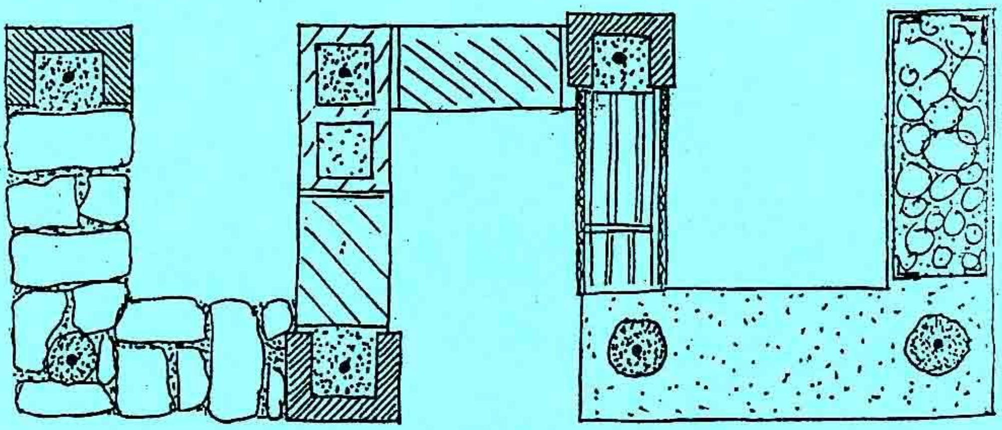
HUYS ADVIES

Yemen Arab Republic

Kingdom of the Netherlands
Commission of European Communities

Dhamar Aided Self Help Reconstruction Project

BUILDING TECHNIQUES, FINAL REPORT NO 5, PHASE 1.
PLANNING ACTIVITY No 32



Sanaa DATE: 21 AUGUST 1984

Report by: Sjoerd Nienhuys
Architect, Seismic Engineer Consultant

Report date: August 1984
Digitized: December 2016
Location: Dhamar and Mahgrib Ans
Project: Dhamar Aided Self-Help (Earthquake) Reconstruction Project

I started to clean up my archives and thought this may be interesting for some people. The information provided herein is still very much valid. Earthquakes do occur, and the earthquake resistant building techniques have not changed at all.

In this period (1983-1984) colour photography was widely used, but computers were only just starting to be used by consultant companies and private persons. Since 1983 I started writing reports on the first Kaypro, a metal box computer with 5" green light cathode tube screen and 5" floppy disks. Without battery back-up, you needed to save your work every 5 minutes, knowing all codes.

The original report was typed on such a Kaypro, and printed by a dot-matrix printer. The printing paper was an almost endless sheet long, folded and in a pack. After printing you needed to tear each sheet loose along the micro perforations. Our photocopy machine allowed to make enlargements and reductions; as a first. Photocopies of reports were bound with 21 slot plastic multi-binders.

ABSTRACT

Illustrated report about the seismic resistant building techniques suitable for aided self-help construction in areas with an abundance of natural stone or clay soils. U shaped cement blocks for wall endings and lintel or roof beams can be hand cast. These U shaped cement blocks provide room for casting reinforced concrete columns and beams, required as basic earthquake reinforcement. The technology about seismic resistant construction is explained. As general wall reinforcement galvanised wire-mesh is used, allowing a lower cement percentage in the masonry mortar, thus economizing costs. The technology with galvanised wire-mesh can also be used to reinforce loam and clay buildings that are constructed on the Dhamar plateau. A new construction method with wire-mesh cages is presented by Nagron. These galvanised wire-mesh cages are filled with rubble stone and cement plastered, providing a highly earthquake resistant building.

Key words: Earthquake, reconstruction, self-help, Dhamar, Yemen, stone, architecture, wire-mesh

CONTENT

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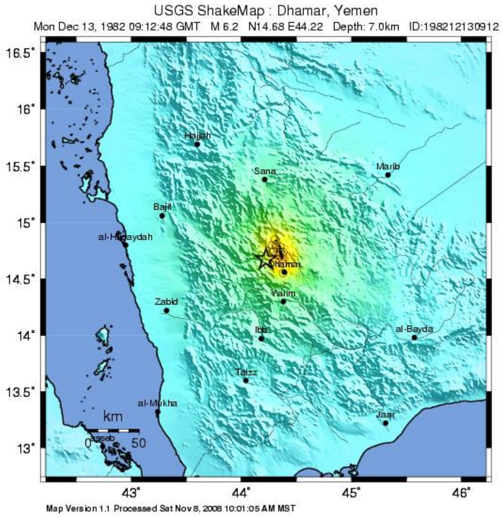
'Notes' at the bottom of the pages, provide additional information, added in December 2016.
The foreword is added with some photos of the houses realised.

Foreword

A magnitude 6.0 earthquake (Mercalli VIII) occurred on 13 December 1982 in the vicinity of Dhamar, causing the death of about 2800 persons.



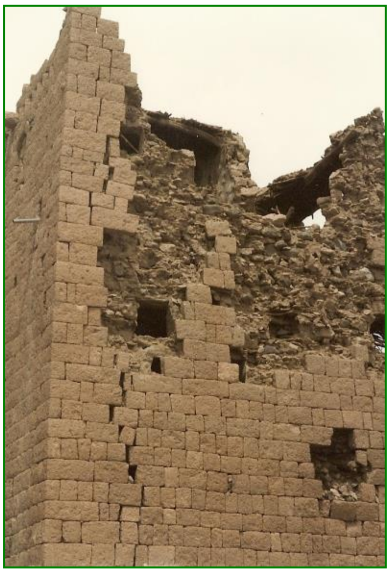
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Many victims were found on the eastern side of the epicentre, being the mountainous areas, down from the high Dhamar plateau, where buildings were constructed from dressed and un-dressed rocks, often masoned without binding cement mortar.

These mountain areas had very few roads, only passable with sturdy 4WD jeeps. The project therefore needed to formulate an improved seismic resistant design, minimising material transport and maximizing the widely available rock material.

Assisted self-help, by which the project would supply the technology and the essential materials such as cement and reinforcement, was selected as the most likely working method. The number of 900 units were built by 1985.

The one floor prototype houses were first constructed on the project office site and had traditional building style elements, such as window design and natural rock walls. After this, a Swiss Aid project team used the construction technology to build their own compound houses, including a larger hall. Houses built in this technology can be horizontally and vertically extended.

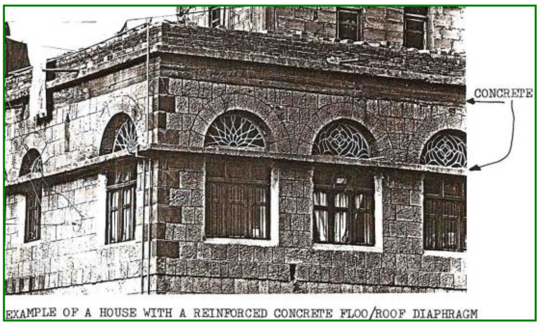


Examples of very large houses, having two or three floors, that were damaged during the earthquake. Studying these (just standing) mansions gave a good indication about what was wrong in the design, and gave cause to collapse with an earthquake. In particular the fine and square tailoring or cutting of only the exterior face of the stones, and the complete lack of cement mortar or other tie-beam constructions, caused a general lack of bonding.

The introduction of cement mortar in combination with steel stress reinforcement and galvanised wire-mesh, plywood floor and roof diaphragms, made the new houses highly earthquake resistant.

The use of a special U shaped cement block for both the wall endings (also door and window sides) and tie-beams makes the construction in combination with the cut natural stones simple. First the cement block corners are masoned, and after that the wall is filled in with the reinforcements. By alternating the cornerstones and introduce colour variations, the traditional architectural elements could be realised

The existing design of the beam through the windows can be used as reinforced tie-beam to enhance the strength of the building.



Local masons first placed the U shaped cement blocks after which the dressed stones were masoned in cement mortar and reinforcements.

Although the project assisted in the construction of single storey core-houses, some villagers extended these, using the same technique, in larger or double storey houses.

Black and white photo: larger building.
Photo right: finished prototypes.

See also the final evaluation report: pdf.usaid.gov/pdf_docs/PDAAV497.pdf

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DHAMAR AIDED SELF HELP RECONSTRUCTION PROJECT
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DATE: 21 AUGUST 1984
SUBJ: BUILDING TECHNIQUES, FINAL REPORT NO 5, PHASE 1.
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INTRODUCTION.

The following document gives a review of the proposals for the self help reconstruction buildings to be erected in the earthquake affected areas such as the Project area of the Magrib Ans.
This document is also a review of the experiences obtained with the construction of the staff houses in Dhamar and the first experiences of the construction of the Building Advice Centers in Dubah and Wathan. Partly based on the latest experiences an additional model house design has been developed which would require even less sand aggregate than the chosen U block design. (paragraph 3.1.pag.9)

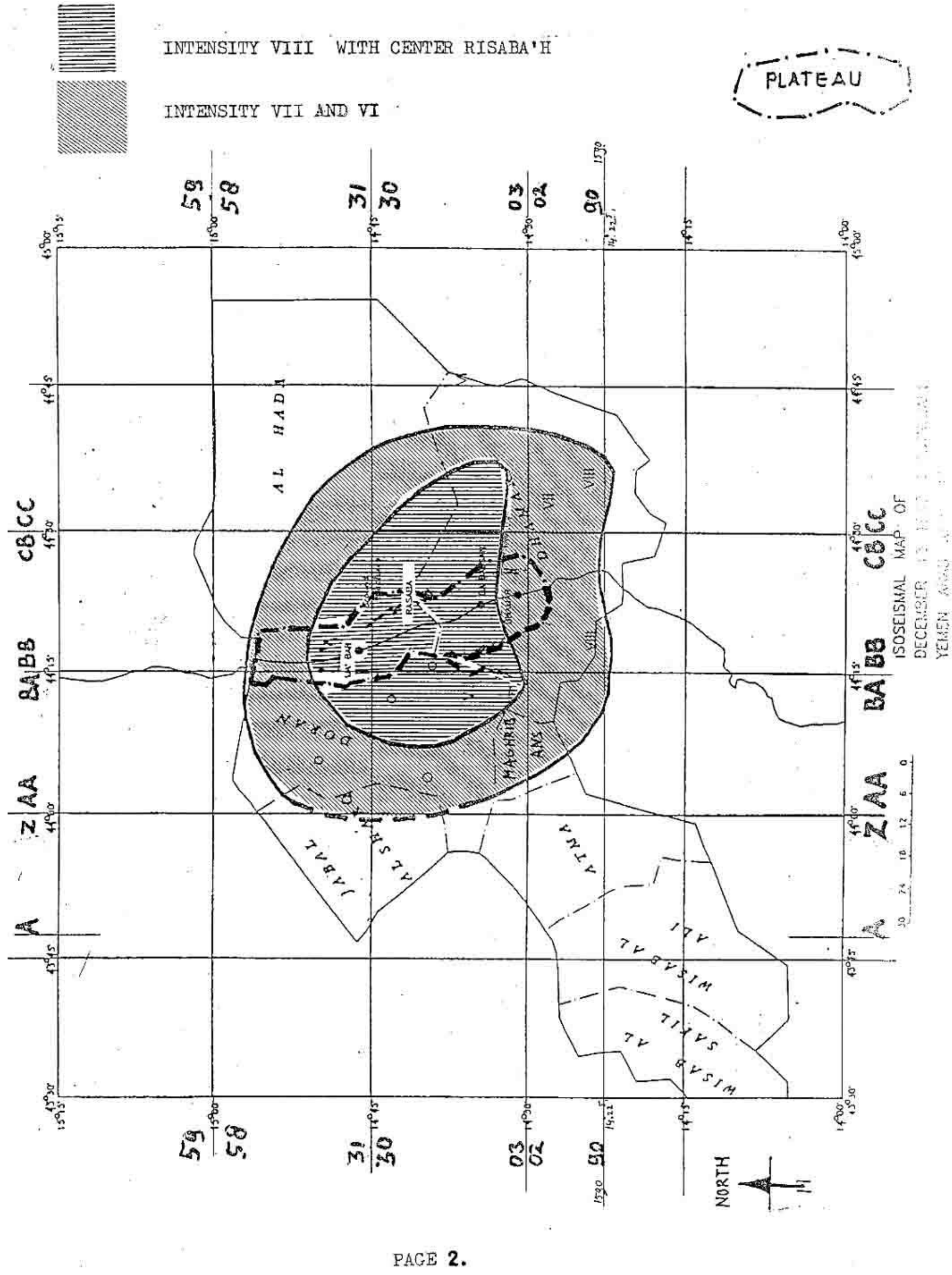
Self-help constructions in the Yemen are those buildings which are constructed with local craftsmen under the general direction of the owner of the dwelling. In practice an experienced mason will build the house for the owner, who will pay the man and his aids, eventually he can participate himself in some labour activities.

A main distinction can be made between systems suitable for self-help construction on the plateau area around Ma'bar (see page 2 and page 35) and those constructions which are considered for the mountain districts such as Dawran, Jabal Al Sharq, Maghrib Ans and large parts of Al Hada.(page 2.)
Such a distinction is based on the influence of the transport possibility and cost on the mass of the building materials. For example the designs with burnt brick or cement blocks are not feasible, when all those materials have to be transported from the plateau area down to the mountains.

This means, that all systems are possible on the plateau area, as well in the mountain area, but some will be more economic than others in the specific situations. For example, the natural cut stone designs, will be more expensive on the plateau area than the cement block designs. However the construction of those types of buildings will be a matter of taste, and for the people who have the money or easy access to natural stones, or to soil or cement blocks, can perfectly build any of the proposed constructions.

All designs are climatological adequate for the altitudes around 2000m (main mountain areas) upto 2500m (plateau).

Note: It was considered afterwards that thermal insulation could be improved with double glass windows and properly attached thick straw-clay and soil plaster on the inside of the walls.



PAGE 2.

Note: The project implementation started between map coordinates 03 – 30 and AA – BA.
The final DHV project area is located on the map between 58 – 03, and between AA – BA.

1. EVOLUTION OF TECHNIQUES.

The first phase of the Project has been characterized by a constant evolution of the designs, as to adapt those to;

a) relevant resistance to the suspected earthquake forces,
b) local technology in building techniques and methods,
c) available materials, labour and transport means,

1.1. Amount of reinforcement.

By further observations in the field, it was felt that the force of the earthquake were not that large in the Maghrib Ans, and hence the suspected future earthquake forces would not be that big. One of the results of this observation is the reduction of the amount of reinforcement steel. This could be done partly because the seize of the window opening was kept relatively small, and the walls would function very well as shear wall constructions.The basic reinforcement will allow a second storey to be constructed.(page 15, 21).

1.2. Type of reinforcements.

In order to have as a minimum joints in the masonry work which would not rapidly erode, a non erosive soil-sand-cement mortar is proposed for one of the modelhouses. The horizontal reinforcement in this case has to be galvanized steel, in order to avoid corrosion. The galvanized steel wire is 2-3mm thick and is factory produced as a wire mesh, which has to be cut to its required width. This is 5-10 cm smaller than the wall thickness.

1.3. Concentration of reinforcement.

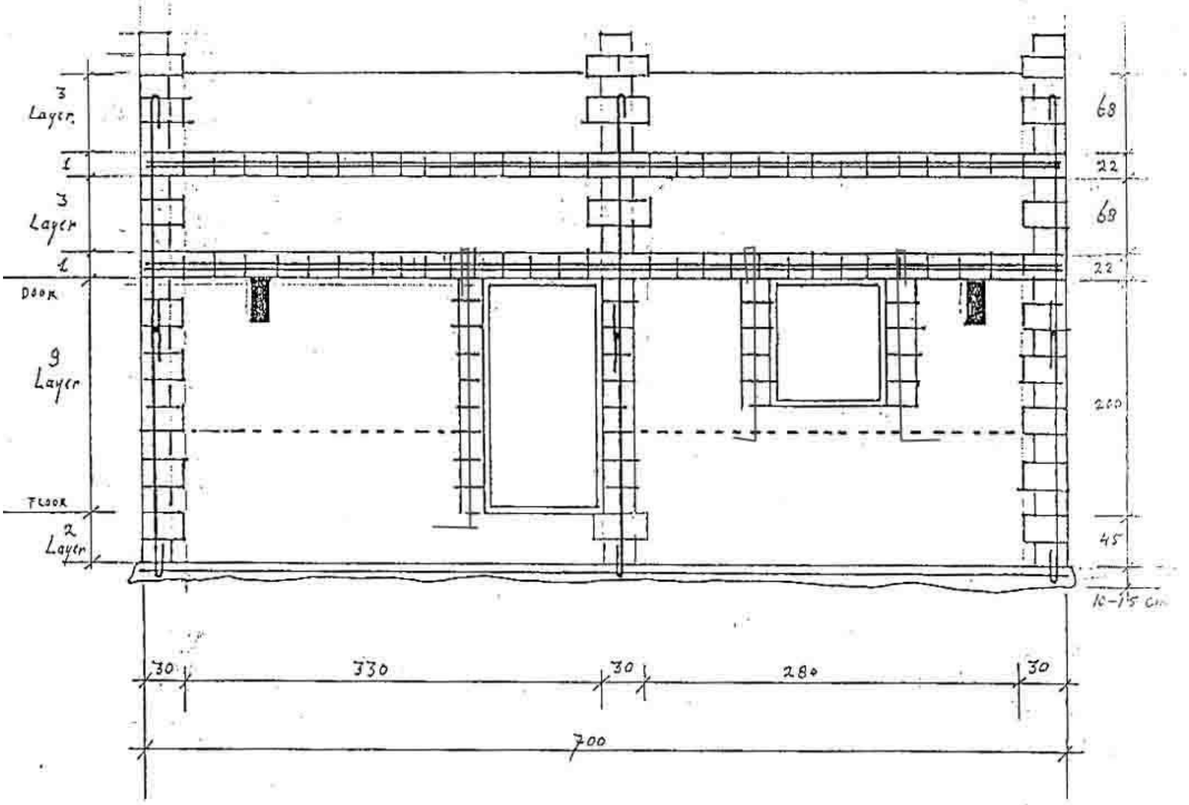
In two of the designs, (3.1. and 3.7.) a spreading of reinforcement is suggested instead of the realization of the concentrated tie beams at the window and at the floor/roof level.(page 11).The spreading of the thinner galvanized steel mesh reinforcement requires a whole zone above the windows in which no openings will be allowed. This zone, together with the floor diaphragm will provide for sufficient stress resistance and coherence of the construction.

1.4. Floor diaphragms.

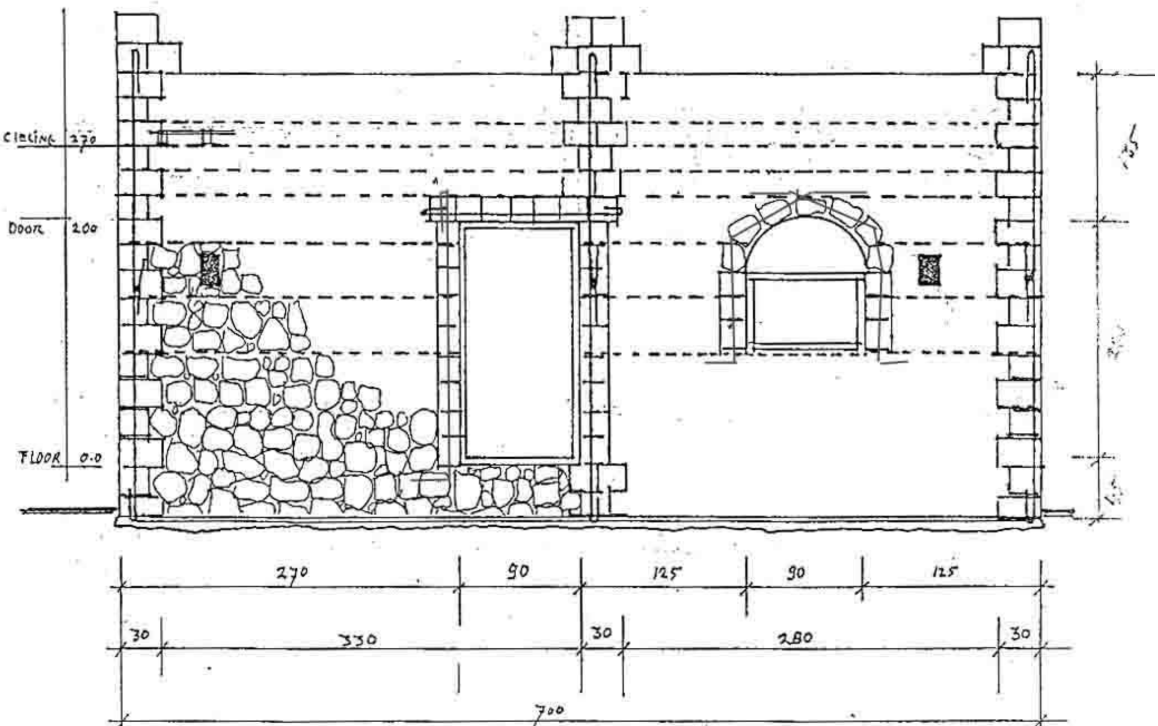
After several try-outs in the staff houses, ways have been suggested for the improvement of the floor diaphragms and their connection in its two horizontal directions to all the walls of the construction. The nailing of the 12mm plywood to ALL the joists will give a stiff horizontal diaphragm,(page 20) and this diaphragm has to be connected to the side walls parallel to the joists with galvanized steel strips or wire mesh. All the joists are tied to the wall with thick galvanized wire.(see page 13.)

Note: Construction details are also provided in the illustrated "construction manual self-help house."

CONCENTRATED REINFORCEMENT IN TWO TIE - BEAMS
2 BARS 8 mm IN TWO TIE-BEAMS



SPREAD REINFORCEMENT WITH GALVANIZED WIRE MESH



PAGE 4.

Note: The arch over the window can also be made with U blocks to accommodate the reinforcement.

2. OVERVIEW OF SYSTEMS.

2.1. Model house and core-house basic type. (page 9-15)
Natural stone walls 30 cm thick, cement mortar.
All wall endings and openings with 30cm U block.
Intersections of walls with 8mm steel bar reinforcement.
U block tie-beams 30cm wide.
Timber joists and plywood floor/roof diaphragm.

2.2. Model house and core-house, alternative. (page 16-21)
Natural stone walls 30 cm thick, soil-cement mortar.
All wall intersections with 30 cm U block.
Intersections of walls with 8mm steel bar reinforcement.
No window openings over the door level.
Above door level all layers with galvanized wire mesh reinforcement.
Timber joists and plywood floor/roof diaphragm.

2.3. Natural stone walls 30 cm thick. (page 22-26).
At wall intersections with casting of concrete and steel reinforcement of 8 mm steel bars.
Cast on reinforced concrete tie-beams 30cm wide.
Use of timber formwork for all casting.
Timber joists and plywood floor/roof diaphragm.

2.4. Massive cement block walls 20cm thick. (page 27-29).
U block corners for wall intersections and 8mm bars.
U block tie-beams 25 cm wide.
Timber joists and plywood floor/roof diaphragm.

2.5. Massive cement block walls 20cm thick. (page 30-32).
Hollow cement block corners for wall intersections, reinforcement 8mm bars and filled with concrete,
U block tie-beams 25 cm wide.
Timber joists and plywood floor/roof diaphragm.

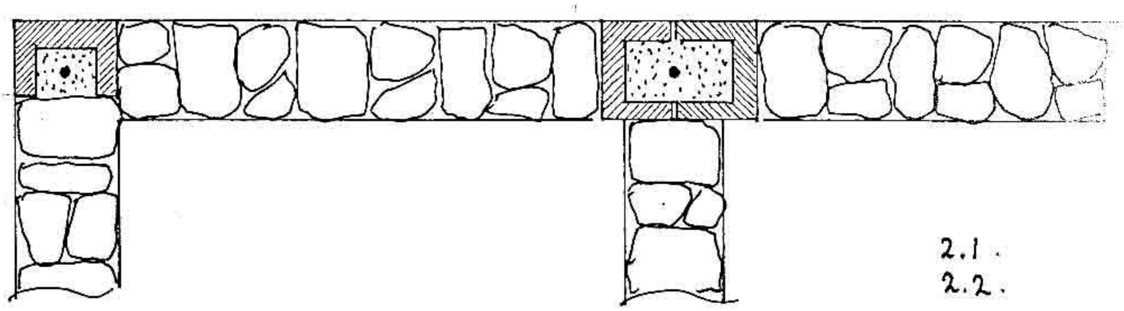
2.5.1. As above but with cast-on corners. (page 31 and 33).

2.6. Hollow burnt brick masonry walls 15cm. (page 34-35).
U blocks at all wall endings and openings, reinforcements at wall intersections, steel bars 8mm.
U block tie-beams 25 cm wide.
Timber joists and plywood floor/roof diaphragm.

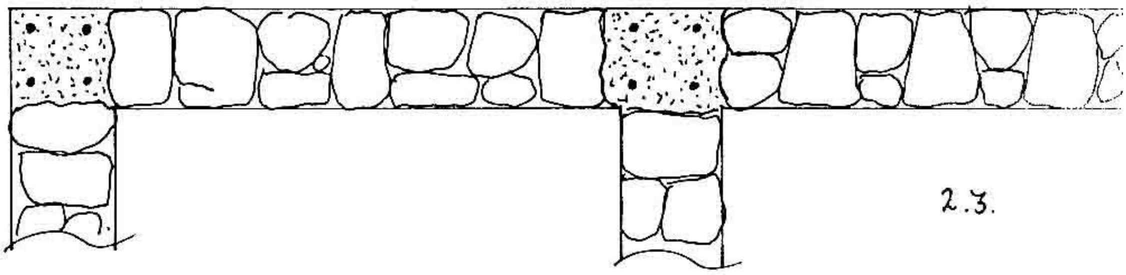
2.6.1. As above but with cast-on corners. (page 35 figure)

2.7. Reinforced soil construction, 40cm thick and with machine compacted walls. (page 36-41)
Formwork of prefab steel and plywood panels.
Galvanized steel wire mesh reinforcement.
Cast in corner reinforcements 8mm bar and concrete.
Reinforced concrete tie-beam constructions, 40 cm wide, or increased application of wire mesh.
Timber joists and plywood floor/roof diaphragm.

Note: The option 2.7. with compacted clay soil was not realized since this was outside the project area of the DHV project assignment. Different aid organisations had each their own working area.



2.1.
2.2.



