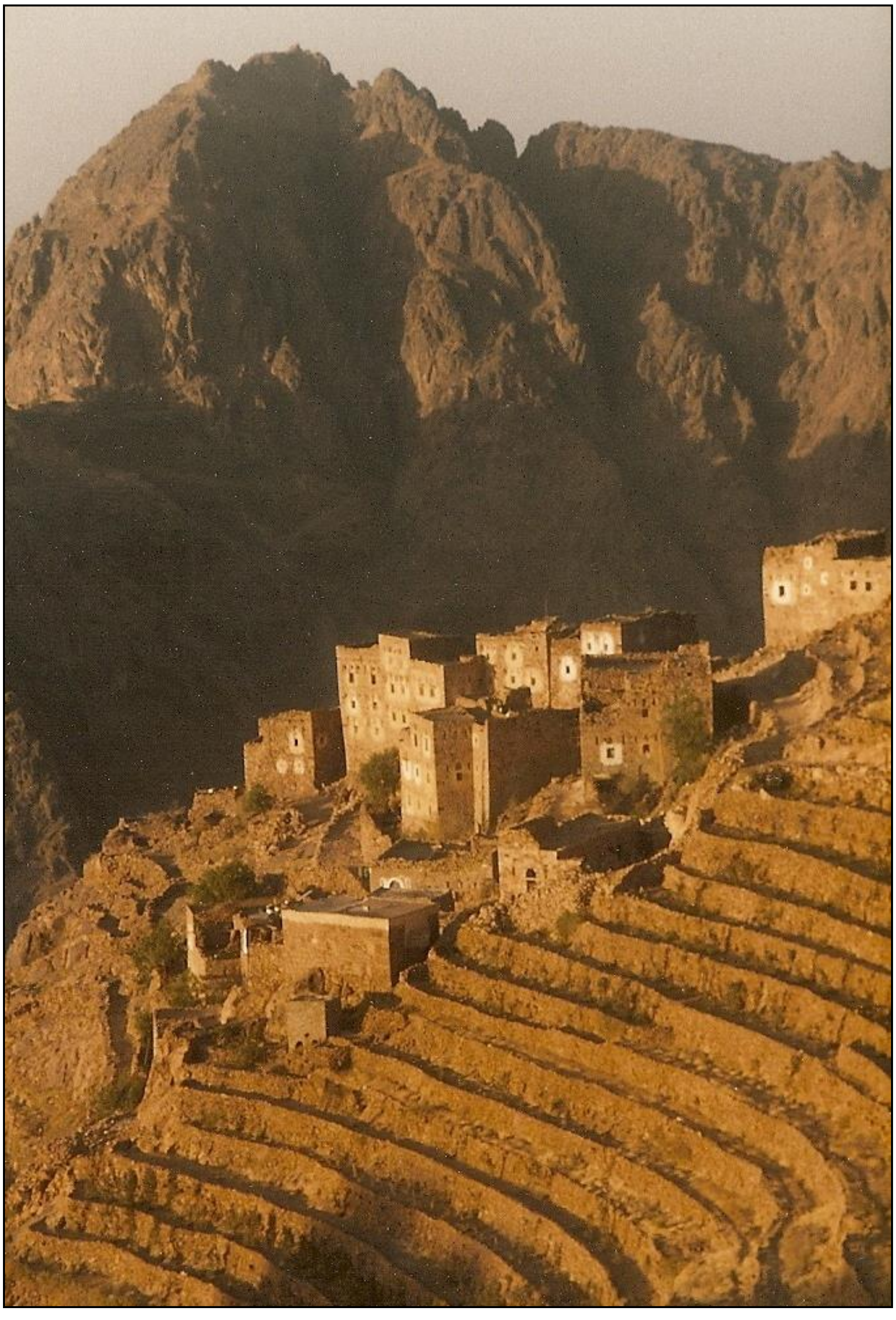
HUYS ADVIES

Dhamar Aided Self-Help Reconstruction Project

Post 1982 Earthquake Reconstruction: Site Selection



By: Sjoerd Nienhuys

April 1984 (Reprint and Photo Update 2008)

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). Basic principles for site selection and preparation, illustrated with sketches as training material. Dry masoned dressed and cut-face stone construction. Photos taken shortly after the earthquake of December 1982.

Foreword

The document was originally prepared in 1984 as part of an educational activity and guideline for local masons and house owners. The paper was translated into local language using the same drawings. Concepts of the designs were taken from United Nations documents, Indian Earthquake Engineering Research Institute (IEERI) documents and a wide range of 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 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 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 scan the paper with OCR, reformat and simplify the same, and add the found photographs.

Sjoerd Nienhuys
Earthquake Engineer, Programme Architect and Trainer
Hilversum, The Netherlands
Email: Sjoerd@nienhuys.info

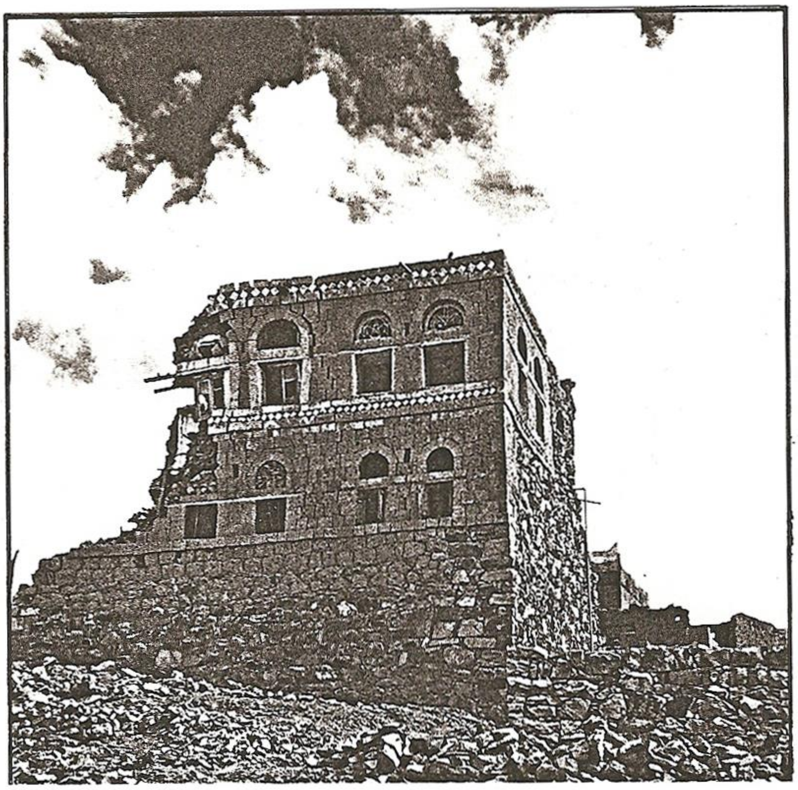
VILLAGE IN THE MAGHRIB ANS WHERE I WAS TEMPORARILY ACCOMMODATED
IN THE WHITER ROOM IN THE MIDDLE

