were placed irregularly, and often too close to the outside. In many cases the lack of reinforcing bar meant that the wall was built with a gap, where a column was to be added later, which in the event would have served little purpose. (Fig.14) Similarly, there were columns where the bars were in place, but no concrete was available to complete them. No ring beams were used: had there been ring beams, the effect of collapsing lintels and the frequency of collapsed walls would have been lessened, and the roof would have been better supported. Local builders said they had never thought a ring beam necessary.

In many buildings, the lintels had fallen out, mainly because they were too short, with only 10 to 15 centimetres projecting into the wall on either side of the opening. Openings were also placed too close together, creating conditions for a concentration of stress during the earthquake.

The conflict of movement between two walls at corners caused considerable cracking. In some cases the corners collapsed. In nearly all cases the wall became separated from the corner column, often with cracking taking place through the bricks. (Fig.15) Both concrete blocks and fired bricks were of very poor quality. The concrete blocks had too little cement and could be crumbled by hand, and the fired bricks were sandy and were frequently cracked even

FIG. 14.

FIRE BRICK WALLS WITH NO BOND AT THE CORNER, AND WITH NO REALISTIC PROVISION FOR PUTTING IN CORNER COLUMN AND REINFORCEMENT.

NOTE DIAGONAL CRACK FROM TOP LEFT TO LOWER RIGHT.



FIG. 15.

CRACKING THROUGH BRICKWORK CLOSE TO A REINFORCED COLUMN AT A CORNER.

BRICKS WEAKER THAN MORTAR.



before the earthquake, because of the way they were made. Bricks in the area are slop-moulded, which means that the mud is used wetter than for a sand-moulded brick, and the result is that there is more shrinking and cracking during the drying period. By contrast to the poor quality of blocks and bricks, the mortars were strong, using more cement than necessary in comparison to the masonry they were binding. Cracks occurred more often through a brick than through the joint between two bricks.

6. CHOICE OF BUILDING MATERIALS AND HOUSE FORMS

6.1 OVERVIEW

The nature of the earthquake resistant building techniques which could be introduced into the Koumbia area had to be made in the context of the materials available, the housing preferences of the local people and what they could afford, and thus the degree to which a new skill or technique might realistically be adopted. Techniques which might be desirable from the point of view of earthquake resistant design might not be realistic in the Koumbia context. There was no point in trying to introduce changes that the people would not be able to afford, nor in trying to persuade people to implement changes which were obviously unrealistic. For example, it would be desirable for people to build houses with lightweight roofs, in order to reduce to risk of injury in the event of collapse, but it has to be acknowledged that most people in the Koumbia area will for the foreseeable future continue to cover their houses with thatch, which is not only heavy, but also a fire risk. The choice of materials had therefore to be pragmatic.

The intention of the programme was, moreover, not to impose earthquake resistant building methods, but rather to introduce techniques and principles which could be adapted by the local builders and assimilated as much as possible into the existing building tradition. In the event, ideas for making buildings which use local materials more earthquake resistant continued to evolve during the practical phase of the programme, and underwent several changes as the local builders began to understand the underlying principles and to see how they could apply them using their own knowledge of how best to use familiar materials. This process of allowing techniques to evolve with local builders greatly increases the likelihood that they will be adopted by the local population.

6.2 MATERIALS AVAILABLE

Materials which can be used for building can be divided into three categories: materials which are produced, grown or extracted locally; materials which come from elsewhere in the country; and materials which are imported. The latter two categories are available only sporadically in Koumbia, and more often have to be brought in specially, but they vary in the degree to which they are hard to obtain.

- (i) Local materials: Locally available materials include the following:-
- bamboo, on the roadside or in the bush; sold in bundles of 10, each pole about 6 metres long;

- mud bricks, made on the edge of streams in the area; average size 10 centimetres high, 30 centimetres long, and between 14 and 19 centimetres wide;
- fired bricks, fired in local kilns; average size 10 centimetres high, 24 centimetres long, and 14 centimetres wide;
- thatching grass, delivered in cut bundles, available in the dry season;
- bamboo matting, sold on the roadside;
- bark strips, for binding roofs, collected in the bush in the area;
- timber poles, of various sizes and not often very straight;
- sand;
- laterite boulders;
- gravel, not very accessible, the main problem being transport;
- rock, from the cliffs which run north-south through the region, immediately to the west of Koumbia.

In addition, the carpenters in Koumbia produce wooden doors and windows, using wood that comes mostly from elsewhere in Guinea. There are several blacksmiths who produce simple metal tools, mostly for agriculture and wood cutting.

(ii) Materials from elsewhere in Guinea:

- cement and corrugated roof sheeting are produced at factories in Conakry, but production does not nearly meet national demand, and it is unusual for either product to reach Koumbia;
- sawn timber of good quality is produced in the rain forests, but transport to Koumbia is difficult;
- fired bricks are produced in Gaoual, in addition to fired bricks being available from time to time in the Koumbia area.

(iii) Imported materials: Most of the key materials for 'durable' construction are imported:

- cement;
- reinforcing bar;
- corrugated roof sheeting;
- nails, screws, wire, tools, etc.

In Conakry, many of these and other imported materials are relatively easy to obtain, although the price varies according to availability and demand. In addition, the Bauxite Company of Guinea (CBG) brings in a large quantity of materials for its own use, a lot of which finds its way onto the open market. The road connection between Kamsar, the CBG port, and Koumbia is good, and so in Koumbia this is an important source of imported material. In both Conakry and Kamsar, the more sought after materials - cement, reinforcing bar, and corrugated roof sheeting - are all harder to get than items such as nails and wire, primarily because these are easier to transport.

Although money to buy materials is a problem, at the moment the over-riding difficulty is transporting them from where they are available to where they are needed.

6.3 HOUSING PREFERENCES AND TRENDS

From discussion with people in Koumbia, it would appear that most people would eventually like to live in a house built with 'durable' materials. There is, however, a very large gap between the local realistic potential of people to purchase and build with 'durable' materials and their stated desire to do so.

Moreover, some people stated that everyone would like to live in a rectangular house, but there was much evidence to suggest that people are happy with the traditional round house form.

The almost complete devastation of housing in the area has created an unusual situation, where practically every family is having to build new homes, and where the normal constraint of having a perfectly serviceable house does not apply. It is in this sense an opportunity to change to new forms and techniques, within the limitations of each family's ability to afford changes. On the other hand, the pressure on people to be rehoused in a satisfactory manner is accompanied by far greater expenditure on housing than would normally be the case, which stretches the capacity of a family to build with the materials they would prefer to use.

Reconstruction activity in the area being carried out by the Government and by external aid agencies will also influence building style and practice, it is to be hoped in most instances for the better, but it is important that people should not be discouraged from using house forms with which they are happy, provided they can be made safer in the event of an earthquake.

The choice of house forms and materials to be worked with during the USAID project was influenced by the reality of apparent housing trends in the area. Two points emerged clearly. Firstly, the majority of people in the Koumbia area will continue - through lack of choice - to live in buildings constructed with the cheapest locally available materials. It was therefore very important that the project tried to meet the needs of these people. Of those using local materials, it seemed probable that the larger number would build in the traditional round house form, whilst some would move to a rectangular form, which introduces new structural problems. Secondly, there is a recognisable - albeit not very large - trend towards 'durable' construction, for which the quality of both materials and skill are extremely poor. This has resulted in housing which is both dangerous and a waste of money. Since people will,

however, continue to try to build in 'durable' materials, it was important to ensure that those who can afford to should at least be able to do so correctly.

6.4 HOUSE FORMS SELECTED

Technical solutions to earthquake vulnerability have been developed in the context of three different housing types, which reflect the sort of problems people are going to face in building their own homes, and which as far as possible will allow the family or builder to develop a house which suits both needs and ability. The project has avoided creating inflexible demonstration layouts which people should adhere to.

The three demonstration house types selected are as follows:-

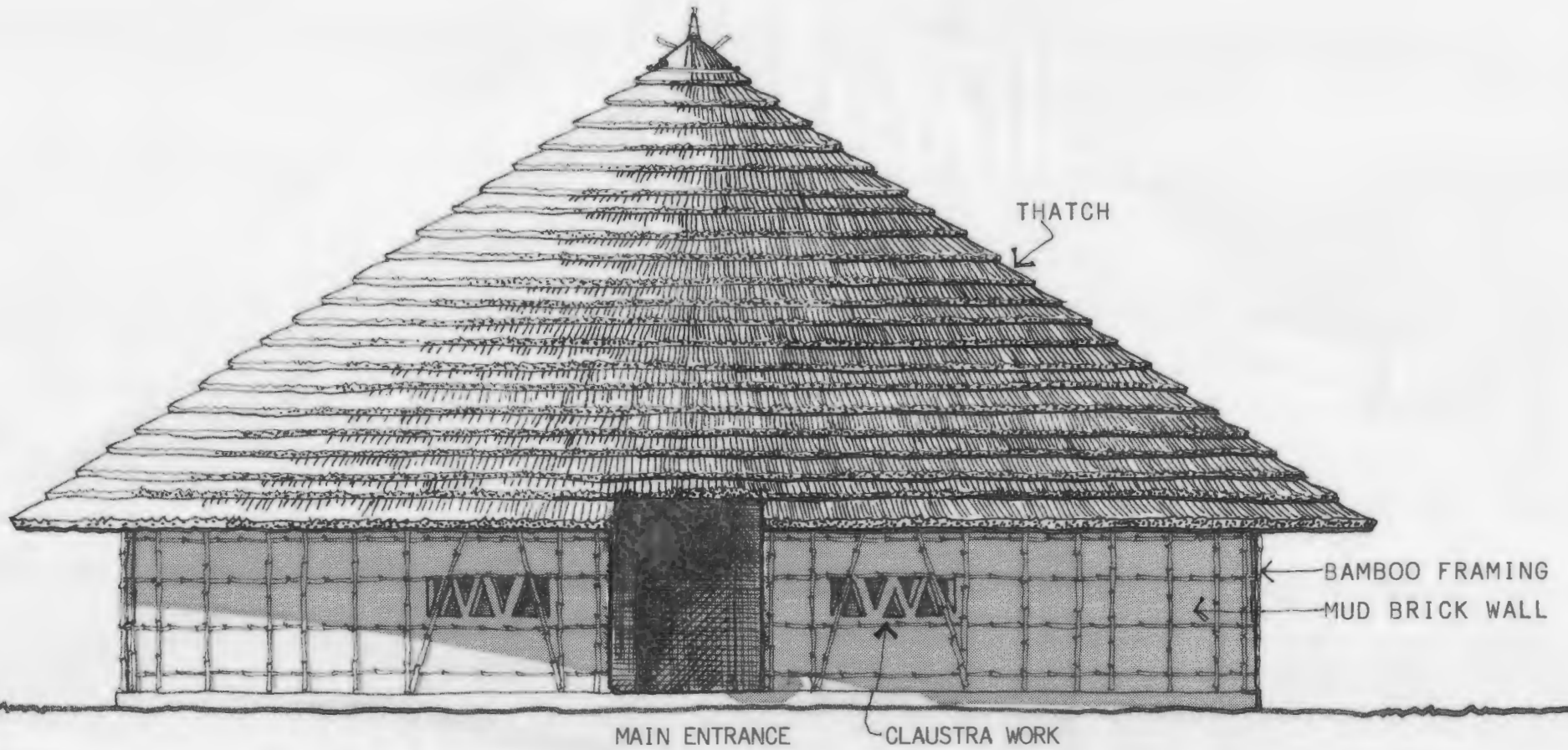
(i) A round house based on the traditional round house layouts in the Koumbia area, and built using mainly local materials. The central room is 4 metres in diameter, and the outer ring 2 metres wide. The outer ring is divided into rooms (Fig.16): an entrance hall, and a rear hall, both connected to the inner room; two rooms opening each into one of the two halls (to be occupied by elder children with freedom to come and go as they wish); and a third room, which is accessible only through the inner room (to be occupied by young children). The overall built area is 61.5 square metres.

Compared with a rectangular house using the same local materials except for the roof structure, the round house works out cheaper to build per square metre. As a house form it also allows more flexibility in its layout within the constraints of earthquake resistant design, particularly because it is easier to keep a relatively balanced and symmetrical plan with the round house form.

(ii) A rectangular house built with local materials. There are four rooms (Fig.17) all of the same size. One room opens directly to the outside. (In an earlier plan, this room also had a door connecting through to the rest of the house, but during the programme the builders requested that this door should be eliminated, to provide a room for a son. (See Section 4.1 'The Extended Family Cluster') Another room opens to the outside and also provides access to the other two rooms. The overall built area is 52 square metres. The plan is intentionally simple, concentrating on symmetry and the correct placing of openings.

(iii) A rectangular house built with 'durable' materials: reinforced concrete, fired bricks, corrugated roof sheeting etc. The plan is the same as for the rectangular house built with local materials. (Fig.18)

