HUYS ADVIES

Dhamar Aided Self-Help Reconstruction Project

Post 1982 Earthquake Reconstruction: Building Technique

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Abstract
Criteria for post-earthquake site selection for the reconstruction process of assisted self-help houses in the Dhamar, Maghrib Ans and Jabal Al Sharq regions in the Yemen Arabic Republic (North Yemen). Analysis of structural failure of the dressed stone masonry. Design principles for earthquake resistant design using U shaped cement blocks, steel reinforcement and full roof diaphragms, illustrated with sketches and used as training material and for the production of manuals. Improved dressed and cut-face stone masonry. Photos taken shortly after the earthquake of December 1982 and during the construction process.

Foreword
The document was originally prepared in 1984 as part of project reports and to develop educational material as guideline for local architects, and engineers. The concept of the designs is based on the need for both horizontal and vertical wall reinforcement, to reduce the amount of stone cutting and obtain an appealing architecture. Some of the engineering aspects were inspired by Indian Earthquake Engineering Research Institute (IEERI) and internationally available documents collected in 1976 during my earthquake research in Ecuador where I developed the national earthquake code.

The original document was typed on a "modern" Kaypro 2000 computer with an 8" cathode ray screen having green light letters and a magnificent 1 MB hard disk drive with an astonishing large 125 kB internal memory. Our dot-matrix printer did at least two full pages per minute, but when you did not frequently save your work on a real 6" floppy, it was often lost because of unstable power supply.

The original stencilled document had dark black and white pictures, which have now been replaced with better quality and colour scanned pictures found in my stored luggage. This luggage I recently retrieved after 25 years of working and living in several countries in Africa, South America and Asia. Because of the timeless value of the information, I decided to reformat and simplify the paper same, and add the found colour photographs.

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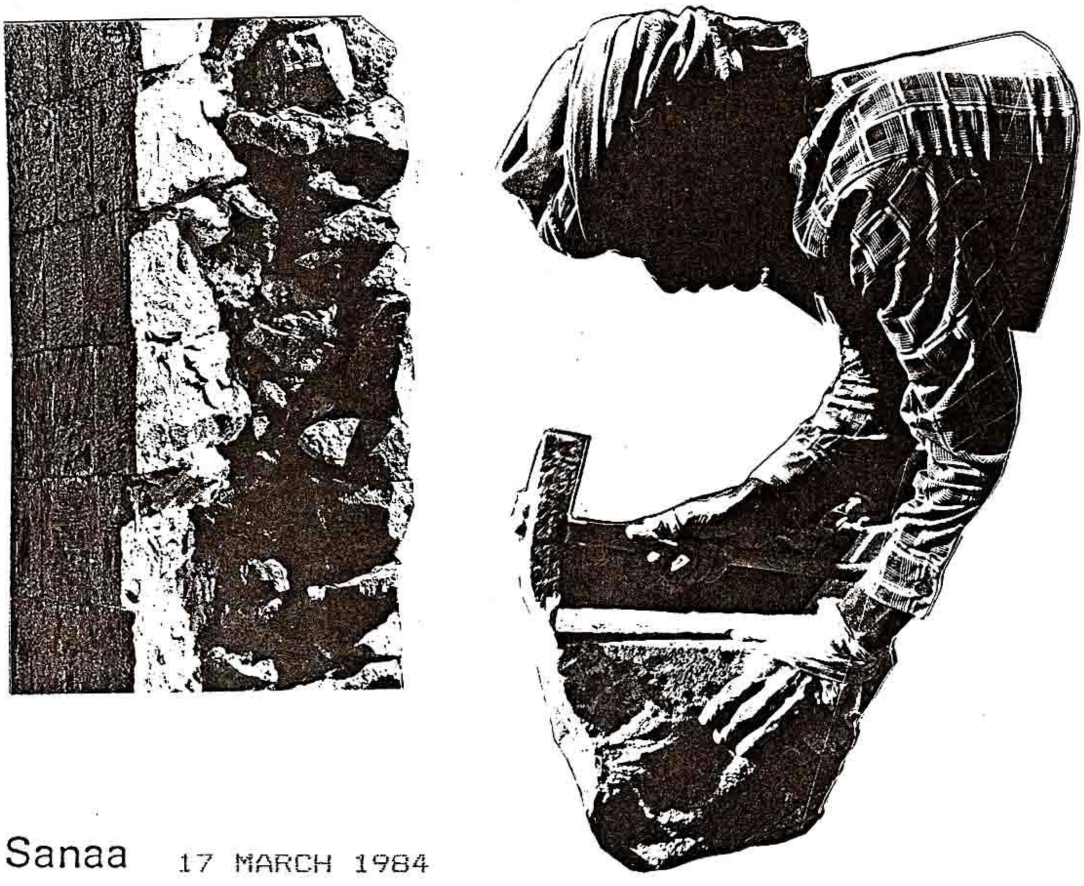
THE PROTOTYPE HOUSE IN DHAMAR WHERE I LIVED TWO YEARS
WHILE DEVELOPING THE TRAINING AND RECONSTRUCTION PROGRAMME