Yemen Arab Republic

Kingdom of the Netherlands
Commission of European Communities

Dhamar Aided Self Help Reconstruction Project

BUILDING TECHNIQUE REPORT, BUILDING SITE SELECTION
PLANNING ACTIVITY NO 33



Sanaa 27 APRIL 1984

DHV

DHV Consulting Engineers

مهندسون استشاريون

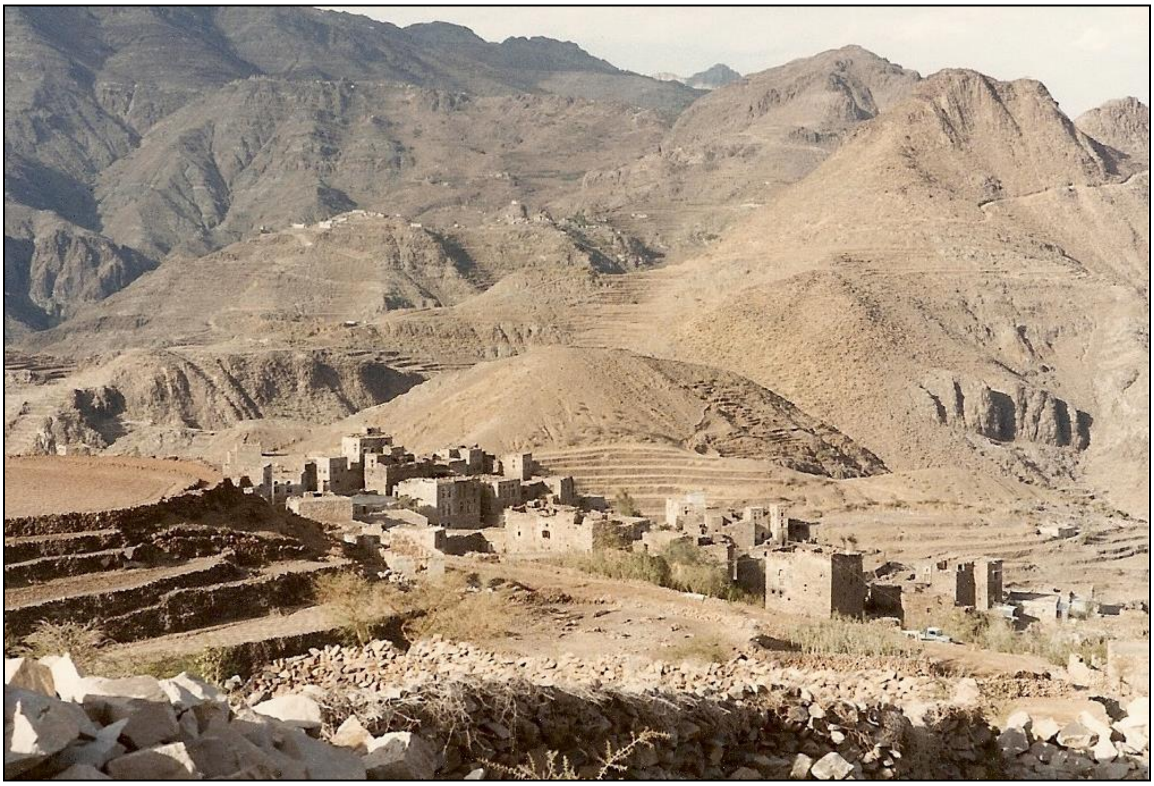
Sjoerd Nienhuys, Architect and Trainer

DHAMAR AIDED SELF-HELP RECONSTRUCTION PROJECT. FILE: 3.4160.62.03
BUILDING TECHNIQUE REPORT, BUILDING SITE SELECTION
PLANNING ACTIVITY NO 33

Research carried out following the December 1982 earthquake should lead to the formulation of recommendations and rules aiming at the reduction of damage in the event of another earthquake. These recommendations should be further developed into a generally applicable set of standards for earthquake-resistant building design in the Yemen Arab Republic (YAR).

Reconstruction and regulatory rules should not only improve technical standards on construction and settlement planning, but also respect socio-cultural criteria. Although no comprehensive study of these aspects has been made so far in the YAR, the self-help reconstruction project did take these elements into account.

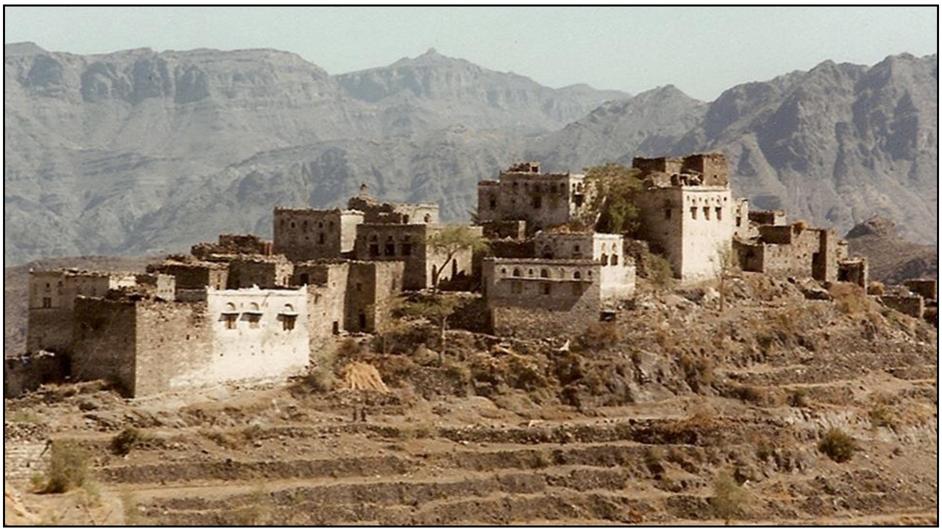
The self-help reconstruction project was not asked to create entirely new settlements, as compared to companies working on the higher Dhamar - Ma'bar plains. In the Maghrib Ans mountain area, assigned to the EC-financed DHV reconstruction team, the houses were widespread with only a few concentrated clusters of houses (picture below).



IN MANY AREAS WOMEN NEEDED TO DESCEND 1000 M TO FETCH WATER

People preferred to remain living in their own villages as much as possible; they had their land property nearby and were socially attached to their original location. Reconstruction therefore took place in the villages and any new site selection had to be in close vicinity to the damaged house and within the original village. Retrofitting of the larger buildings took place in a later phase of the project, but most ancient constructions were structurally too unsafe for retrofitting.

Although the earthquake took place 10 km under the Ma'bar plateau, mainly consisting of alluvial sediment, the effects of the December 1982 earthquake were more severe for those houses built on top of rocks and rock outcrops as compared to the houses on the plateau soil. The difference is briefly explained.