FIG. 16B.
DEMONSTRATION ROUND HOUSE ELEVATION.
SCALE: 1:50



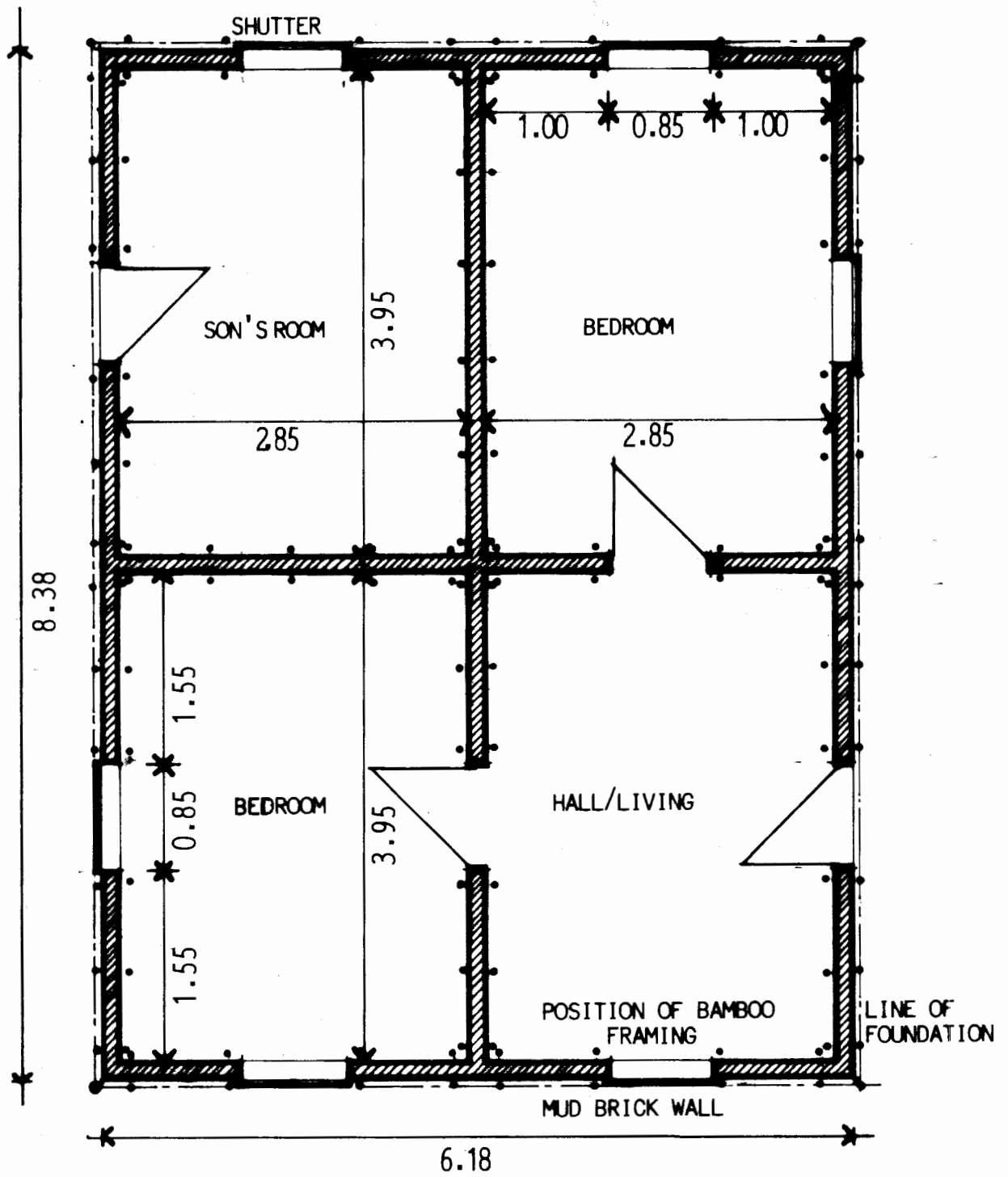
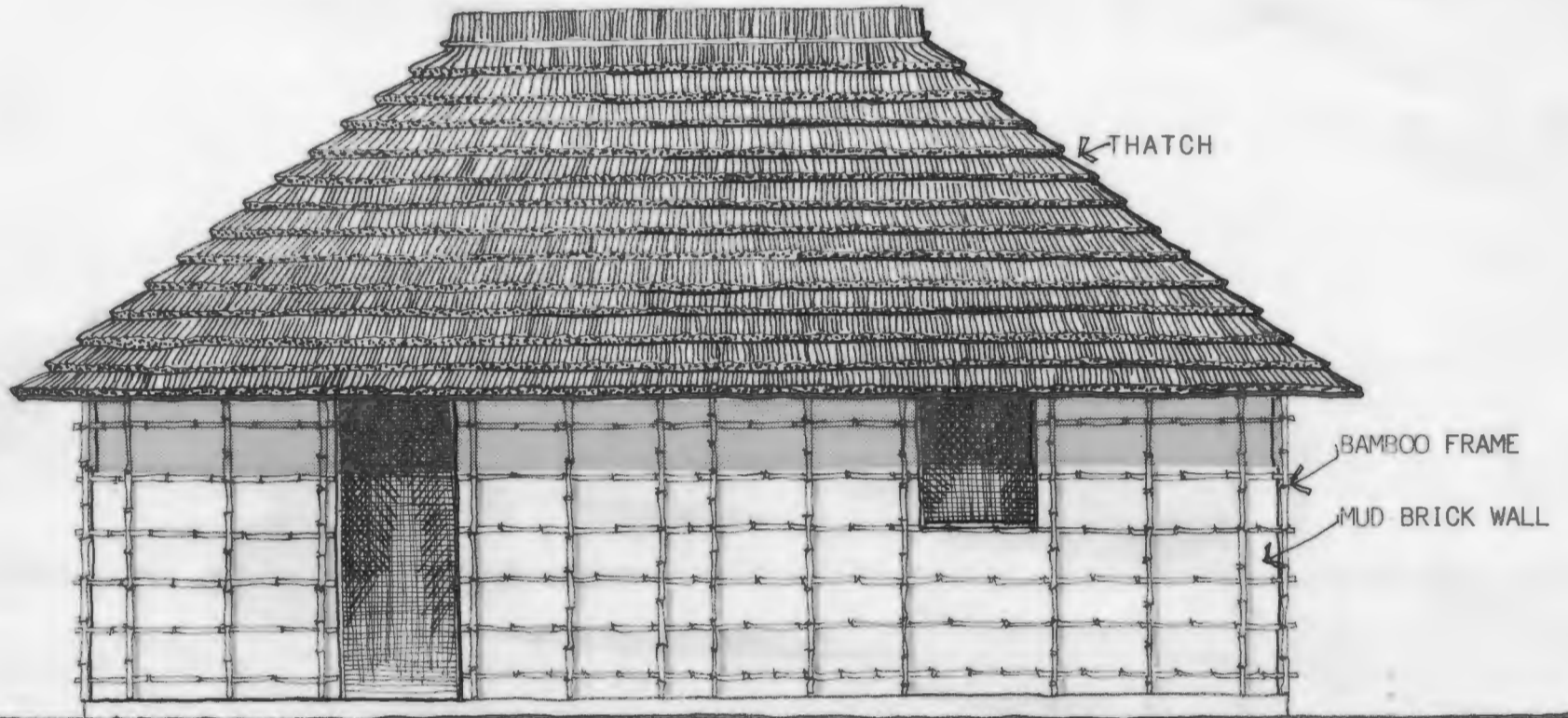


FIG. 17A.
 DEMONSTRATION RECTANGULAR HOUSE PLAN.
 LOCAL MATERIALS.
 SCALE: 1:50

FIG. 17B.
DEMONSTRATION RECTANGULAR HOUSE ELEVATION.
LOCAL MATERIALS.
SCALE: 1:50



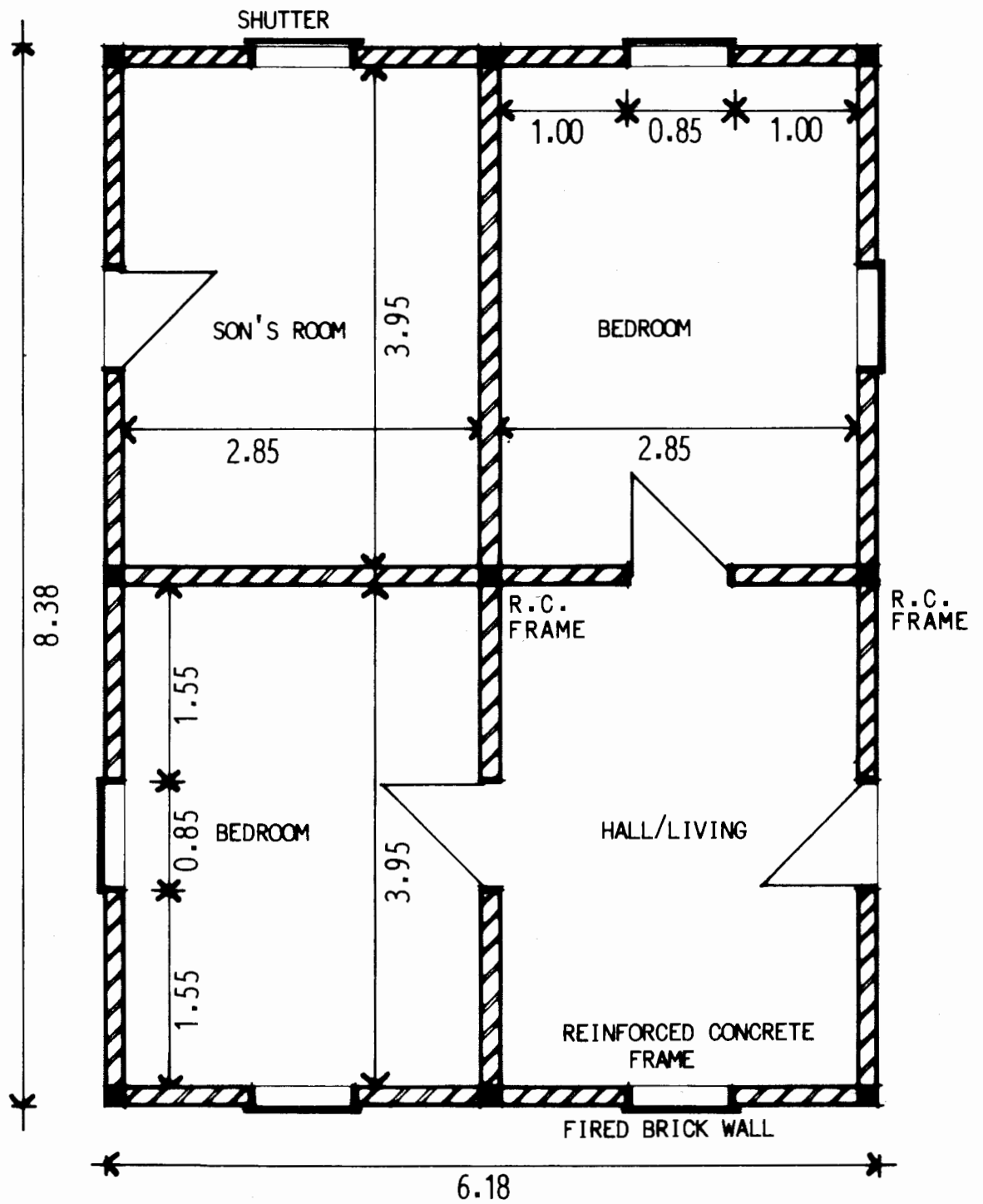
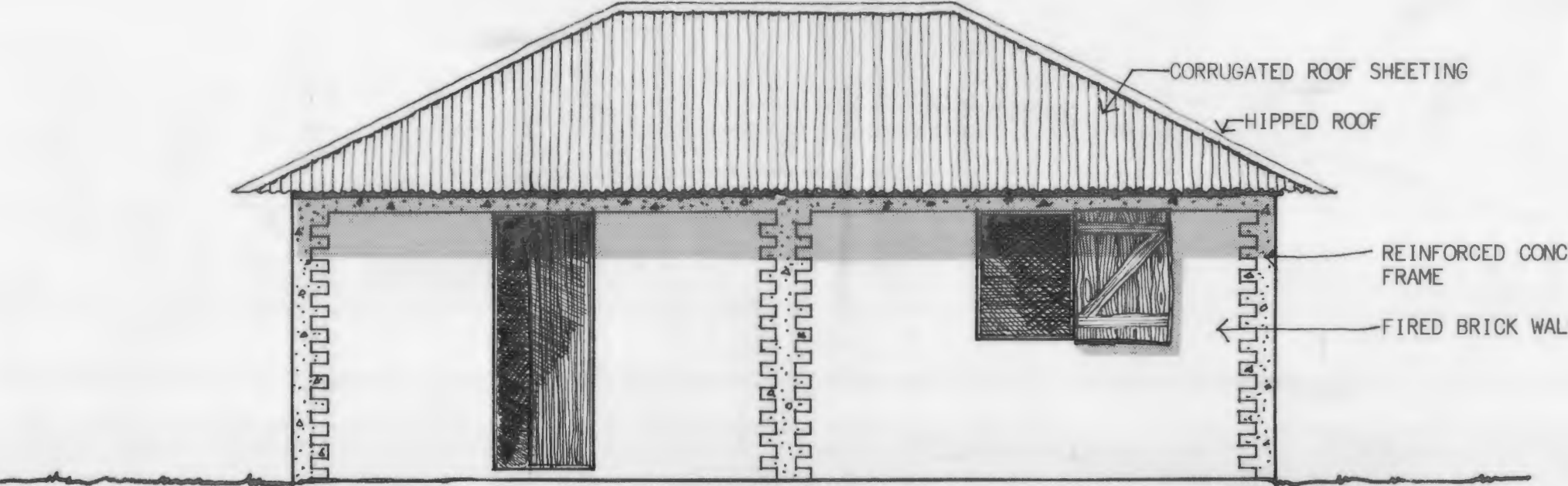


FIG. 18A.
 DEMONSTRATION RECTANGULAR HOUSE PLAN.
 DURABLE MATERIALS.
 SCALE: 1: 50.

FIG. 18B
DEMONSTRATION RECTANGULAR HOUSE ELEVATION.
DURABLE MATERIALS
SCALE: 1:50



7. LOCALLY APPROPRIATE EARTHQUAKE RESISTANT BUILDING CONCEPTS

7.1 LOCAL MATERIALS CONSTRUCTION

Given that the majority of people will continue to build with local materials, it has been necessary to find ways of using these materials which will improve their resistance to earthquakes, and which will also take account of other building problems, notably termite attack on organic materials. (Bamboo, bark, and wood - all essential to the structural integrity of traditional housing in the Koumbia area - are in some cases destroyed in as little as a year by termites.)

In Section 4.2 'The Traditional Round House', two types of traditional wall construction were noted: (a) walls made of mud plastered over a wood and bamboo lattice (Fig.6); and (b) walls made of mud blocks. Method (a) provided greater resistance to movement and damage caused by the earthquake, but it has the major drawback that the structure of the wall is made of organic material, and therefore easily destroyed by termites. This leaves the wall structurally weak even though the outer coating of mud plaster may show little sign of deterioration. Method (b), using mud blocks, is not subject to termite attack, but has little resistance to movement and shaking caused by an earthquake. In normal circumstances, when no movement occurs, this type of wall, if protected from moisture, will last a very long time, certainly in comparison to the lattice wall (a).

It was thus necessary to develop a building system that made use of the mud block wall's potential long life and stability under normal conditions, but which also incorporated the benefits of having a wooden or bamboo frame which could provide resistance to movement and collapse during an earthquake. The system also had to address the problem of termite attack, and avoid the need to rebuild a house after the organic materials have been destroyed.

The system developed included the following concepts:-

(i) Walls: One basic building concept was developed for both the round house and the rectangular house using local materials, and although the construction process was refined during the training programme, the concept remained the same. The wall is built of mud blocks and mud mortar, which provides the load-bearing structure of the building. The roof is supported by this wall, although it actually rests directly on a ring beam of bamboo in the case of the round house, and of bamboo or wood in the case of the rectangular house. Horizontal and vertical lattices of bamboo are placed on either side of the wall, and are tied tightly together by wires which pass through the wall. This enveloping lattice restrains the wall in the event of movement. The

bamboos are intentionally left visible (unlike in the traditional lattice wall where they are buried inside the wall) so that the house owner can see when they are rotten, and replace them without touching the structure of the building, simply by undoing the attaching wires, removing the destroyed bamboos, and replacing them with new ones.

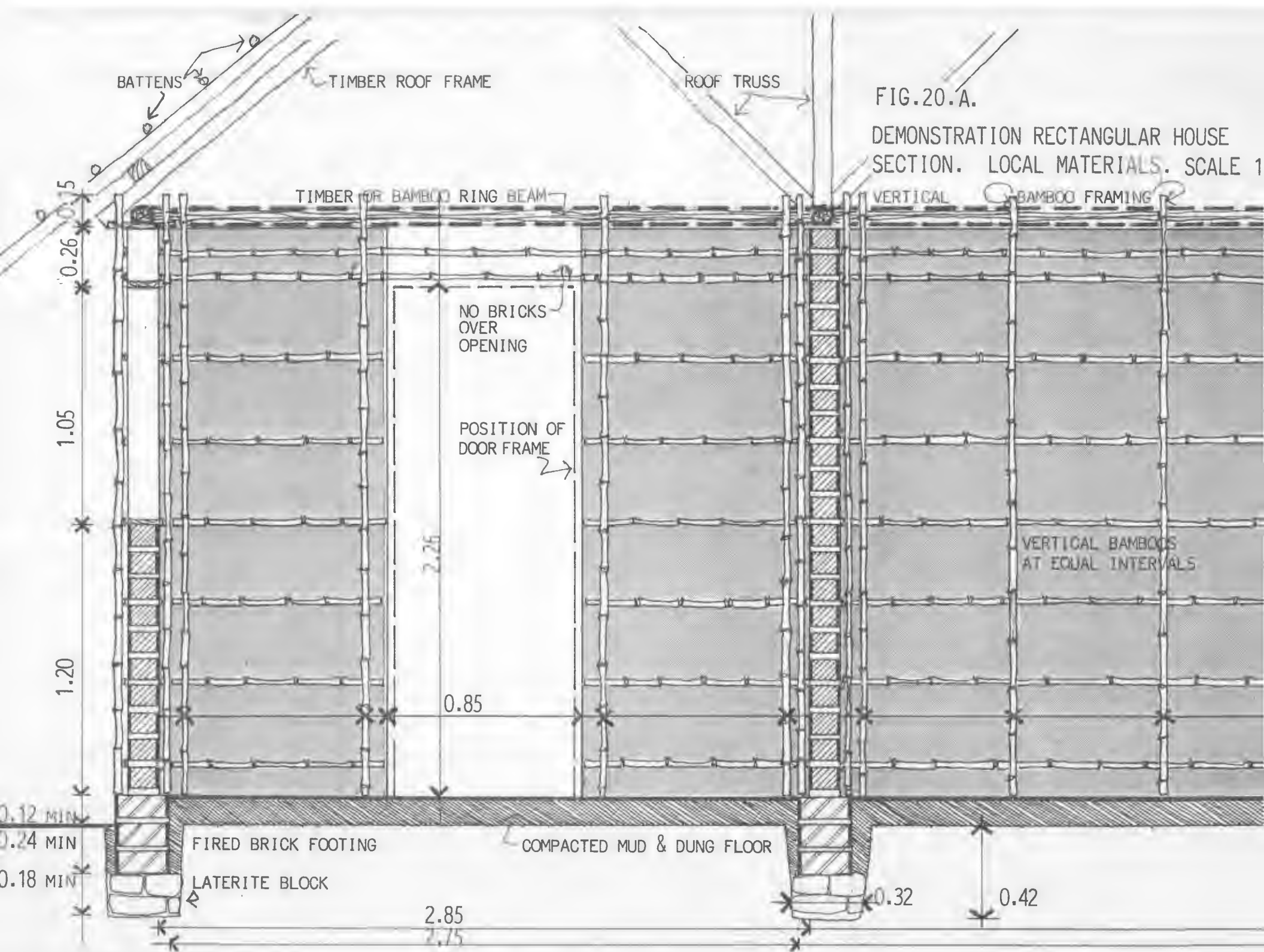
(ii) Lintels: In order to avoid the problem of walls collapsing over openings following the failure of a lintel, the lintels have been completely eliminated in the low walls, so that the window and door openings are carried on up to the top of the wall. This applies to all openings in the rectangular house using local materials, and to all openings in the perimeter and partition walls of the round house (Fig.19) The framing is carried on across the top of the openings (Fig.20). For openings in the tall inner circle wall of the round house it was not practical to continue the opening up to the top of the wall.* Instead the stability of the tall inner wall was increased by maintaining a complete circle of brickwork at the top of the wall. In this instance, in order to avoid the vulnerability of lintels, corbel arches are used to close in the top of the opening. The corbel, formed by stepping out bricks from either side of the opening, takes the same form as that which would be created if bricks laid horizontally over an opening were allowed to fall i.e. an open triangle. (Fig.21)

An acceptable alternative, and one which would be favoured locally, is to put in a complete door or window frame, where the lintel is an integral part and unlikely to fall out on its own. This option, however, carries with it the risk that - given the shortage and cost of sawn timber - people will dispense with the frame, and revert to having a simple lintel only, which recreates the weakness that one is trying to avoid. On the Madina Guiledji site, the frame option was tried, but exactly what was feared happened: the lintel was ready and installed without the rest of the frame because the carpenter had not prepared the frame, with the result that an incorrect practice was demonstrated.