Yemen Arab Republic

Kingdom of the Netherlands
Commission of European Communities

Dhamar Aided Self Help Reconstruction Project

BUILDING TECHNIC REPORT RESEARCH CONSTRAINTS PROPOSALS
PLANNING ACT 28 29 30.



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DHV

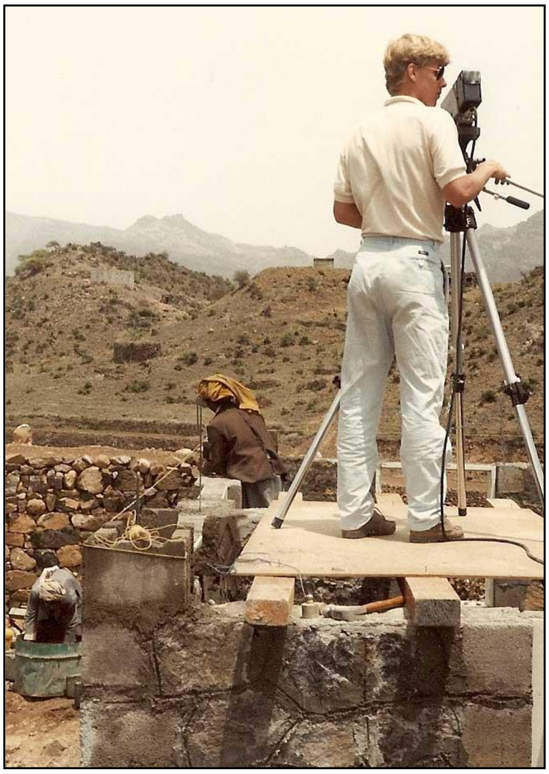
DHV Consulting Engineers
Sjoerd Nienhuys, Architectural Engineer and Trainer

Introduction.

Research carried out following the December 1982 earthquake in the Dhamar and the Mahgrib Ans regions showed the weakness of the traditional non-bonded dressed stone architecture, its failure and collapse, causing thousands of victims and substantial economic damage. By analysing the failure patterns of nearly and partly failed structures one would understand where the reinforcements should be applied and how they should bond the building with tie-beams and diaphragms.

The technical design was developed on the concept that the villagers and their skilled stone cutters and masons should be able to reproduce the system and expand the small core houses by replication of the technology.

Although a large number of stone cutters and masons would be involved in the assisted self-help reconstruction process, visual training materials were developed in the form of step-by-step picture manuals and a series of six short video films showing the entire building technique and process of the construction of the core house.



The report is presented in three sections

Chapter two is a short review of the main problems found in the partly collapsed buildings, and some examples of buildings that survived the earthquake because of proper structural design. Here it shows that in the country the right building knowledge was available, but that information for the self-help construction was not accessible or not practised.