EXAMPLE OF SMALL VILLAGE ON A ROCK OUTCROP

The differences in damage between the rock constructed houses and the adobe houses of the plains is based on a series of differences between the houses, such as:

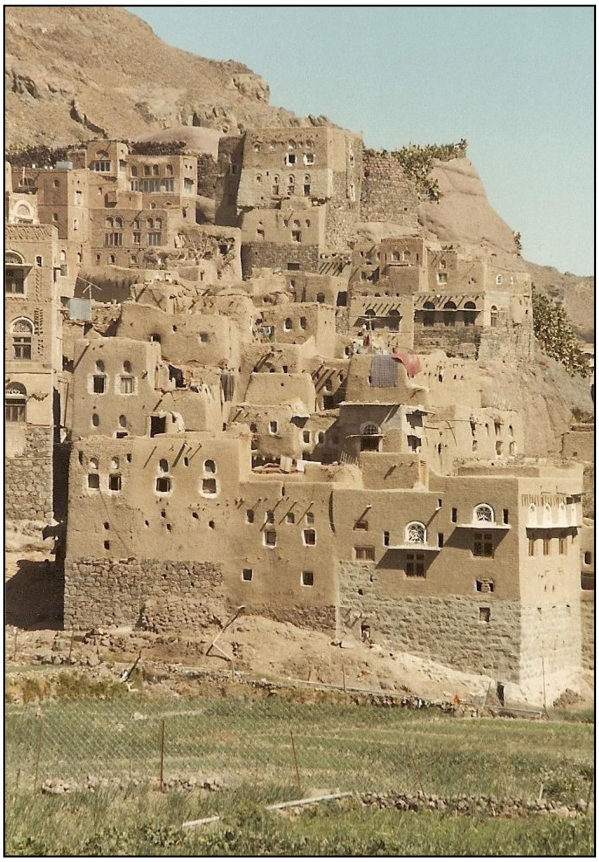
- Different earthquake force related to the distance from the epicentre.
- The pinnacle position of the rock outcrop may have amplified the acceleration.
- The softer adobe subsoil of the plain may have dampened the acceleration.
- The stone constructions are heavier than the adobe.
- The stone constructions have less internal bonding inside the structural walls.
- Anchorage of wood construction to the walls is better in the adobe constructions.
- Series of small vibrations will have a more cumulative effect on rock masonry than on adobe because adobe may compact and fill in the cracks.

One of the main conclusions to be drawn from professional comments on the December 1982 earthquake is the following:

"The degree of damage is to be explained first and foremost by insufficient resistance as a result of:
(I) bad state of maintenance, and
(II) inadequate construction techniques."

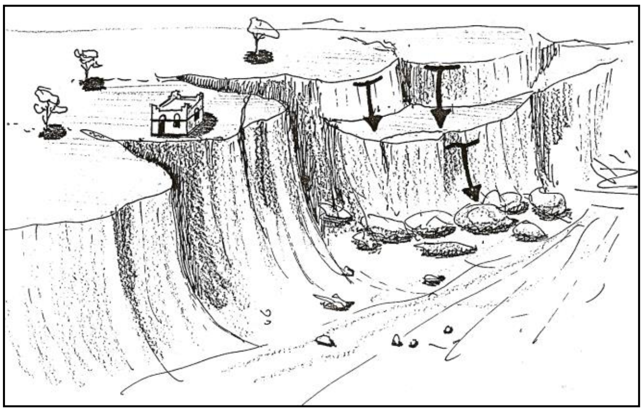
Although the role of the soil or the subsoil is not to be excluded as a factor, it can be concluded that it is considered only marginal in comparison to other explanatory factors.

It was observed in the mountain regions that the landowners rented out houses to labourers and these labour accommodations usually were in very poor state of repair. Hence these collapsed first, although many of these shacks were only ground floor buildings.

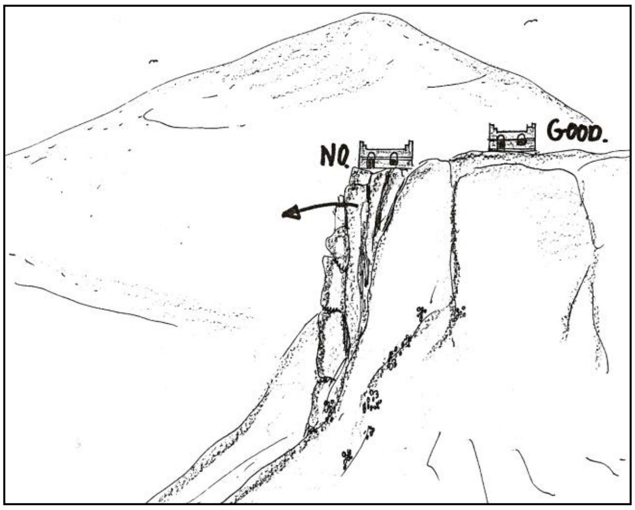


Some of the plateau houses on the right have stone construction basements with a lighter adobe upper structure. Regular maintenance of the adobe by filling in cracks may have contributed to their better resistance.

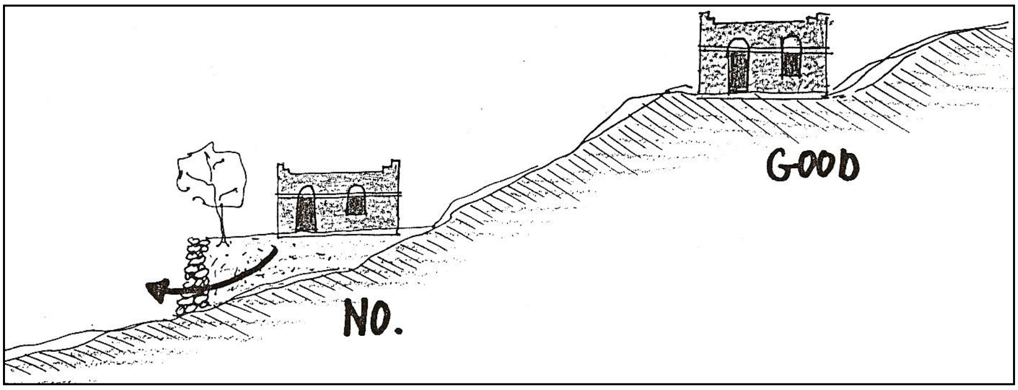
A number of obvious signs can be identified and interpreted in terms of concrete risk. Evidence of active faults, tectonic lineaments, potential sliding planes and trajectories can be identified. Certain areas can be considered as **potential dangerous for building houses** in earthquake areas:



= On the rim of an escarpment, consisting of alluvial soil or moderately compacted conglomerates.