The attempt to eliminate lintels altogether is a much clearer alternative to the traditional - and weak - use of a simple lintel, and therefore to be preferred to the whole frame alternative.

(iii) Tie beams: Tie beams have been put in on the top of every wall, so that in the case of the round house both the lower outer circular

* One prototype round house was built with the opening going up to the top and a wooden infill frame placed in-between. (Fig.22) It would be unrealistic, however, to expect people to have access to this much timber.



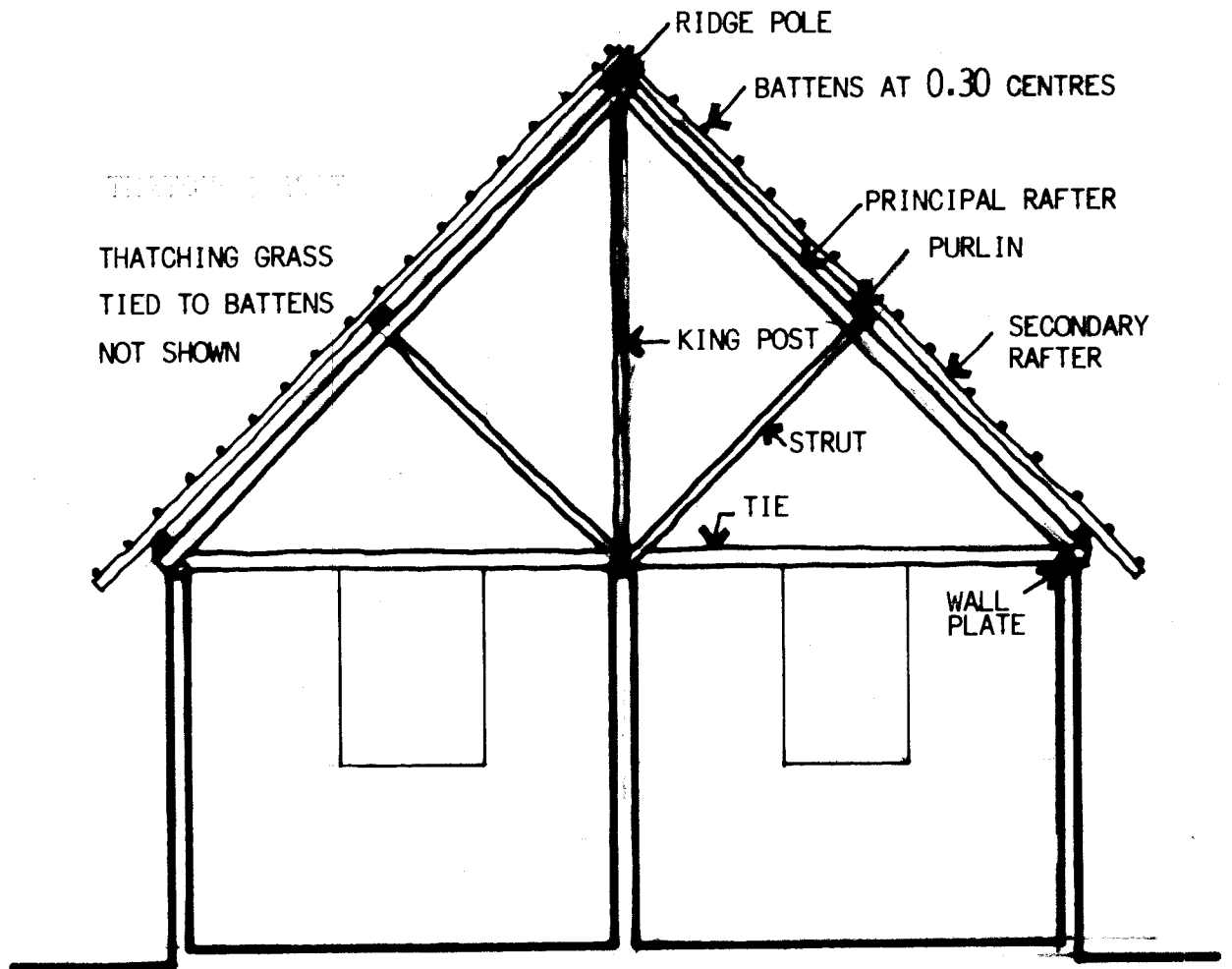


FIG. 20.B.
SECTION THROUGH DEMONSTRATION RECTANGULAR HOUSE,
USING LOCAL MATERIALS, SHOWING ROOF TRUSS AND FRAMEWORK.
SCALE. 1:50



FIG. 21.
CORBEL ARCH OVER OPENING,
INNER CIRCLE WALL OF
ROUND HOUSE.
VERTICAL BAMBOOS ALREADY
IN PLACE.



FIG. 22. OPENING IN TALL INNER WALL FRAMED UP TO TOP OF WALL - A VARIANT

wall and the higher inner wall are encircled at the top by tie beams, and - along the top of the partition walls - tied to each other. All the walls of the rectangular house are similarly capped by a tie beam. (Fig.23) Whilst this had not been the practice in rectangular houses, tie beams made with large bundles of bamboo had been used on top of the perimeter wall of the traditional round house.

(iv) Building practice: Beyond these major changes every effort has been made to work with the existing building techniques. Emphasis has been placed upon improving the quality of the materials and of building work. It was stressed in the training programme that the walls should be placed upon a stone or fired-brick foundation set when possible in a cement mortar, and that the best use of limited quantities of cement when available is in the foundations. Importance was also placed on the careful bonding of blocks or bricks, on ensuring that every single block or stone should be wetted immediately before being laid on the mortar to give good adhesion between the masonry and the mortar, and that all joints should be filled in at the time of laying the masonry, (and not - as had been normal practice - after a complete course had been laid, or indeed not at all.)

(v) Roof: The roof structure of the round house remains exactly as before the earthquake, but it was suggested that when enough wire is available two tie wires should be added across from one side of the roof to the other, one at right angles to the other, at the level of the top of the higher inner wall. In practice this is a refinement that few people are likely to adopt, and providing the circular rings of bamboo which hold the roof frame together remain strong, the existing roof system is good.

In the rectangular buildings the form of the roof truss normally used is weak, since it relies on having a number of supporting points along its length, in the middle as well as at either end of the truss. Efforts were made to change this, although the time needed to ensure that people would take up an apparently subtle change was limited.

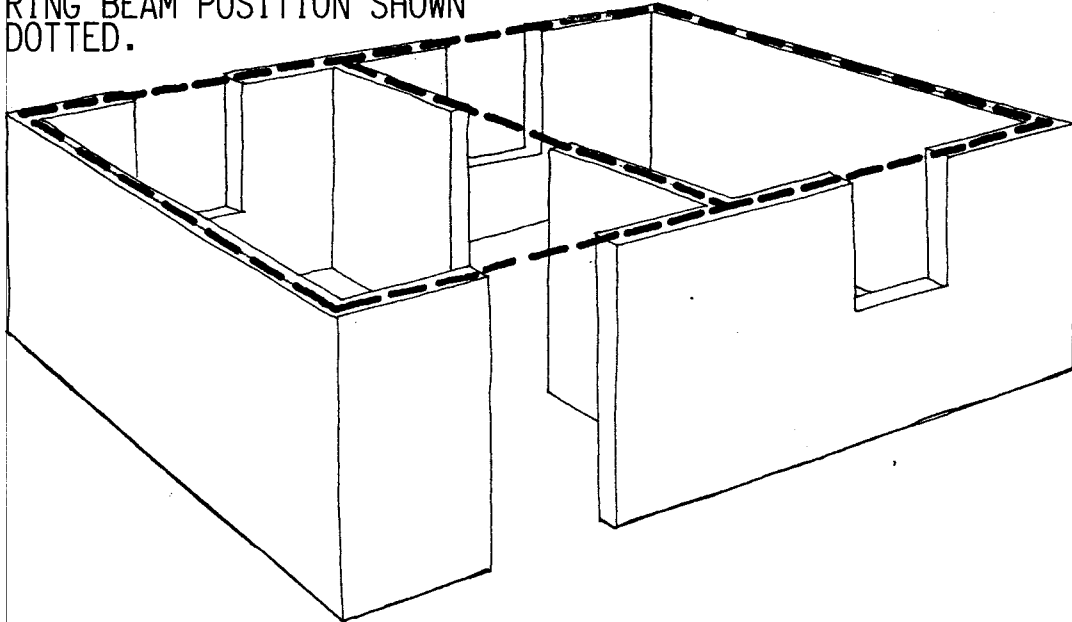
7.2 DURABLE MATERIALS CONSTRUCTION

Section 4.3 'The Rectangular House' describes the general building practice using reinforced concrete and fired-brick or cement-block walls as it was before the earthquake. A major problem has been that people start to build, but have not enough money or access to sufficient materials to finish the building. Hence a number of typical weaknesses which result in part from having no reinforcing bar or no cement. There is little that one can do to persuade people that they should not try to build with these materials until they are sure that they can get enough to complete each part of the building.

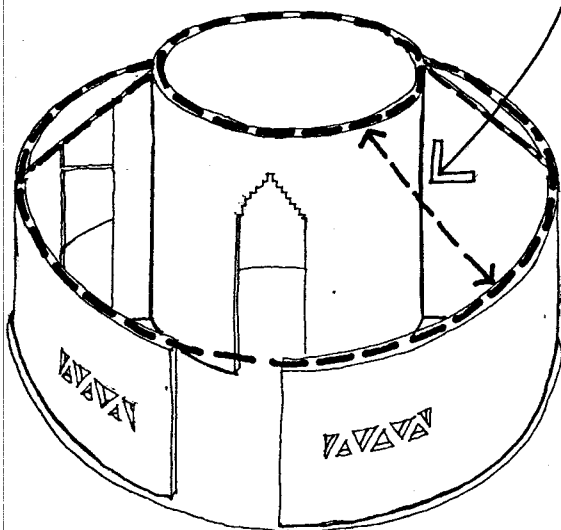
POSITION OF RING BEAM ON LOCAL MATERIAL BUILDINGS.

C'est la sablière qui tient le haut du bâtiment.

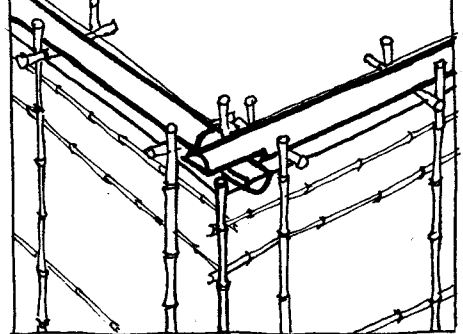
RING BEAM POSITION SHOWN DOTTED.



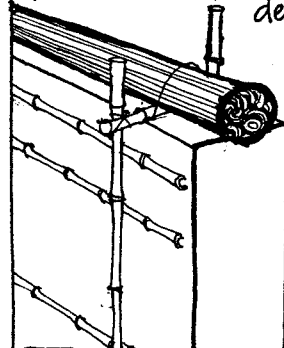
Dans les bâtiments ronds tous les murs doivent être couronnés d'une sablière, et toutes les sablières liées les unes aux autres.



La sablière peut être en bois, avec un bon joint aux coins



S'il n'y a pas de bois, on peut utiliser une botte de bambou.



The project itself ran into serious difficulties of material supply, despite many promises and assurances, which serves to illustrate how erratic and unreliable material supply can be, even when the money is available to pay for them. This will inevitably continue to be a flaw in the development of earthquake resistant construction using 'durable' materials.

The project did, however, attempt to demonstrate building practices which would at least correct some of the technical weaknesses which lead to building failure. The most notable of these were the absence of ring beams; short lintels; the widespread practice of laying fired bricks on edge; pouring concrete columns in several stages; and not vibrating concrete when it is poured.

The basic concept adopted was that there should be a frame, incorporating a reinforced concrete strip foundation, with reinforced concrete columns at every wall junction, tied into the foundation below, and tied to a continuous ring beam at the top of the wall. (Fig.24) This reinforced concrete ring beam should be low enough also to act as a continuous lintel. In theory the space below the ring beam and between two columns can be filled with a solid wall, a wall with a door or a window, or even left entirely open. (Fig.25) In practice whenever possible the brick or block work of the wall has been used as part of the shuttering for the columns and for the ring beam. (Fig.26) This significantly reduces the amount of timber needed for shuttering compared with the amount needed if the columns are poured before the masonry is laid. This technique of using the masonry as part of the shuttering had already been used in Koumbia. It has a further advantage that a good joint between masonry and concrete is achieved. Failure on buildings where this method had been used usually occurred through the masonry, and not through the joint between masonry and concrete.

Reinforcement has been kept to a minimum: two horizontal bars (10 millimetres in diameter) placed in a shallow strip foundation; four bars placed vertically in each column; and two bars placed side by side for the ring beam reinforcement. Where the horizontal bars meet with the vertical bars of the columns, an upper layer of reinforcement is added to take the strain of negative bending over the column. (This negative bending produces tension on the upper side of the ring beam, as opposed to the potential positive bending in between columns, which creates tension on the lower side of the beam.)

Using a low ring beam means that two more courses of brick or block work have to be added above to reach a reasonable roof level. A timber wall plate is placed on top of these bricks and tied to the vertical reinforcement at the top of the columns. Fig.27 shows a detail of the building concept.