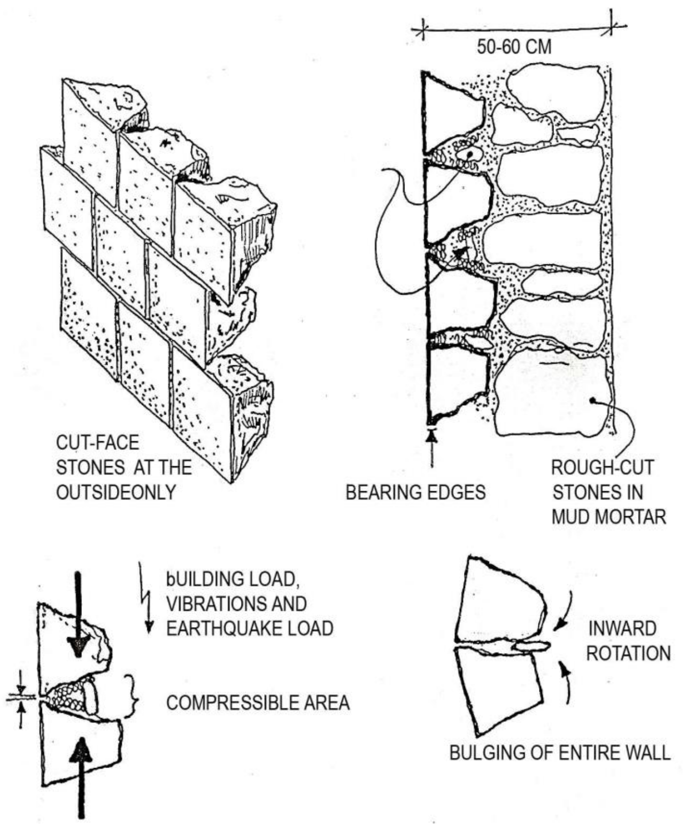
Also an introduction is provided to the solutions.

Chapter three gives an overview on how the new building system was designed with its tie beams and how the floor diaphragms are resolved in the new design. What was proposed is a building system which can be realised by self-help construction and replicated by the local craftsmen.

2. Existing building practices

Traditional buildings, especially in the earthquake affected area, are mainly using volcanic stone and mud soil for the construction of heavy walls. The outside and most visible face is often made from tailored or dressed stone, but inside walls are rough and all stones are masoned without cement or lime mortar, having no internal bonding. The inside of the walls are plastered with loam, sometimes with added manure and straw for bonding; final finishing is lime wash. Short span floors and roofs are made from round wood, covered with branches, straw and compacted soil layers. The floor beams are not anchored into the walls otherwise than by their friction and weight of the above wall mass.

Photo's of traditional buildings and their damage can also be viewed in my paper on site selection see: http://www.nienhuys.info/mediapool/49/493498/data/Dhamar_Site_Selection.pdf, or from my website www.nienhuys.info and look in Earthquake Constr. Size 3.7MB, 15 pages.
The pictures in the above mentioned document also illustrate the problems related to the technique of making nicely dressed cut-face stones for dry masoned stone wall constructions.



The volcanic stones can be finely shaped with enough time and skill (costs), but many masons apply the cut-back technique.

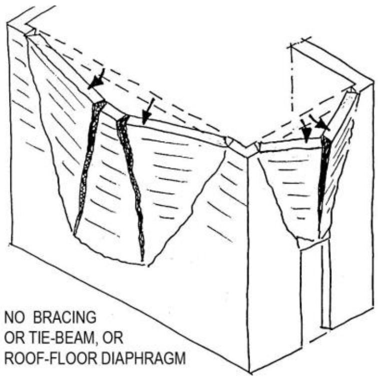
When mainly the face of the stone is tailored with straight sides, the rear sides are cut back to minimize the joint in the façade of the building. The inside is supported with rubble.

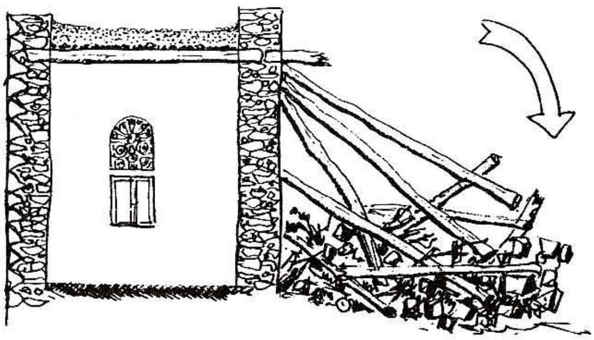
With the many vibrations, like the small and large earthquakes, this allows the cut-face stones to bulge outwards and come loose from the rubble masonry of the inside of the walls.