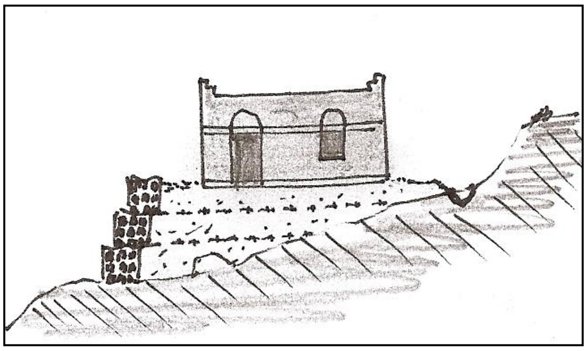
= On the rim of fractured rock outcrops.



= On rock soil or gravel which has been filled in, even if it has been later compacted.

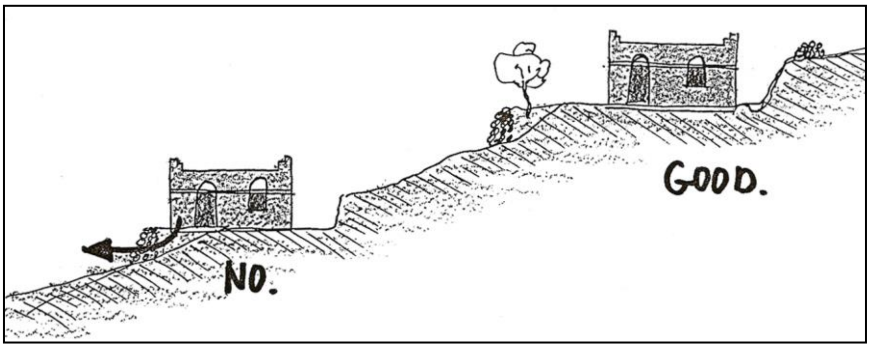
Agricultural land cannot be used because of its high value for crop production.

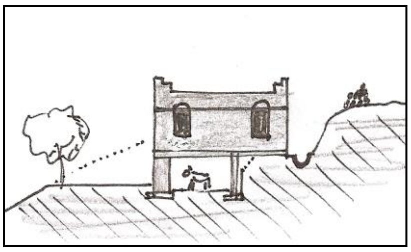
When infill soil cannot be avoided, such as when there is no level rock available, the retaining walls should be very stable, such as post-masoned gabion constructions. Additional soil stability can be created with horizontal anchorage from the retaining gabion wall going under through the building; a solution used in road construction. Drainage of rainwater must be assured on the high side.



ANCHOR WIRE OR CLOTH
CAST INTO THE GRAVEL

= On soil that is a partial area of terraces. Differences in soil density will cause cracking from the foundation upwards. Very strong foundation beams will be required.

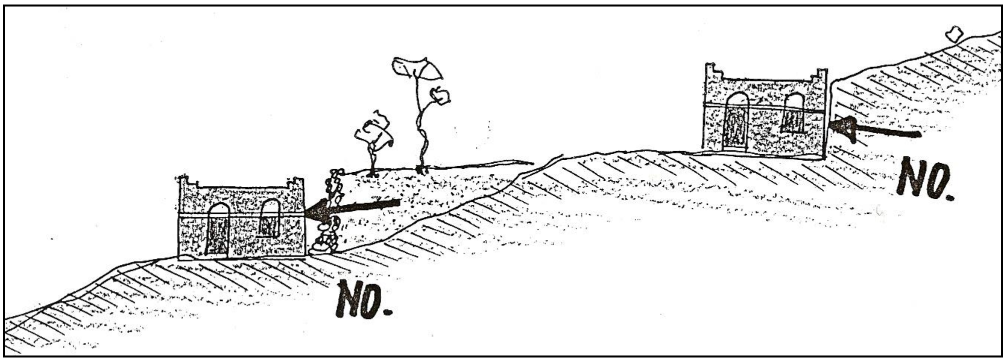




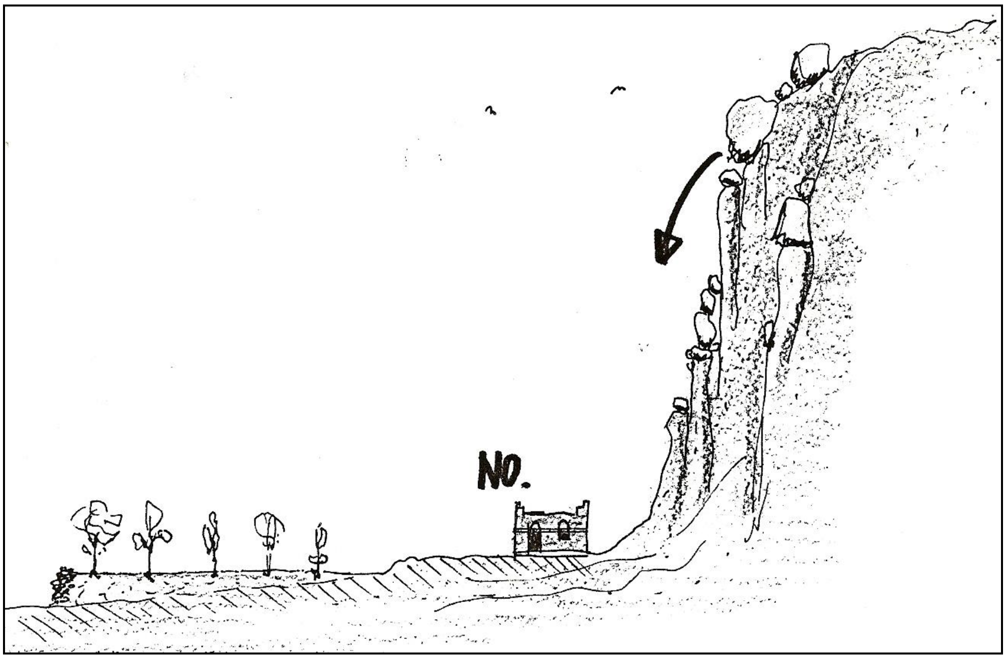
CATTLE SHED UNDER BUILDING

As an alternative to the above situation, the foundation of the lower side of the hill can be excavated deeper, creating storage areas or cattle sheds.

= With the back of the building against a loose stone wall with an in-filled terrace. This terrace wall can collapse and crush the sides of the house. In the case of countries with more rainfall, the walls of the house may block the evacuation of water, and water soaked soil may give the same effect.