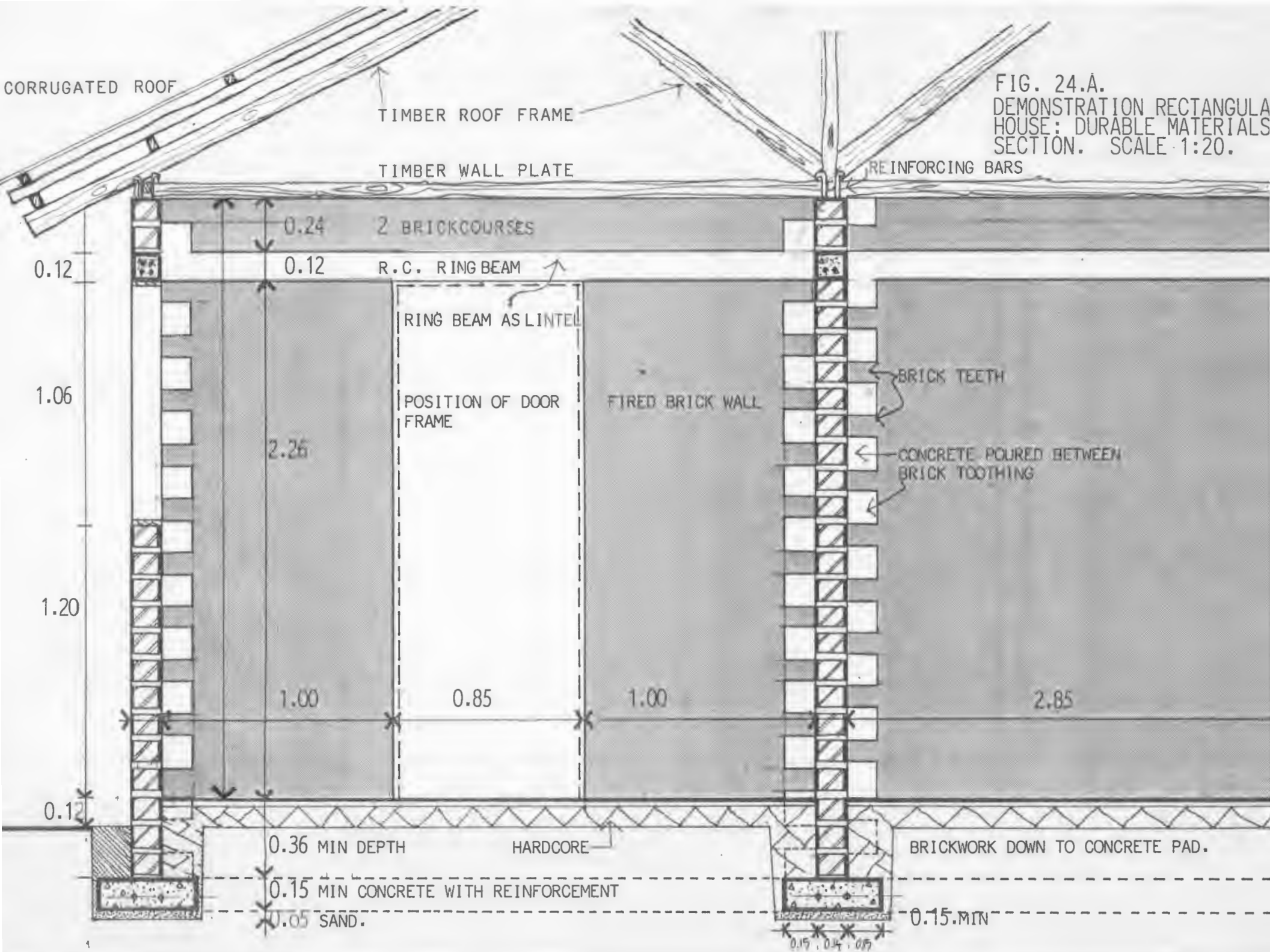


FIG. 24.A.
 DEMONSTRATION RECTANGULAR
 HOUSE: DURABLE MATERIALS
 SECTION. SCALE 1:20.

FIGS. 25 & 26: ILLUSTRATIONS FROM THE MANUAL.

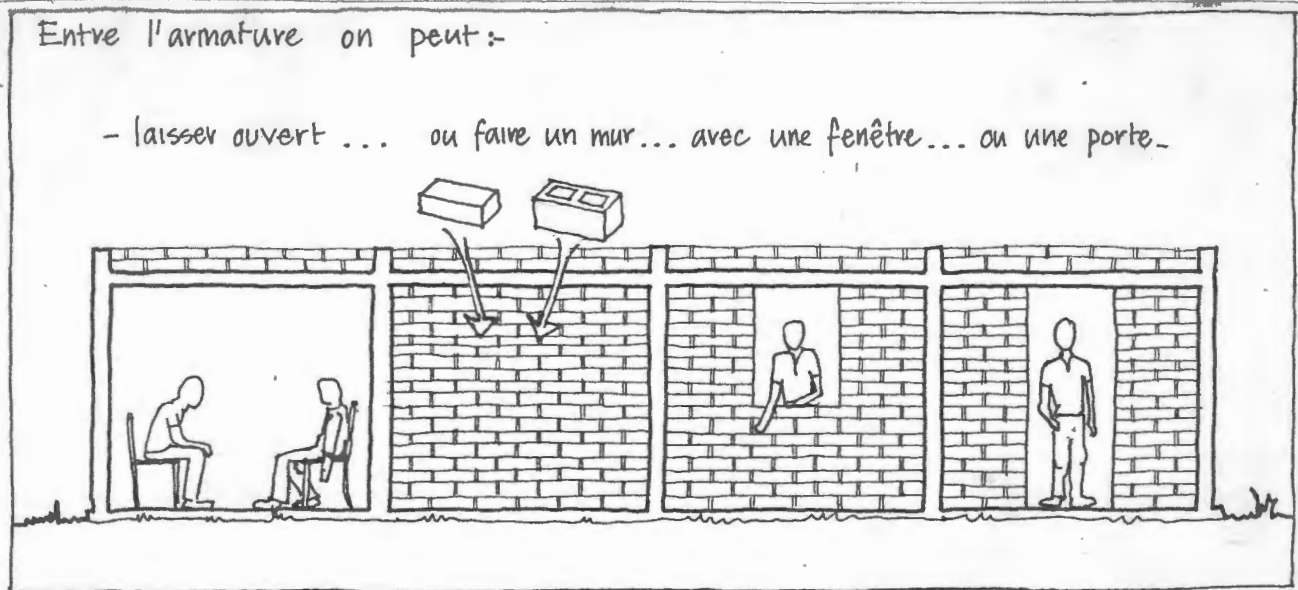


FIG. 25. BUILDING CONCEPT USING R.C. FRAME AND WALL INFILL OPTIONS.

FIG. 26. PRACTICAL APPLICATION: WALLS USED FOR SHUTTERING COLUMNS.

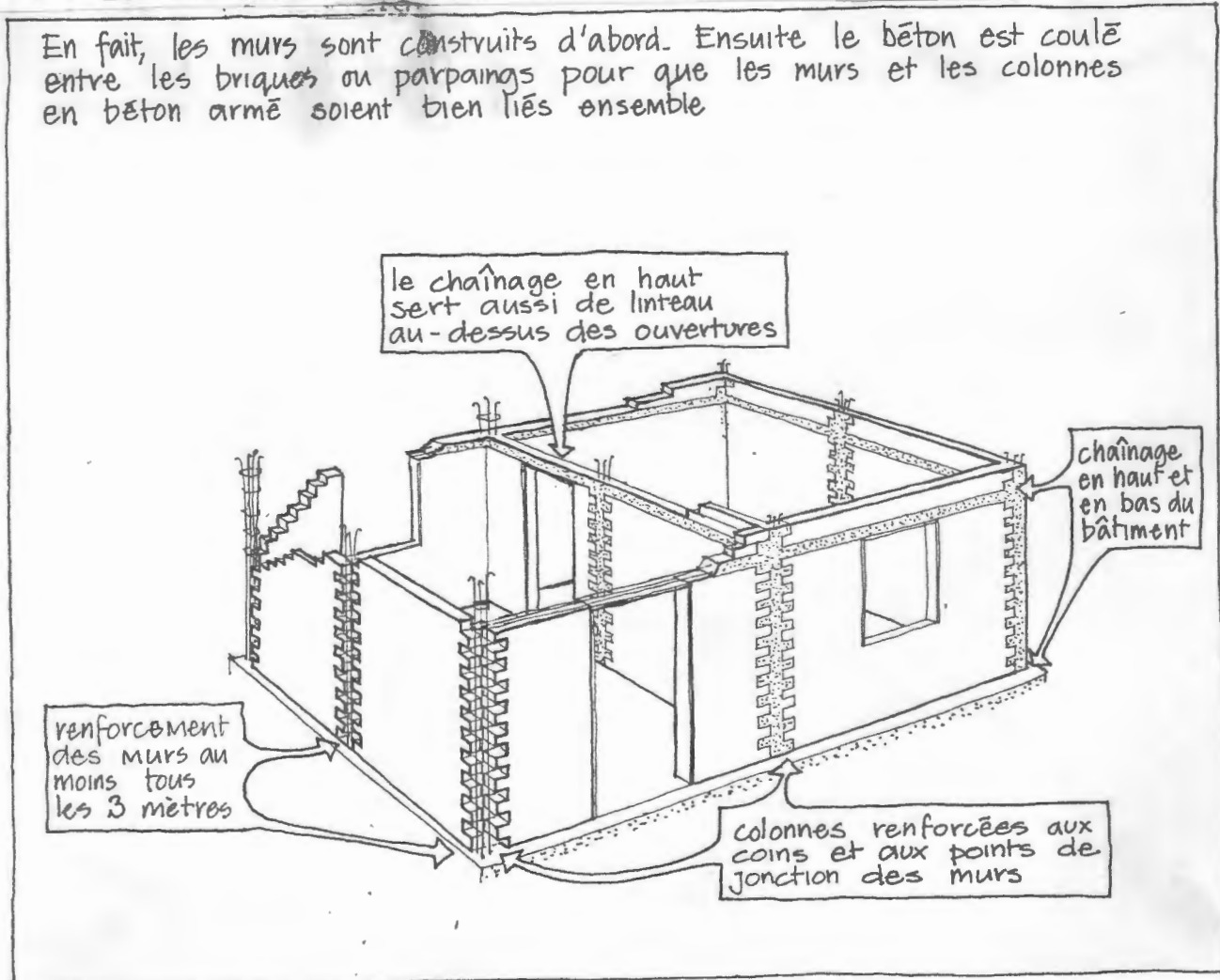


FIG. 24. B.
 DEMONSTRATION RECTANGULAR HOUSE WITH DURABLE MATERIALS.
 ROOF FRAME: SHOWING TRUSS, & PART PLAN VIEW OF ROOF ELEMENTS.
 SCALE: 1:50

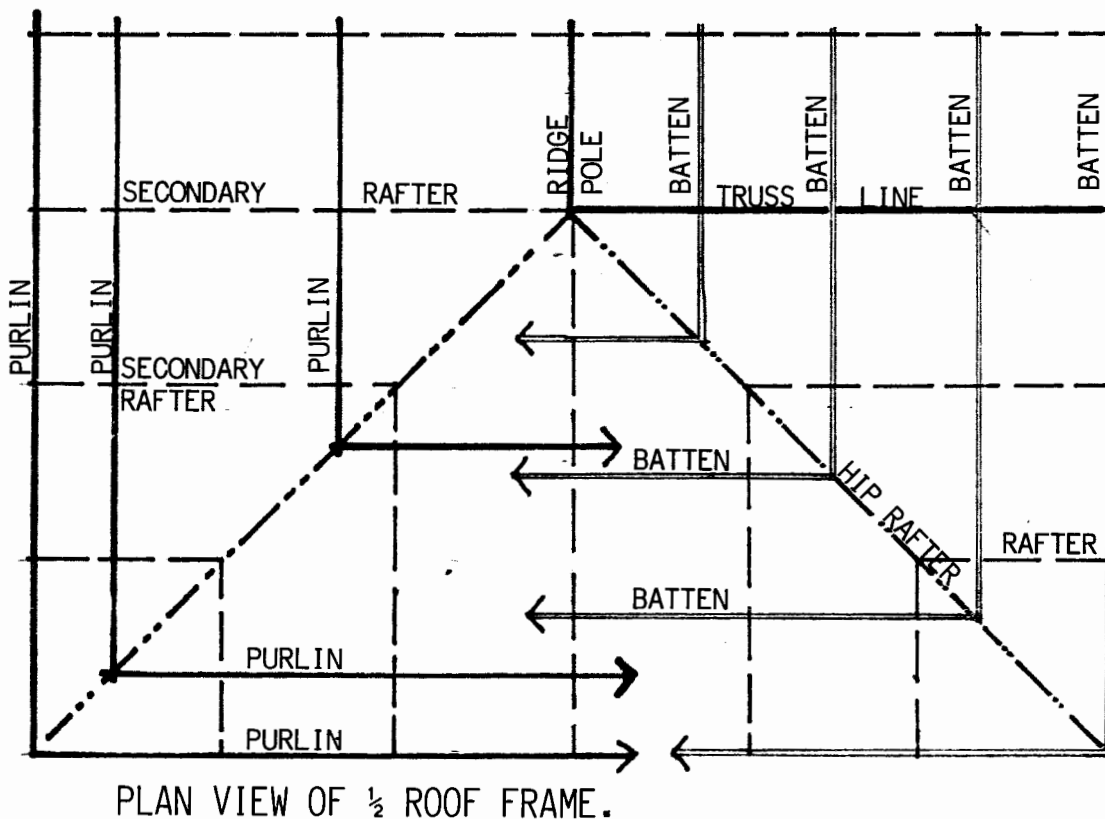
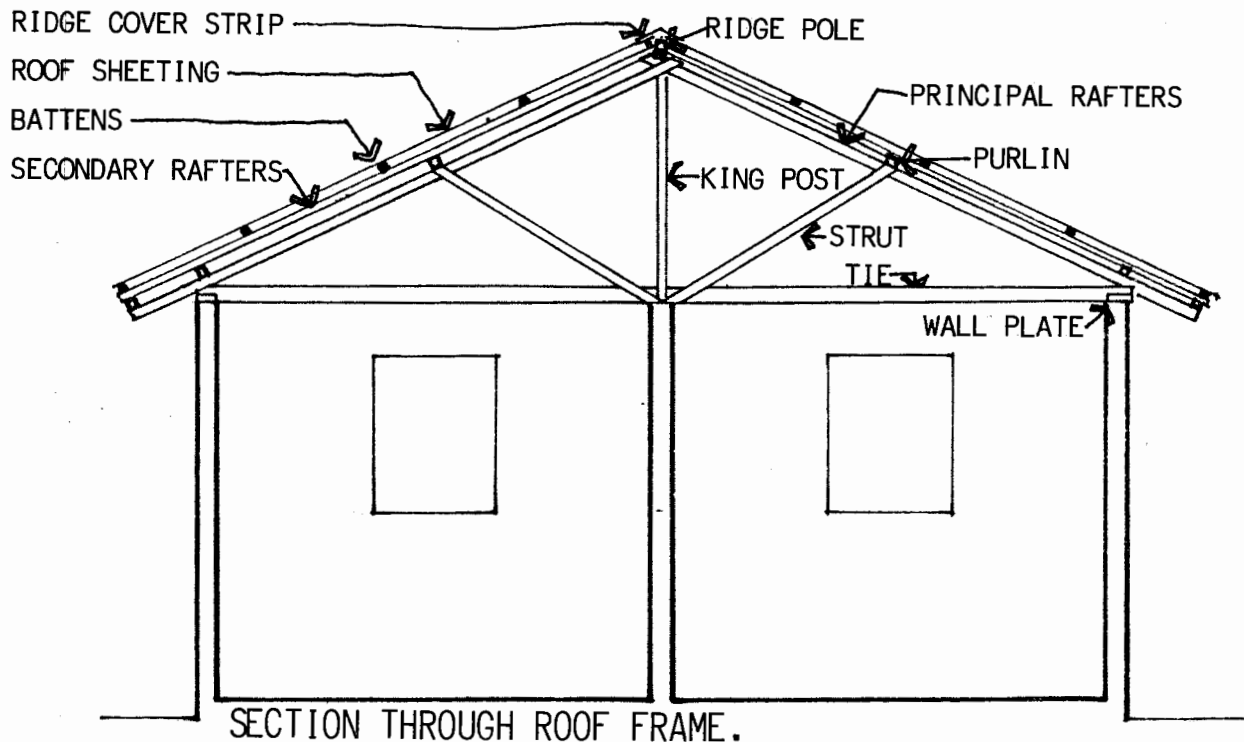
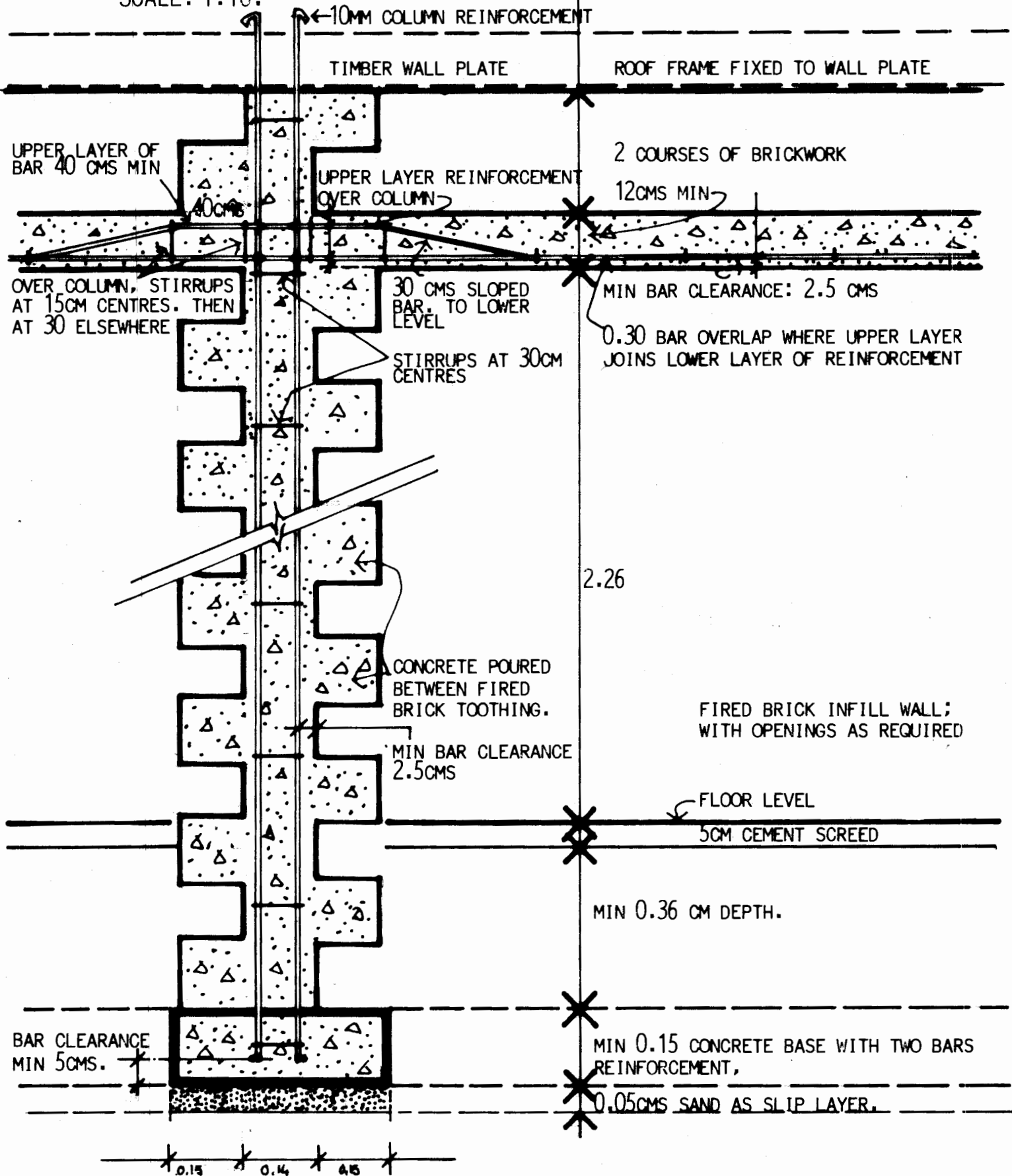