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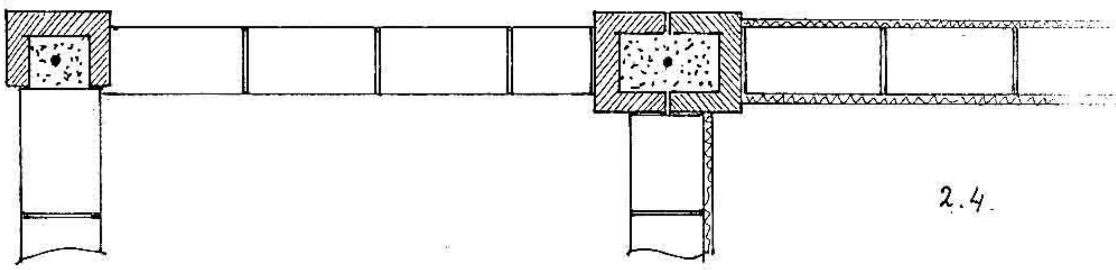

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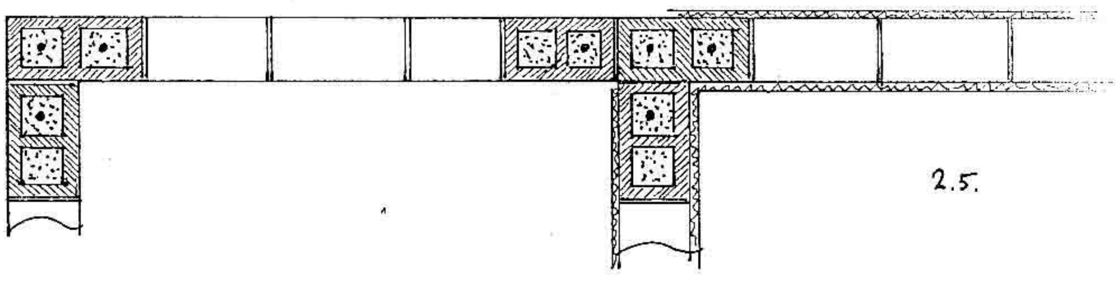

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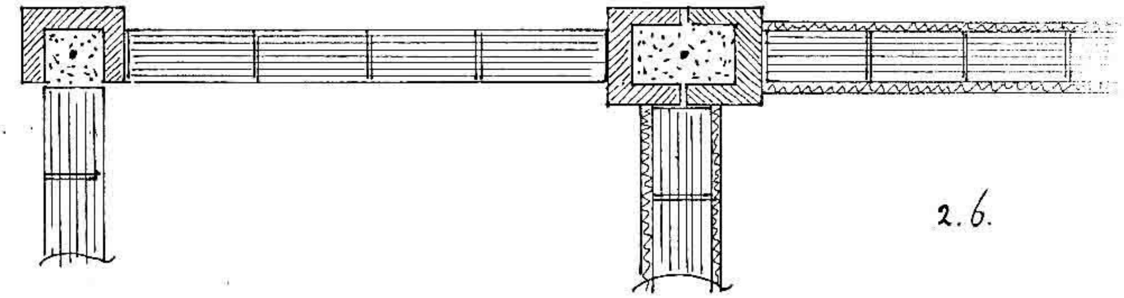

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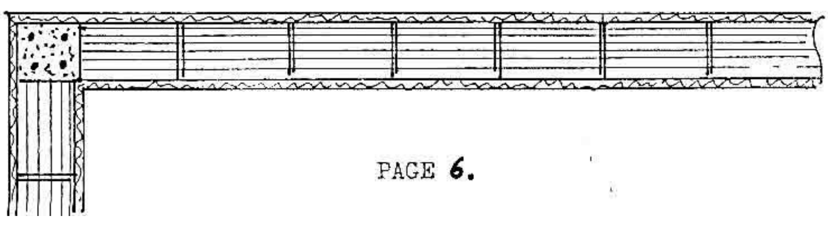


2.6.1

2.8. Wire-mesh-frame NAGRON system, 25 cm rubble walls. (pag 42-44)
Factory prefabricated steel frames with mesh, all galvanized. Plaster inside and outside.
Steel floor/roof canal sheets with rubble fill.

The last system, the prefab NAGRON galvanized wire-mesh frame can be modified for use with soil-fill. This variety is not independently elaborated. With this variety, the larger mesh is covered at the inside of the wall with a fine mesh. The plaster should be an elastic lime-mud plaster to allow swelling and contraction due to hygroscopic activity of the clay component in the walls.

All suggested building methods, except the NAGRON prefab system have a timber floor/roof diaphragms, covered with an impermeable plastic roof foil and a mud cover for the roof.

Reinforced concrete constructions.

The proposed systems, the U block and stone architecture, with and without the tie-beams are developed partly as an alternative to the wholly reinforced concrete design which is proposed by the Executive Office. This design would be filled in with hollow burned bricks.
Both elements, the reinforced concrete and the burned bricks, are transport intensive and complicated to realize in rural circumstances by self-help methods.

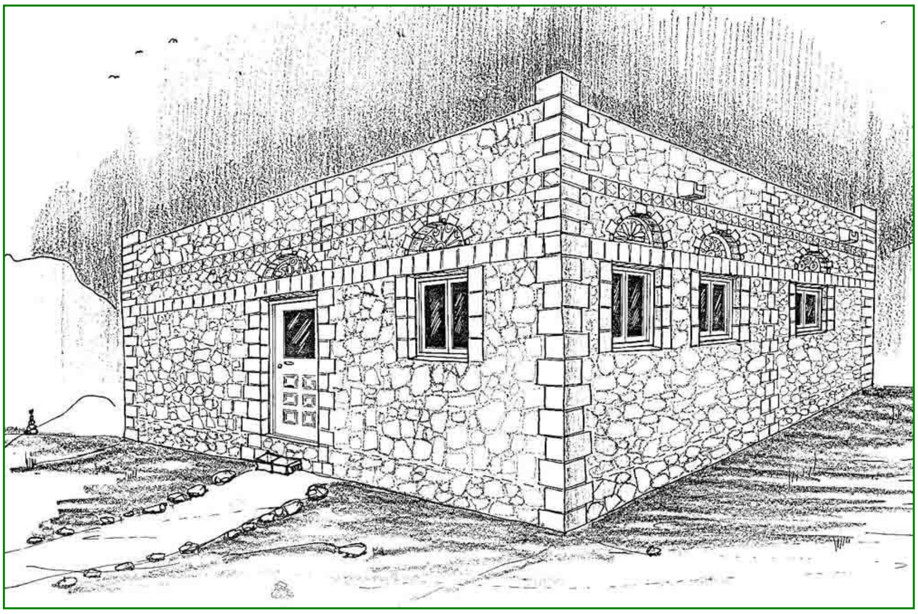
Lack of sand aggregate.

Apparently the availability of sand aggregate for the masonry mortar is scarce in the higher regions of the mountains, where the wadi does not have large deposites of gravel and stone. Unless the project will consider the crushing of aggregate to sand, the latter will become more and more expensive.
To avoid this problem and to provide a design which is adapted to these circumstances, the alternative design was developed and it is suggested to build the core-house in Dubah according to this design. In Wathan which is farther away from the plateau and the wadi is considerable larger, the problem of sand does not occur.

Since sand aggregate is required in the masonry, the amount of required sand is reduced by replacing 40% with soil, thus obtaining a stabilized earth joint, resistant against wind and rain erosion.

Note: In the mountain areas down from the high plateau, the supply of sand proved to be rather difficult. The sand was to be found only at the riverbeds, often hundreds of meters to one km lower in altitude than the locations where the house construction took place.

First concept drawing of the planned prototype houses showing the use of the U shaped cement blocks as decorative element, disguising the structural reinforcement along the wall endings and openings and the in-between window tie-beam and the wall plate and floor tie-beam.



The overall design concept needed to conform with existing architecture that can be found in countries where an abundance of natural stone exist, and is used as primary building material. The corner cement blocks and the cement blocks around the openings in the façade, have a similar appearance as natural cornerstones that are used in traditional stone architecture.

Houses in Britain with straight tailored cornerstones, providing a distinctive architectural feature.

Houses under construction with wall corner blocks.

Left: Ladakh.
Right: Tajikistan.

The use of pre-fabricated cement blocks along the wall endings and around the windows, allow the making of straight corners, after which the wall is filled in with slightly tailored stones. The house on the left has no tie-beam under and above the windows. The house on the right has adequate tie-beams. It is important that the floor diaphragms are intimately connected to these tie-beams. A light-weight and insulation roof structure avoids large earthquake loads.

3. SPECIFICATION OF SYSTEMS.

3.1. Natural stone wall 30cm, U block.

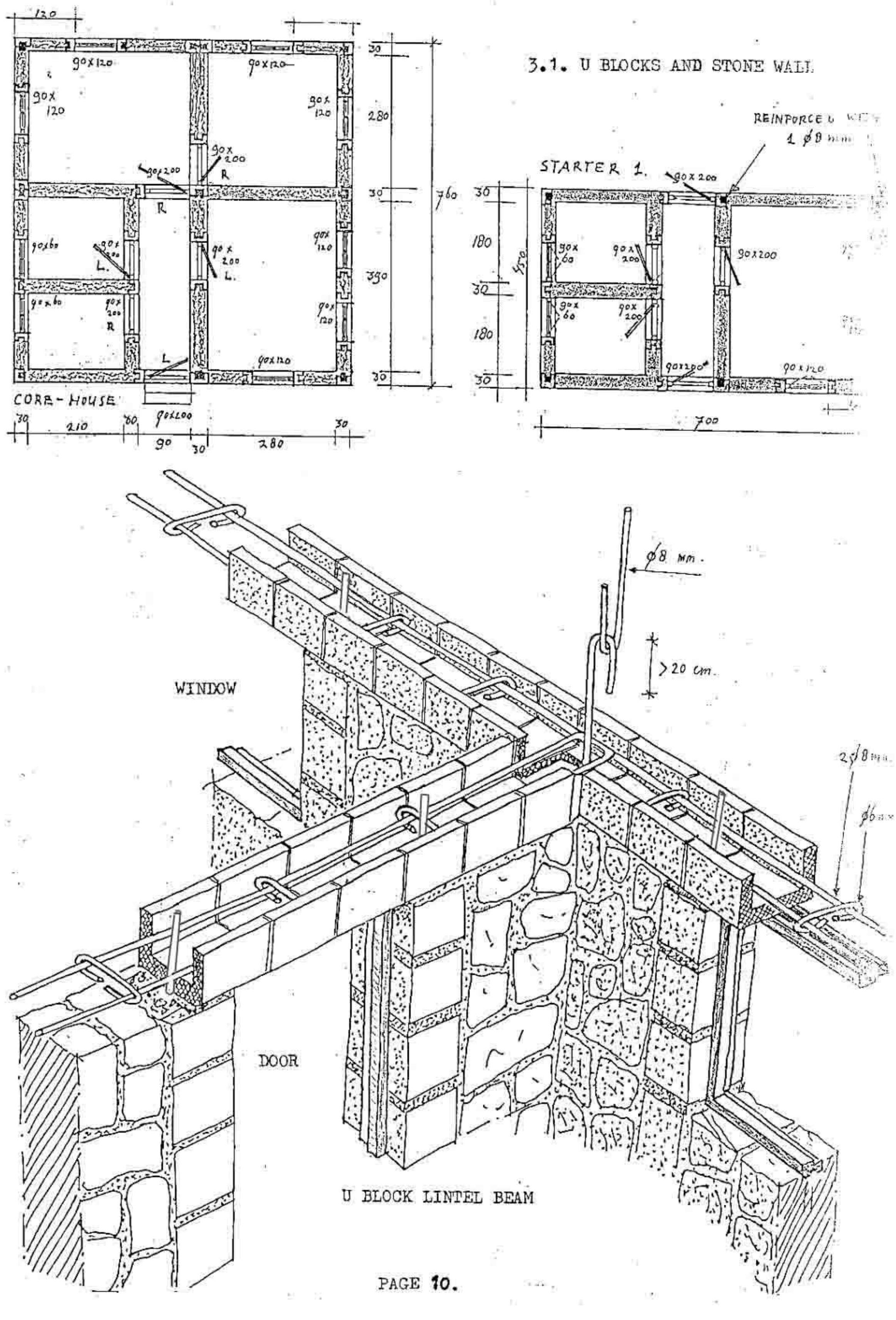
This selection is extensive commented in the Model house design report and the introduction document, reports 63/7. and no 86. (For general perspective see page 8)

Traditional buildings have thick and heavy, lose stone walls, (often more than 50cm wide) climatologically advantageous, but seismically extremely instable and dangerous. Basic improvement is the use of erosion resistant cement mortar for the masonry. However for those thick walls enormous amounts of mortar and cement will be required, whilst with cement mortar the wall has not to be so wide to obtain stability. Considering the climatological conditions, a minimum wall thickness of 30 cm was chosen.

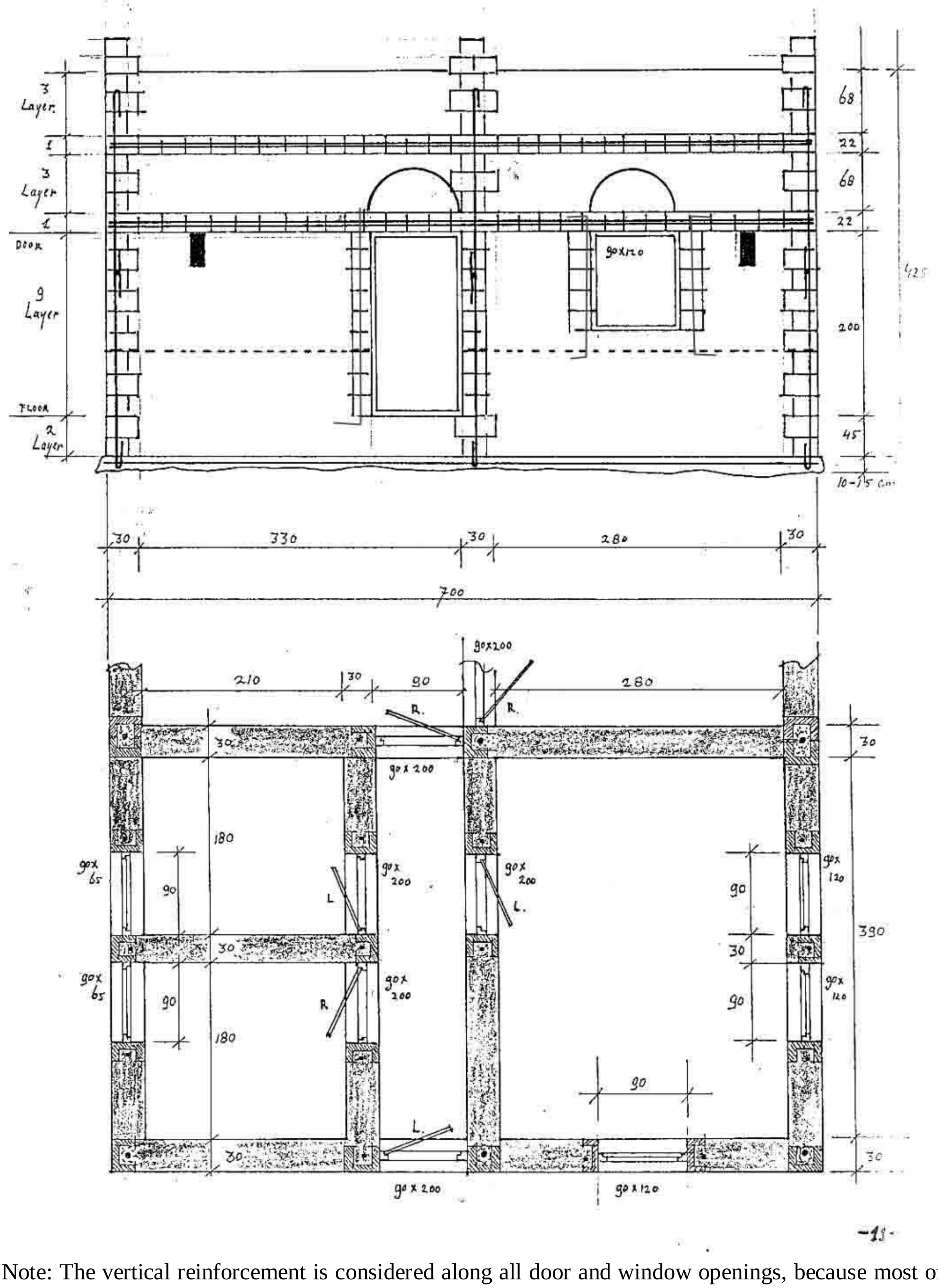
The thinner stone walls have less weight, thus the forces effected by the earthquake are smaller than with the thick traditional walls.
The **U** block allow straight and rapid construction of all corners of openings and wall endings, and it allows the easy placement of vertical reinforcement. The concrete cast in the **U** block gives ample protection of the reinforcement bars, it further provides a cheap formwork and good protection for tie-beams.(page 10)

The design has excellent climatological conditions, including adequate heat storage capacity and a sufficient heat transmission time-lag.
The architectural design is appreciating and within the Yemen characteristics of architecture. It allows both rubble masonry work and cut-stone masonry.(see page 12).
The special architectural feature of the use of the **U** block is the fact that even with rough rubble masonry a nice facade is obtained, due to the straight sides.(see page 14).
The rubble masonry is considerable less expensive than the cut-stone masonry. Within this system old stones from collapsed buildings can be used.

The choice of this construction method is based on the optimum use of the locally (abundant) available natural stone (tuff) and the existing skill of working this stone.
Due to the transport difficulties in the mountainous project areas, large material transports have to be avoided. It is suggested to find ways of local production of aggregates for the (limited) block making and the concrete. The **U** blocks can be hand-produced as was shown with the construction of the staff houses in Dhamar. They can also be machine produced with both the block laying machines as with the smaller pallet machines.

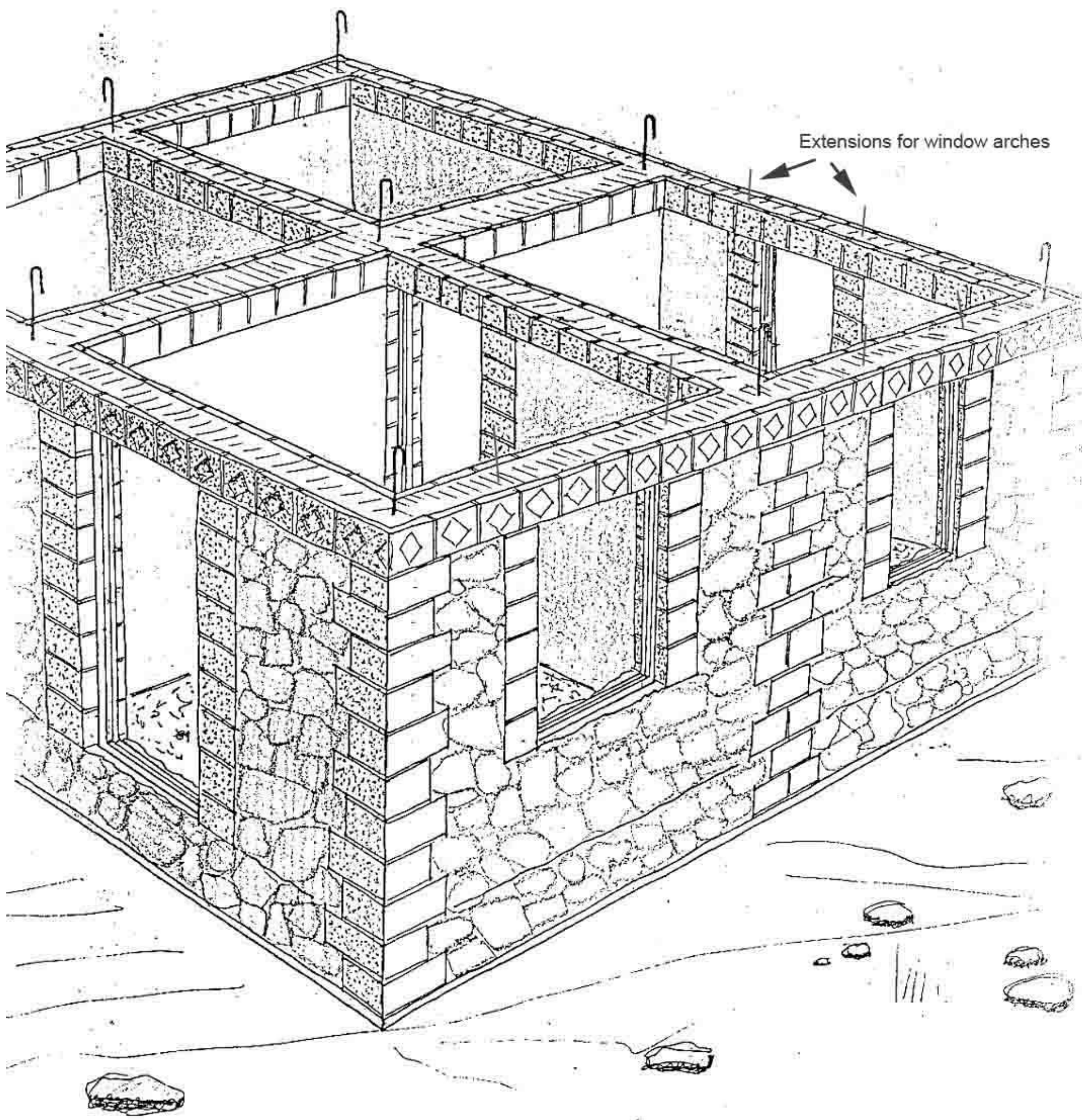


Note: Manufacturing details of the U block are given in the “construction manual self-help house”. Vertical reinforcement is required along all vertical openings of doors and windows.



Note: The vertical reinforcement is considered along all door and window openings, because most of the houses will be in the future vertically extended with one or two floors.