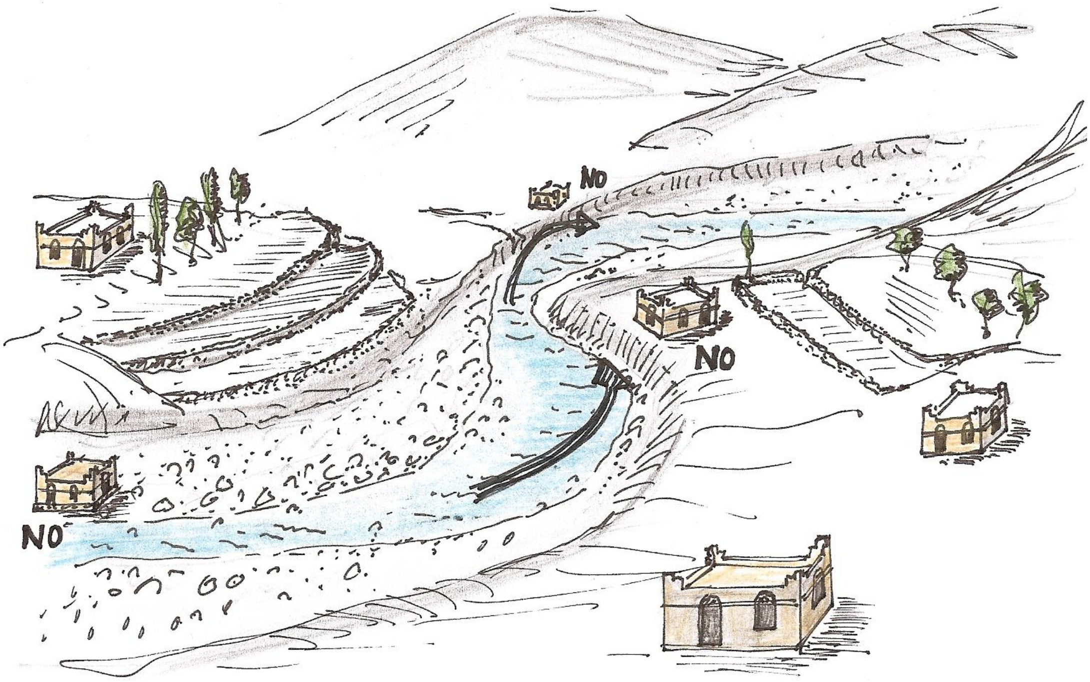


= Too close to high mountain sides having loose or many fractured outcrops. A 1 m^3 size boulder falling or rolling from a great height will destroy any type of building.



IN THIS CASE OF A FORTIFIED HOUSE INSIDE THE ROCK, LOOSE STONE PIECES MUST BE CLEARED AWAY REGULARLY FROM THE ROCK ABOVE.

= Deposition sites of stones on the "Point Bars" (being on or alongside the inside bend of a river) should not be used for housing. "Cut Bank" sites (being the sites directly above the outward bend of the riverbed) should also be avoided. Although many riverbeds may be dry, such as is the case in many Yemeni rivers in the Maghrib Ans, occasional floods may occur, destroying everything in its wake. This is also the case when a dam bursts following an earthquake.



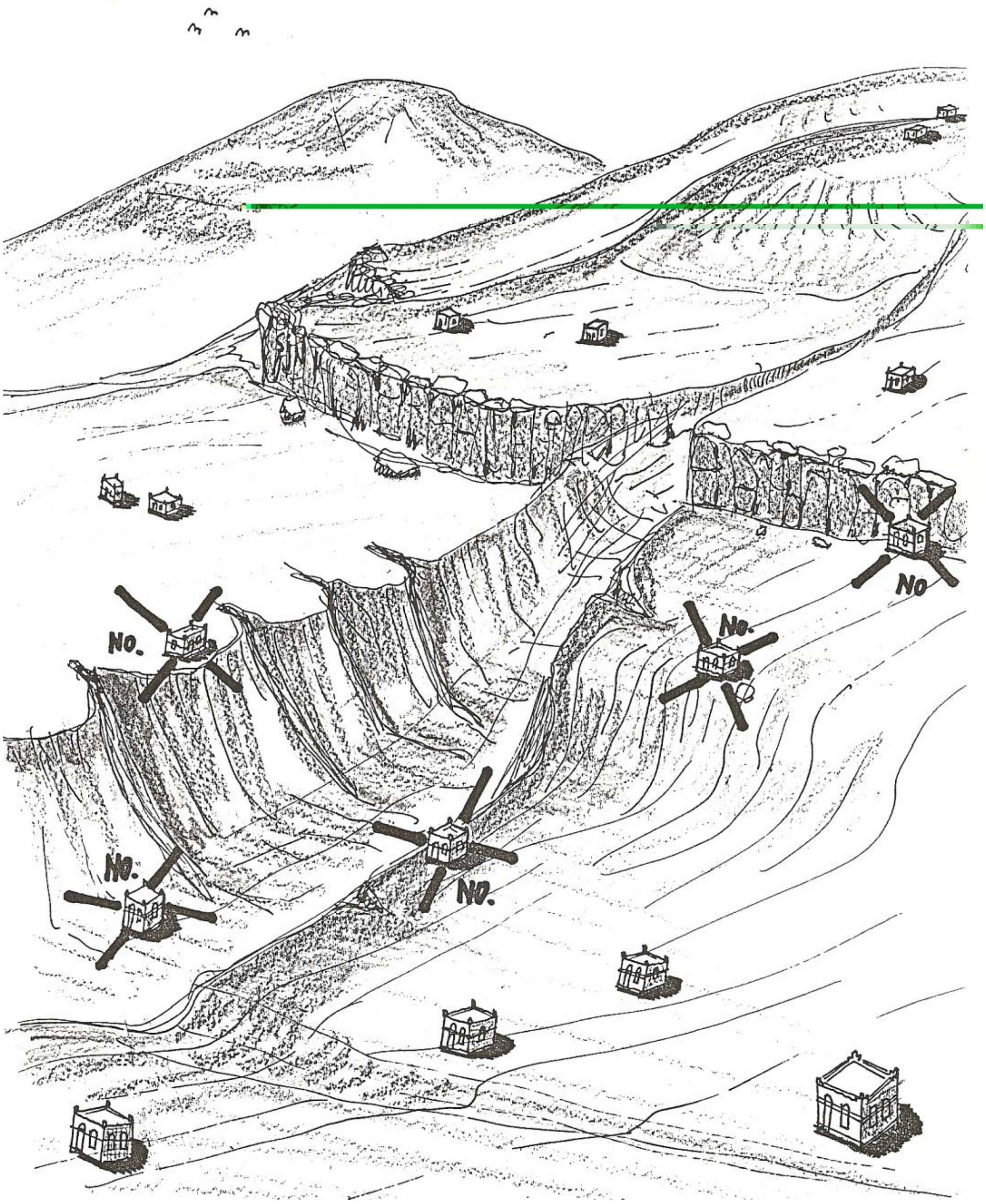
Seismic activity is a risk for the Yemen Arab Republic as a whole and micro-mapping of high risk zones is required. Earthquakes often occur at or near former active zones and these must be mapped. The elderly local people with their knowledge of the terrain and happenings of the past should be consulted in the field studies.

Education of People

For obtaining the best dissemination results, easy to comprehend drawings should be field tested first for understanding with Yemeni professionals and villagers in order to determine the interpretation by rural people with a Yemeni cultural background.