FIG. 27.

DETAIL: REINFORCED COLUMN: RING BEAM AND FOUNDATIONS.
DEMONSTRATION RECTANGULAR HOUSE USING DURABLE MATERIALS
SCALE: 1:10.



8. THE EARTHQUAKE RESISTANT BUILDING PROCESS - LOCAL MATERIALS

8.1 EVOLUTION OF WALL AND FRAME CONSTRUCTION

The process of wall and frame construction was refined during the training programme. In order to emphasise the two elements of the wall - blocks and framing - to begin with the bamboo for framing the wall was 'prefabricated' in panels. These consisted of whole vertical bamboos at a maximum of 80 centimetres apart, and horizontal bamboos, split in half and woven through the vertical bamboos, one every 36 centimetres up the height of the frame. Each prefabricated panel was made for a specific wall, and they varied greatly in size. Each whole panel was placed vertically in position and held with supporting staves. (Fig.28) The wires which were to hold the two panels on either side of the wall together were placed at the time of laying the bricks, every third course. Having the prefabricated panels in place enabled the builders to see exactly where the wires had to be situated in order to correspond to the position of a vertical bamboo. This system allowed the relationship between mud-block wall and bamboo frame to be quickly and clearly established at the critical first stage of the practical training.

Prefabricating the bamboo panels was, however, time-consuming and in addition the bark bindings which were used to hold the panel together loosened, with the result that the panels became untidy and irregular. This less attractive appearance could have potentially reduced the likelihood of the idea being adopted by the people.

Once the builders could see where the vertical bamboos had to be placed, using the first round and the first rectangular houses as models, it was found to be easier to build the wall up first and to assemble the bamboo framing directly on the completed wall. This was both quicker and gave a neater and more attractive result.

8.2 SUMMARY OF THE BUILDING PROCESS

(i) Foundation/Walls: The foundation is laid starting with a base of laterite stones, and finishing off with two or three levelling courses of fired brick, depending on the slope of the site and on the relative availability of stone and bricks. (Fig.19) The mud block wall is laid with the blocks centred on the foundation, which is twice the thickness of the wall. The mud blocks are built up laid with mud mortar. Following along behind the mason, a second man makes a hole through the damp mortar at the correct position, using a sharpened length of reinforcing bar. (Fig.29) He then passes the two ends of a piece of wire through the hole, so that on one side - preferably the interior

FIGS. 29, 30 & 31. ILLUSTRATIONS FROM THE MANUAL.

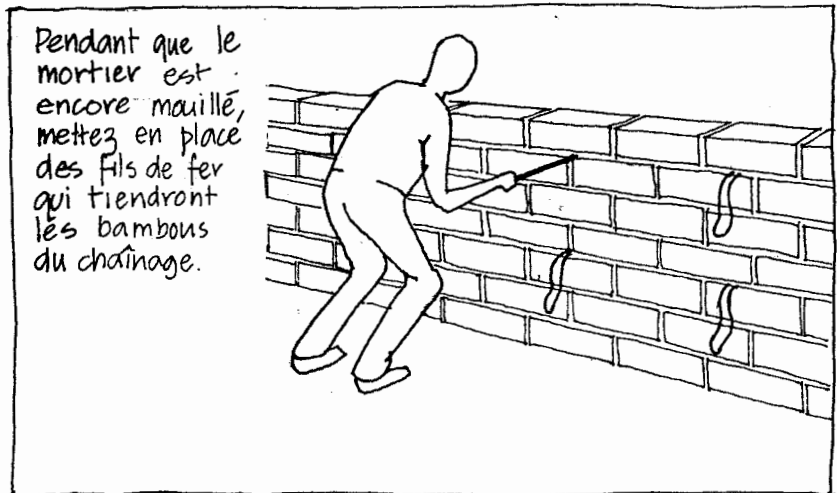
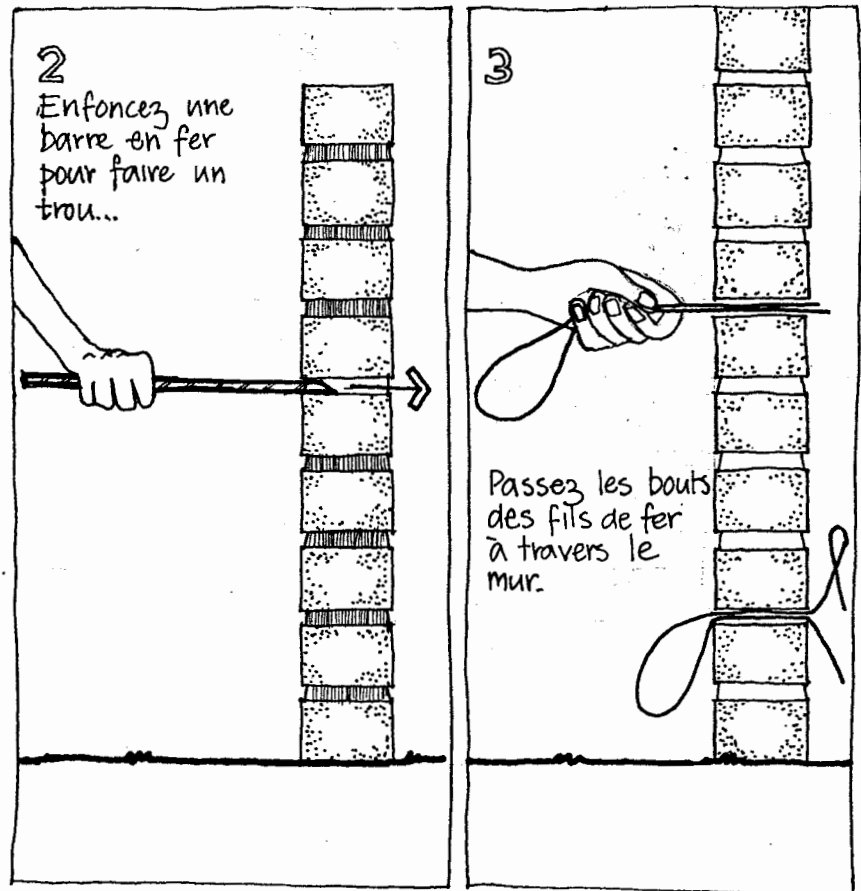
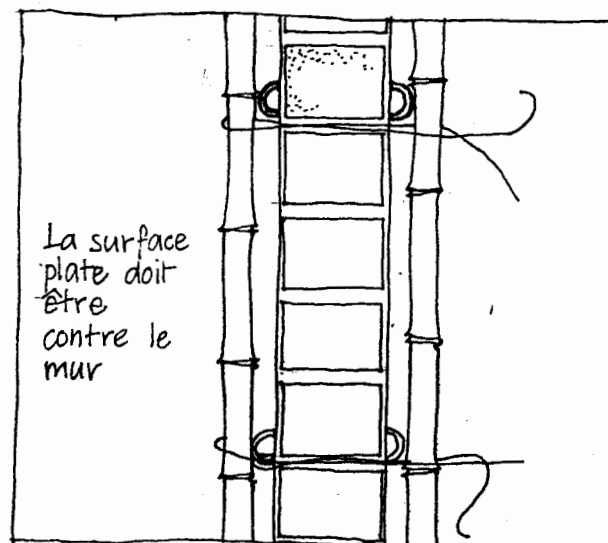
FIG. 29.
MAKING HOLES IN
THE BRICKWORKFIG. 30.
DETAIL OF PLACING
WIRES.

FIG. 31.

VERTICAL BAMBOOS
LOOSELY HELD BY
WIRES; SPLIT
HORIZONTAL BAMBOOS
PACED BETWEEN
MUD PLASTERED WALL
AND VERTICAL
BAMBOOS.



side of the wall - there is a loop large enough to pass a 4 centimetre diameter bamboo through, and on the other side there are two tails of wire, some 20 centimetres long, hanging out of the hole. (Fig.30) When the wall is finished it is plastered with mud.

(ii) Frames: The vertical bamboos can now be put into position. These should already have been cut to the right length: each bamboo rests on the top of the foundation and projects at least 20 centimetres above the top of the wall (so that they can be attached to the framework of the roof). On one side a vertical bamboo is passed through the wire loop, whilst on the other side a bamboo is loosely held in place by twisting the two wire ends round it. (Fig.31) Vertical bamboos are placed 10 centimetres from each corner and from the edge of every opening, and then at regular intervals between corners and openings, at a maximum separation of 80 centimetres. Every bamboo on one side of the wall has to be matched by a corresponding bamboo on the other, directly opposite it.

Split bamboos are prepared for the horizontals, by smoothing off each half round bamboo split face so that it will lie flat against the surface of the wall. The horizontal bamboos are then slid along between the vertical bamboos and the wall, resting on the wires, which are placed every three courses.

When all the bamboos are in place, two short sticks are attached to the wire ends. (Fig.32) While one man pushes the bamboos against the wall on the side of the loops of wire, another takes the two short sticks and pulls the wires tight, twisting them to secure the frame. (Fig.33) At the same time pressure is applied to the bamboos to bring them as tight as possible against the wall. When the wires are secure the sticks are removed from the wire ends (to be used again on the next pair of wire ends) and the loose ends of wire are tucked neatly in behind the bamboos. (Fig.34) To make sure that all the bamboos lie flat against the wall, the wires are tightened first of all half way up the wall, and then at the top and the bottom.

On top of the wall a short transverse bamboo is placed, lying across the wall, between two vertical bamboos, and attached to them with wire. A large continuous bundle of split bamboos, some 14 centimetres in diameter and bound tightly in a roll, is then laid along the top of the wall to act as a tie beam.

The rectangular house has one difference from the round house: because there are external corners, there is an additional corner detail. The horizontal bamboos from both sides of an external corner are continued out from the corner so that they overlap each other. A thick bamboo is placed in the V-shape created by the overlapping bamboos and secured with wires. (Fig.35)

FIGS. 32, 33 & 34. ILLUSTRATIONS FROM THE MANUAL.

FIG. 32.

SHORT STICKS ATTACHED TO TIE WIRES.

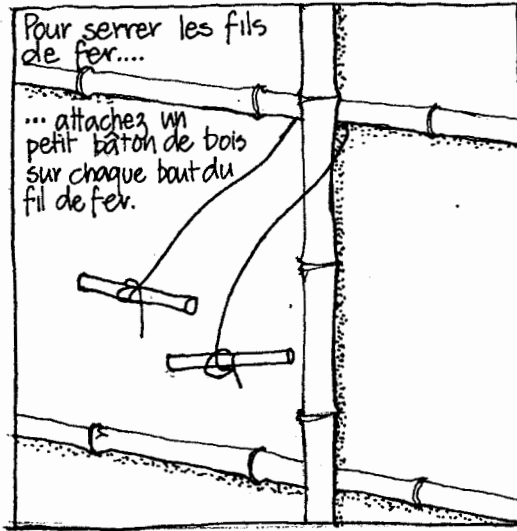


FIG. 33.

PULLING THE FRAME TOGETHER BY TIGHTENING THE WIRES.