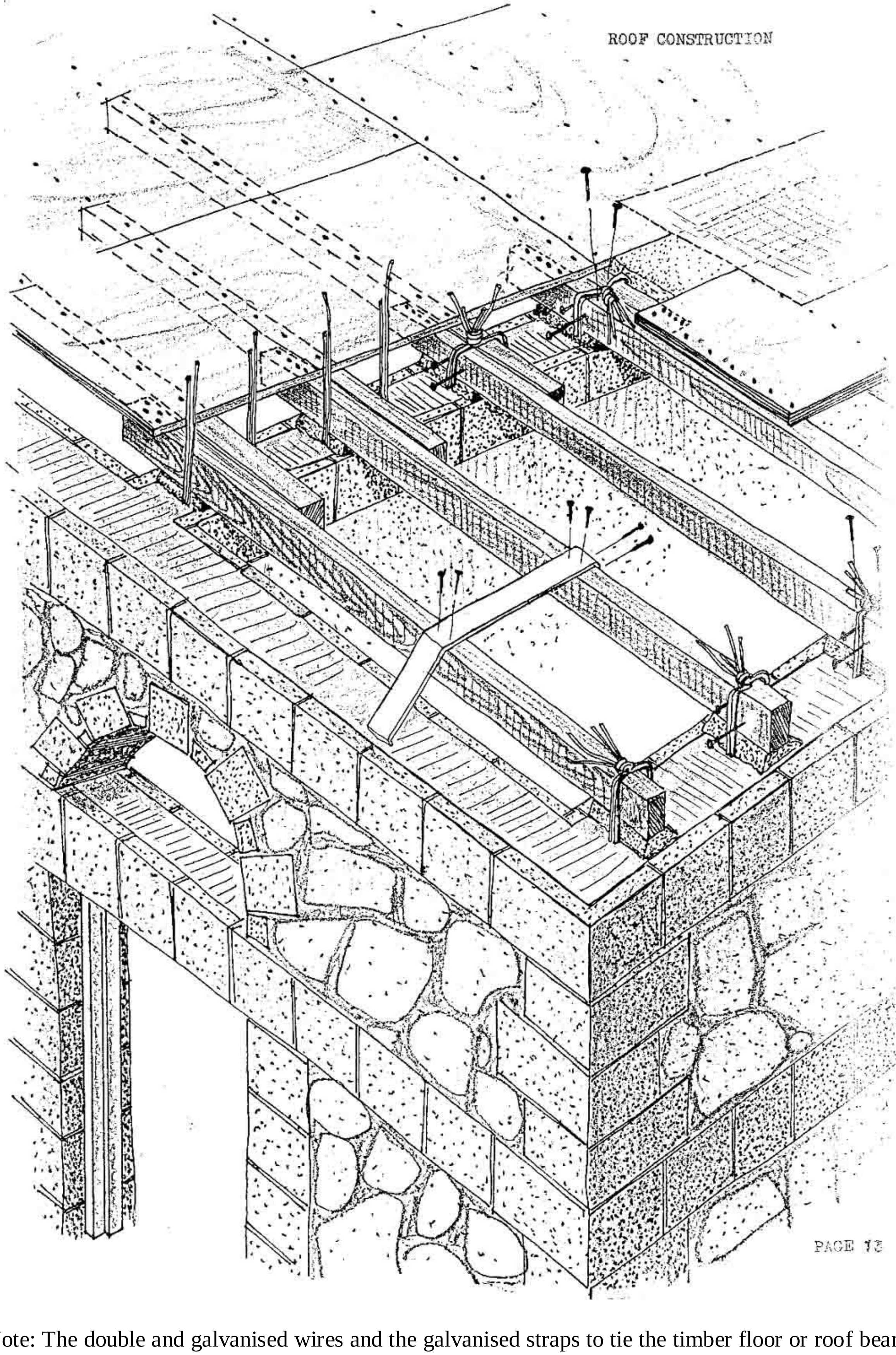
BUILDING SHOWN AT LINTEL BEAM-LEVEL



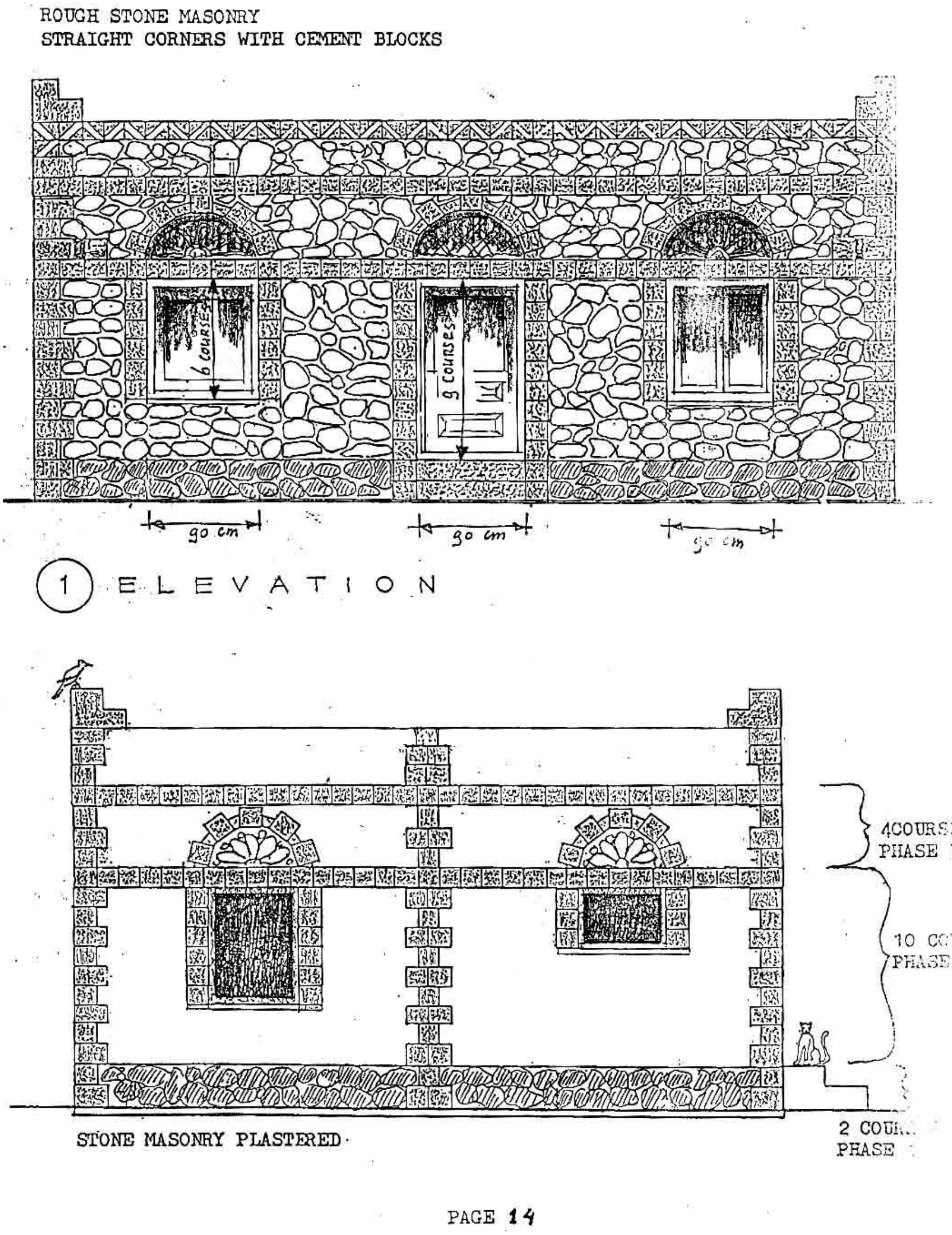
THE PREFAB STEEL DOOR AND WINDOW FRAMES
ARE PLACED BEFORE THE MASONRY IS MADE

PAGE 12

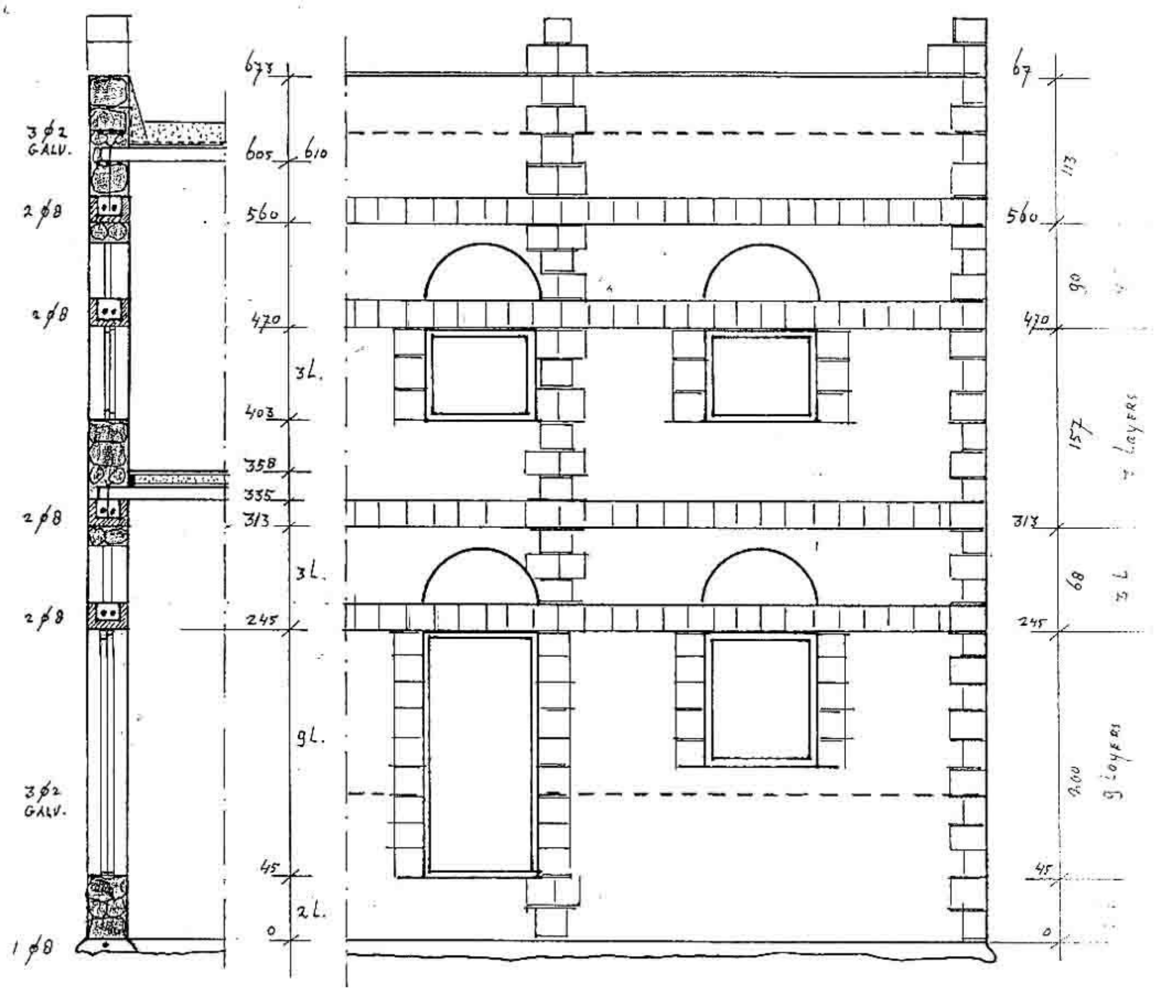
During the project implementation, many of these drawings were provided in a booklet to the masons, in order to give them instructions for the correct construction method. Most masons and stone cutters only had limited literacy skills, while the non-Yemini project staff had little Arabic language skills. From the buildings under construction video films were made and dubbed in Yemini language.
With a house extension, the new reinforcement bars need to be connected to the existing bars.

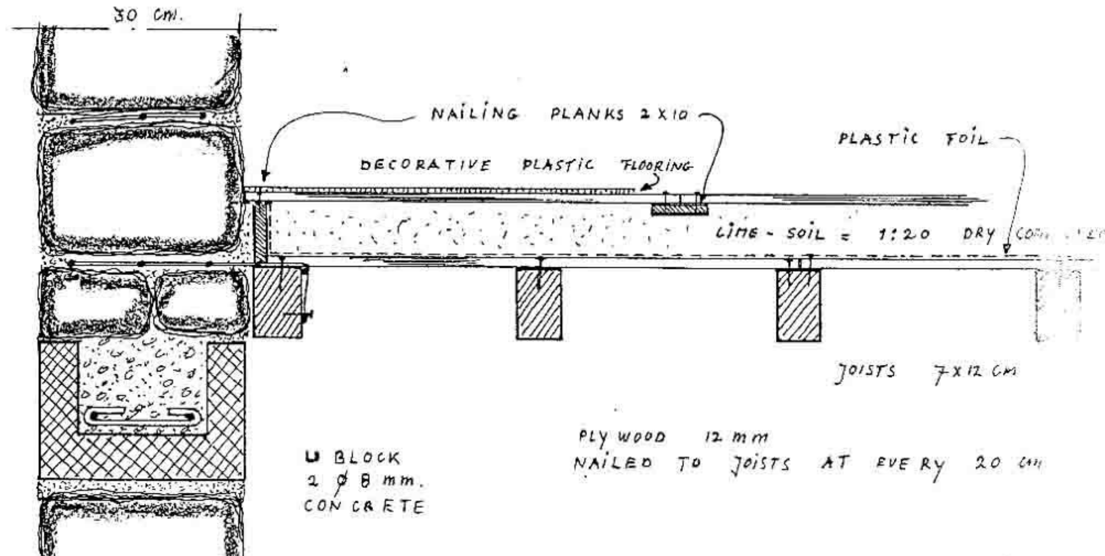


Note: The double and galvanised wires and the galvanised straps to tie the timber floor or roof beams need to be hooked under the tie-beam reinforcement and cast in the concrete on the correct locations.



The diamond indented patterns and the diagonal bars in the cement blocks were made by inserting a thin metal plate into the moulds with the figure welded on it. The cement mortar used was rather dry and strongly compacted with a double metal U frame section. After de-moulding the freshly cast cement block, the plate was pulled away from the fresh mortar.
The corner roof extensions covered the reinforcement bars required for vertical house extension.





-15-

Note: Most people wanted the upper storey windows to start one block above the floor for the Mufraz. In the Mufraz the people sit on pillows on the floor. This way they could easily look outside.

3.2. Natural stone walls, 30cm thick, U blocks for reinforcement of intersections of walls, galvanized wire mesh wall reinforcement.

This design is a variation from the fore mentioned U block design, developed in order to reduce the amount of sand aggregate. The masons mortar will be composed of 1 part of cement, 2 parts of clay containing soil and 3 parts of sand. This mortar will be sufficiently resistant against rain and wind erosion and much better than the present used mud for the joints.

Galvanized reinforcement steel wire mesh is used for the horizontal reinforcement. The reinforcement is evenly spread in the walls as also the earthquake forces are evenly spread. Above the door level, upto the floor level every layer of stone masonry has a reinforcement mesh. (see page 17 and 18). This band or series of layers shall not be interrupted by window openings. This is different compared to the other designs where a concentration of reinforcement is found at the lintel beam and the roof/floor beam. (page 11) The galvanization of this mesh avoids corrosion in the stabilized soil-cement joints.

The thick galvanized wire mesh is provided in rolls and with a greater width than the walls. It has to be cut at the proper width. (page 19). It also means that this system of construction and reinforcement is directly transferable to the traditional architecture with eventually thicker walls. With the thicker walls, automatically more and wider wire mesh is required, thus creating a heavier reinforcement for the heavier walls.

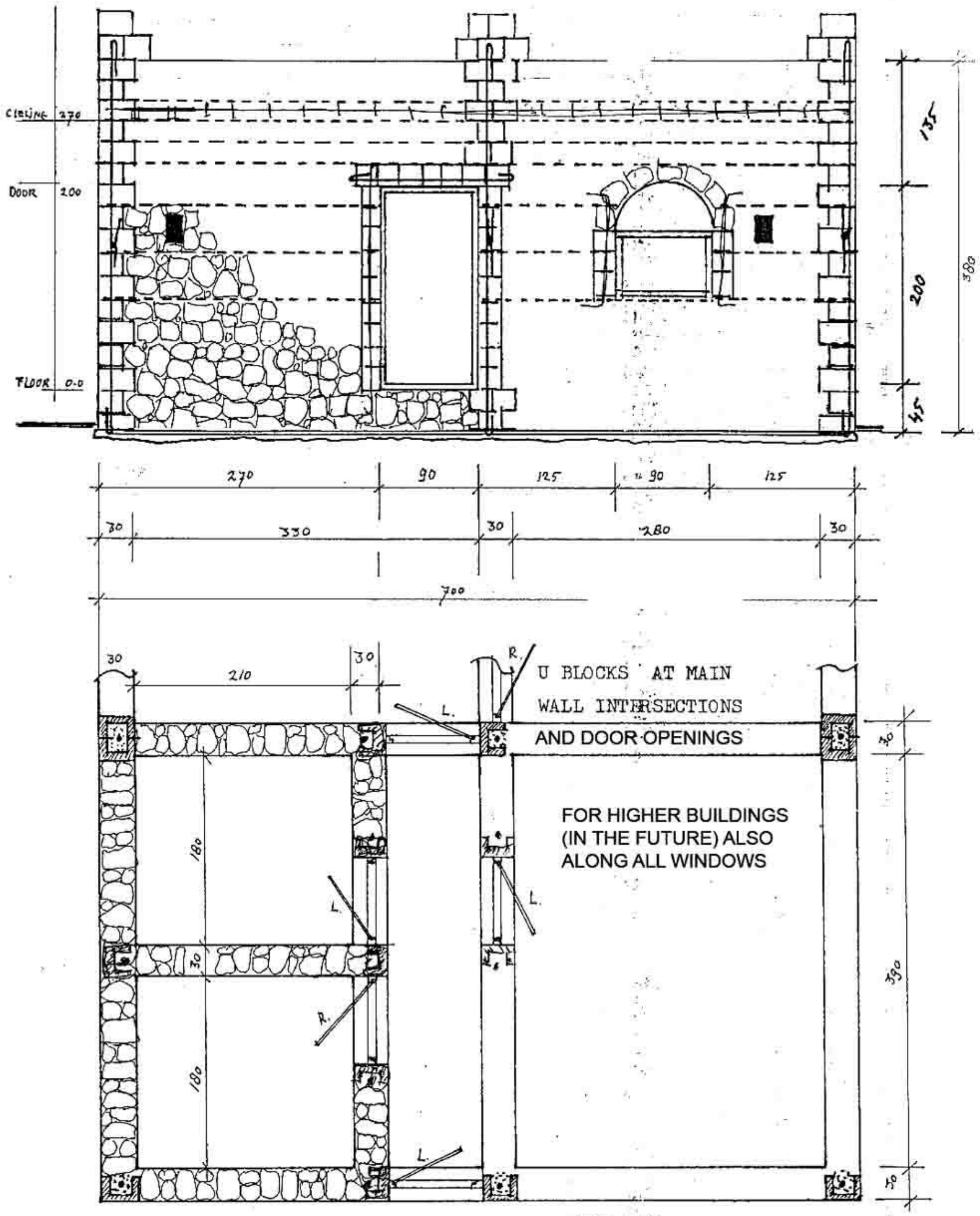
The wire mesh is used further for the fixation of the parallel joists of the floor diaphragm to the outside walls. (see page 20) Steel concrete nails are used to nail it to the (red) hard wood floor or roof joists.

The U block is used for the intersections of the main cross walls, where one bar 8mm of normal steel reinforcement is applied. This vertical bar has to be cast in concrete of a mixture of 1 cement 2 sand and 3 fine aggregate, since this bar is not free from corrosion if it comes into contact with moisture through a porous mortar.

The U blocks can be used around the inside doors, but if the wall will be plastered afterwards, the use of the special blocks there is a matter of calculation of labour costs.
With the U blocks in the facade it becomes a recognizable architecture, whereas the location of the vertical reinforcement is clear. (page 17).

GALVANISED WIRE MESH REINFORCEMENT

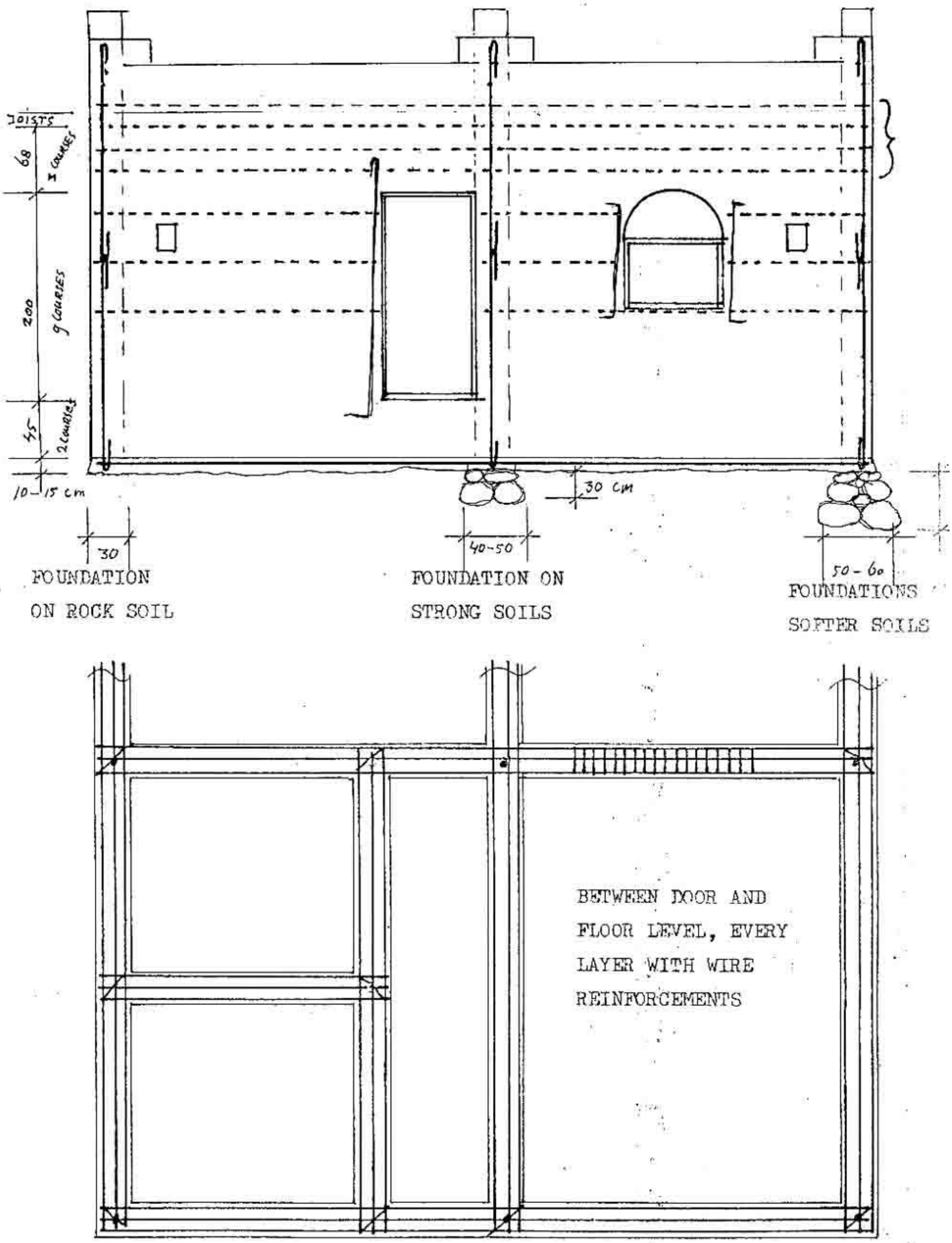
ELEVATION FROM DOOR SIDE



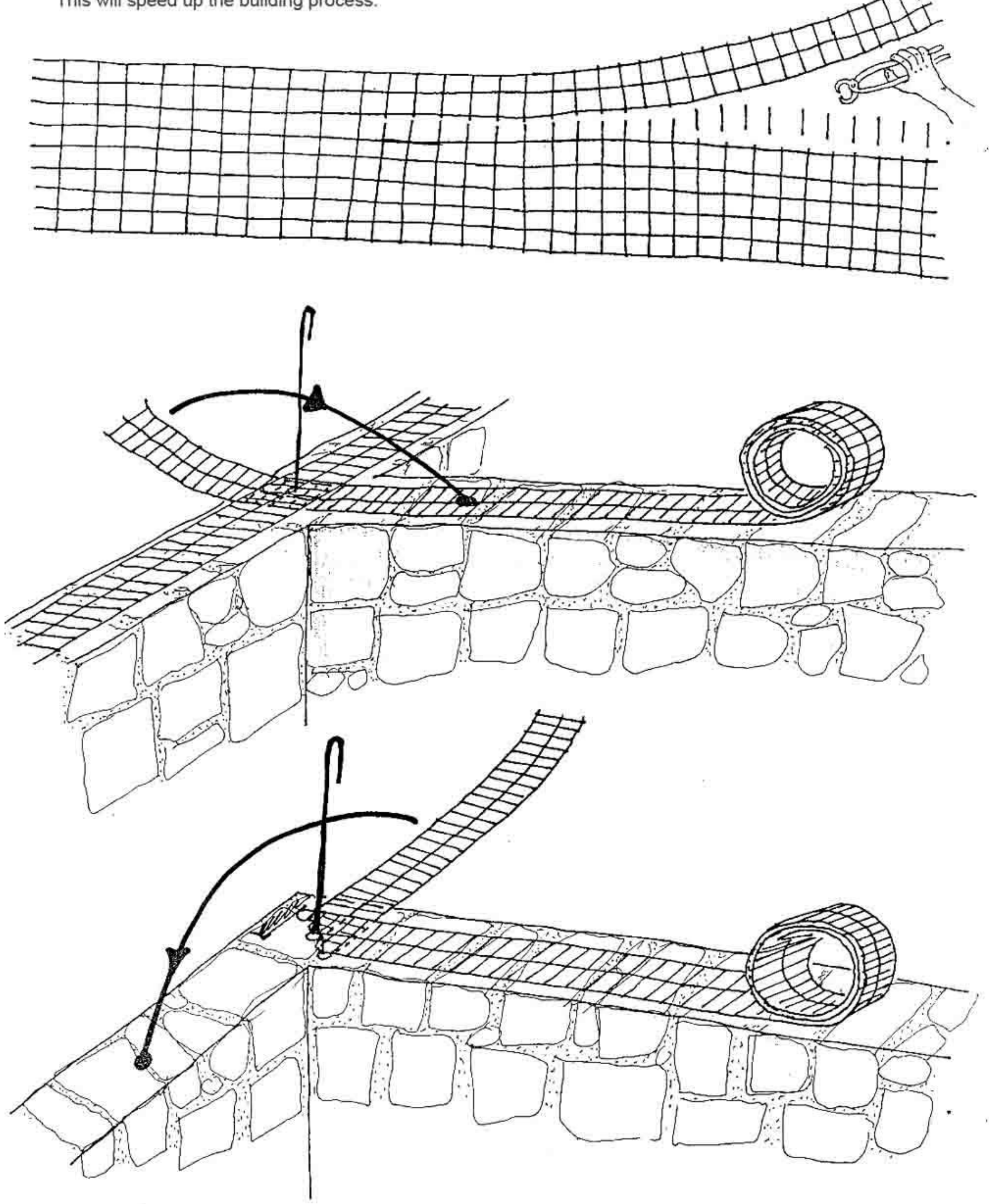
PAGE 17

Note: The reinforced concrete tie-beam at floor level can be substituted for two layers of wire-mesh in single floor buildings. However, this difference will be difficult to explain. Also, most houses will be extended vertically in the future, for which the concrete beam is more secure.

GALVANIZED WIRE MESH REINFORCEMENT



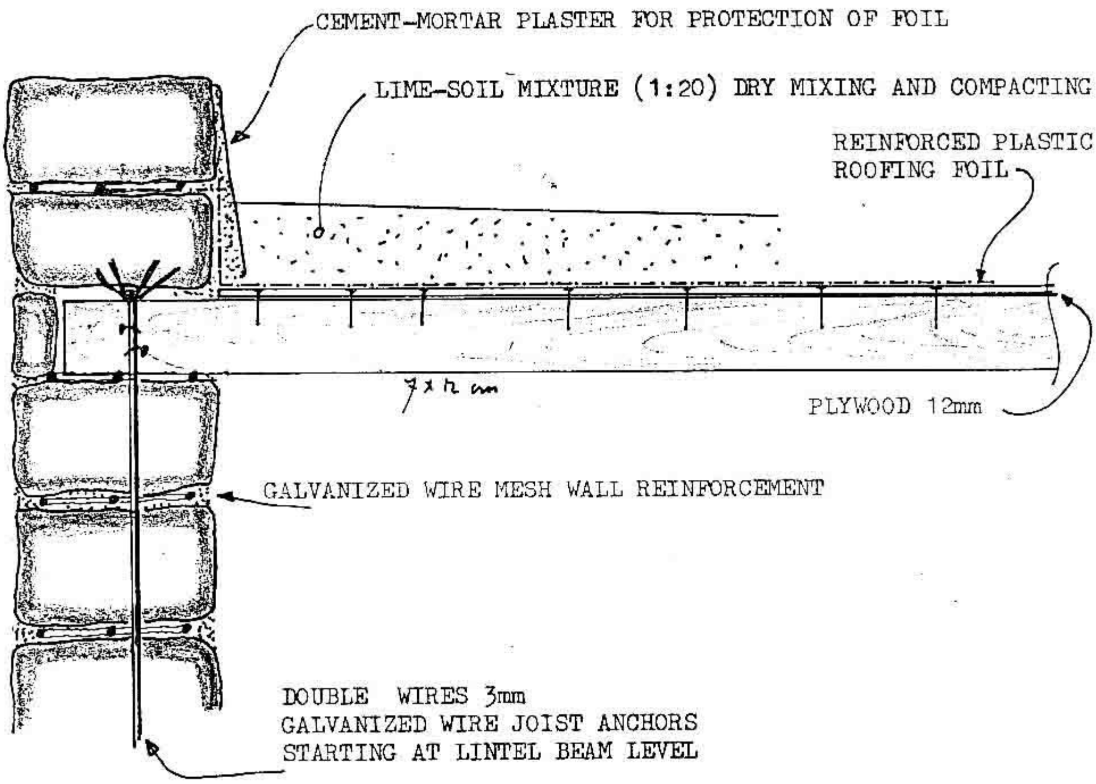
It is feasible to manufacture rolls of wire-mesh of the required width
This will speed up the building process.

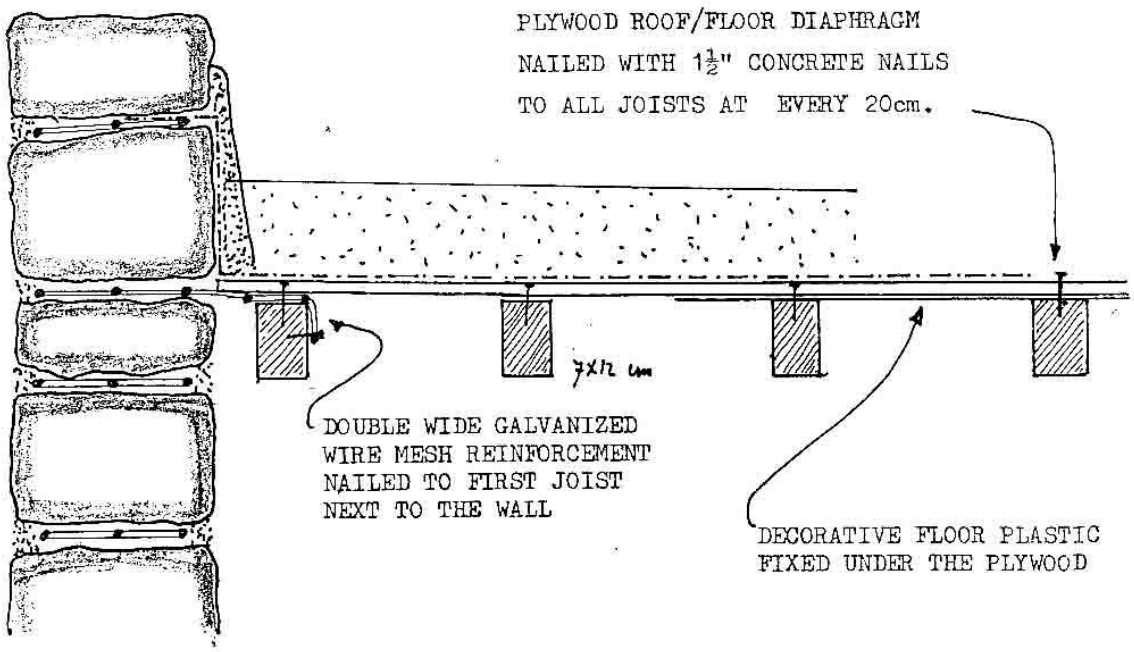


PAGE 19

Note: The galvanised wire-mesh allows the use of less cement mortar between the stones than when the common 8 mm steel bar reinforcements are used. These bars require strong concrete to avoid rust.