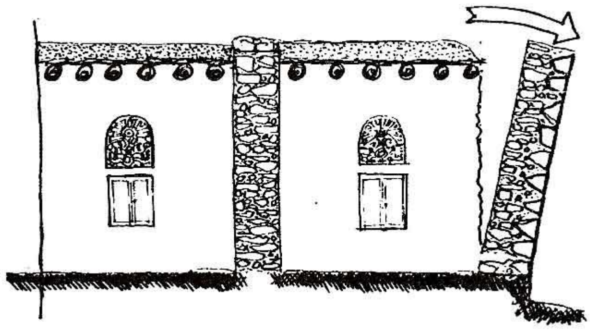
When the outside face falls off the walls, only the mud masoned inside wall may sometimes keep up the construction, but in most cases the entire wall collapses. On the picture below one can notice that left the cut-face walls have peeled off, and on the right side and the rear the entire wall is collapsed.

The stone mass of the above building is considerable, causing large earthquake forces. The collapse of the above building is also caused by lack of tie-beams, floor or roof diaphragms and adherence between floor beams and the walls.
To avoid this type of damage a combination of measurements are necessary such as:

a. Lighter construction materials, thinner walls.
b. Cement mortar inside the walls, in between the stones and anchorage between the inside and outside faces of the walls.
c. Sufficient inside cross and shear walls with full height anchorage of the outside walls to these inside walls.
d. Tie-beams through all the walls and duly anchored to these walls, the floor and roof diaphragms.
e. Floor and roof diaphragms providing also anchorage on all four sides to the inside shear walls.