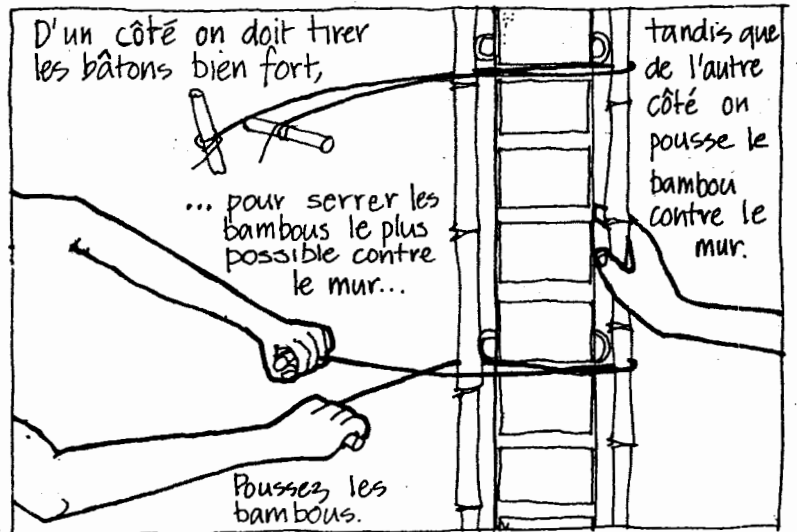
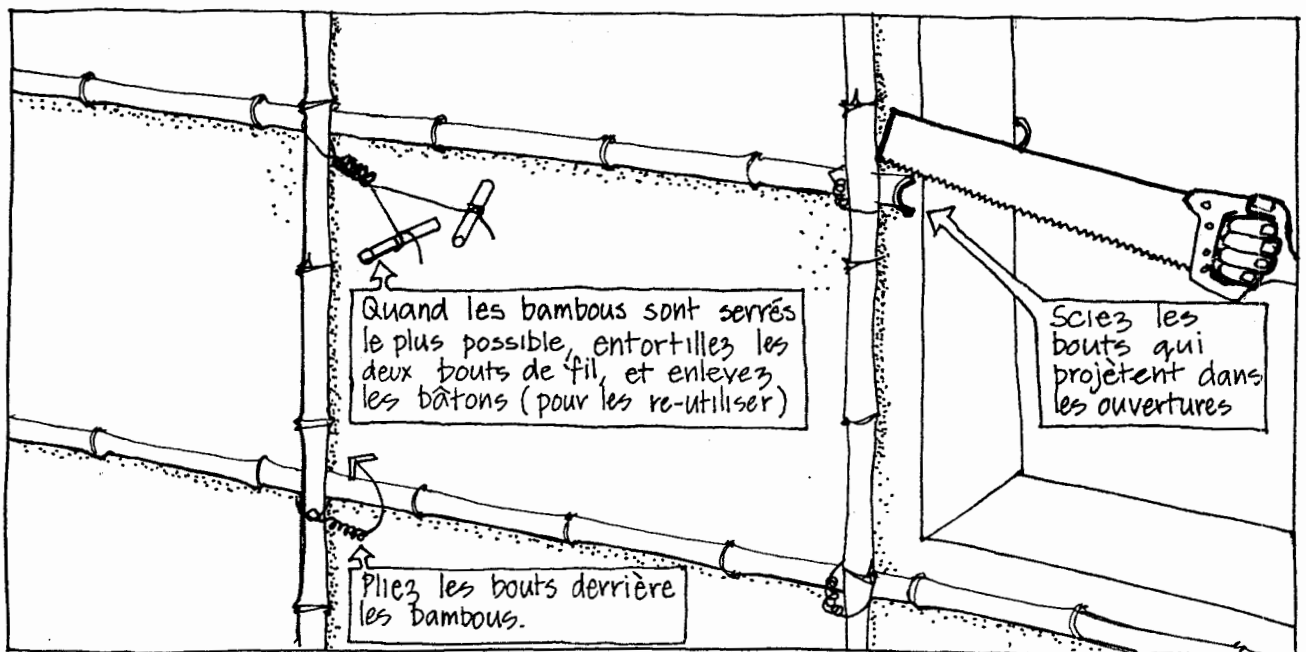


FIG. 34.

STICKS REMOVED FOR REUSE. WIRE END PUSHED BEHIND FRAME.



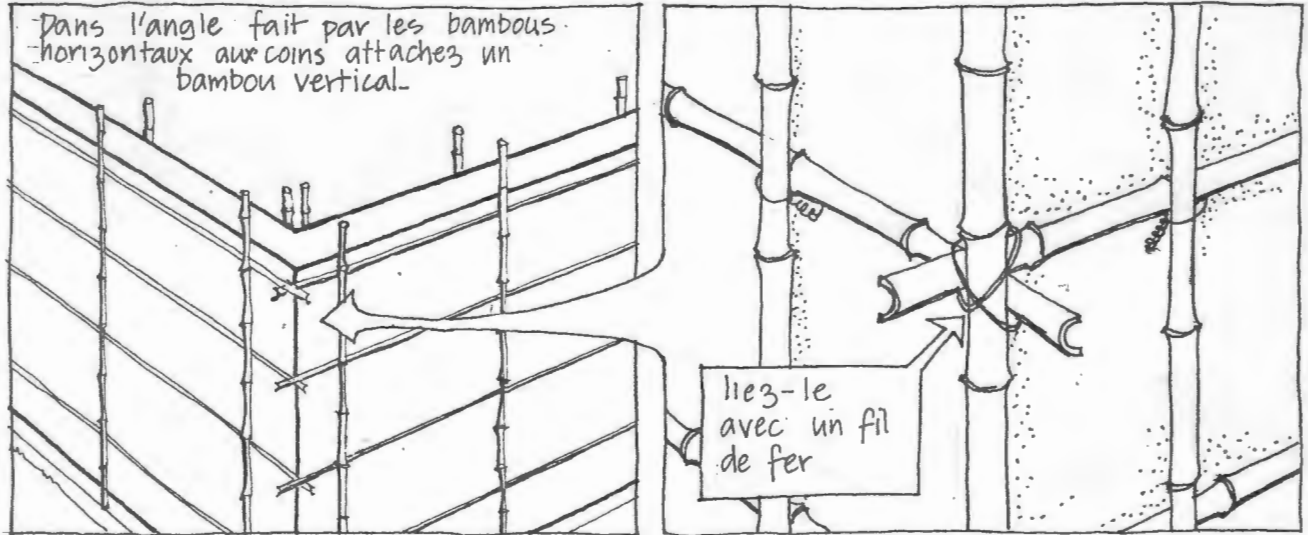


FIG. 35. ILLUSTRATION FROM THE MANUAL.

DETAIL OF VERTICAL BAMBOO POSITION AT EXTERNAL CORNERS ON RECTANGULAR HOUSE BUILT WITH LOCAL MATERIALS.



FIGS. A - G : THE FRAMING PROCESS



A). ROUND HOUSE OUTER WALL BEING PLASTERED (AT MADINA GUILLEDJI).



B). VERTICAL BAMBOOS
BEING PLACED



C). PUSHING THE FRAMES AGAINST THE WALL. VIEW LOOKING DOWN.

D).
TIGHTENING WIRES,
BEGINNING AT THE
MIDDLE OF THE
VERTICAL BAMBOO.





E). PULLING WIRES TIGHT



F). BINDING THE WIRES
USING STICKS



G). OUTER WALL FRAMING IN PLACE. INNER RING WALL BEING PLASTERED.
(MADINA GUILLEDJI.)

(iii) Roof: For the round house the roof frame is assembled upside down on the ground, using a supporting framework (Fig.36) erected beside the building. When the upper part of the cone of bamboos has been tied together, the whole roof frame is picked up, turned over, and placed on top of the house. (Fig.37) Additional horizontal rings are added, one ring every 30 to 40 centimetres up the slope of the roof. Each ring uses a small bundle of 4 to 8 split bamboos. (Fig.38)

The thatch is then laid on top of the framework, secured with bark strips, with each layer starting about 30 centimetres up from the layer below. (Fig.39)

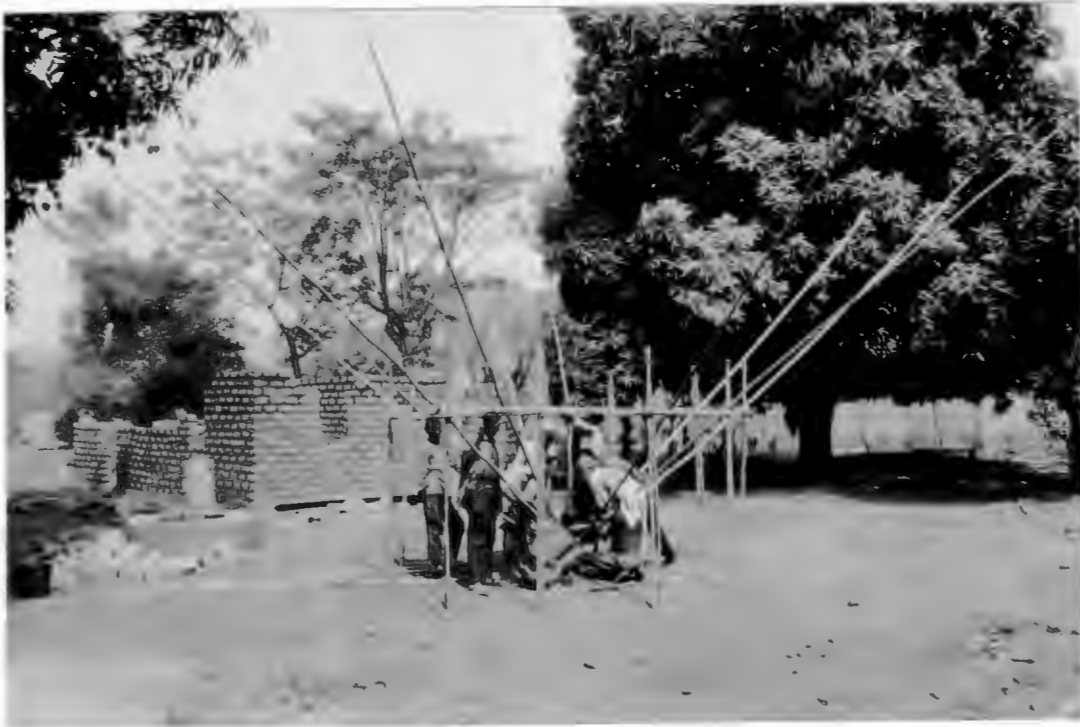


FIG. 36. ROUND HOUSE ROOF FRAME BEING PREPARED ON SUPPORTING FRAMEWORK...

... ROOF FRAME TURNED ON ITS SIDE, READY FOR PLACING OVER THE FINISHED WALLS OF THE HOUSE.



FIG. 37.



ROOF FRAME IN POSITION ON WALLS. ROUND HOUSE.

ROOF FRAME ATTACHED
TO WALL FRAME.

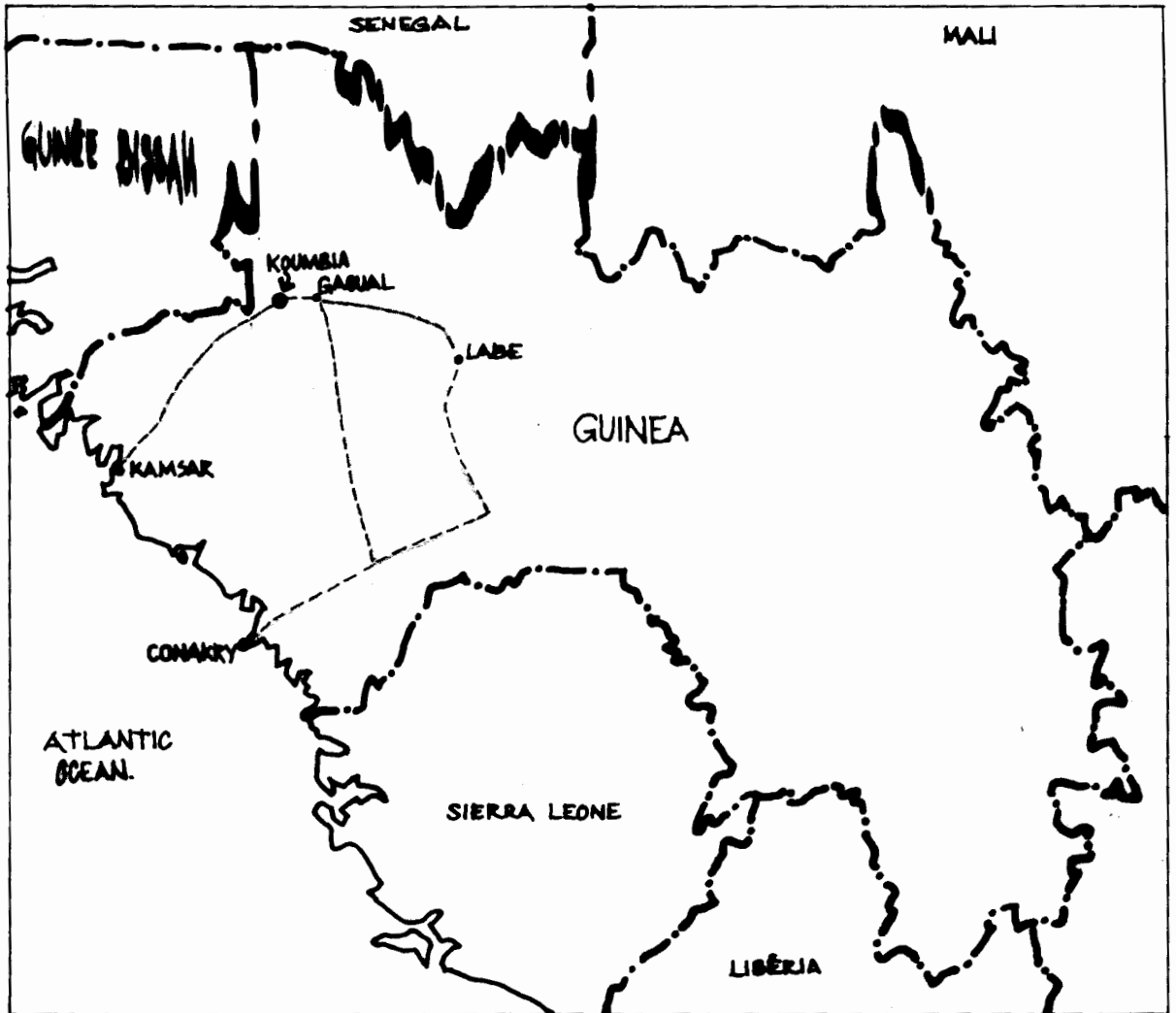


FIG. 38. ADDITIONAL HORIZONTAL BAMBOO RINGS BEING PLACED ON ROOF FRAME

FIG. 39. THATCHING THE ROOF

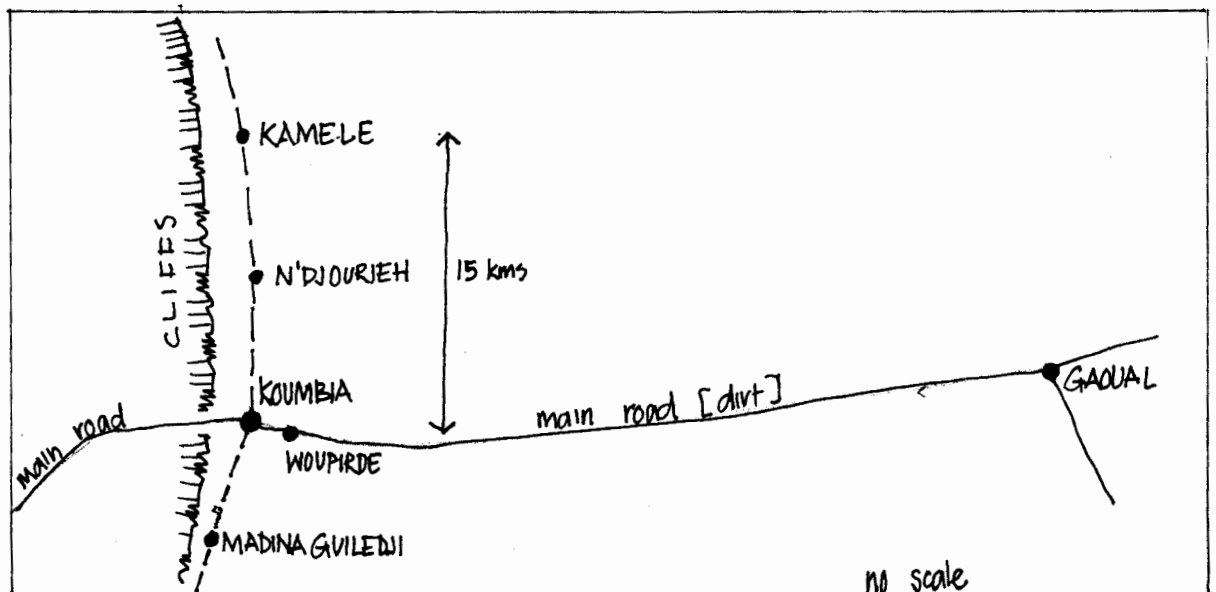


ANNEXE 1. LOCATION OF KOUMBIA IN GUINEA.
LOCATION OF SITES IN RELATION TO KOUMBIA.