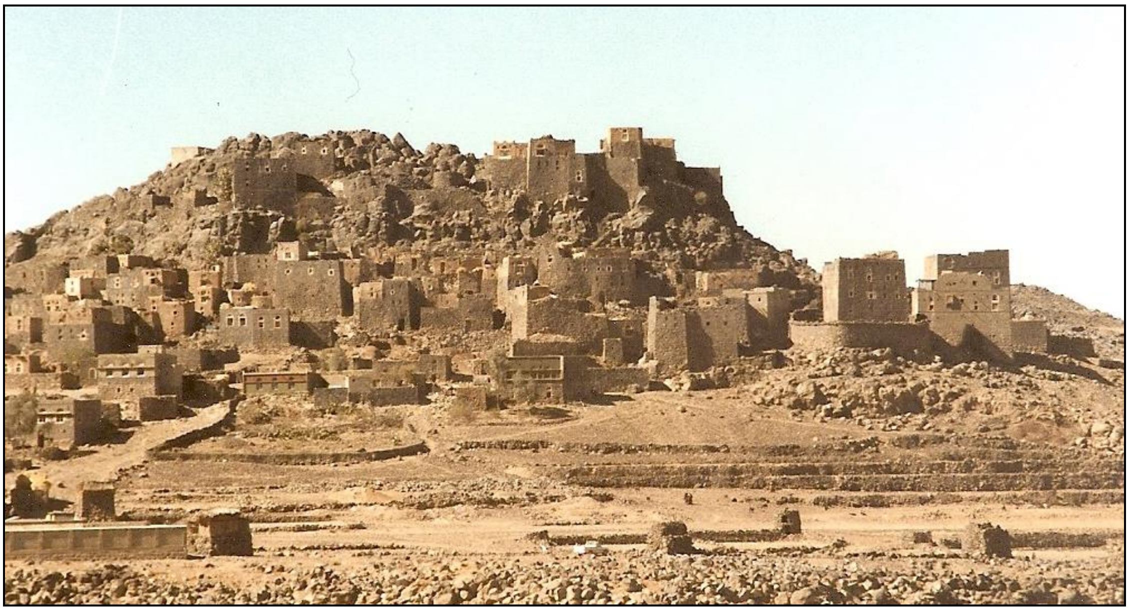
Many villagers are not only illiterate (women) but also have difficulties understanding certain types of pictures. An advantage is that people living in mountain areas will easily understand bird's-eye type of perspective drawings because these are part of their common environment.

Series of images used in the earthquake protection campaigns of the Turkish government can be adapted to the specific needs and to the particular context of the Yemen Arab Republic. Drawings should resemble the local landscape and architecture. By placing these images at much frequented places like mosques, schools, clinics and markets, the rural population will be constantly reminded of the major errors to be avoided.

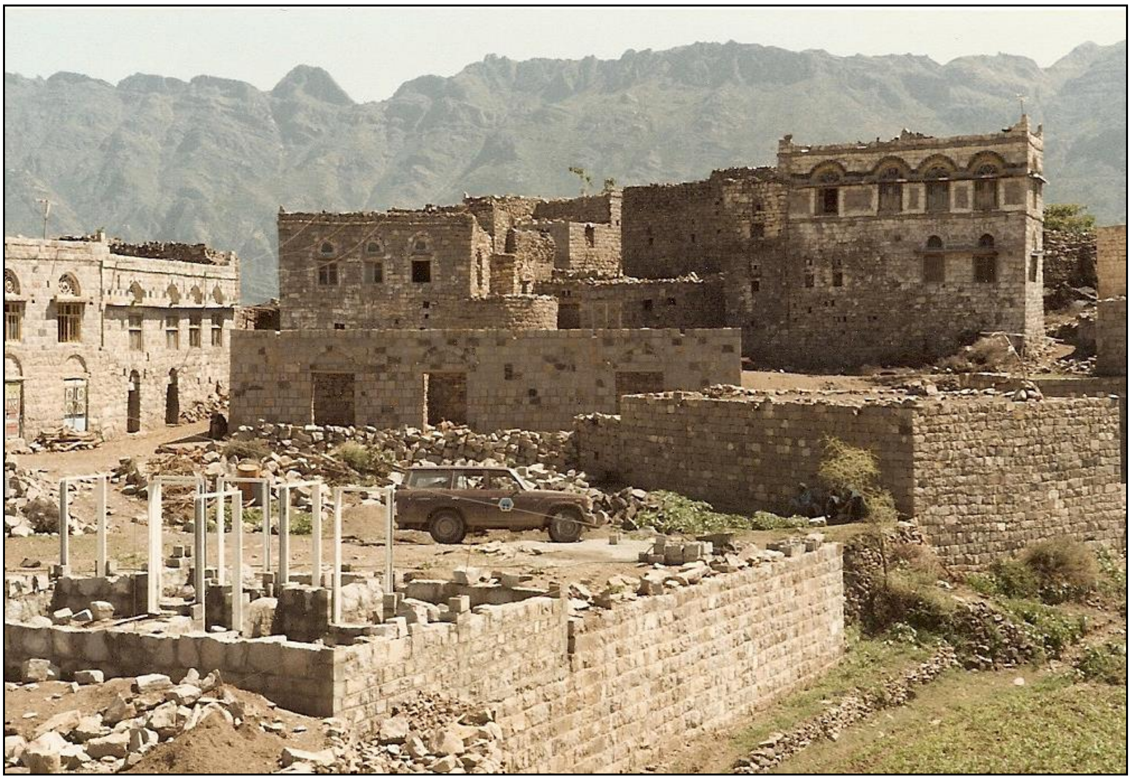


Although in the Maghrib Ans and Jabal Al Sharq mountain regions no new villages will be created as a result of the earthquake, the following points apply:

- The steep slopes are to be avoided for larger agglomerations of houses due to the high cost for circulation roads; the steeper the slope, the more expensive it will be to provide access roads and protection against erosion (for rainy areas).