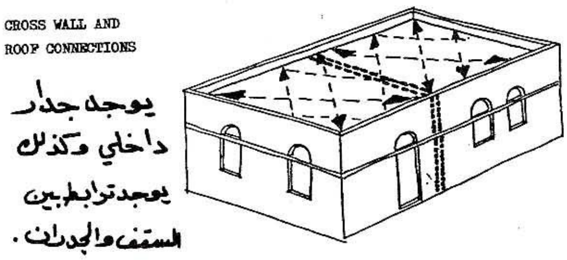


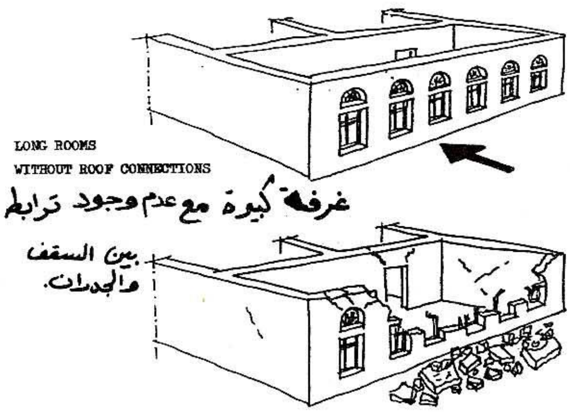




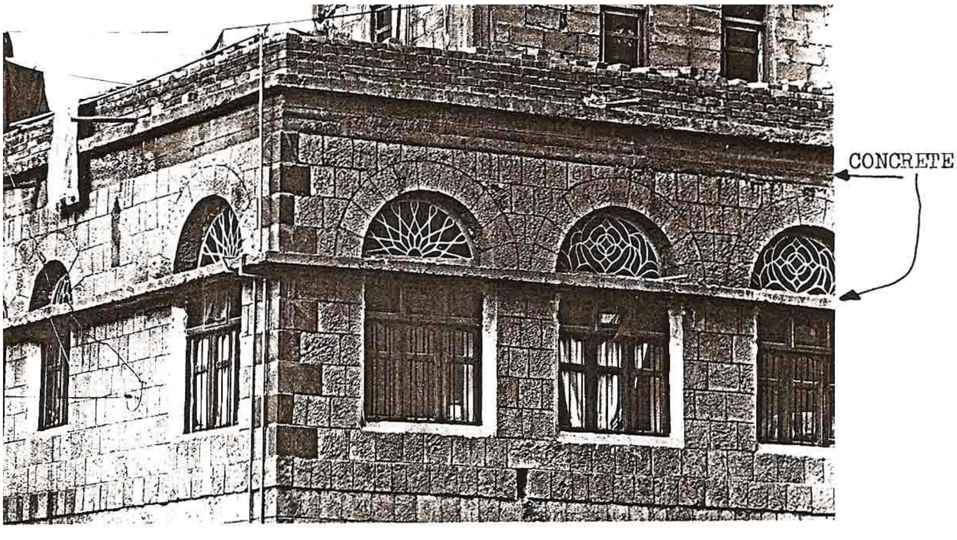
On the above sketch and the following picture (top middle room) it can be seen that the roof beams have just kept the outside wall up, although the wall itself is vertically split. The two walls in the other direction have separated from the building. This is because these were not anchored on the topside whereas the main earthquake movement probably was forward-backward in relation to the picture. In developing a floor or roof diaphragm, one must assure that the diaphragm is adequately anchored in both directions.

Some town houses, however, have through going reinforced concrete tie beams at window and floor level, providing adequate anchorage of the walls. Most likely the walls of this surviving building in the picture below also were masoned with cement mortar.





Common in the Yemen Arab Republic is the existence of a large and often long room on one side of the building having a line of tall windows, *the Mufraz*. These long rooms, in combination with the window openings are vulnerable during earthquakes. Developing a wide, reinforced concrete lintel through this line of windows is strongly advised. The same beam can be used as a shading element and will block most of the sun in its high position.



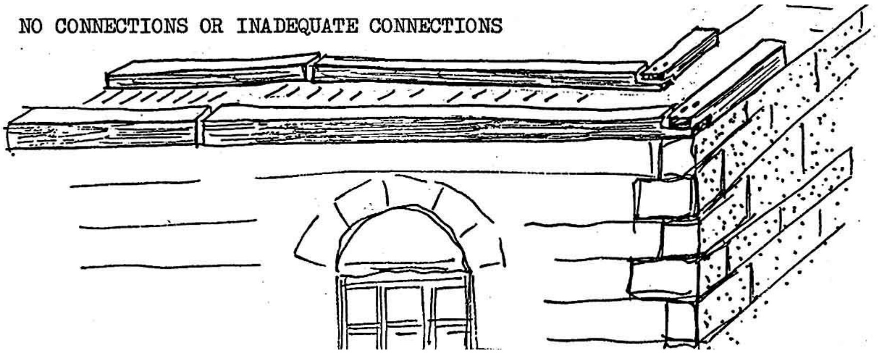
EXAMPLE OF A HOUSE WITH A REINFORCED CONCRETE FLOO/ROOF DIAPHRAGM

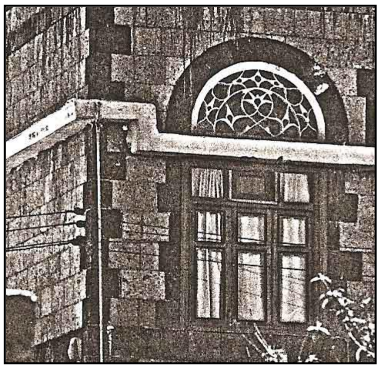
The feature of the coloured glass and gypsum plaster windows under which the through going lintel is constructed, strongly reinforces the façade, especially when it is made wider and serves as well as a sun shade.

Also as the different corner stones of the building have been used in the new house design of the project.