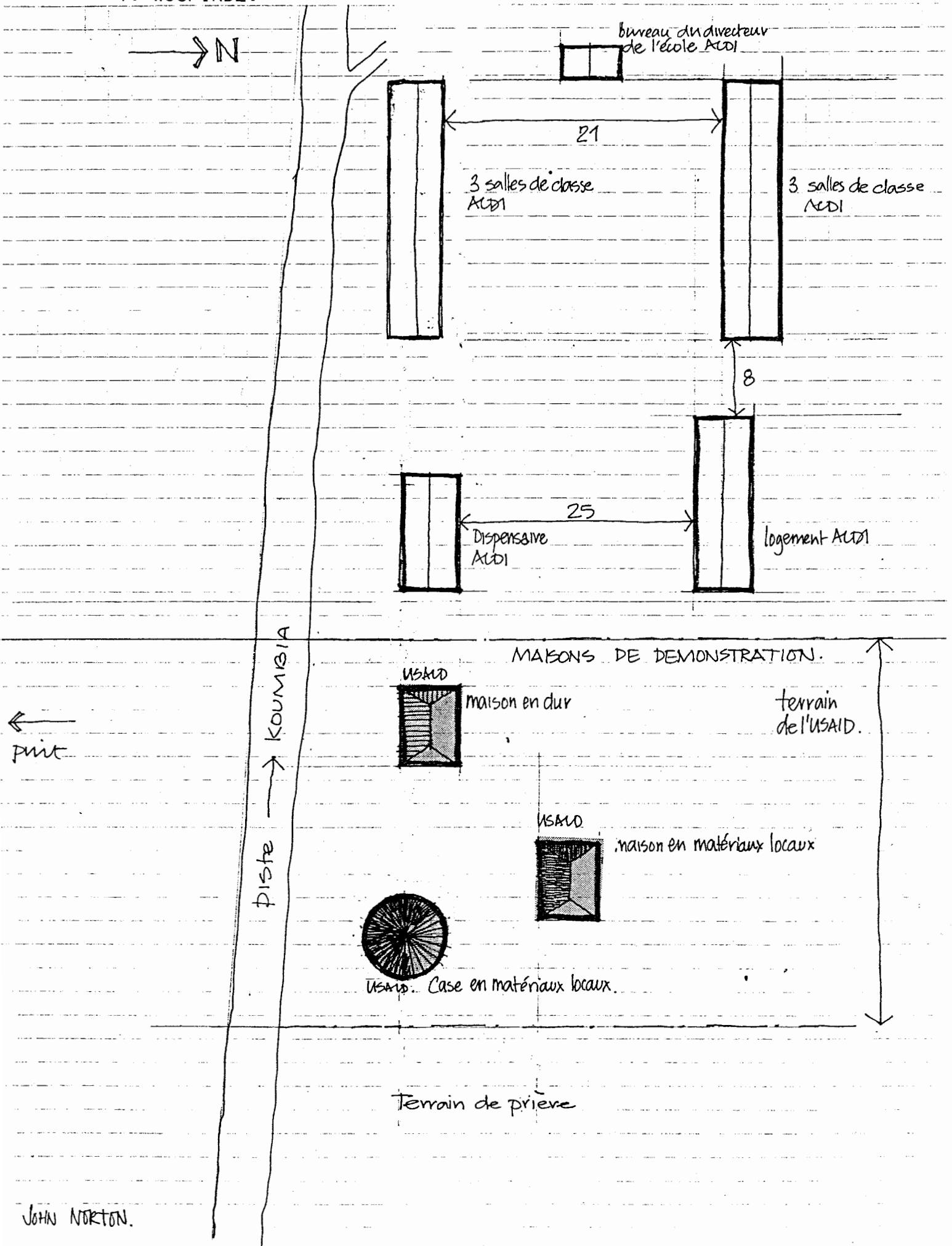
LOCATION OF KOUMBIA IN GUINEA. ~435 KMS BY TRACK FROM CONAKRY.

LOCATION OF SITES IN RELATION TO KOUMBIA.



ANNEXE. 2. SITE PLANS FOR THE DEMONSTRATION BUILDINGS.

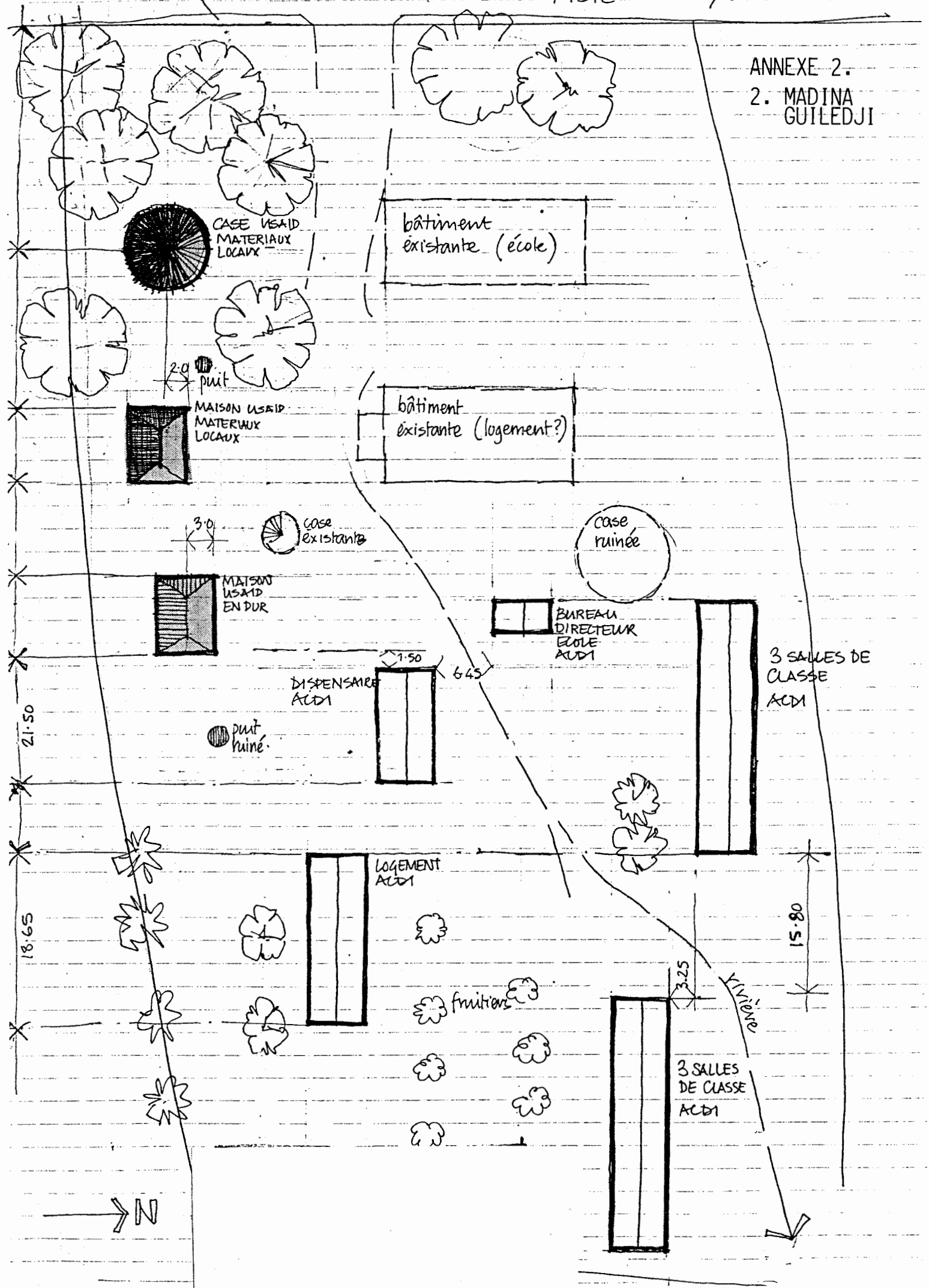
1. WOUPIRDE.

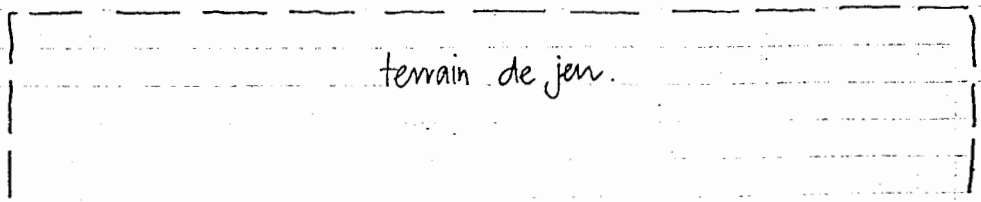
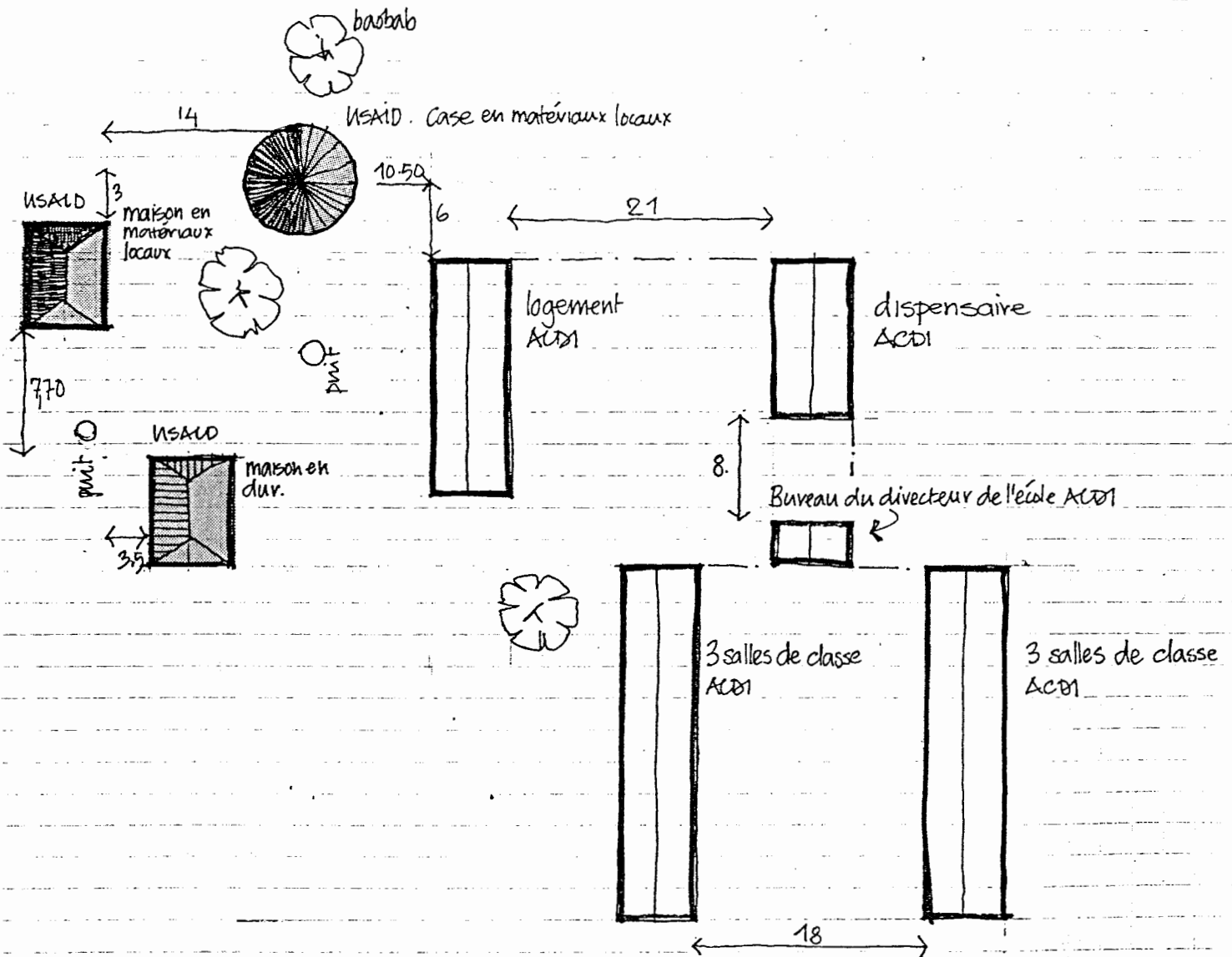
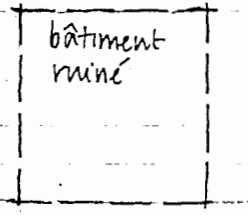
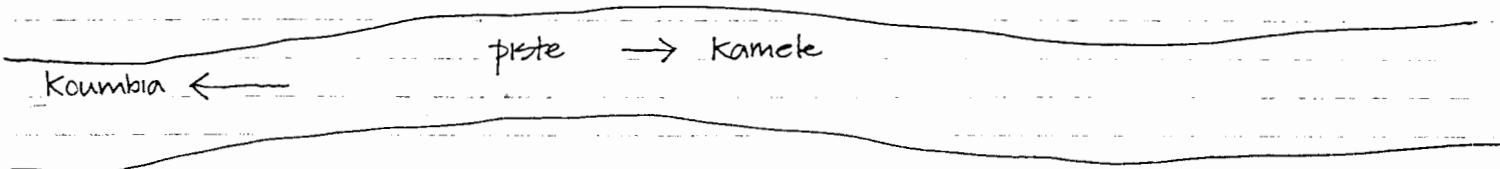
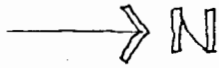


puit nouveau

PISTE → direction Koumbia

ANNEXE 2.
2. MADINA GUILLEDJI





ANNEXE 2. 4. KAMELE



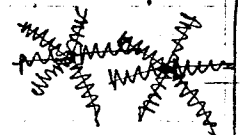
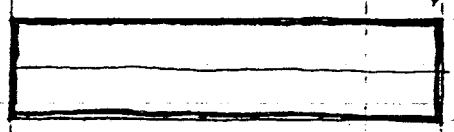
3 salles de classe ACDI



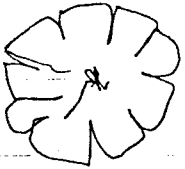
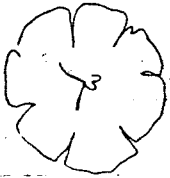
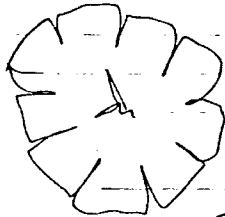
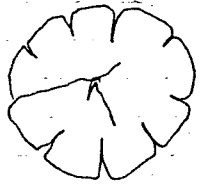
18



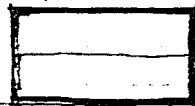
3 salles de classe ACDI



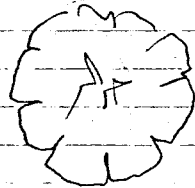
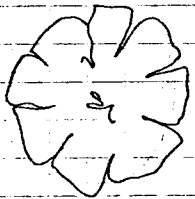
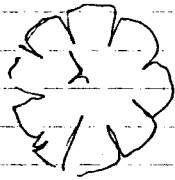
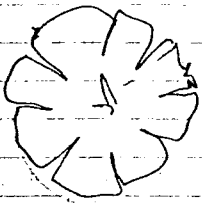
KUMBIA
↑
PISTE
↓
KAMELE CENTRE



Dispensaire ACDI



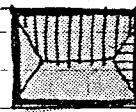
terrain de jeu



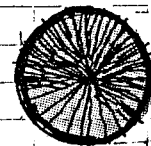
logement ACDI



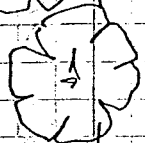
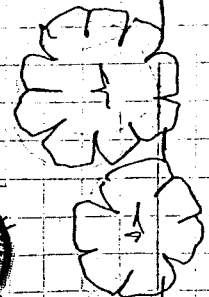
USMD maison en dur



USMD maison en matériaux locaux



USMD case en matériaux locaux



ANNEXE 3. TEMPORARY SHELTER AFTER THE EARTHQUAKE

Immediate post-earthquake shelter was provided by tents, and a few people were still using tents for part of their shelter 18 months later.