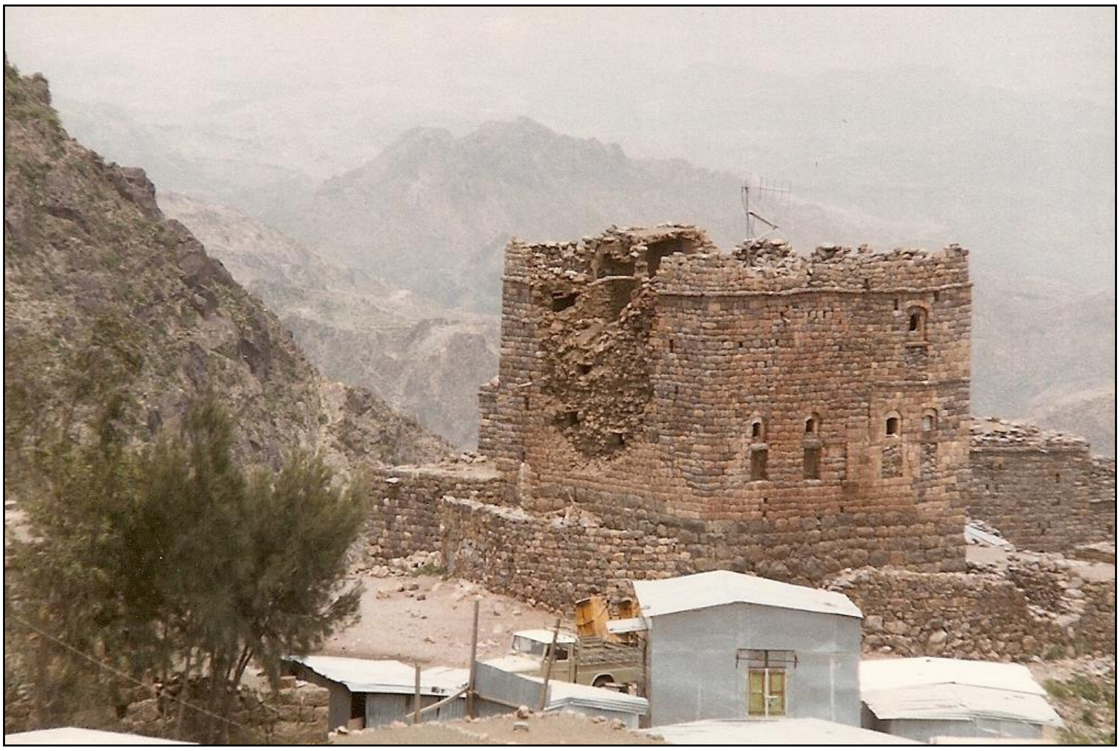


- Site location is often a compromise between specific requirements, such as the property, proximity to village and shops, easy access to the fields and orchards, water supply, etc., and easy access to regional road systems.



RECONSTRUCTION ON AN EXISTING PLOT IN A VILLAGE. THE MASONED RETAINING WALL WAS CONSIDERED ADEQUATELY STRONG ENOUGH FOR THE NEW ONE-STOREY HOUSE. AFTER THE RECENT EARTHQUAKE, THE WALL DID NOT SHOW ANY DAMAGE.

- The amount of transport that will be involved in the reuse of building materials from the damaged house to the new location (picture below).



BUILDING A NEW EARTHQUAKE-RESISTANT HOUSE ON THE LOCATION OF THE ABOVE MASSIVE STRUCTURE POSSIBLY REQUIRES (TEMPORARY) TERRAIN SWAPPING WITH NEIGHBOURS

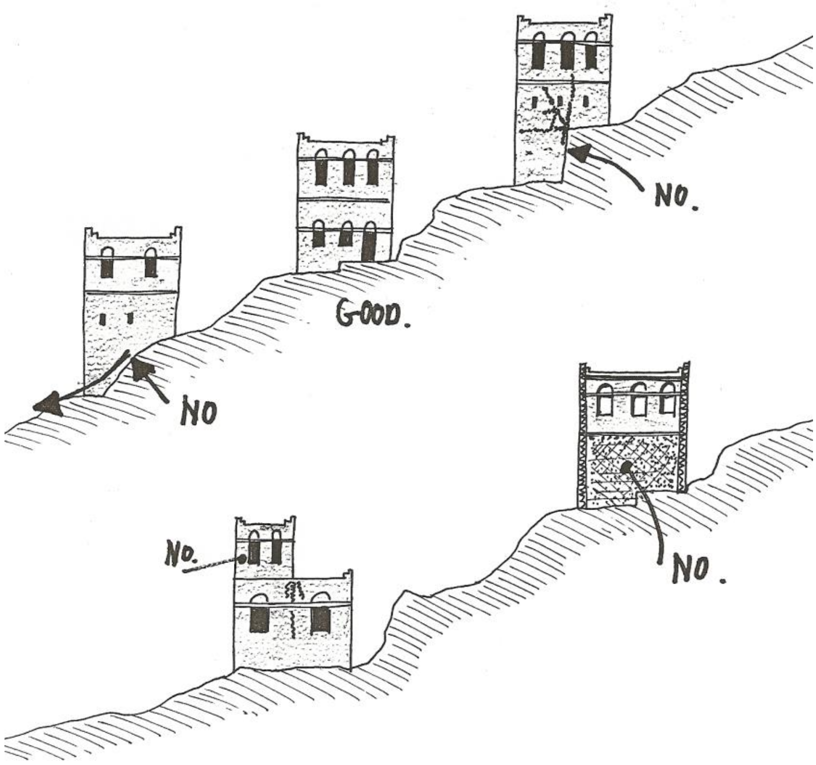
In the case of the above building, only about 1/3rd of the mass of the stones (or even less) should be used in the reconstruction of the same size building. To make buildings more earthquake resistant, the total mass of the building needs to be considerably reduced and the structure tied together. The open inside space in the building will substantially increase, keeping the same outside perimeter. This also means that a new smaller building made from the same materials as the old building will most likely be more spacious inside than the old one.

In the picture above, one can see that the cut-face dressed stone façade has fallen off the rubble inside wall. The above case is typically a situation where retrofitting is not an option, but reconstruction on the same site will eventually take place. The new house should have larger rooms, more windows for solar heat intake in the winter, and improved sanitation and kitchen facilities.

- The possibility of constructing an access road.

Site and House Design

For the shape of the houses in a village, the following recommendations can be made:

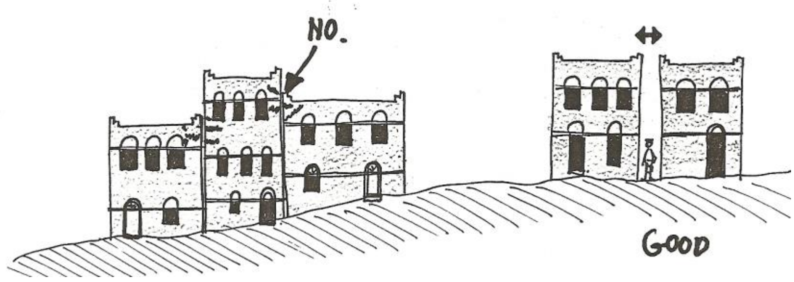


= Highly stepped foundations are to be avoided. In cases of too steep slopes, soil or rock excavation is recommended. Make horizontal tie beams at every step interval.

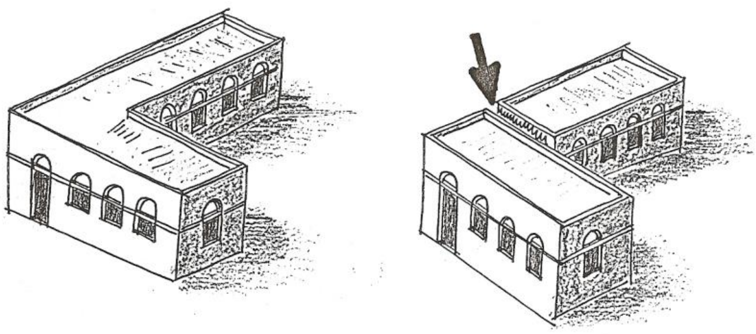
= Non-horizontal foundations are to be avoided. These need to be cut out horizontal and stepped into the rock bottom.