The traditional use of wooden (timber) lintels should be discouraged for three main reasons;

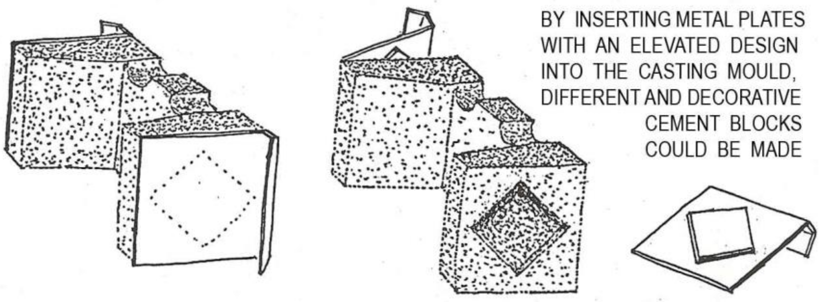
a. In fact the timber causes a vertical separation in the masonry structure, especially when the walls are masoned with a bonding mortar. This will be especially so when the wall is made smaller to reduce weight.
b. The corner connections and the lengthwise connections are usually made of half overlaps and nailed; this connection has only a fraction of the strength of the timbers.
c. The timber is extremely scarce in Yemen and therefore expensive; at least four to five times more expensive than wire mesh having the same strength.





In the photo on the right the horizontal continuity of the concrete lintel is not correct. The same picture also shows the different colour dressed stones around the windows and for the corner of the building, a feature the project adopted for the design of the prototype house (photo page 1).

The U or C shaped cement blocks I designed for the corners of the walls and around the openings, allowed both vertical and horizontal reinforcement bars to be masoned into the stone work. It also allowed faster and straighter masonry, saving time and money.



The stone material found in the Dhamar and Mahgrib Ans regions is mainly from volcanic origin. The black basalt is used for foundation, is heavy and difficult to work, and therefore expensive.

The light coloured (yellowish, pinkish and grey) *Tuff* stone is light weight (< 1800 kg/m^3), is easy to work and has a very porous structure.

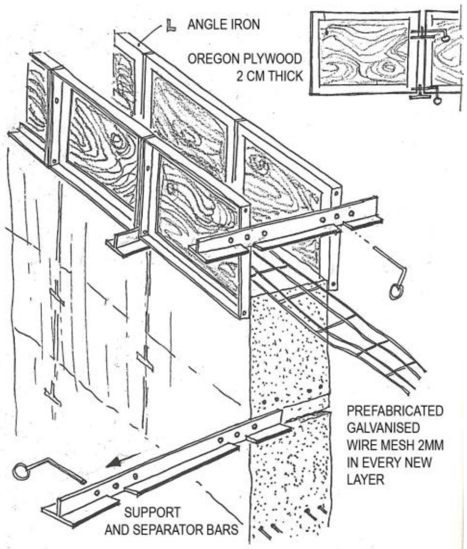
For the outside walls various ways are used for shaping the stone to obtain either a smooth surface or a rough finish.

Because it is porous, it allows high water absorption, a factor to be considered when masoned in cement mortar. Like burned brick, the stones must be soaked before being masoned with cement mortar.

In the many small mountain villages it was observed that very rough and less dressed stone work was used in the walls. All horizontal and vertical joints were filled with chips and little pieces. The thickness of these walls is 80-90 cm at their base and 50-60 cm for the highest floors. These walls were invariably constructed with mud as a filler agent; with the dry weather and the wind the mud does easily erode out of these joints. The result of this design is a complete lack of horizontal binding, both in the length of the wall as across the wall; bonding depends on friction by weight. The heavy soil roofs provide some blockage of the hot sun, but are a lethal danger in case of an earthquake.

On the Dhamar plateau a very large number of houses was constructed out of loam-clay soil, being compacted between formwork panels, also 80-90 cm at their base and 50-60 cm for the highest floors.

The Dhamar aided self-help reconstruction project was not asked to provide a solution for the construction of houses on the plateau. However, the galvanised wire mesh wall reinforcement could be applied on each layer of compacted clay-soil and a fresh layer compacted on that wire mesh.



Also a polypropylene netting could be used as reinforcement, a material which had recently entered the market.

With the reinforcement applied in each layer (see the horizontal lines in the building on the left), substantial wall reinforcement would be obtained in its two horizontal directions as well as good connections with internal shear walls.

3. The building system

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