Most people have built small 4m diameter round huts, with bamboo matting (seco) walls, a post frame, and a thatched roof. (See photos overleaf.) The huts have one or two openings. These huts have had to be replaced 2 or 3 times since the earthquake.

Some people have repaired their round houses by taking down the mud walls to a maximum height of 0.75 - 1 metre and putting bamboo matting higher up.

In most cases the bamboo matting has been plastered with mud, which has contributed to its rapid deterioration.

The temporary shelter conforms with the proposal made by Scott Johnson, RHUDO Abidjan, following his visit to the Koumbia area in February 1984.



TEMPORARY ROUND HOUSES WITH BAMBOO MATTING WALLS.



ANNEXE 4. BASIC MATERIAL QUANTITIES FOR EACH BUILDING TYPE

1. DEMONSTRATION ROUND HOUSE WITH LOCAL MATERIALS

ITEM	UNIT	QUANTITY	10% ON WASTABLE ITEMS
1.1 FOUNDATION			
(i) Excavation	m ³	6.54	
(ii) Laterite block footing 0.18 x 0.32 (d x w)			
a. Laterite blocks	m ³	1.96	2.20
b. Mortar 1:6			
- cement	sack	5	5.5
- sand	m ³	1	1.10
(iii) Foundation wall - 3 courses of fired brick laid laterally			
a. Bricks	unit	770	850
b. Mortar 1:6			
- cement	sack	6.5	7
- sand	m ³	1.3	1.5
1.2 WALLS : Mud bricks and mud mortar			
(i) Mud bricks (0.24 x 0.14 x 0.10)	unit	2560	2800
(ii) Mud mortar	(m ³)	4.25	-)
dry volume x 1.5 = loose earth	m ³	6.40	7.0
(iii) Mud plaster (0.015 thick)	(m ³)	2.75	-)
dry volume x 1.5 = loose earth	m ³	4.13	4.5
1.3 BAMBOO FRAMING			
(i) Verticals			
41 x 1.70)			
41 x 1.85)			
10 x 1.90)			
10 x 2.20)			
10 x 2.95)			
10 x 3.20)			
24 x 3.25)			
24 x 3.40)			
using bamboos 6m long in bundles of 10	fagots	7	8
(ii) Horizontals using split bamboos 6m long: total 600m ÷ 2	fagots	5	5.5
(iii) Bamboo battens on top of walls 65 x 0.30	fagots	0.35	0.5
(iv) Tie wire : length 350m x 0.0183 kg.	kg	6.4	7
1.4 RING BEAM			
5 split bamboos in a bundle x 4lm (bamboos 6m long in bundles of 10)	fagots	3.5	4
1.5 ROOF FRAME			
(i) Vertical bamboos, 6m long, at 15cm centres at perimeter = 200 bamboos	fagots	20	
(ii) Horizontal, allowing equivalent 2½ bamboos at each layer, 30cm centres, bamboos 6m long = 138 bamboos	fagots	14	
(iii) Binding bark	m	500	

ITEM	UNIT	QUANTITY	10% ON WASTABLE ITEMS
1.6 THATCH			
Bundles	bundles	200	
1.7 FLOOR			
Compacted earth (& dung) 0.5cm deep	(m ³)	3	-)
loose earth volume x 1.5	m ³	4.5	5
1.8 OPENINGS			
(i) Doors and frames 1.20 x 1.50	unit	2	
hinge sets x 4 + 1 lock/latch	set	2	
(ii) Doors and frames 0.85 x 1.92	unit	4	
hinge sets x 2 + 1 latch	set	4	
(iii) Window shutters 1.00 x 0.60	unit	3	
hinge sets x 2 + 1 latch	set	3	

2. DEMONSTRATION RECTANGULAR HOUSE WITH LOCAL MATERIALS

ITEM	UNIT	QUANTITY	10% ON WASTABLE ITEMS
2.1 FOUNDATION			
(i) Excavation (average)	m ³	5.6	
(ii) Laterite block footing 0.18 x 0.32 (d x w) average			
a. Laterite blocks	m ³	1.6	1.75
b. Mortar 1:6			
- cement	sack	4	4.5
- sand	m ³	0.8	0.9
(iii) Foundation wall - 3 courses of fired brick laid laterally			
a. Bricks	unit	720	790
b. Mortar 1:6			
- cement	sack	6	7
- sand	m ³	1.2	1.3
2.2 WALLS : Mud bricks and mud mortar			
(i) Mud bricks (0.24 x 0.14 x 0.10)	unit	2532	2785
(ii) Mud mortar	(m ³)	4.25	-)
dry volume x 1.5 = loose earth	m ³	6.38	7.0
(iii) Mud plaster (0.015 thick)	(m ³)	2.73	-)
dry volume x 1.5 = loose earth	m ³	4.10	4.5)
2.3 FRAMING IN BAMBOO			
(i) Verticals : 124 x 2.67 bamboos 6m long in bundles of 10	fagots	6.5	7
(ii) Horizontals : 8 layers of split bamboos : 582m run	fagots	5	5.5
(iii) Bamboo battens on top of walls 61 x 0.30 = 18.3m in 6m lengths	fagots	0.3	0.5
(iv) Tie wire : 550 x 0.50 = 275 275 x 0.0183kg	kg	5	5.5
2.4 RING BEAM			
Timber : 10cm Ø	m	44	48
2.5 ROOF FRAME			
(i) Truss (two times)			
a. Principal rafters 120cm Ø	m	4 x 4.50	
b. Struts 10cm Ø	m	4 x 2.30	
c. Tie beam 12cm Ø	m	2 x 6.18	
d. King post 10cm Ø	m	2 x 3.25	
(ii) Hip rafters	m	4 x 5.50	
struts	m	4 x 2.75	
(iii) Ridge pole	m	2.40	
(iv) Purlins	m	2 x 5.50	
	m	2 x 8.50	
	m	2 x 3.30	
	m	2 x 6.18	
	on hip		
(v) Secondary rafters : 5m runs at 50cm centres (29 ÷ 10)	fagots	3	
(vi) battens at 30cm centres 333m ÷ 6 = 55.5 bamboos	fagots	6	
(vii) Nails (10cm)	kg	4	
Binding strips	m	500	
2.6 THATCH			
Bundles	bundles	200	

ITEM	UNIT	QUANTITY	10% ON WASTABLE ITEMS
2.7 FLOOR			
Compacted earth (& dung) 0.5cm deep			
- 11.5m ² x 4 x 0.005	m ³	2.5	
- loose earth x 1.5	m ³	3.75	
2.8 OPENINGS			
(i) Door and frame 0.85 x 2.26	unit	4	
hinge sets x 2 + 1 lock/latch	set	4	
(ii) Window shutters and frame 1.05 x			
0.85	unit	6	
hinge sets x 2 + 1 Latch	set	6	

3. DEMONSTRATION RECTANGULAR HOUSE WITH REINFORCED CONCRETE AND FIRED BRICK

ITEM	UNIT	QUANTITY	10% ON WASTABLE ITEMS
3.1 FOUNDATION			
(i) Excavation (average)	m ³	7.65	
(ii) 5cm layer of sand	m ³	0.91	1.0
(iii) Concrete footing (vol. 0.15 deep x 0.44 wide; mix 1:2:4 -	m ³	2.75)	
a. cement	sack	18	20
b. sand	m ³	1.25	1.38
c. gravel	m ³	2.50	2.75
For detail of rebar, see end of section.			
3.2 REBAR in 6m lengths -			
- 10mm Ø : 60 bars	kg	223	
- 5mm Ø (at 0.154 kg/m)	kg	15	
- tie wire	kg	3	
(including FOOTING, COLUMNS, RING BEAM)			
3.3 COLUMNS including teething into brickwork			
Concrete (vol. mix 1:2:4	m ³	1)	
a. cement	sacks	7	8
b. sand	m ³	0.45	0.5
c. gravel	m ³	0.63	0.7
3.4 RING BEAM 0.12 x 0.14 (vol. mix 1:2:4			
a. cement	sacks	4.5	5
b. sand	m ³	0.31	0.35
c. gravel	m ³	0.63	0.7
3.5 BRICKWORK (wall vol. $\frac{1}{3}$ mortar; $\frac{2}{3}$ brickwork bricks (local size 0.14 x 0.24 x 0.10) mortar 1:6			
a. cement	sack	20.5	22.5
b. sand	m ³	4.1	4.5
3.6 TIMBER WALL PLATE 10cm Ø in 1m lengths			
	m	44	
3.7 ROOF FRAME			
(i) Truss (two times)			
a. principal rafters 120cm Ø	m	4 x 3.95	
b. struts 10cm Ø	m	4 x 1.95	
c. tie beam 12cm Ø	m	2 x 6.18	
d. king post 10cm Ø	m	2 x 1.50	
(ii) Hip rafters 12cm Ø			
struts 10cm Ø	m	4 x 5.00	
struts 10cm Ø	m	4 x 2.00	
(iii) Ridge pole 12cm Ø			
Ridge pole 12cm Ø	m	1 x 2.50	
(iv) Purlins 10cm Ø			
Purlins 10cm Ø	m	2 x 6.20	
Purlins 10cm Ø	m	2 x 8.40	
Purlins 10cm Ø	m	2 x 3.10	
Purlins 10cm Ø	m	2 x 3.10	
Purlins 10cm Ø	m	2 x 4.20	

ITEM	UNIT	QUANTITY	10% ON WASTABLE ITEMS
(3.7 ROOF FRAME contd.)			
(v) Secondary rafters : at 1.2 centres, and 10cm \emptyset half poles.	m	8 x 4.0	
	m	8 x 2.7	
	m	8 x 1.4	
(vi) Battens : 7cm \emptyset half poles	m	75	
(vii) Nails (10cm)	kg	5	5.5
3.8 CORRUGATED ROOF SHEETING			
2.40 x 0.65 sheets with 5 cm horizontal lap, and 15cm vertical lap	(m ²)	75)	
ridge covering	sheet	54	
roof nails	m	23	
washers	kg	10	
	kg	3.5	
3.9 FLOOR SCREED : 5cm concrete			
floor area 46m ²	(m ³)	2.3)	
concrete mix 1:2:4 -			
a. cement	sack	15	16.5
b. sand	m ³	1.04	1.15
c. gravel	m ³	2.1	2.3
3.10 OPENINGS			
(i) Door and frame 0.85 x 2.26	unit	4	
hinge sets x 2 + lock/latch	set	4	
(ii) Window shutters and frame 0.85 x			
1.06	unit	6	
hinge sets x 2 + latch	set	6	

REBAR DETAIL (See Fig.40)

ITEM	QUANTITY	LENGTH	N ^o OF BARS	DESCRIPTION	
A	16	6.00m	16	Horizontal bars	
B	32	2.60m	end of column bars		
C	8	2.00m	2	Corners	
D	36	3.35m	36	Column bars	
E	4	1.60m	}	Upper layer, ring beam, outside corner	
F	4	1.60m		6	Upper layer on ring beam, straight run
G	16	1.40m			Upper layer, inner bend of ring beam

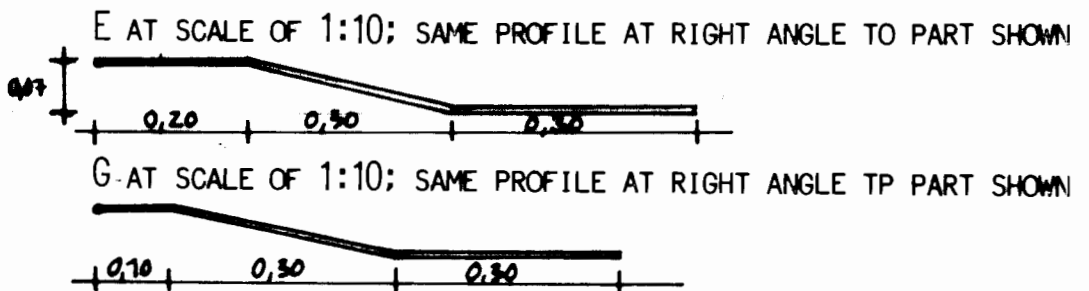
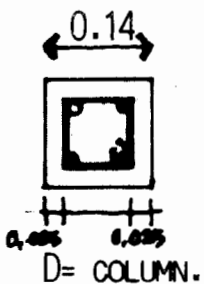
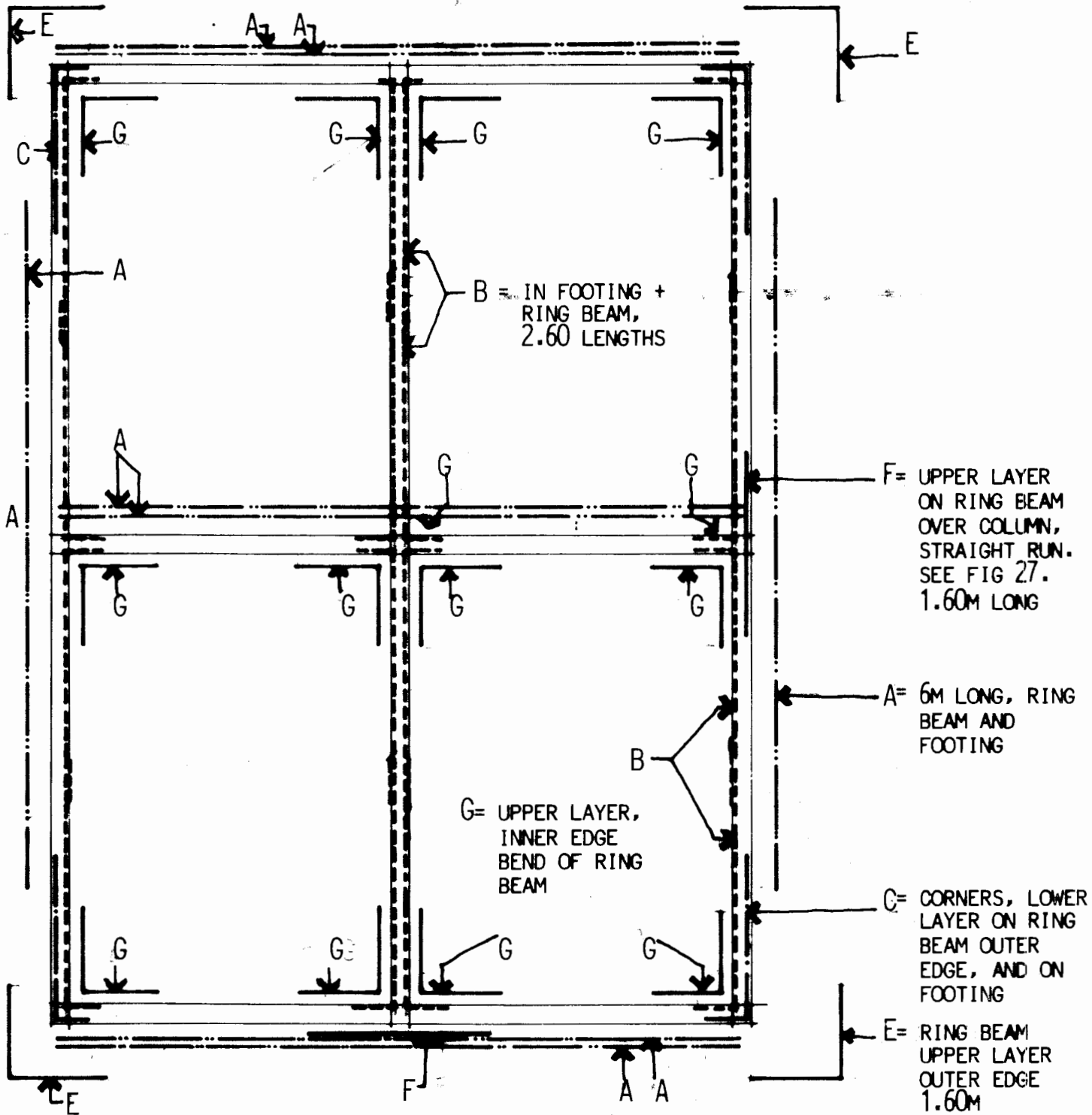


FIG. 40. REBAR LENGTHS AND POSITIONS, RELATED TO QUANTITIES LIST. DEMONSTRATION RECTANGULAR HOUSE WITH DURABLE MATERIALS.