ROOF CONSTRUCTION

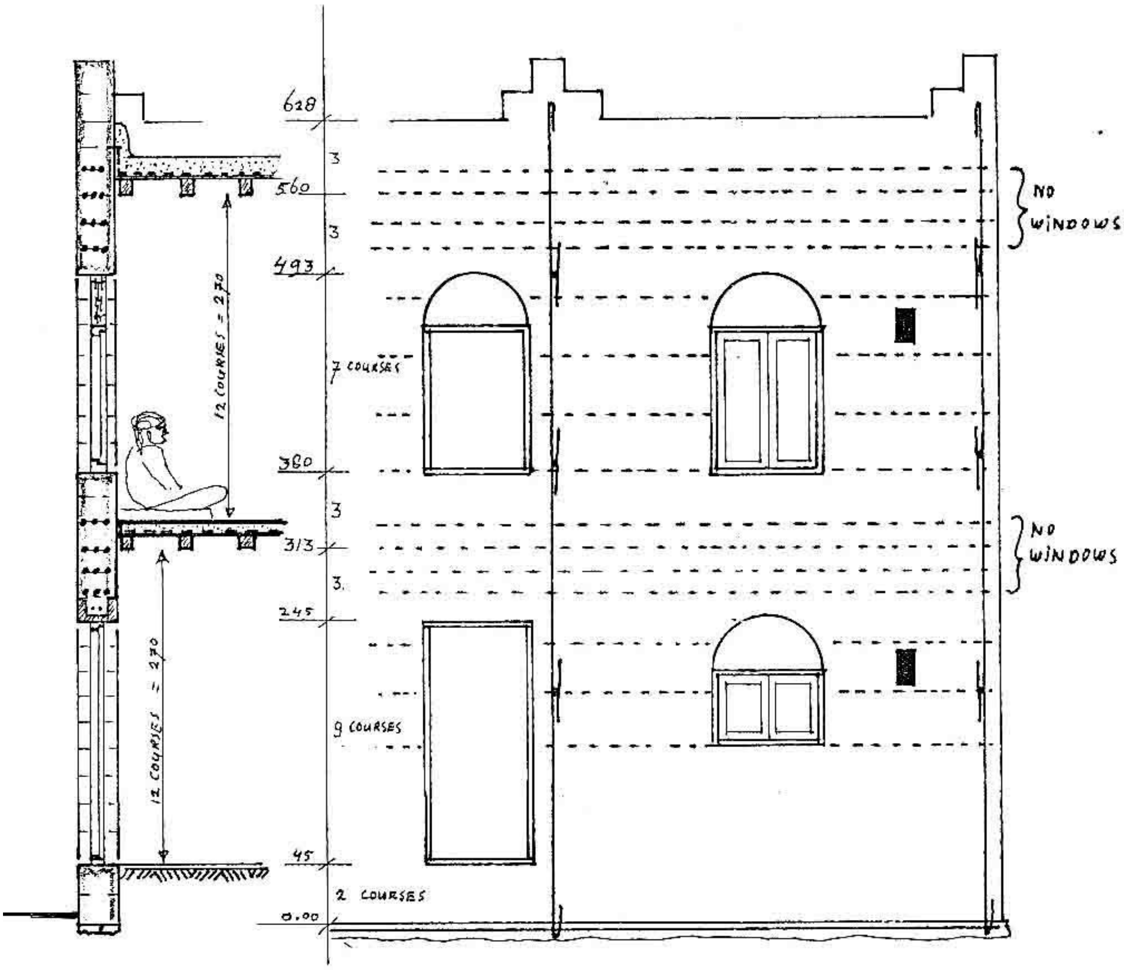


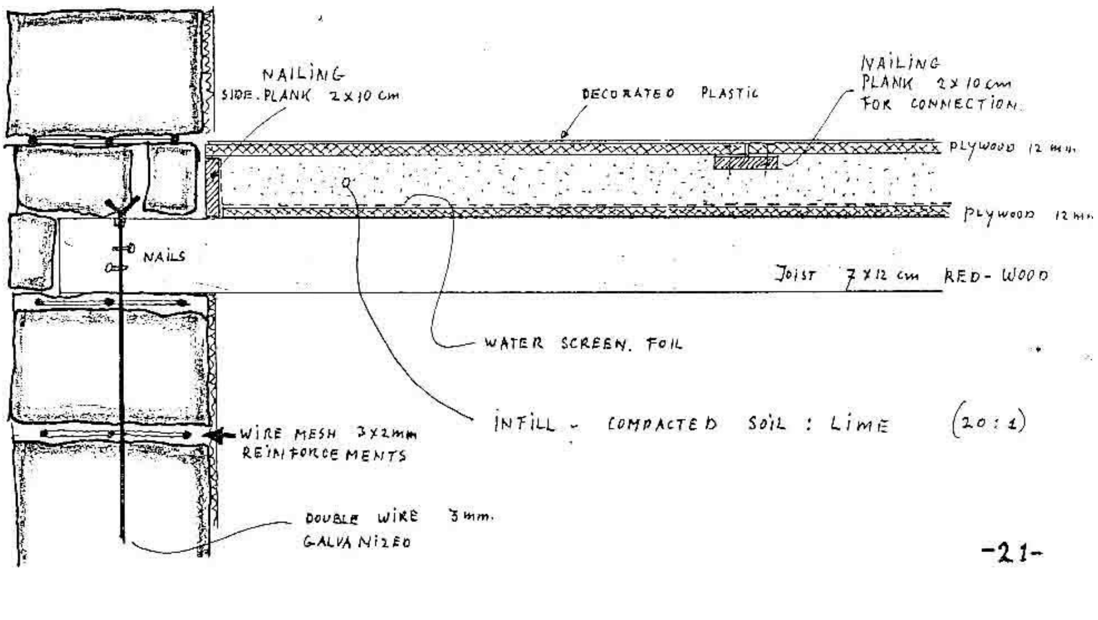


Note: Better thermal insulation is achieved by a suspended (plywood or board sheets) ceiling under the floor joist, with on that ceiling a damp proofing plastic. The created 15 cm high space is filled in with dry straw. The DHV project did not provide suitable information to this effect.

WIRE MESH REINFORCED
WALL CONSTRUCTION

TWO STOREY BUILDING





Note: This option for only the use of the wire-mesh reinforcement was not applied in the project. It was considered that too many variations in the design would confuse the masons and villagers.

3.3. Natural stone walls, 30cm thick, no U blocks

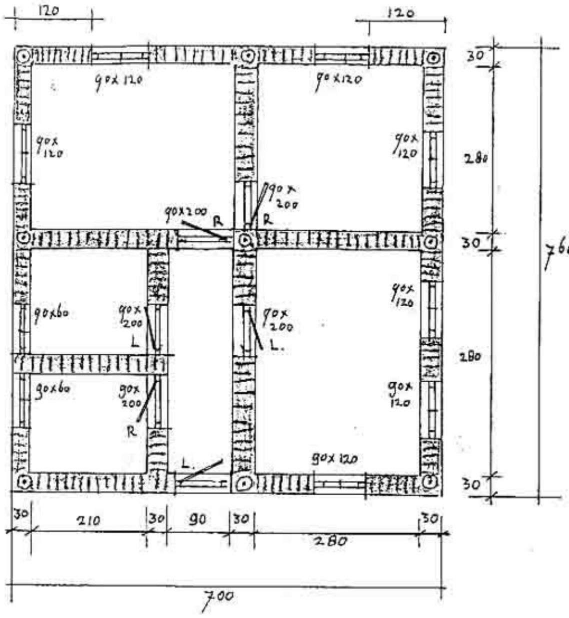
This variety was suggested in the event that it will be impossible to realize the recommended U Block because of lack of adequate aggregates. However after experience with the hereinafter mentioned plastic pipe it seemed that for the vertical reinforcement the U block was more logic and practical. Also the biggest quantity of the total amount of sand aggregate is not in the U blocks but in the masonry mortar.

This technique consist out of the use of a small piece of wide plastic drainage pipe(10-12cm), placed around the reinforcement bar, and around which the stones are masoned. (See pages 24 and 25). After each layer the pipe is removed and the hollow with the steel bar in the center is filled with concrete. This way the concrete protects adequately the reinforcement bar and gives good adherence with the stone masonry.
In the experiments of the staff house construction, it proved that the plastic pipe should be short and that a 7cm diameter is unpleasant to work with. The 10 and 12 cm pipes gave a better result.

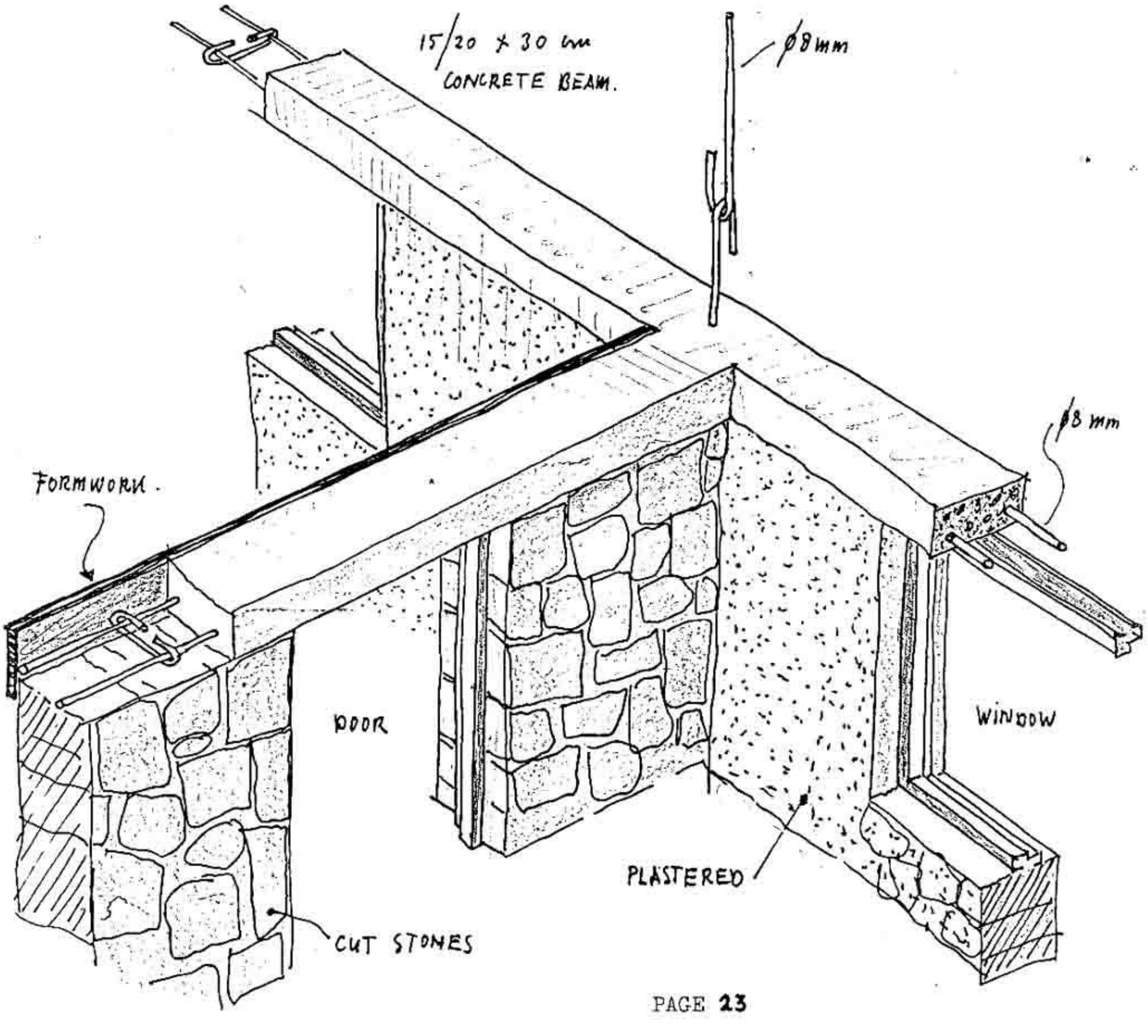
A consequence of this system is the cutting of many little pieces of stone for the wall intersections, where these are placed around the plastic pipe. There where the openings of doors and windows are planned, the stones are to be cut at three sides. When the labour is provided by the owner of the house or is not paid for, this system might be less expensive than with the U blocks, but definitely it will result in an other architecture.(See page 26) As such, this method will not be very recognizable from the outside as being different, or executed with special reinforcements.

When the U blocks can not be produced, also the tie-beams have to be cast without them, in concrete, direct on the walls, using a standard wooden formwork. (see page 23). Care must be taken to allow for sufficient (more than 3cm) coverage of the reinforcement steel, and to use aggregate which has a maximum stone seize of 1/2" or 1,5cm.

Alternatively to the use of a concrete beam (see page 23), horizontal wall reinforcement can be achieved as indicated in parragraph 3.2 by the prefabricated galvanized wire mesh. The wire mesh reinforcement is rather flexible and will settle easy between the irregular courses of stone masonry. The advantage of a good galvanization (more than 200gr/m2) is that the cement mortar of the joints can be the normal masonry mortar of 1:6, (1 cement:6 sand) without danger of corrosion. Also a mix of 1 cement, 2 soil and 3 sand aggregate can be used.(see page 16).

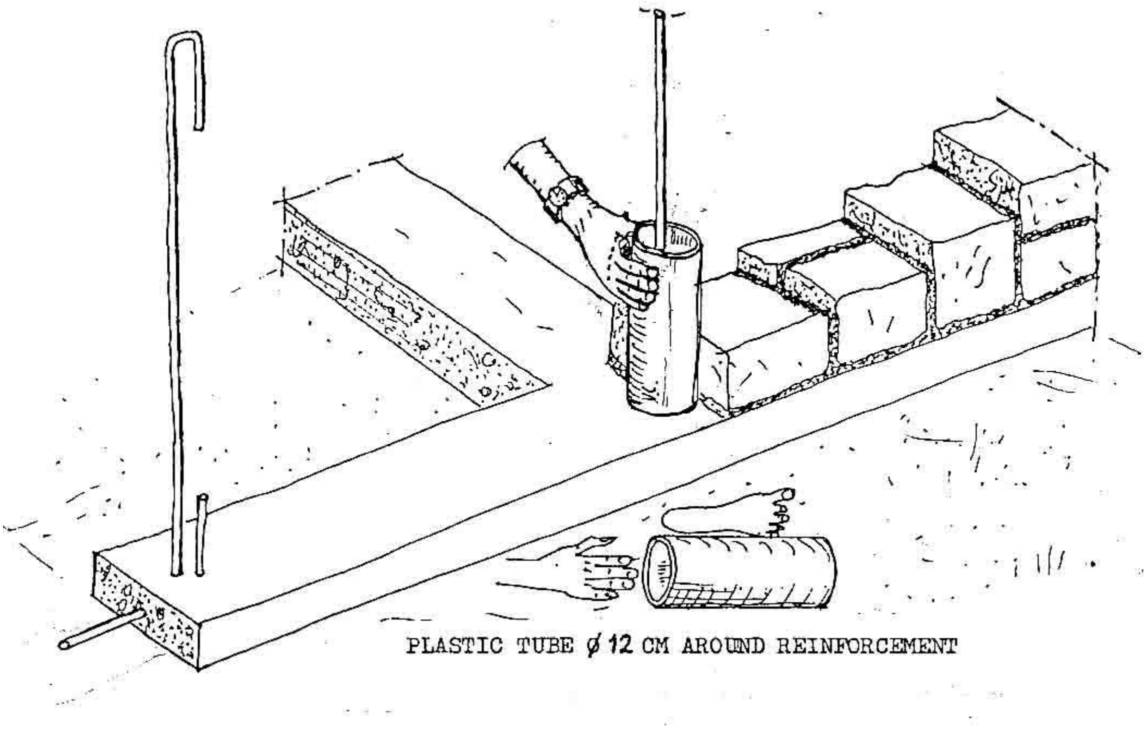


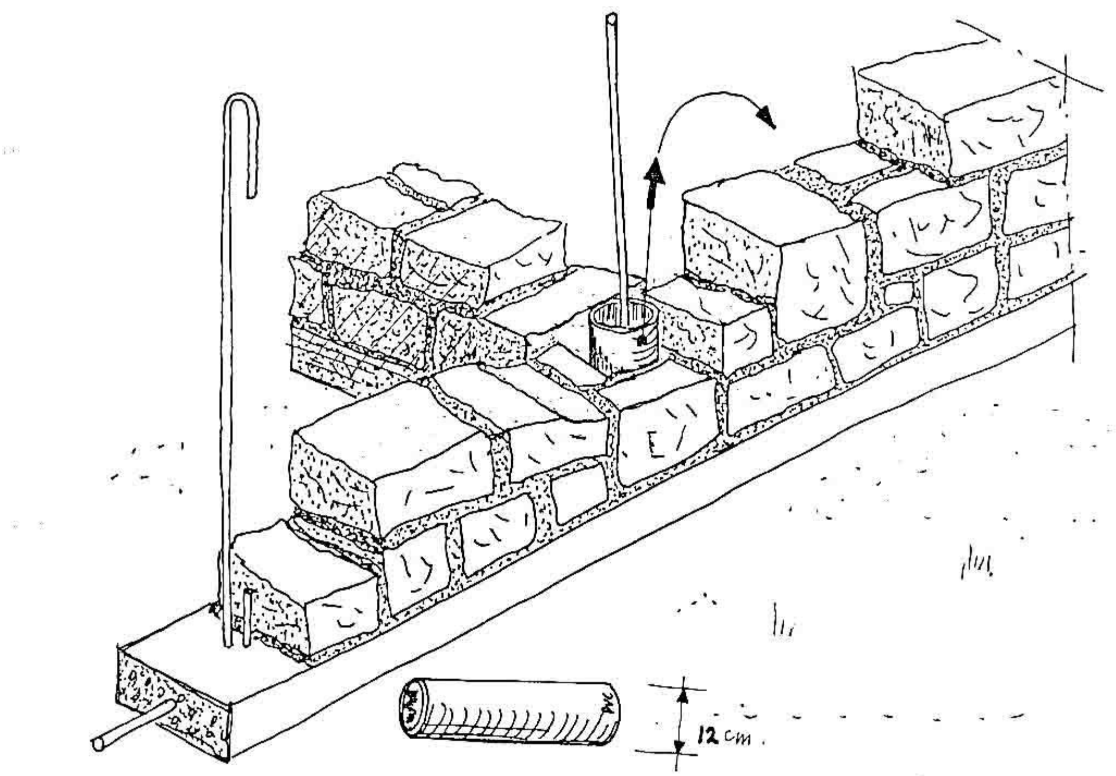
STONE HOUSE WITH 8mm VERTICAL
CAST-IN BARS AND
REINFORCED CONCRETE TIE- BEAM



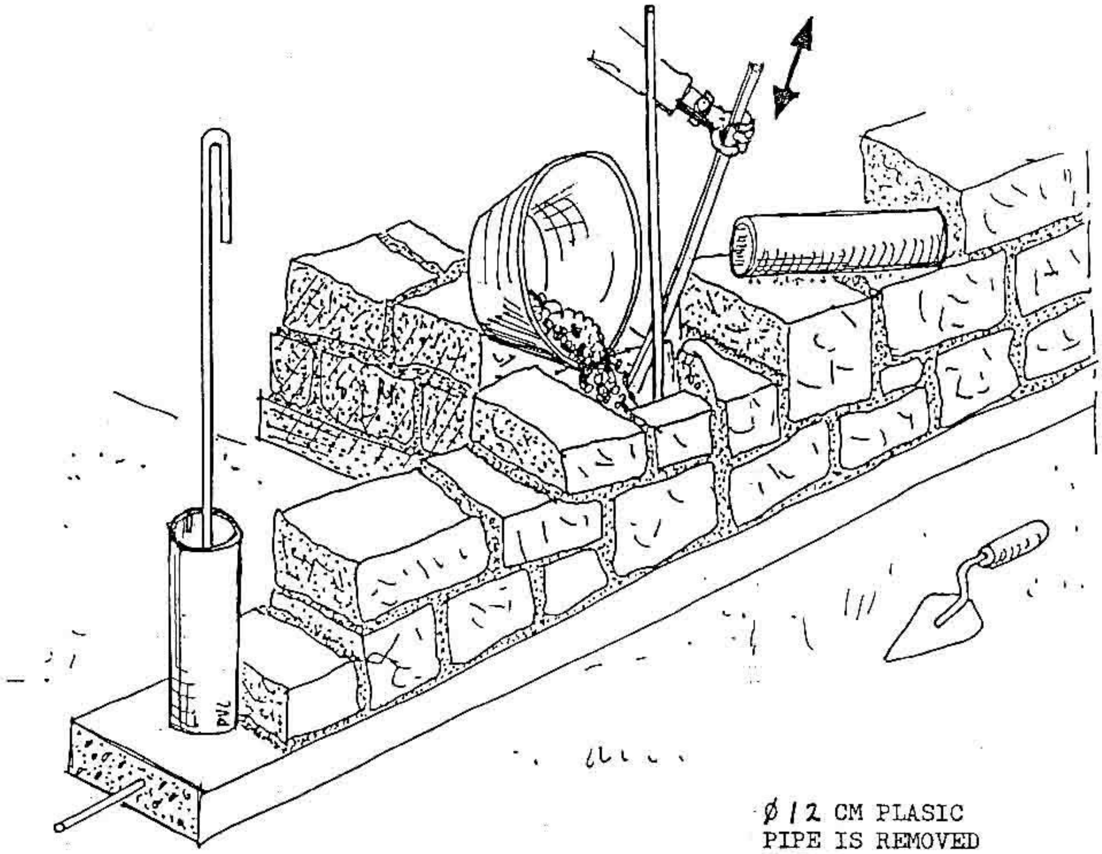
PAGE 23

Note: This option with the use of the reinforced concrete tie-beam was not applied in the project. It was considered that too many variations in the design would confuse the masons and villagers.

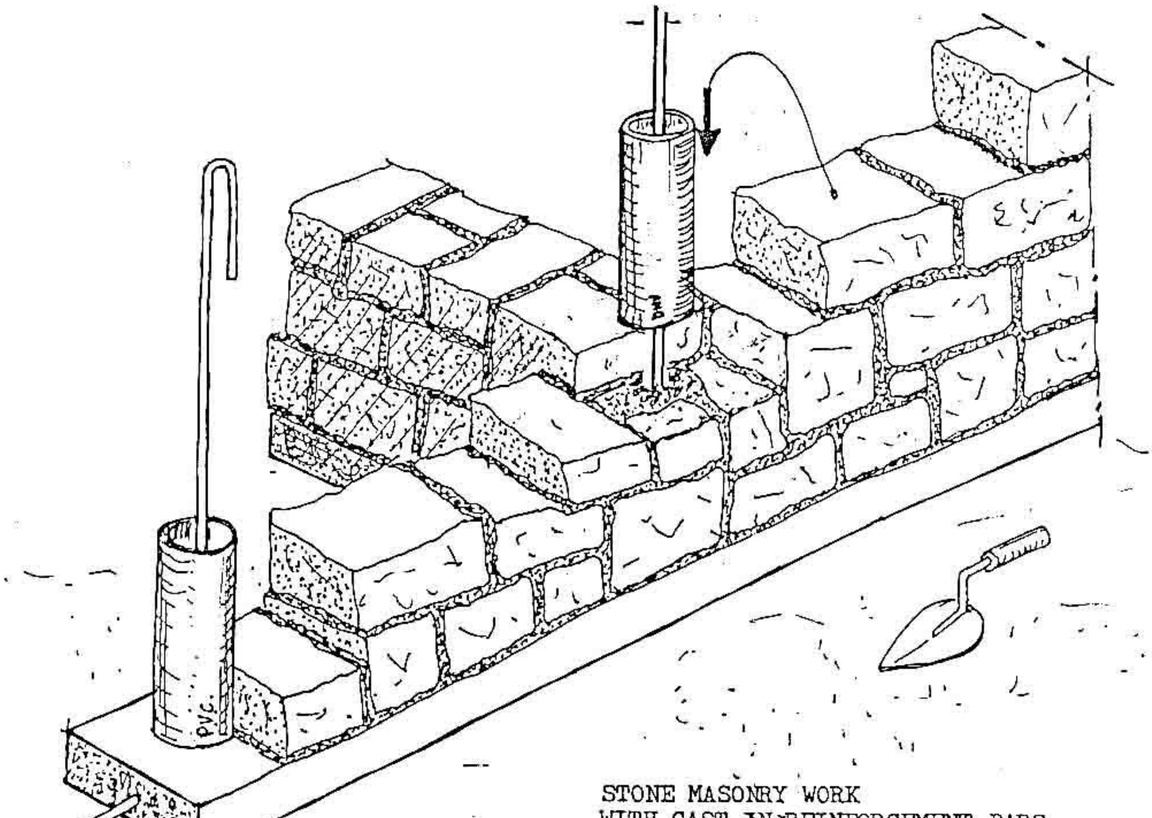




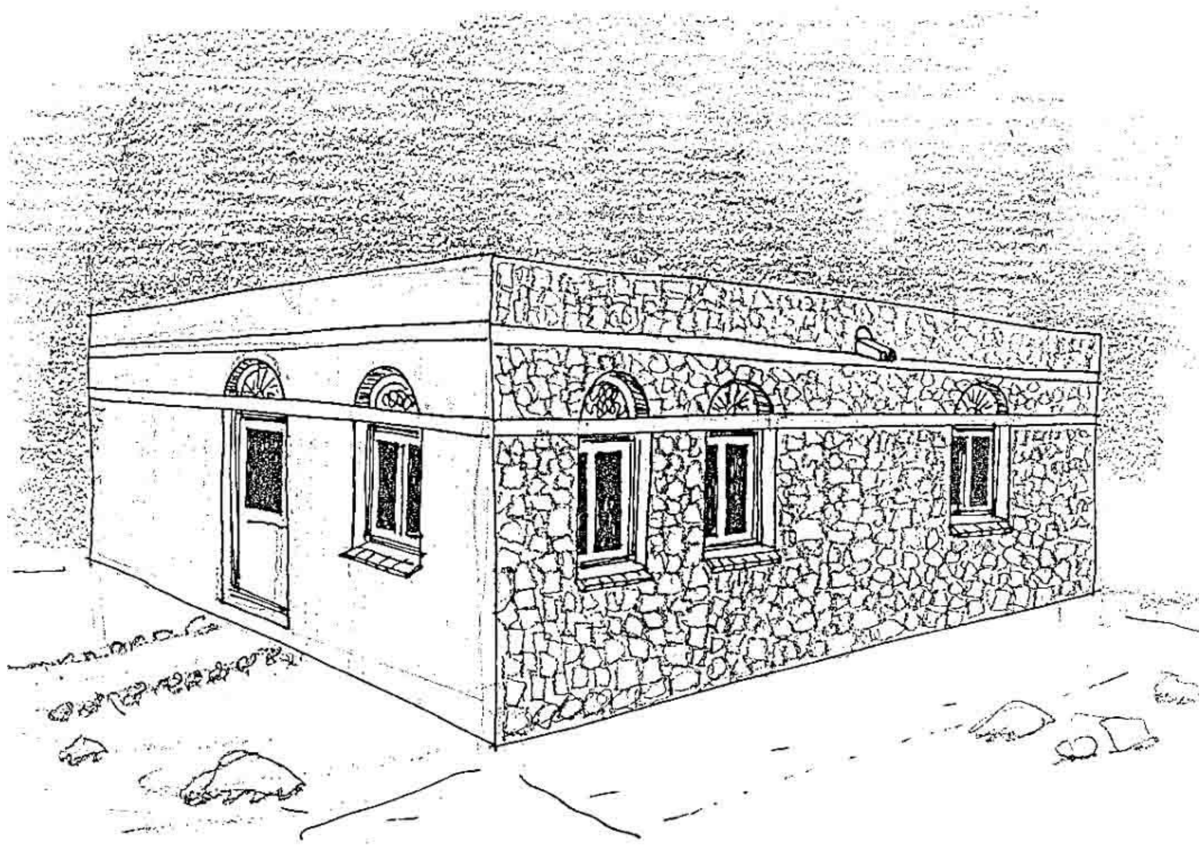
Note: This option is considered at T junctions to minimise the number of U shaped cement blocks.

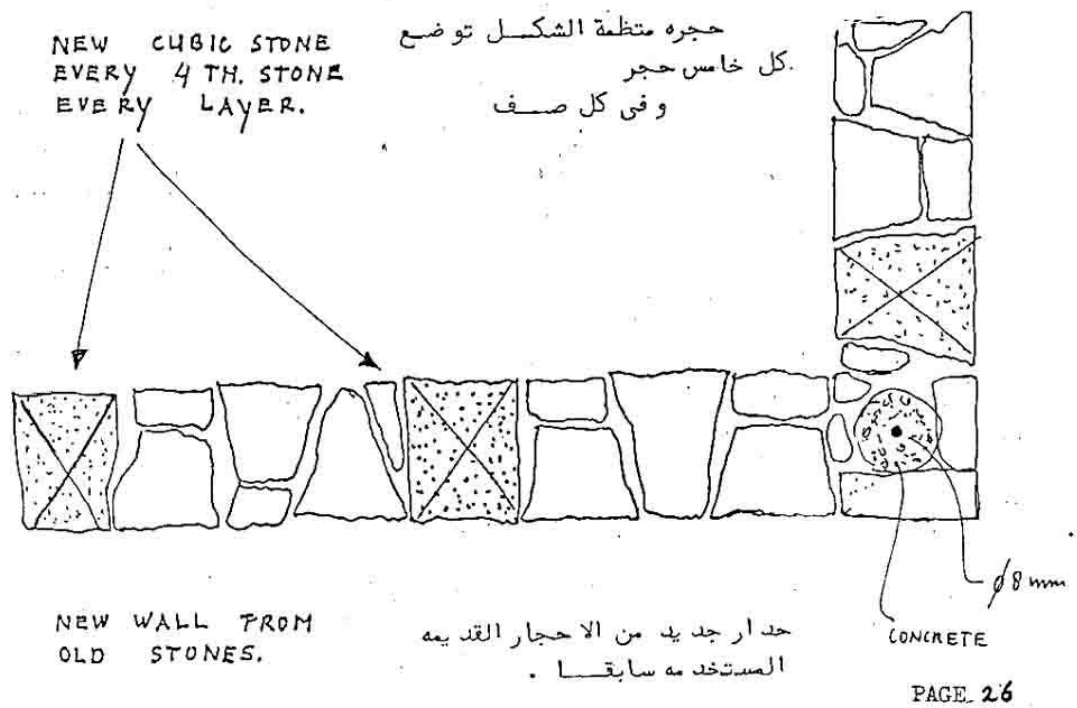


Ø 12 CM PLASIC
PIPE IS REMOVED
CONCRETE IS POURED IN.



STONE MASONRY WORK
WITH CAST IN REINFORCEMENT BARS.





Note: For many of the new houses, stones from the collapsed houses were used and better dressed/cut. Since the wall thickness is considerably reduced as compared with the old buildings, most dressed stones now could be used as through stones. By using the wire-mesh bonding is created between the inner and outer face of the wall. In thicker walls this will be a very important improvement.

3.4. Massive 20cm cement block walls with U block.

In those areas where mass machine made cement blocks are produced, and easily transported, as is the case on the whole plateau area, the cement block is a cheaper construction than the natural stone masonry.

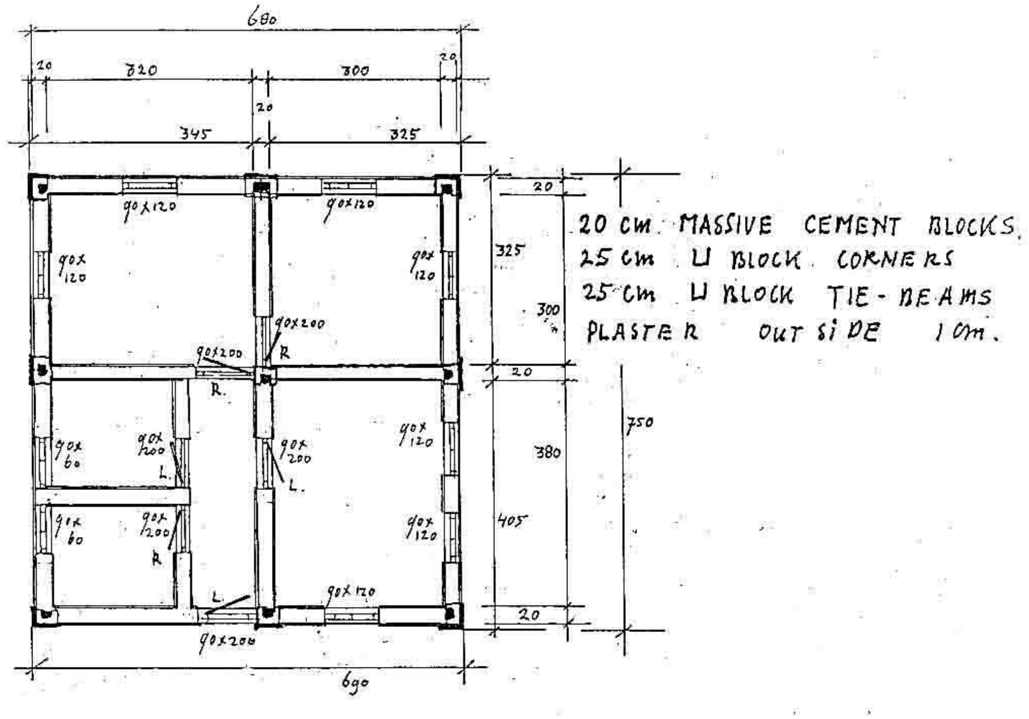
Cement blocks have a higher heat transmission coefficient and a lower heat storage factor. In order to allow a kind of minimum climatological quality of the houses, a minimum thickness of the massive walls is recommended of 20 cm. The use of hollow blocks or the blocks with the 11 holes is not recommended, not for the shear function of the wall, nor for climatological reasons.

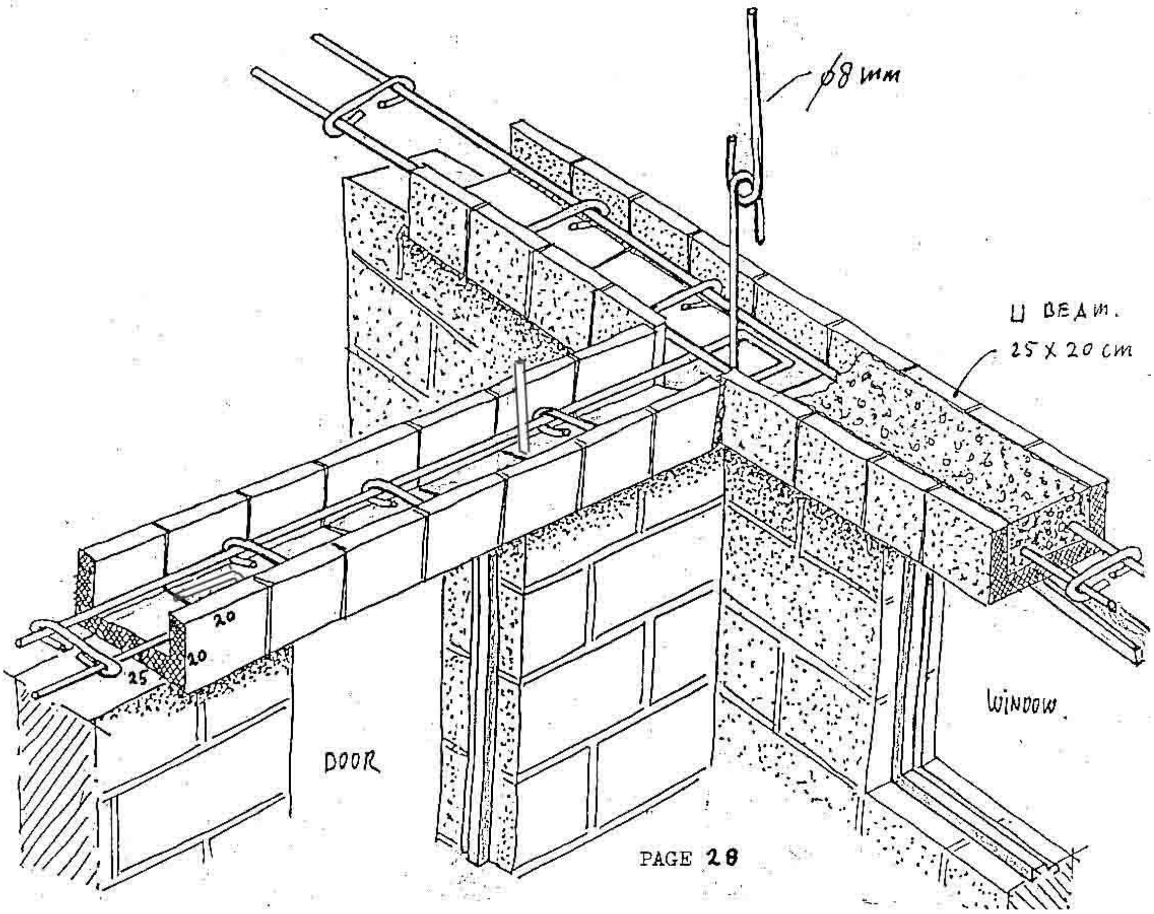
The proposed building system under this heading is similar to the first one (paragraph 2.1 or 3.1.) considering the use of the **U** blocks in the corners of the building. This will give an interesting architectural feature to the building, especially when the **U** block is slightly wider than the 20cm block wall. (see page 29). For this reason the design recommends the use of 25cm wide **U** blocks, and the plaster of the walls stopped at the corner blocks. This can be repeated around the window and door openings, although this is not really necessary since with the standard cement blocks reasonably straight masonry work can be achieved.

Also the tie-beams are constructed with the **U** blocks, using the wider 25cm block. An advantage of using the wider U block is the actual width of the tie-beam. The wider the tie-beam, the greater its rigidity in horizontal sence. With the inward or outward flexion of the wall due to earthquake forces perpendicular to the wall, this horizontal rigidity becomes important. For that reason it is essential that a wide block is chosen for the tie-beam constructions.

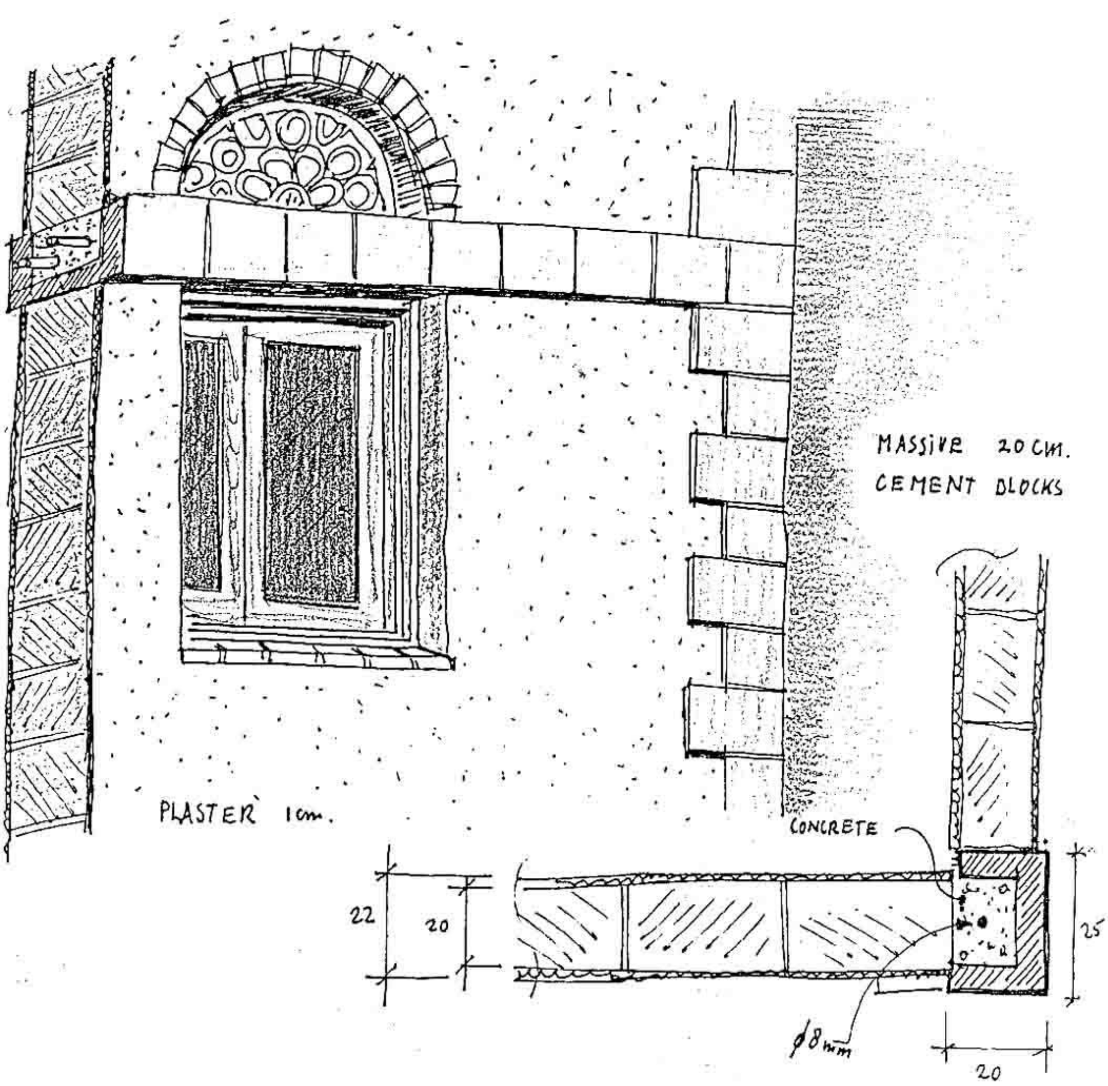
In the wall horizontal reinforcement is to be applied, especially under through the window level. (as in page 11). The same galvanized reinforcement can be used as is recommended for the stone masonry, but because of the horizontally straight joints, a more ridged prefabricated wall reinforcement can be used. This type of reinforcement is readily available on the European market.

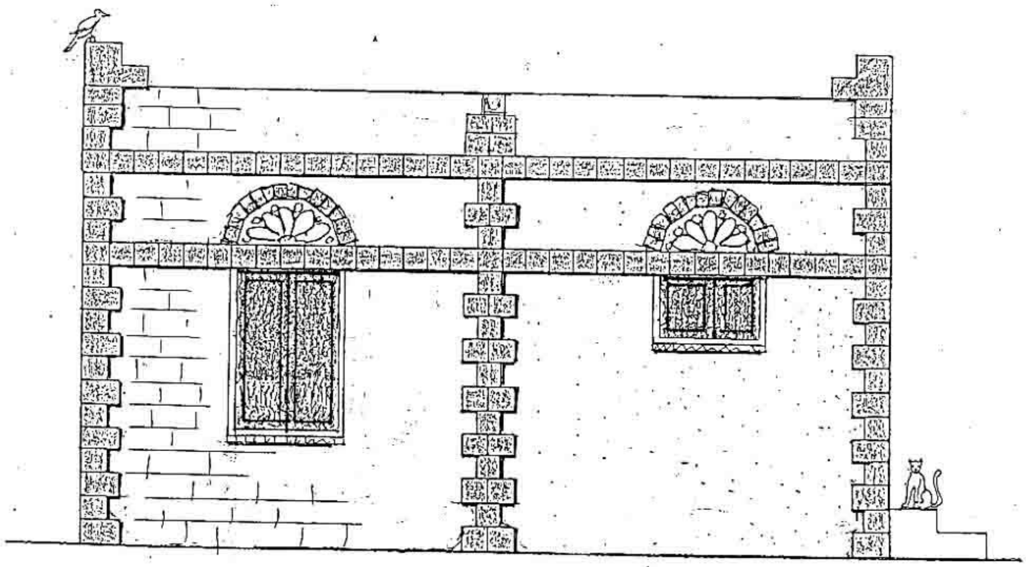
The outside finish of the block wall can be either a thick cement plaster or a thin brush. The thin cement brush is less expensive in material and can be applied by means self-help because it does not require special skills. Beauty failures in the masonry work become less visible and the wall gets an even texture, suitable for painting.





Note: This option with the construction with solid or hollow cement blocks was not used.
The amount of sand and cement for this design is very high and not replicable for the villagers.
Hollow cement blocks would have an advantage over solid cement blocks because of lesser weight.





PAGE 29

Note: The use of solid cement blocks allowed the accentuation of the reinforced corners. The U shaped cement blocks provide the formwork for the concrete and are wider than the solid blocks.
The thermal insulation of cement block houses is very low and the houses will be very uncomfortable.

3.5. Cement block wall 20cm, hollow **B** block corners.

This system is rather traditional, using the massive 20cm cement blocks for the walls and the **B** shaped hollow cement blocks in the corners and the intersections of the walls.

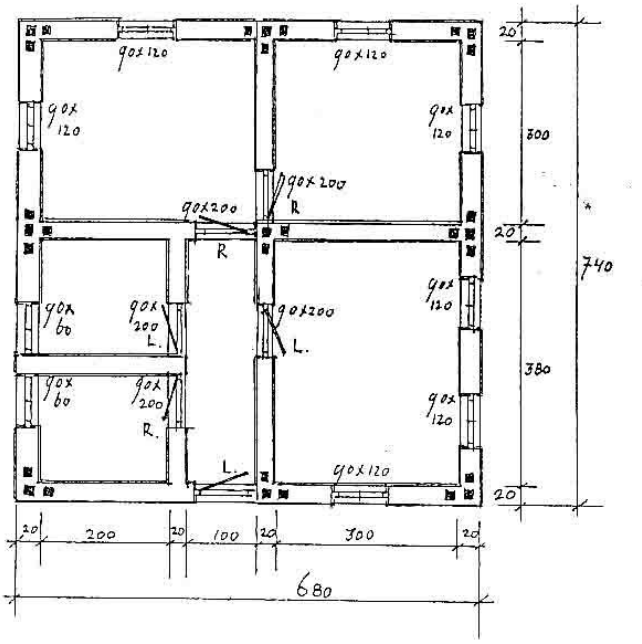
For the tie-beams it remains recommended to use the wider **U** block. When it is possible to produce both the massive and the hollow cement blocks it is also possible to produce the cement **U** block, so no need exists for the casting of a reinforced concrete tie-beam over the walls which requires a timber form.

The **B** shaped hollow cement blocks are rather fragile of structure, contrary to the **U** block and it is essential to fill ALL the holes of the hollow blocks with concrete. In the superposed hollows of the corners a vertical reinforcement bar can be placed (8mm or 10 mm). These bars should be completely cast in the concrete as with the former designs. (see page 32)

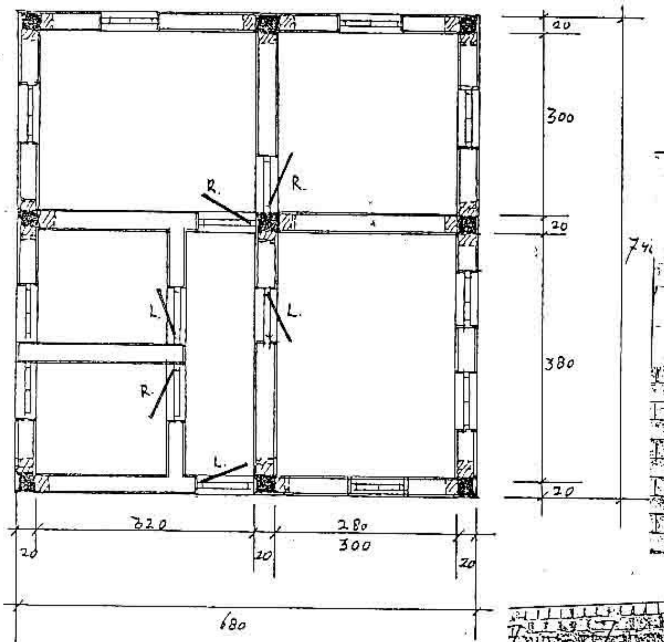
A disadvantage of this system, as was clearly demonstrated in the building of the staff-houses is the fact that the hollow cement blocks have to be lifted over the vertical bars. For this reason the lengths of the vertical bars should be rather short, about maximum 1m above the working level of the mason.

It is important that NOT the 11 holes cement block is used instead of the **B** shaped hollow cement block, since the first will not allow the correct concrete casting around the reinforcement bars. Also the hooks on the bars, required for the connection will give problems when the 11 holes block is tried to put over it.

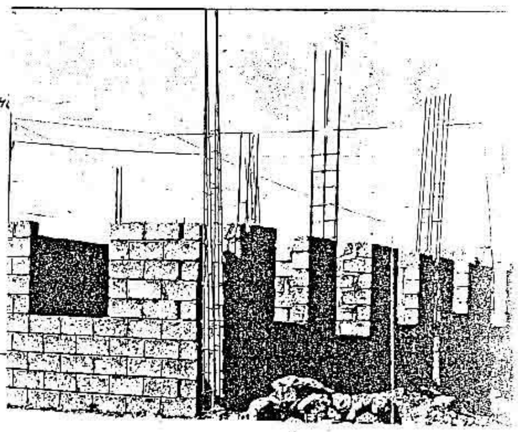
The hooks for lengthening the vertical bars are recommended, not only for obtaining the required connection, but more to avoid that the minimum traslapping length of 60 times the bar diameter is not achieved. (60x8mm=48cm). The hooks are for educational reasons better recommended. The concept of the effect of the chaining is more clear. (See page 32).
The standard overlap formula (60 times the bar diameter) between bars is dangerous to use since it is hardly controllable and the overlap length may reduce far under the safety limits. In laboratory tests, realized in may 1984, the recommended hooks of about 20 cm each gave satisfactory results. The full stress was developed to break the 8mm reinforcement bars, provided that the bars were reasonably packed into the concrete.

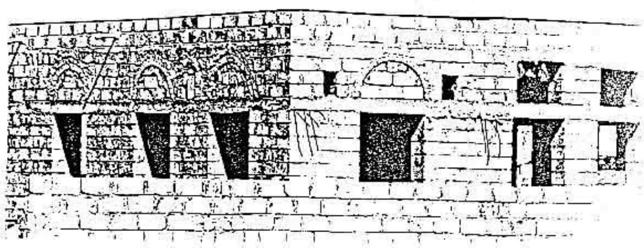


20 CM MASSIVE CEMENT BLOCK
HOLLOW CEMENT BLOCK CORNERS
ALL HOLLOWS FILLED WITH
CONCRETE (CORNERS 1 Ø 8)
25 CM U BLOCK BEAMS.
1 CM PLASTER OUTSIDE
2 CM INSIDE PLASTER



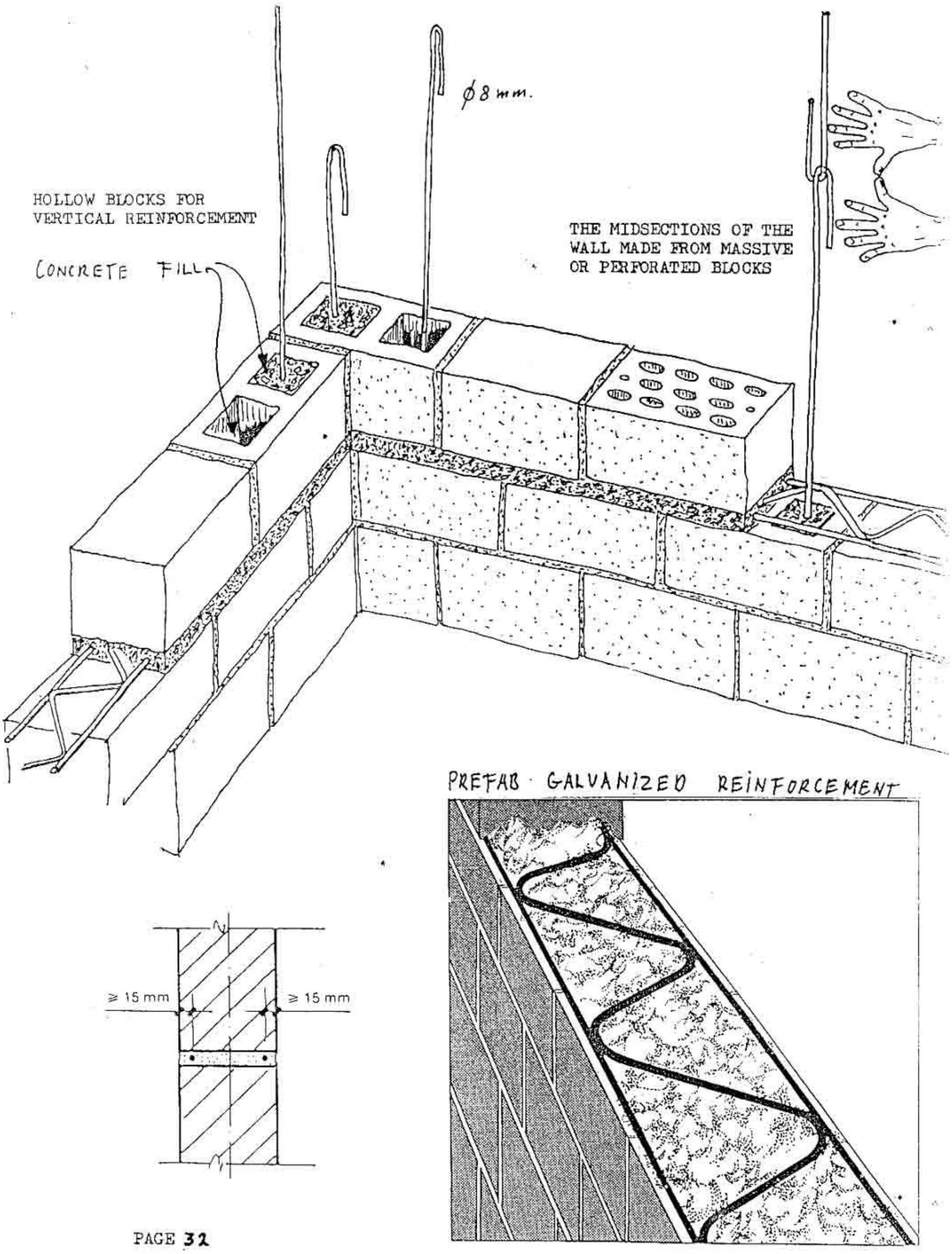
20 CM MASSIVE BLOCK
CAST - ON CORNERS
CAST - ON TIE - BEAMS





PAGE 37.

Note: This option with the construction with solid and hollow cement blocks was not used.
The amount of sand and cement for this design is very high and not replicable for the villagers.



Note: This option was not further considered for the project in the mountain regions.

3.5.1. Solid cement block wall 20cm, cast-on corners.

The system described here is in fact similar to the system with the hollow burned brick with the cast-on corners.

The cast-on corners as shown in the small pictures on the page 31 (lower part), show a system which is traditionally well known and used in many countries;

= The corner of the masonry work is left open or dented.
= Steel column type of reinforcement is placed.
= A simple formwork is placed flush with the wall, both on the outside as well as on the inside.
= The formwork is cast full with concrete.
= The mould is removed.
= The concrete is repaired.
= The exterior is left as it is, plastered or eventually painted.

Although the construction is structurally stronger than the fore mentioned hollow block construction, it has some disadvantages, which are essential drawbacks for the Yemeni situation;

a) The amount of steel is excessive for the encountered stress forces in the construction.
b) The tendency exists to regard these 'columns' as structural load bearing columns as in a space-frame or skeleton construction. This is not at all the case.
c) The concrete protection is usually inadequate and the repair of the honeycomb holes and aggregate pockets may not prevent corrosion and consequently destruction of the 'columns'.
d) When using the dented design, good adherence with the blocks (or burned tubular bricks) is achieved, but also twice to three times the amount of concrete is used compared to the system with the U blocks.
e) The cost of the formwork, including material and labour is definitely more expensive than the earlier proposed two systems, using the massive cement blocks.
f) The architectural appearance of this design is subject of personal preferences, these however are influenced with the presumed status of the reinforced concrete constructions in general.

When chosen for this design, it might be considered as logical to make the tie-beams also as a cast-on construction.

3.6. Hollow brick masonry 15cm, and U block corners 20cm.

Traditionally, a lot of burned brick (small seize) masonry has been done in the Dhamar district, and with the reconstruction program many houses will be reconstructed in a reinforced concrete skeleton with an infill of hollow burned bricks. (see page 35).
The particular type used, is the tubular honeycomb brick with dimensions of 15 x 15 x 20 cm. The internal canals are in the length of the refractory bricks.
This means that the masonry of those bricks will be in courses of 15-16cm each.

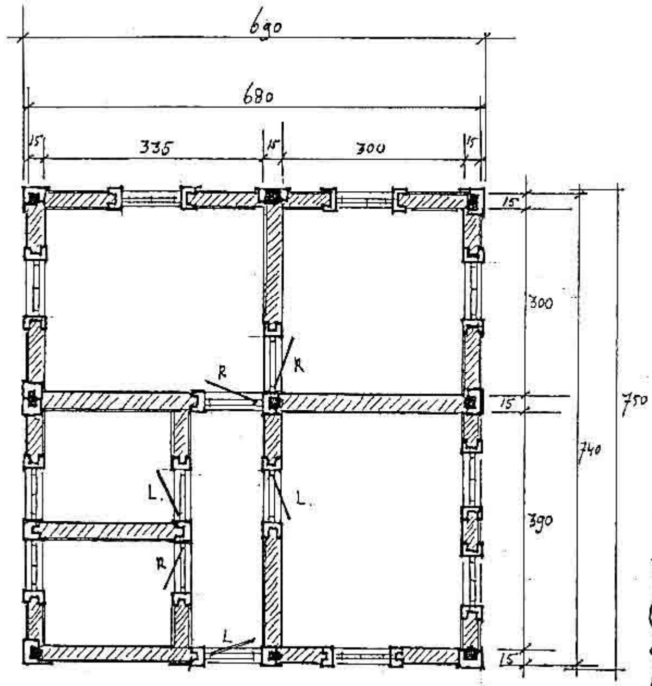
The reinforced concrete skeleton construction is not at all recommended for self-help construction, subject, which has been elaborated in the former reports. In this concept of a full bearing space-frame construction, the infill of hollow tubular burnt bricks will be adequate. However for load bearing shear-wall constructions, this material is less appropriate, especially when considering the construction of an extra storey in the future.

When the burnt, tubular brick is purchased at low cost, the houses constructed with this material will be economic, but the hollow brick wall has to be plastered at both sides.

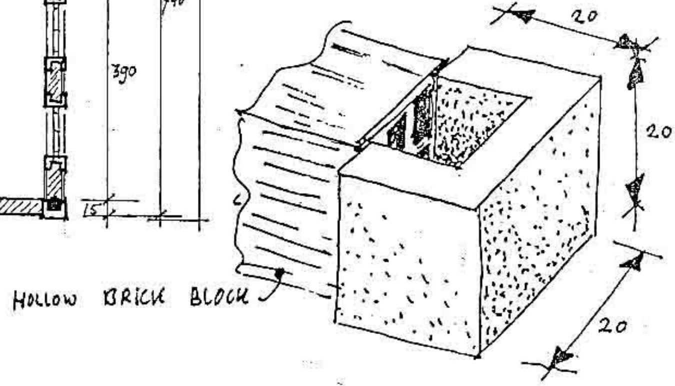
The climatological characteristics of this type of construction is the least of all of the 7 mentioned systems. The heat transmission factor of the refractory brick is rather high, whilst the heat-storage capacity is really low compared to the other systems. Both aspects will improve with a thick (2-3cm) sand-cement-lime plaster applied at both sides of the wall.
The low weight on the other hand is advantageous, considering the mass of the construction and thus the related earthquake originated forces.

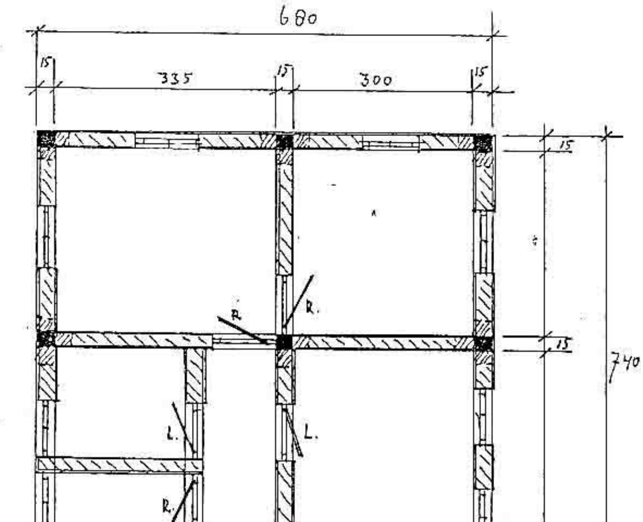
The vertical compression strength of the construction as a whole is rather limited, because of the multiple holes. For this reason it is recommended to use a small U block at all wall endings and openings. (see page 35) The blocks will be cast full with concrete, providing at the same time an interesting facade architecture. (see page 29) Also the tie-beams should be made of a wider U block, in order to provide some additional width. Both the burnt bricks and the cement blocks are readily available at the plateau area without mayor transport costs.

When vertical reinforcement is recommended at the wall intersections, for additional stories vertical reinforcement has to be placed at the sides of the door and window openings, the U block or alternatively the B shaped hollow cement block becomes essential.
When not a cement block is used at the door and window openings, the exposed holes in the heading of the tubular burnt bricks have to be closed with plaster.

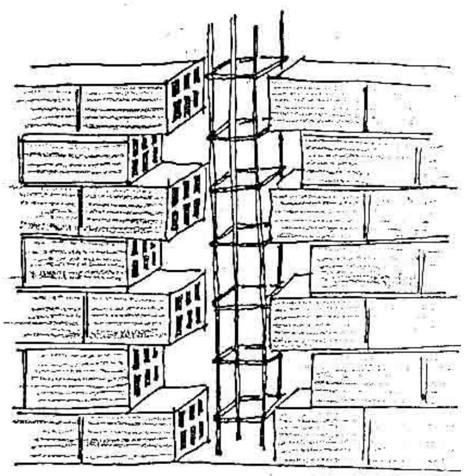


15 cm HOLLOW BRICK
U BLOCK CORNERS 20 cm
20 cm U BLOCK BEAM
WALL INTER SECTIONS Ø8
2 cm OUTSIDE PLASTER
2 cm IN SIDE PLASTER





15 cm HOLLOW BRICK
CAST ON CORNERS
CAST ON TIE - BEAMS.



PAGE 35

Note: This option was not possible in Yemen at the time; there were hardly any refractory bricks.

3.7. Machine compacted, reinforced soil construction.

On the alluvial soils of the plateau area around the city of Ma'bar(see page 39), traditionally soil or adobe construction has been practiced for ages. In the Yemen as country, soil construction is a main cultural and architectural inheritence, which has proved to provide excellent climatological conditions inside the dwellings, especially when walls are as thick as 60cm to 1m.

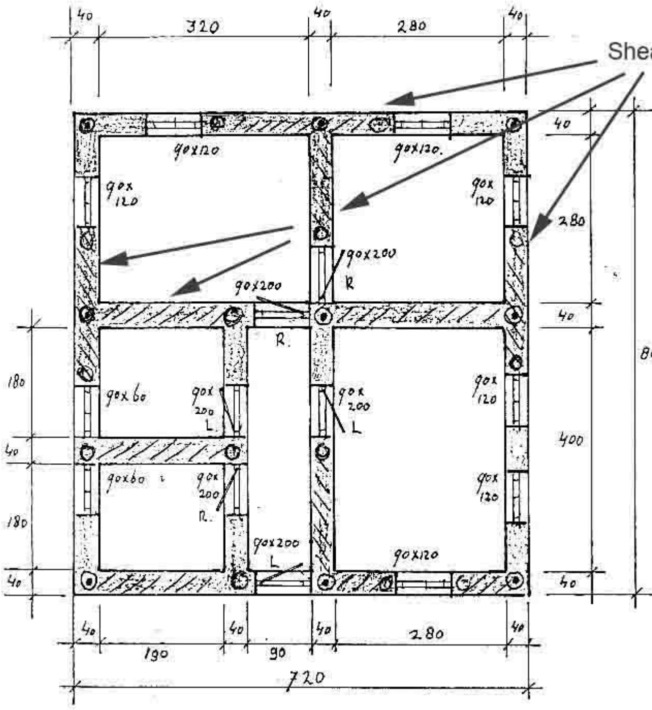
Improvement of this construction type is achieved by densive compacting the soil in the walls during the construction phase.(See page 41) Further, by providing horizontal reinforcement to interconnect all walls and to provide a better stress resistance.
The compacting the soil in the wall will allow thinner walls, thus less weight and also create a better resistance against wind and rain erosion. The foundation has to be made with stone, cast in mud-cement mortar, in order to avoid excessive erosion by the splashing rain at the ground level.

To achieve compacting, use of a climbing type of formwork is necessary, (page 38 and 40) as well as a mechanized compacting device. (page 40 and 41).The hand compacting is both heavy work and gives inadequate results. The best results are obtained with the Ram 30S (S stands for silencer), which is driven by a small compressor.

The soil has to be triturated or sieved and should have a specific humidity content. The pulvarization of the hard clay soil is satisfactorily achieved with the BRE soil crusher. (picture at page 41) Two pieces of this equipment were made available to the Executive Office in the month of May 1984.
The soil for the filling of the walls should have a specific clay content and has to be slightly and evenly moistured before casting, preferably with an agricultural sprinkler.

The economy of the system can be very high since the soil is obtained at practically no cost at all, whilst the investment cost of the prefab, movable formwork and the compressor with the compacting hammer is to be used for many buildings. The estimated investment is about YR 50.000 for the equipment and another YR 50.000 for a complete mold. The YR 100.000 can be amortized over about 100 houses, which means an investment per house of only YR 1000.=
Labour in this system will be comparable with the labour of other houses, but for self-help systems the local or unskilled labour factor is less important.

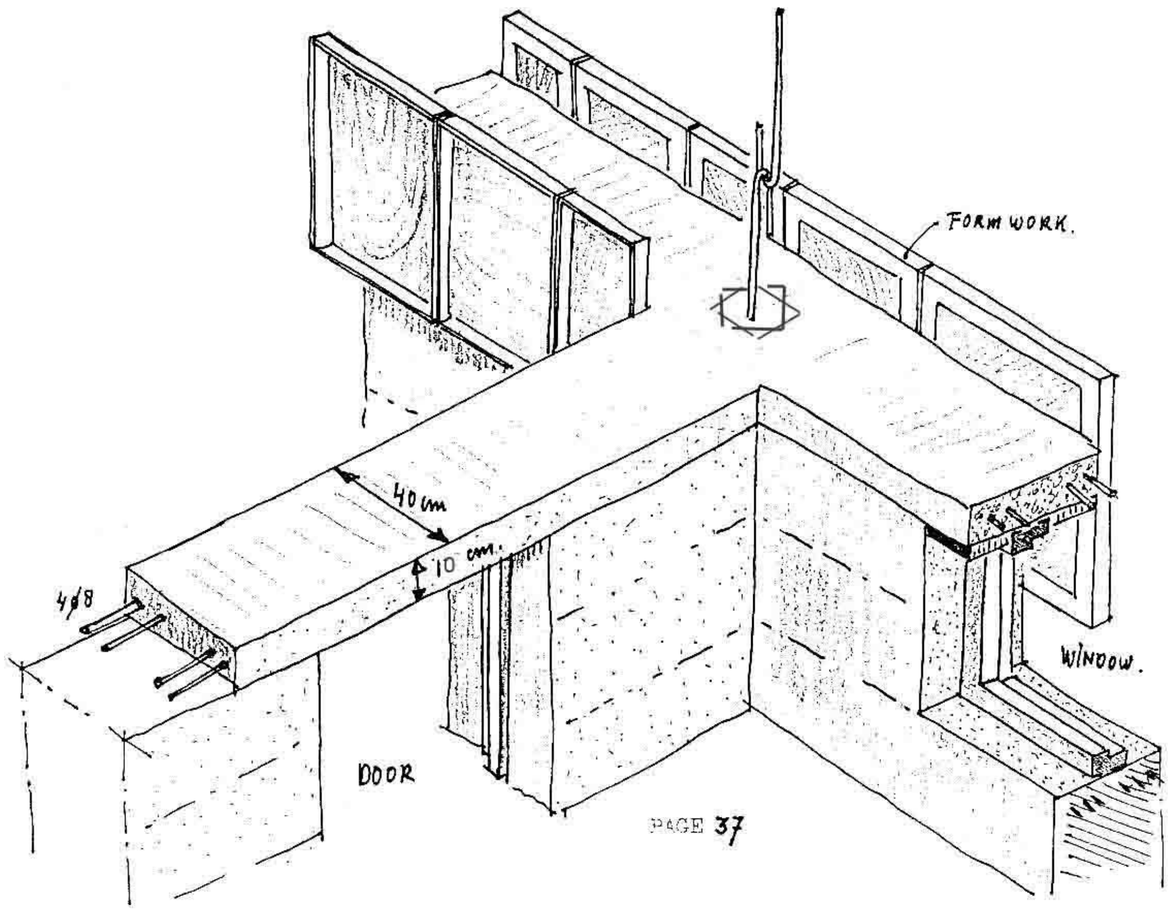
For higher buildings it is possible to make thicker walls with the same mould system. The vertical reinforcement is realized the same way as with system mentioned under paragraph 3.3.(page 24 and 25) The horizontal lintel beams can be cast directly on the compacted wall,(page 37) but also on a small setup formwork as is showed in the drawing. (page 40) The latter allows better access to the placements of the reinforcement.



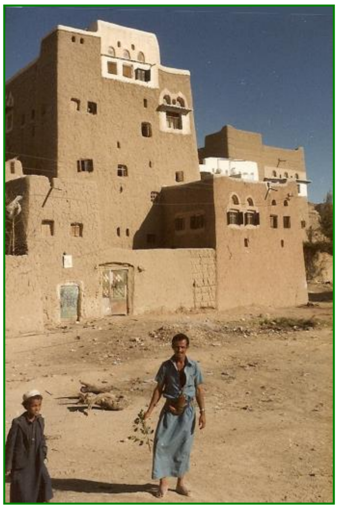
Galvanised wire-mesh under and above all openings, in all walls and connected to the vertical reinforcement.

Casting the concrete can be in woven mats to ensure rough outside surface for better attachment with the compacted clay-soil.

The walls are 40 cm thick machine compacted claysoil with corner reinforcements 8mm bars in 10cm concrete.
Shear walls must be distributed evenly over both sides of the building and in both horizontal directions.
Reinforced concrete tie-beams.



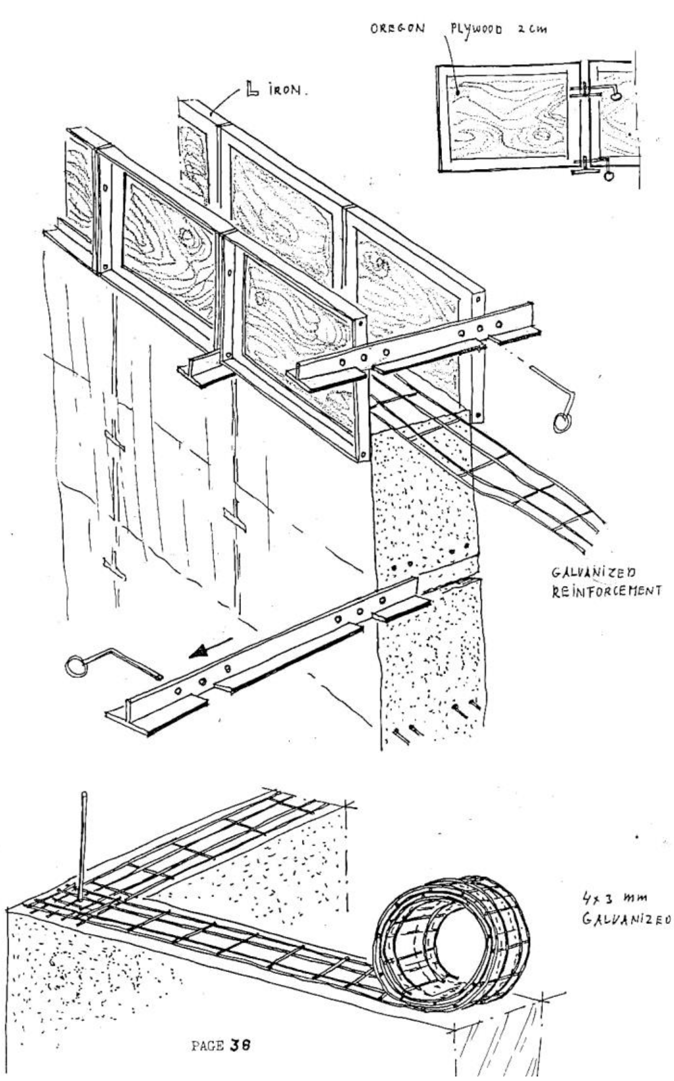
Note: In 2016, ample technical information can be obtained about improved compacted earth construction (Craterre). However, the use of galvanised wire-mesh or HDPE geo-mesh as earthquake reinforcement in compacted clay-soil has not been elaborated. For moderate intensity earthquake areas, this is a very feasible construction option. In the area north of Dhamar (map page 39) many earth constructions of 2-3 stories survived without significant damage (magnitude VI or PGA=0.25g).



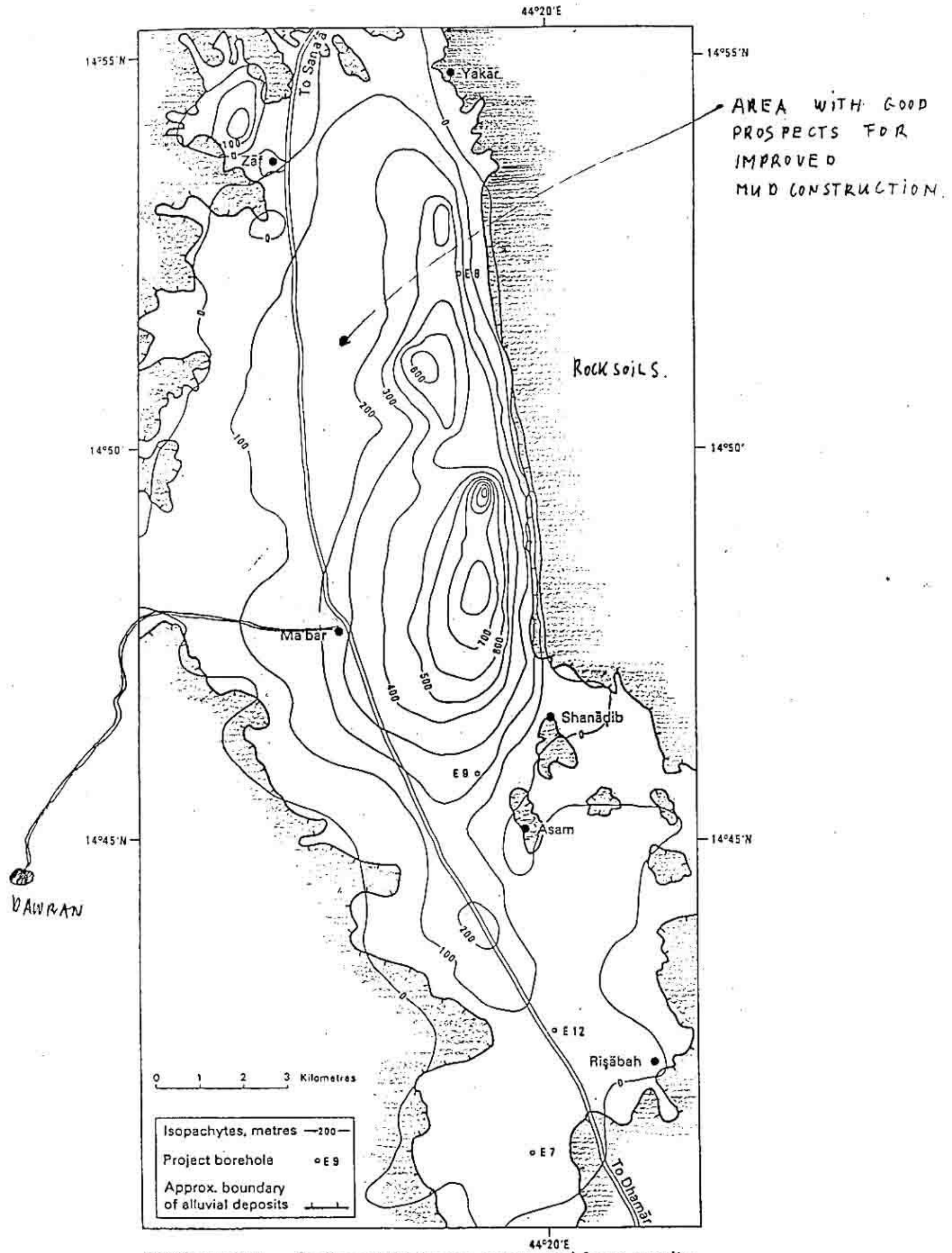
Photos (1983) from high adobe houses, 50 km north of Dhamar, not affected by the earthquake.

The ground floor walls of these multi storey houses are very thick (> 1m), becoming slimmer towards the top. At the top floors these walls are 30-40 cm thick and provide good thermal insulation. These tall houses have experienced many light earthquakes, but regular surface maintenance such as white wash of the roof and window areas.

The photo of the house below was taken at a distance of only 30 km north of the epicentre along the road near Ma'bar and shows no earthquake damage at all. It is possible that the adobe material has some shock absorbing characteristics that reduced the earthquake impact on the higher floors.



The following two photos are of non-reinforced compacted adobe houses on natural stone foundations in the Indian Himalaya. This is a mountain area with frequent earthquakes. Hence this design is not recommended, but allows reinforcement as in the drawing right.

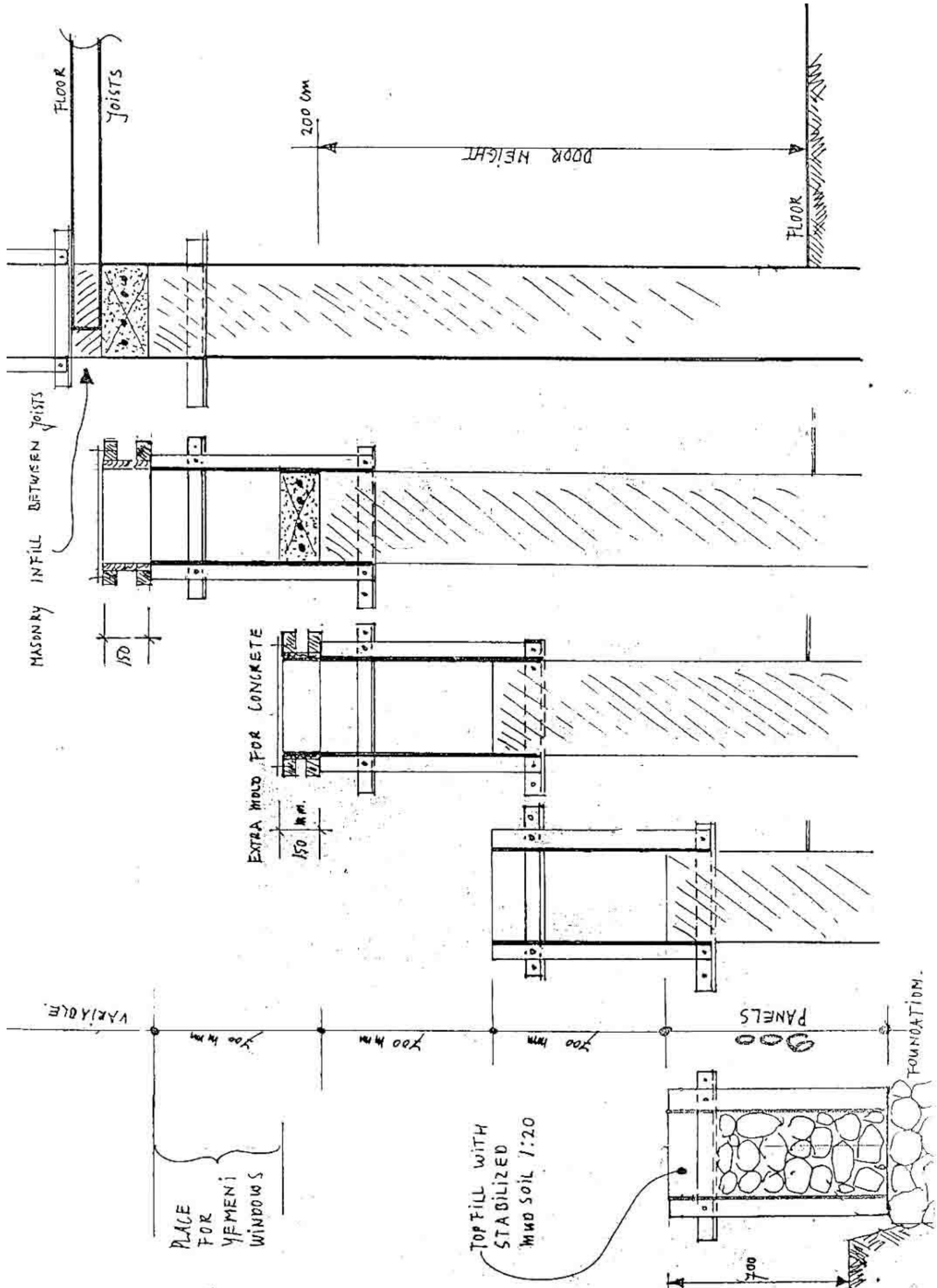


TEXT MAP 3 Sediment thickness computed from gravity survey. Qā' Jahrān

PAGE 39

Prepared by Land Resources Development Centre 1980

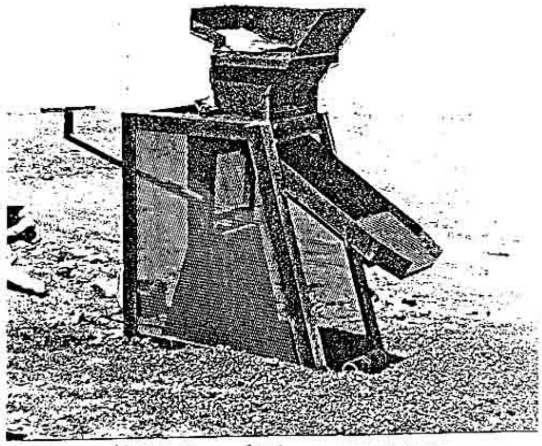
Note: This map covers the northern area of the 1982 earthquake showing very thick clay soils. Most houses in this area are constructed in compacted adobe; from which most survived the earthquake. Many houses on the rock outcropping of Asam totally collapsed or suffered very large damage.



PAGE 40

Note: For buildings higher than ground floor only, the lower storey is to be made with thicker walls.

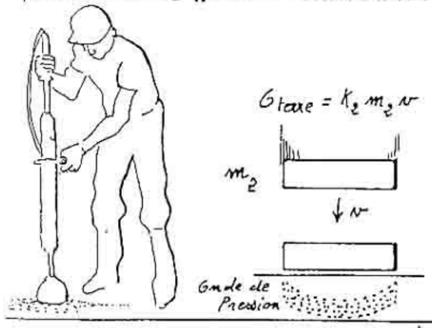
Nom du Fabriquant	Atlas Copco
Appellation	RAM 30
Poids (kg)	18,5
Hauteur (m)	1,23
Fréquence nbr de coup/mn	440
Course (mm)	284
Consommation	0,8 m^3 air /mn
Prix	
Dimension du Mattoir cm	ϕ 145 mm

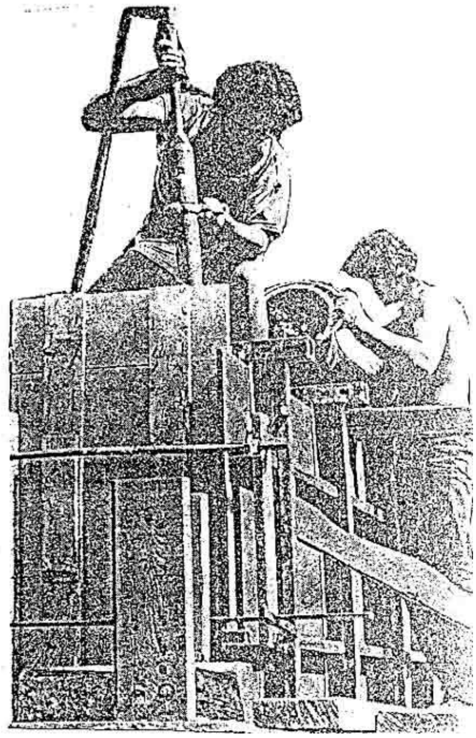


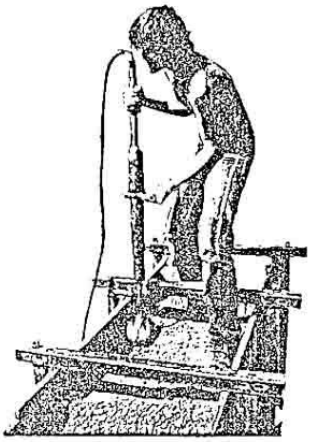
BRE MANUAL SOIL - CRUSHER.
(WITH OXFAM)

fl 3100 . . Ram 30 S
fl 18.000 . . Compressor XA 30 S
fl 2000 - air hose
fl 1900 Transport.

fl 25.000 Total cost = YR 42.000







PAGE 41

Note: The cost of the Ram and compressor was estimated in 1983 at about Euro 10,000. Although this is a high cost for one house, one Ram and compressor can serve for an entire village.

3.8. The wire-mesh-frame prefab building from NAGRON

This construction is considered as a self-help building system as far as the filling and the plastering and other finishings of the building are considered.

The system is also described in the report no 51, project office design report. (see page 43 and 44)

It is assumed that the filling of the double wire-mesh panels would not cause any difficulty on the plateau area, but the availability of about 30m3 rubble of the required dimension might cause some problems in the mountainous areas. It is evident however that special crushing of stones to fill the structure will be too costly an exercise.

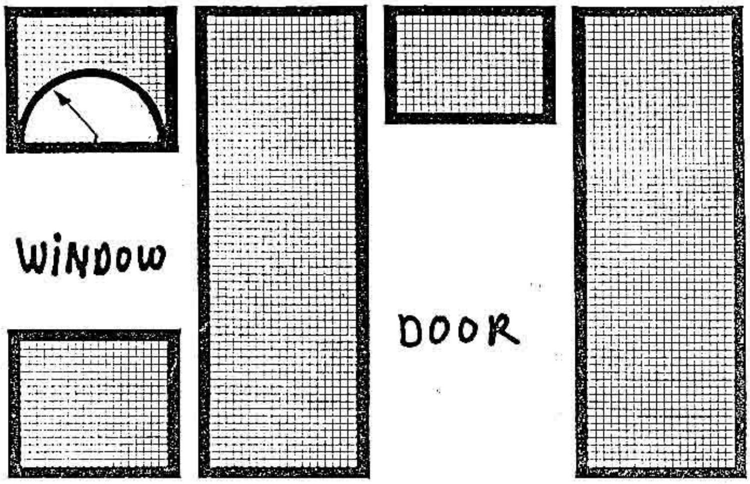
The construction may be adaptable for filling with loam or even rough sandy soils. The inside should in that case be covered with a fine galvanized wire mesh of a much smaller seize than the mesh which retains the rubble. In case of loam or soil filling the wall thickness can also be adapted.

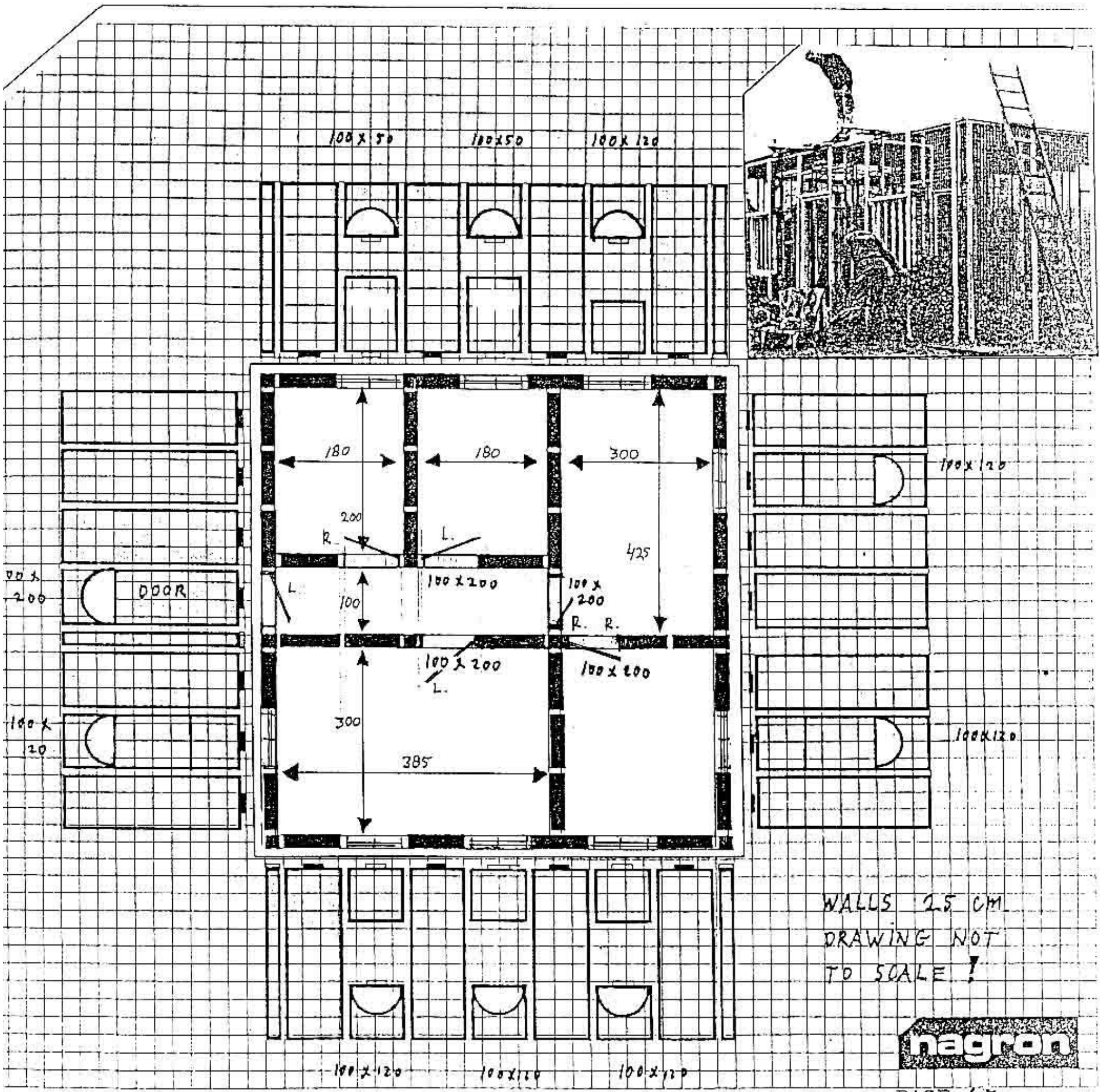
The structure has excellent climatological characteristics due to the wall thickness of 25 cm and the lose structure of the filling which gives it also a low heat transmission coefficient.

In the present situation the entire structure of the house is manufactured abroad, but it is suggested to have the system locally produced. The angle steel, the wire mesh as well as the whole galvanization process has to be imported anyhow. The local production of the system will be a stimulation for the local labour development, but it will take some time before efficiency and quality standards are met, to make it comparable with the imported product. One of the attention points is that the galvanization is complete, and realized as last step in the fabrication process. Internal corrosion of the steel structure will result in the elimination of its special earthquake resistant characteristics within a few years.
The system is strong enough to carry a first or even a second floor.

If mass produced and efficiently filled, this system is probably one of the cheapest.

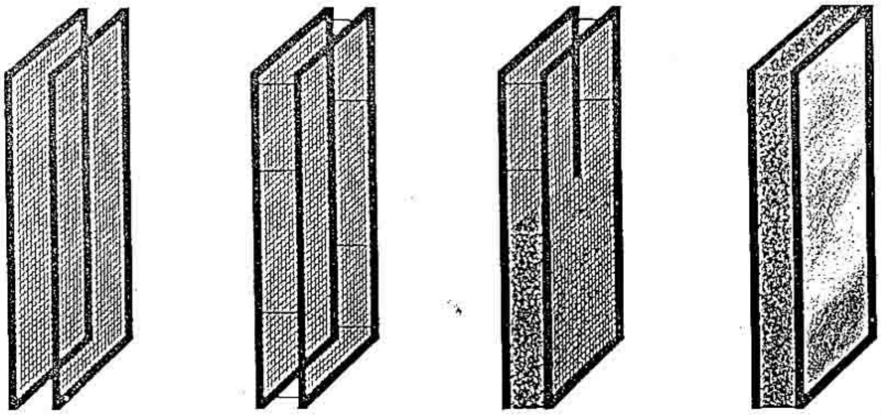
Note: The 1986 evaluation report indicates that the 100 Nagron houses were not very successful, but adequate for the occurred emergency phase, with adequate quality, design and execution.
Note: The amount of 30 m3 of rubble stone to fill the cages was managed with machines and likely to be very hard to realise by hand as a self-help activity. The amount of sand-cement plaster was very large and prohibitive for local villagers to finance.
The local manufacturing of the wire-mesh cages system did not materialize, and two-storey buildings were not made.
The technology of high quality wire-mesh cages (without the angle irons), filled with rubble stones is currently applied in road construction, sound absorbing walls, city landscaping and garden features.

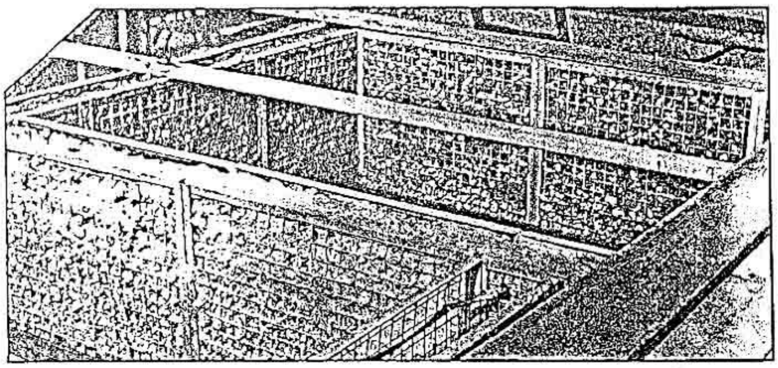


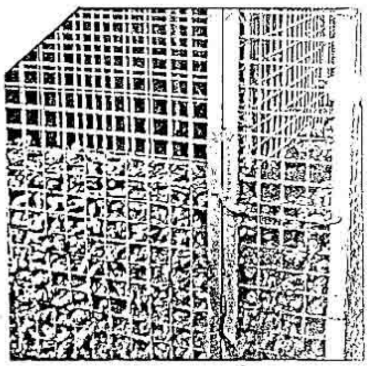


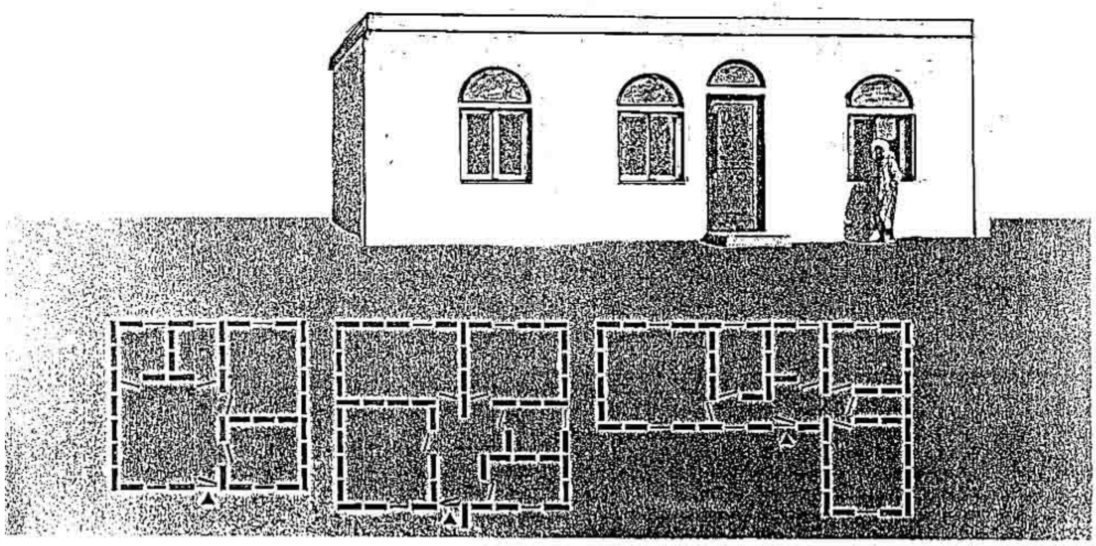
PAGE 43

Note: The overall design of the finished house was very well accepted by the population, but the construction was not replicable or extendable because the frames were not locally available.









nagron holland

PAGE 44

Note: Although all the panels were connected between each other and additional connections were fixed at ceiling level, the whole construction still had some flexibility. In the event of a very large earthquake, the entire construction should flex and the plaster break, but certainly not collapse.

4. Review of main characteristics of rural construction.

The rural buildings in Yemen Arab Republic, especially those from the earthquake affected area, are characterized by the following elements.

a) High labour and transport costs. Especially in the rural areas where people have their daily activities, additional labour is not readily available. Labourers normally receive their food, qat and a daily YR 50.=, which will be the equivalent of at least YR 100.=. In the mountainous areas transport cost may be as high as YR 10/ton/km.

b) In the remote areas, little or no experience exists about reinforced concrete constructions and its special characteristical behaviour during earthquakes. No supervising organisations are existent, in order to safeguard the quality of design and execution.

c) Traditional heavy stone architecture with small windows and extremely thick walls. The thick walls are technically necessary, because of its loose construction and have the advantege of creating a cool and stable inside climate.
The cut-face stone technology is the origen of wall constructions with a heavy, but non-load bearing, facades with an irregularly piled up rubble innnerwalls which are load bearing. (see page 46)

d) Little or no cement or lime mortar is used for the for the masonry work in the bearing wall construction.
The stones are laid in a wet clay-mud mixture which will rapidly erode due to wind and rain erosion.

e) Any stress reinforcement, which would resist the horizontal forces originated by earthquakes, is often inadequate or not existing at all. Some timber ties, when applied, often have insufficient linkage.

f) The mufraj, as being the largest room in the building has often an elongated shape, This is disadvatageous for the stability of the house. (see page 47)

g) In traditional buildings, with floors made from tree trunks, sticks, mud and stones, a lack of floor/ roof diaphragms is identified.

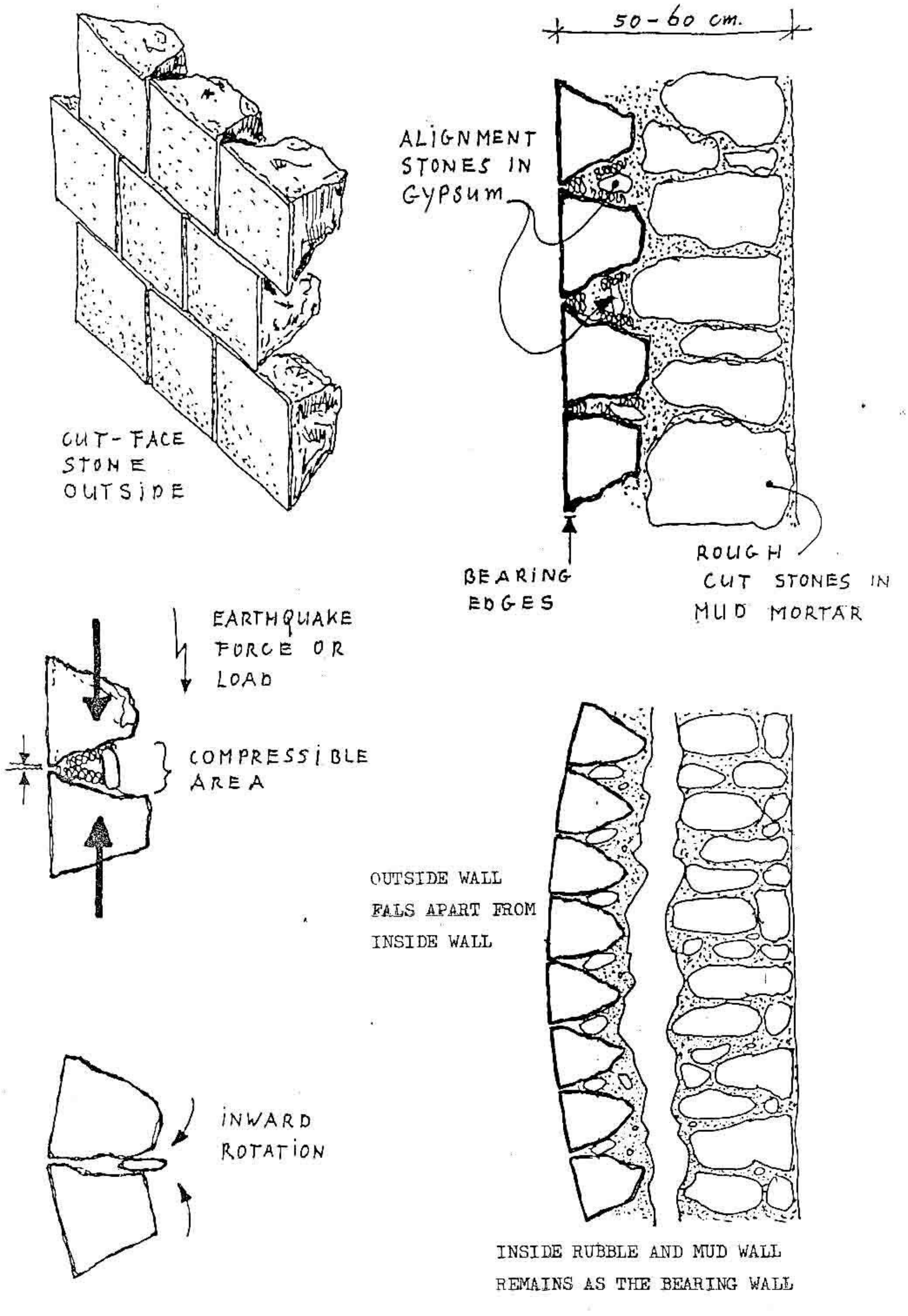
h) The same type of roofs mentioned under g), have also inadequate waterproofing. This leads to adding more material to the roof which will increase the weight.

i) Regular earthquakes of moderate strength, at intervals of maybe less than one generation.

Note: The houses were to be built directly next to the collapsed houses, avoiding any construction on the scare agricultural land. The project therefore did not develop any infrastructure. People re-constructed their squat toilets. Some projects improved access to water by pumping it from the rivers deep below in the valley. Most occupants indicated that they would extent the house vertically.

Note: The Nagron wire-cage houses had poor thermal performance due to non-insulated roofs and condensation caused by the high conductivity of the metal frames. The metal sheet roof-floor construction was difficult to insulate or provide acceptable finish. Most plasterwork started to crack. The long-time curing of the thick plaster was a problem due to the dry climate and lack of water.

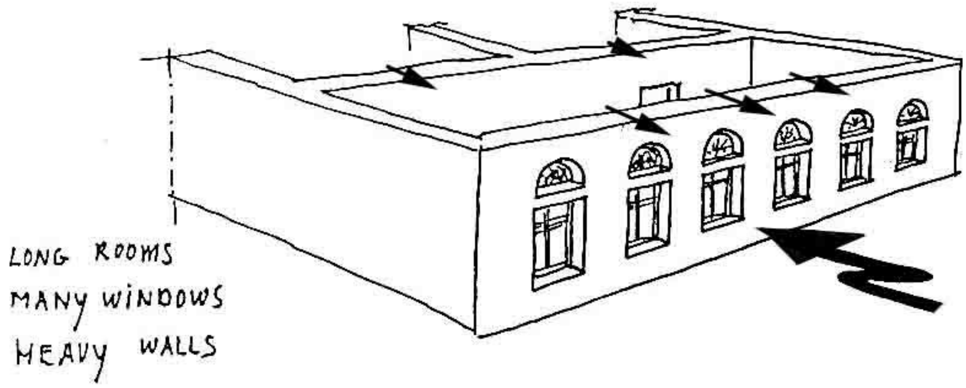
CUT -- FACE STONE MASONRY

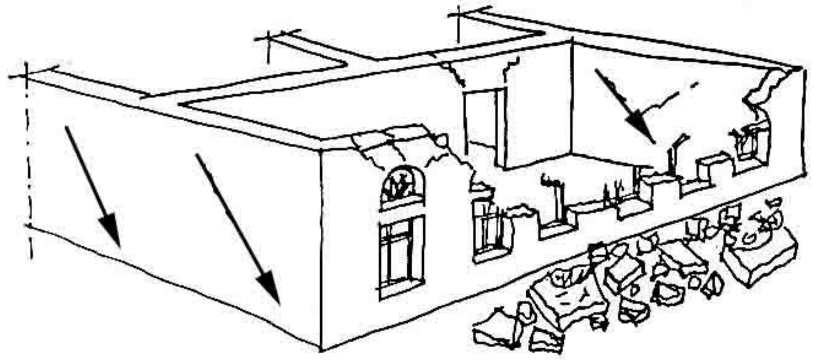


PAGE 46

Note: The 20th century introduced technique of the square cut-face stone with conically cutting away the rear side, caused a serious problem due to wind and water erosion, and foremost with earthquakes.

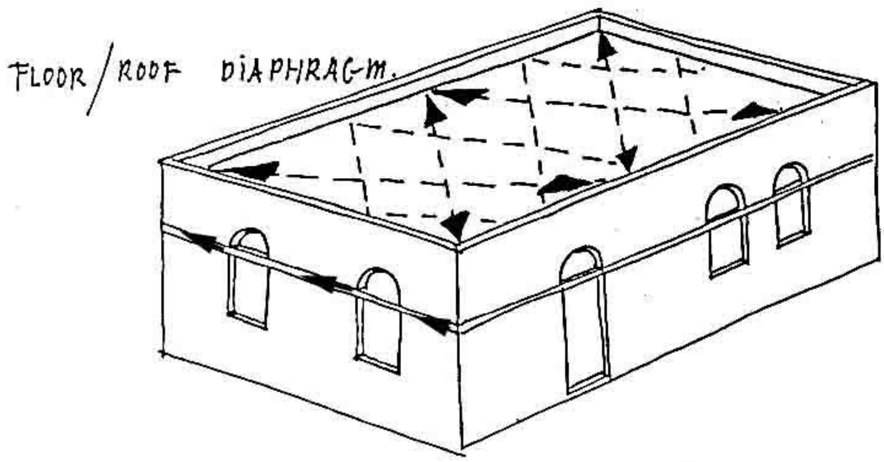
The force of the earthquake and the inertia of the building mass, causes both vertical and horizontal loads on the building construction.





Shear walls will resist forces in the plane of the wall. These forces go to the foundation.
Forces perpendiular to the plane of the wall may cause them to break or topple over.

Floor and roof diaphragms are important building constructions to collect horizontal forces and carry these to the shear walls.
The window and door lintel beam is connected to the cross walls and carries a large portion of the horizontal loads to the shear walls.



PAGE 47

Note: Currently (2016) ample information is available on the Internet about seismic resistant design. This was not the case in 1970-75, and by postal mail information was obtained from USA and India.

To overcome the fore mentioned elements (a-h), and to counter (i), the following proposals were incorporated in the fore mentioned designs;

ref.a) Use of local materials and development of building systems which are reproducible by the local population.
Elaboration of the labour less intensive cement blocks, combined with the possibility to use this U shaped cement block in combination with less expensive rough cut stone masonry.

ref.b) Elementary application of the use of concrete and steel reinforcement, without development of special load bearing column designs or space-frame constructions.

ref.c) Rejection of the so-called cut-face stone technology which gives cause of delamination and spontaneous desintegration of walls, leaving the inner mud and rubble wall as the bearing element.
Reduction of wall thickness in combination with the use of through stones in the whole structure.

ref.d) Use of cement mortar for the masonry work. This has not to be an extremely strong mortar but sufficiently resistant against long duration wind and rain erosion. The high cost of the mortar and the large quantities of mortar required for thick walls is one of the reasons to reduce the wall thickness.
In an attempt to reduce once more the cost of the mortar, especially the cost of sand aggregate, a mixture of 1 cement, 2 soil and 3 sand is recommended.

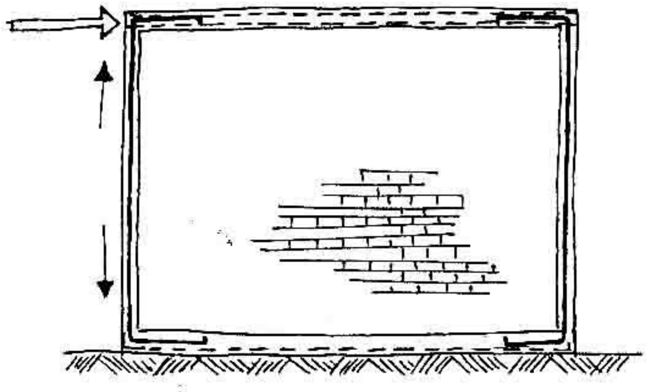
ref.e) Stress reinforcement is brought into the construction by means of simple reinforced concrete tie-beams or by means of galvanized steel wire mesh reinforcements, which are incorporated in the masonry work.
The difference between the two methods is the distribution. The tie-beams (U block) are concentrated, whilst the wire mesh is evenly distributed. (compare page 11 and 18)

The total stress capacity of the steel in the concentrated tie-beams is equivalent with the total stress capacity of the distributed galvanized wire mesh.

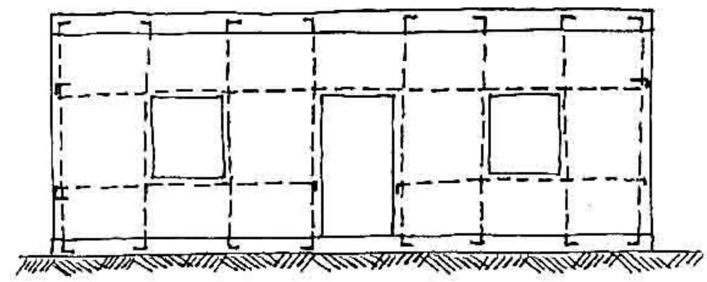
The vertical reinforcement is the stress reinforcement for the framing of the shearwalls such as the main cross walls and the outside walls. (page 49) This stress reinforcement is not necessary for a one storey building only, but it is considered that all buildings will have in future a second storey added. However when the remaining piers between the walls become small, vertical stress reinforcement is necessary (see page 50)
The vertical reinforcement is connected with long hooks instead of with overlaps. This is in order to make sure that the connection is made and from an educational point of view it is easier to understand. (for total system see page 51)

VERTICAL REINFORCEMENT
TO RESIST TENSION

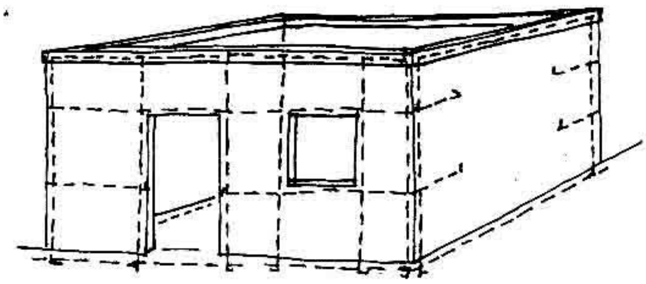
FRAMING OF SHEARWALL



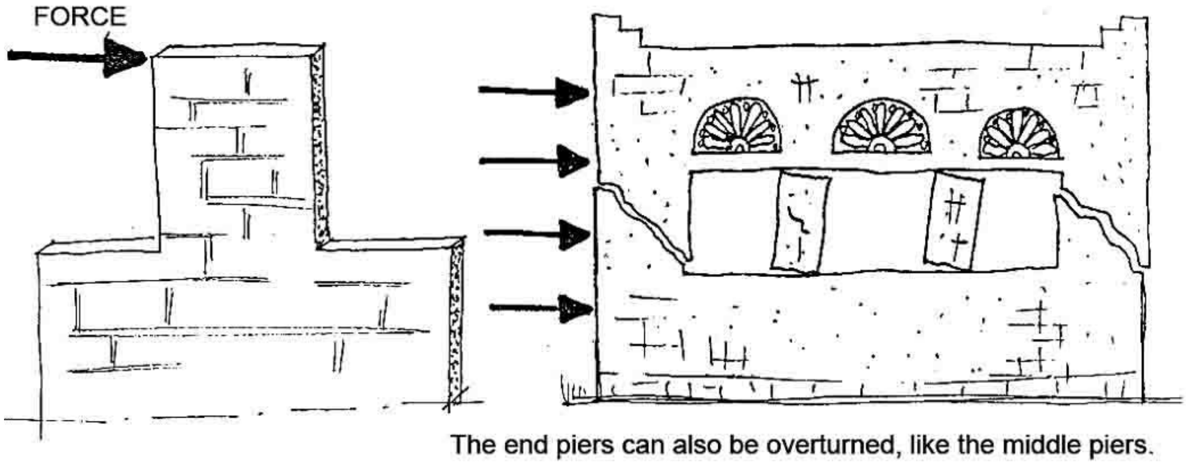
TENSILE REINFORCEMENT
AROUND ALL OPENINGS
AND WALL ENDINGS



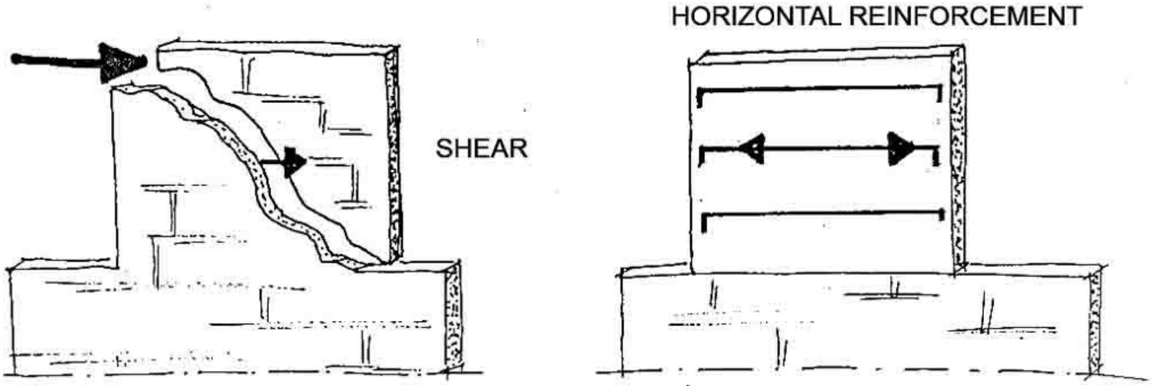
ROOF TIE BEAM
TO RESIST BENDING AND
STRESS AND PROVIDES
ANCHORAGE VERTICAL STEEL



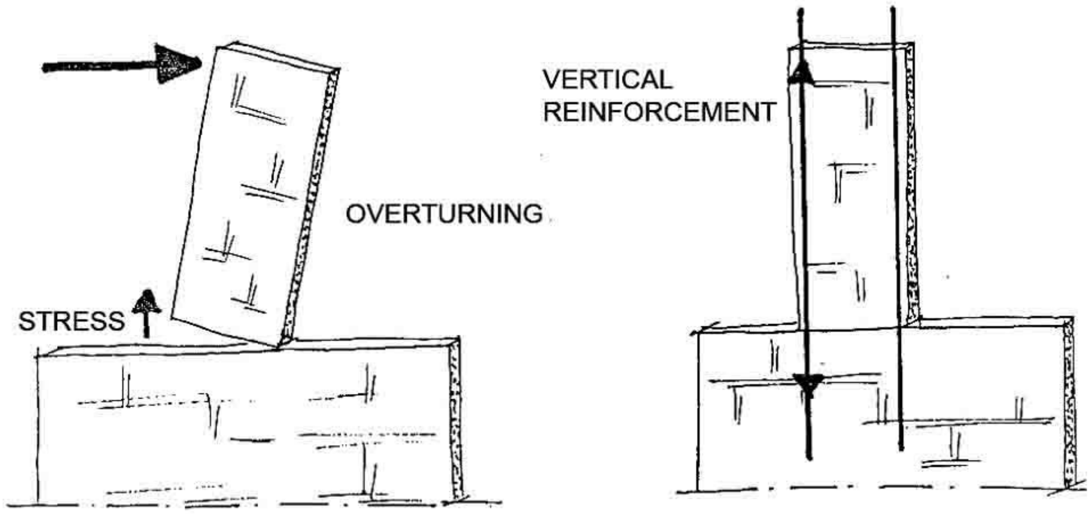
Note: Information (1975) from the Indian Earthquake Engineering Research Institute (EERI). Indian engineers from the EERI were realising reconstruction houses in other sections of Dhamar.



The end piers can also be overturned, like the middle piers.



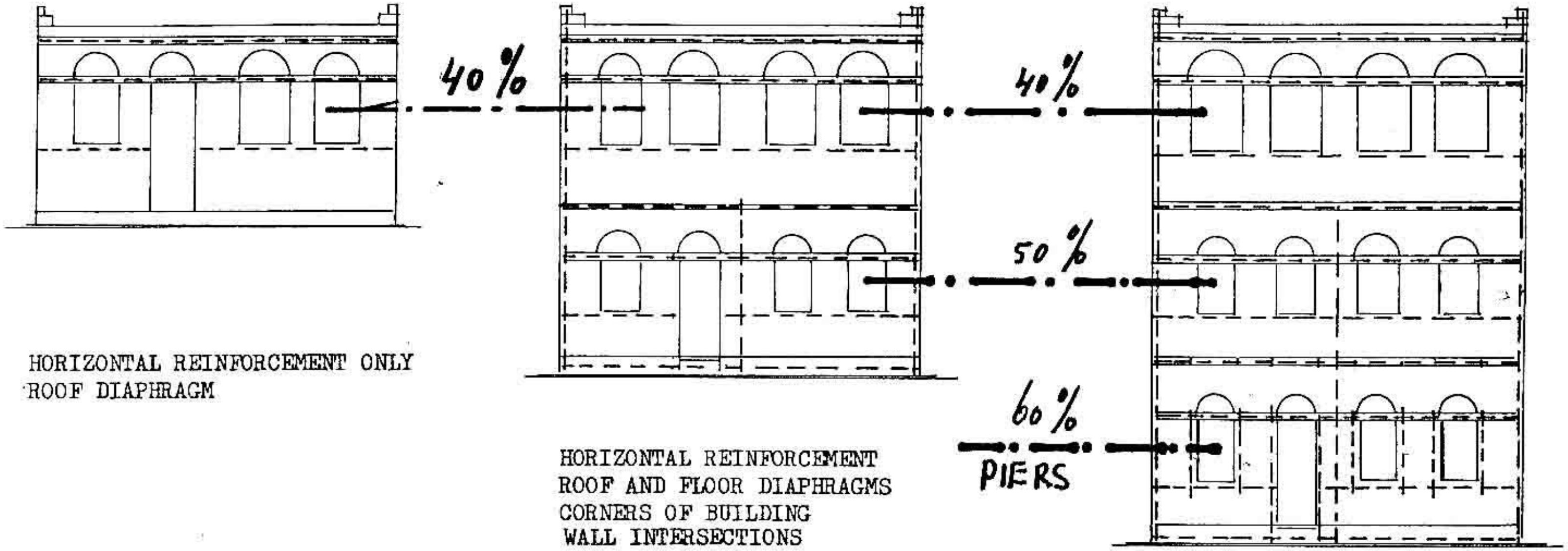
With wide piers, horizontal reinforcement is more effective when shear forces occur.



The sketches show why pier reinforcement is required.
With small piers the vertical reinforcement is more effective than horizontal reinforcement.

-50-

Note: When the piers are smaller than their height, the vertical reinforcement becomes more important. This however, depends on the vertical load factor that applies to those piers.



BASIC REINFORCEMENT PATTERNS
WITH MINIMUM WALL SECTIONS OF FACADES
VERTICAL REINFORCEMENT Ø 8 mm, ONE BAR in concrete.
HORIZONTAL REINFORCEMENT 2 x Ø 6 mm in concrete or 4 x Ø3 mm galvanized.

The piers need to transport the earthquake forces in the plane of the wall downwards back to the foundation.
This schedule for the width of piers is based on a practical assessment, without theoretical calculations.
Since in self-help construction the quality of the execution may vary greatly, such as the amount of cement used, general guidelines with an adequate safety margin are more practical than precise calculations based on vague information.

When the building is to be made one storey higher, vertical reinforcement is required in the second floors as well.
The above means that by construction the groundfloo, the final (maximum) height of the building needs to be known.

Note: In practice, full reinforcement for the three-storey building should be made for all buildings, because nearly all house owners wanted to extend the house vertically due to lack of ground area.

ref.f) The elongated rooms are to be avoided. In the designs of the modelhouses, two rooms are connected by means of an opening, leaving a pier in the middle of the room, on which a low arch is built. The masonry work of the arch upto the roof/floor level must be reinforced every layer with the galvanized wire mesh. This way, a bridge is build between the inner walls and the outside wall of the longer room (mufraj).
In general it is not recommended to have longer side walls or larger spans than 4.00 m. Larger spans than 4.00m will be also more costly in timber, because the joists must have larger sections, whilst the cost for long timbers is relatively more expensive than the ones of about 3.00m to 3.60m.

ref.g) The roof/floor diaphragms are all from timber in order to keep the weight of the construction down and to conform with local practice. All joists are tied to the wall construction with double galvanized wires (3mm) and nailed to these wires (hard steel nails because of the hard wood). (see pages 13,15,20 and 21)
The joists parallel and next to the walls, are fixed to the walls with a stress connection of either strips of galvanized sheet metal, or a wide galvanized wire mesh, both nailed with steel nails onto the hard wood. (page 20)
Over this whole construction a 12mm thick plywood is nailed with steel nails (1,5") to ALL joists.
The plywood diaphragm is stopped between the walls, to allow the walls later to be continued for a second storey.

ref.h) The waterproofing for the roof is established with a reinforced plastic foil (type Miofoil, clear, 0.25mm). This and similar plastics are commonly used for temporary closures and weather proofing of unfinished buildings in wintertime (Europe). However this foil is not permanently resistant against the Ultra Violet Solar Radiation (2 years), and should be covered with a layer of soil.

The traditional roof is also covered with soil and especially in the hot period of the day it provides an excellent thermal insulation.
For this reason it is recommended to have the modelhouses realized with a soil roof of about 10-15 cm thick and stabilized with 1:20 lime, against washing out of the rains.

With the construction of the roof the gutter pieces should be laid between the roof joists to allow an uninterrupted flow off from the water which leaks through the soil cover.
The different sheets of roofing foil are glued to each other by means of a double sided tape. This activity has to be done the same time as the roofing foil is placed, in order to allow clean work. The roofing foil has directly to be covered with the lime-soil mixture to avoid punctures.

ref.i) Not only the Dhamar plateau area is subject to regular earthquakes, but the whole Yemen is. Information shows that also the former generation has had its catastrophe, and it is statistically spoken very real that within this generation an other mayor earthquake will occur.
Since most of the building volume in this country is constructed or directed by the owner, that owner-built construction has to be guided towards building methods which better withstand moderate earthquakes.

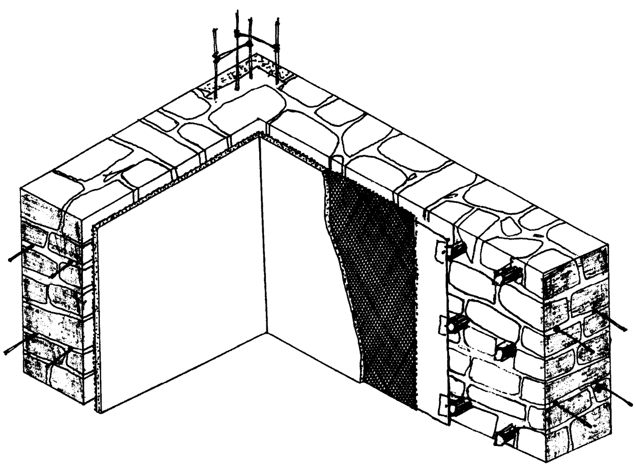
In order to achieve such a goal, educational systems have to be found through which urban and rural, mostly illiterate people can profit and understand better ways of building, which better will withstand the espected earthquakes.

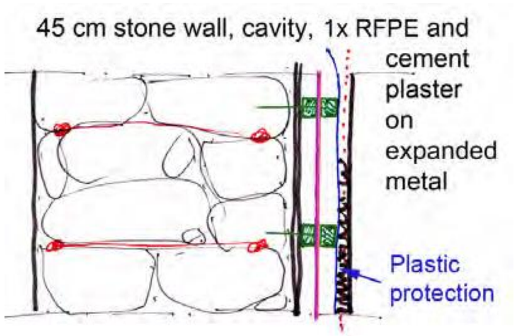
Real examples of good buildings, which can by copied with the use of mainly local or available imported building materials is one of the best methods, which will directly appeal to the population. These real models can partly be worked open, to show the otherwise hidden internal reinforcement structure. (see page 54)

Next to this practical visual training object, extention methods shall have to be developed which will have a remaining impact on the larger population.

- 53 -

Note: In relation to the construction of thinner (lighter) natural stone walls, masoned in cement mortar, the technique of inside wall insulation was developed, using plaster on small gauge wire-mesh, or plywood panelling creating an air cavity. In later designs, the use of shiny reflective foils was used to substantially enhance the thermal insulation. This would have been useful in the YAR.



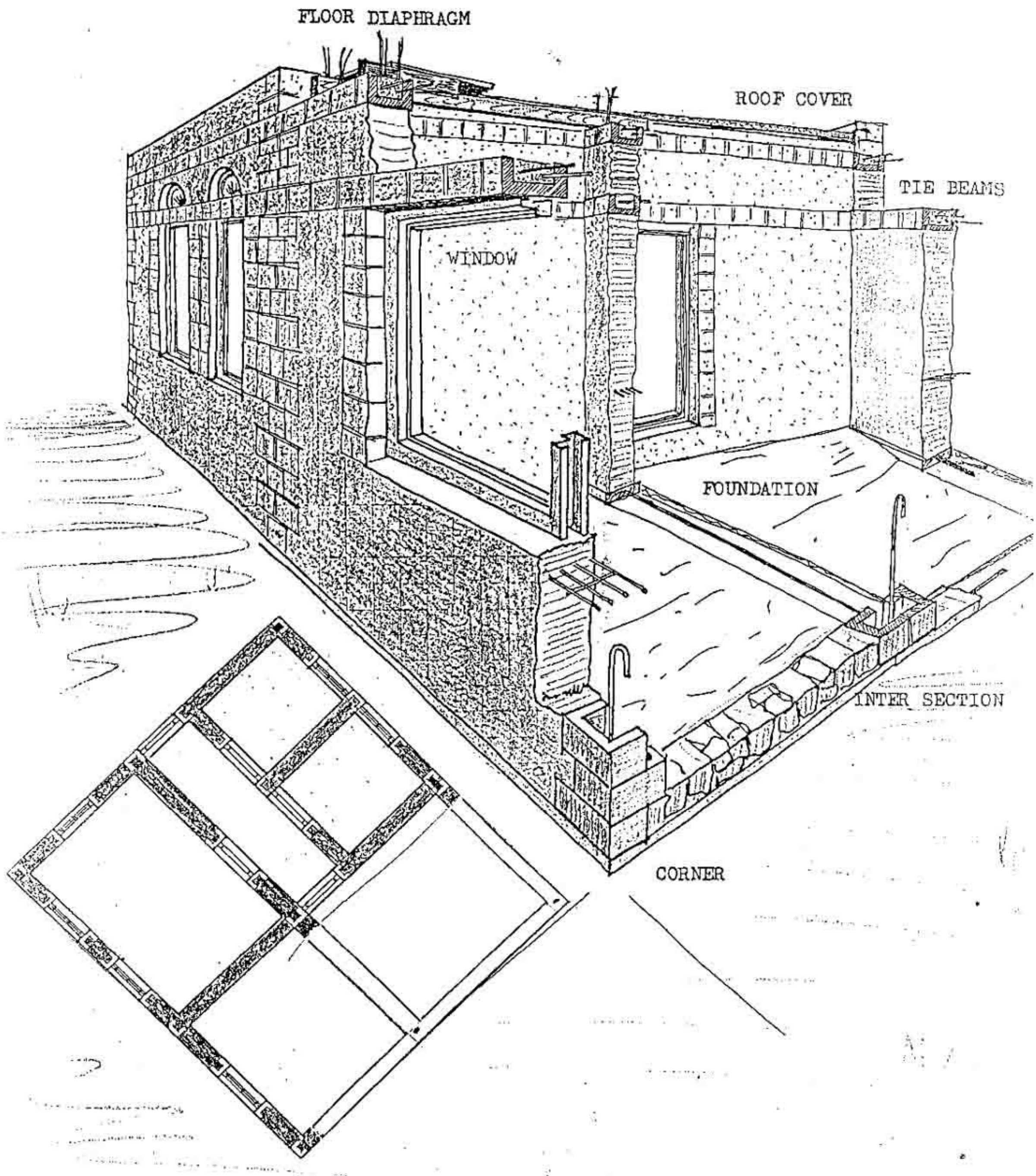


Use of an additional highly reflective foil for substantially increased thermal insulation.

Sketches from one of the documents of the Building and Construction Improvement Programme (BACIP) in Pakistan and the House Improvement programme in the Hindu Kush area of Tajikistan.

More details in documents on the website: www.nienhuys.info

HOUSE
WITH UNCOMPLETED EXTENSIONS
FOR SHOWING THE CONSTUCTIONAL DETAILS



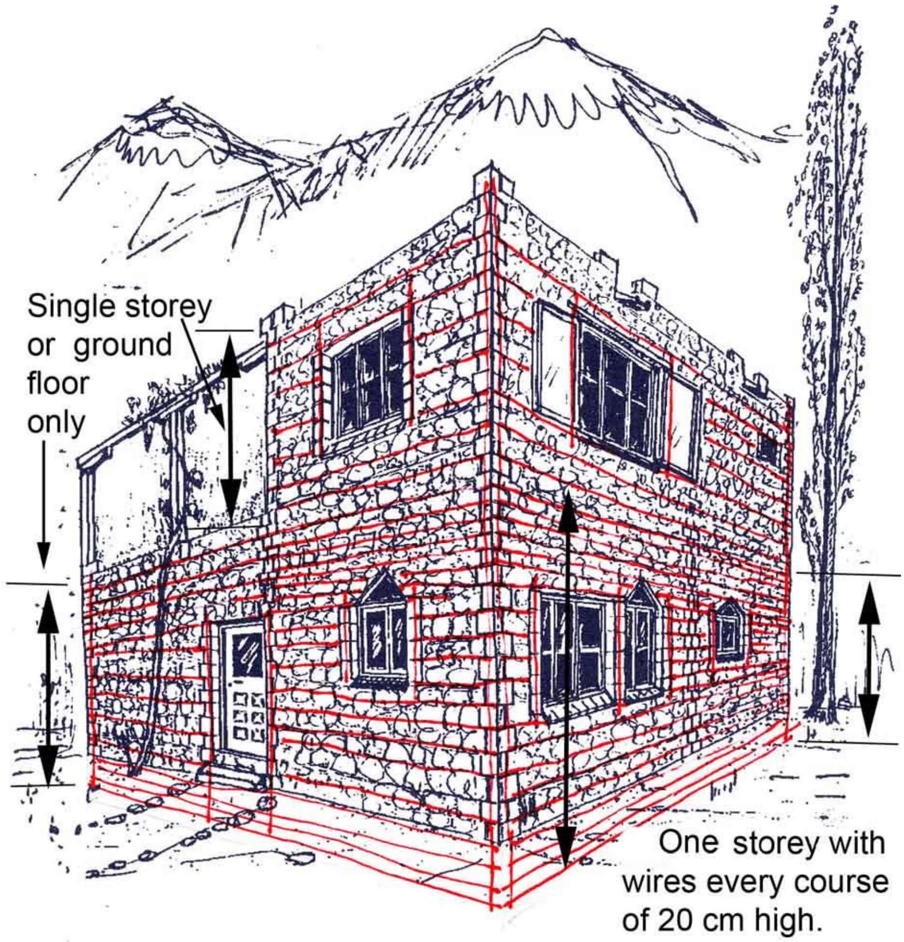
PAGE 54

Note: Several manuals provide detailed construction information in axonometric and perspective sketches. The local craftsmen had no difficulty understanding these drawings correctly.
The reconstruction project provided pre-fabricated steel doorframes. This allowed fast construction. As with many projects, windows and roof beams were salvaged, but the traditional arched windows with coloured glass were made from gypsum and manufactured on the building site.

Note: The technology of galvanised wire-mesh wall reinforcement has been further elaborated and published in several documents about the above mentioned BACIP project in Pakistan Himalayas.

The galvanised wire-mesh reinforcement design would be suitable for remote villages where transport of bags of cement and steel reinforcement bars will be very costly for the house owners. Usually the supply of sand is equally difficult since this needs to be drawn from remote river beds. The tendency exists to minimise the use of cement in the mortar, which will cause corrosion of common steel bar reinforcement. The option of the use of High Density Polyethylene (HDPE) geo-mesh can eventually substitute the galvanised wire-mesh, but also needs to be imported.

Villagers who had sufficient funds, commonly decided to built earthquake resistant stone houses with reinforced concrete columns in all wall intersections and along door and window openings.



- Page 55 -

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