= High foundation in-fills are to be avoided. House designs should be made with storage or living rooms at lower levels.

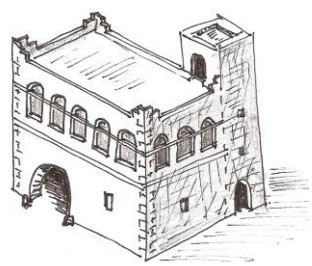
= Abrupt differences in the mass and shape of the building should be avoided. A tie beam is required at every change of mass.



= Different houses should be built with a separating area in between the houses. On solid rock soil, the space between the constructions should be 1-2% of the height of the building. On more elastic or softer clay soils, this space should be about 4-5% of the building height.



= The buildings should not be very elongated or have extended wings in an L, U or T floor plan. Those buildings should be built in separated sections.



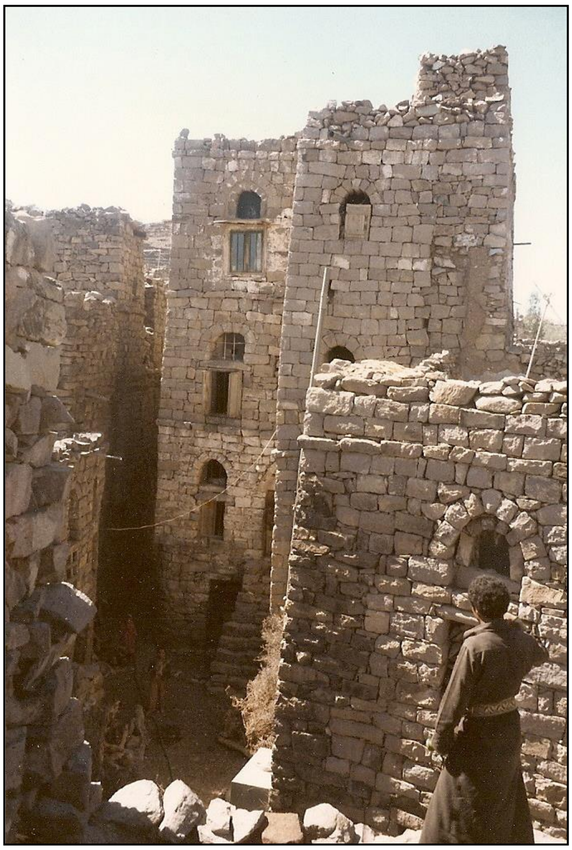
= Buildings should be symmetrical in their plan and mass distribution, and have an even distribution of openings in the facade.

= When one side is full of windows and has a large "mufraj", whilst on the other side there are no windows, small rooms or a massive stone staircase will create <u>torsion</u> forces in the building during an earthquake. These unequal forces require additional structural adaptations such as internal shear walls to provide adequate strength.

The above details all relate to the site selection and planning of the building design.

= The building height for so called non-engineered constructions should never be more than three storeys. The building on the right, photographed outside the 1982 Dhamar earthquake area, would have certainly collapsed in an earthquake.

= It is recommended that above the 10 m height, engineering calculations are made and strict control on the use of the building materials and the quality of the construction is applied according to the code.

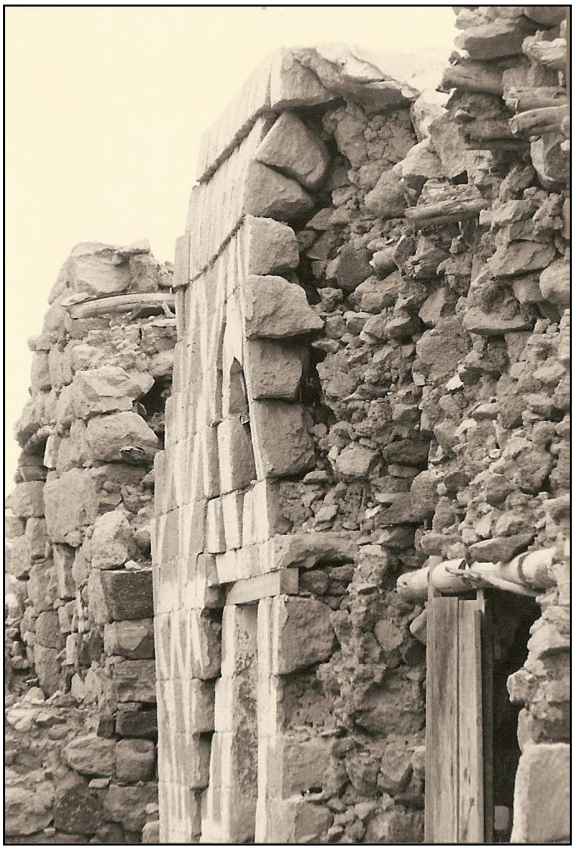


Cut-face Stone Façades and Dry Masonry Walls

= All thick and dry stone walls (no cement masonry) are to be avoided because these have no internal bonding.

The cut-face façade stone assures that the outside face of the stone looks nice and flat with straight edges. To achieve this at minimum labour cost, the back of the stone is cut back inwards. This way the outside edges of the stones support, but the inside is propped up with rubble. With the many small vibrations of regular mini earthquakes, the supporting rubble wall comes loose from the cut-face façade. With a slightly larger earthquake, the façade bulges first outwards and then falls off. With a heavy earthquake, the entire building collapses.

The other result of the cut-face dressed stone façade is that very heavy, two-foot thick inside walls are necessary to keep the structure up. These inside walls are made in dry soil mortar, commonly without cement or lime bonding. The two to three-foot thick walls and small rooms require large construction sites.



The flowing two photographs illustrate the issue explained above.

New Building Sites or Old Sites?

Most traditional Yemeni villages were built on rock outcrops to save valuable agricultural land. Most of the rock outcrops had a volcanic origin and had an entirely fractured structure. The building sites in the project area of the Maghrib Ans district were almost exclusively on conglomerate rock soil or directly on the volcanic rock outcrops. So far, there was no evidence of landslides to be seen by which constructed houses were destroyed.

The question was whether post-earthquake reconstruction should be realized on totally new building sites, or that reconstruction could be realized on the old site? Apart from the village planning aspects, some geological or soil conditions needs to be taken into account when undertaking construction on new building sites. The answer lies in the calculation according to the building code.

Calculating Earthquake Forces on Buildings

For earthquake calculations, the internationally widely used formula V = I.K.CS.W is considered as the best applicable and appropriate. Extensive information about the calculation methods can be found in the "Building Code Requirements for Reinforced Concrete" of the American Concrete Institute, the "Uniform Building Code" from the International Conference of Building Officials, and in the "Recommended Lateral Force Requirements and Commentary" of the Structural Engineers Association of California, USA. Most new building codes are derived from these documents.

The following text is taken from the General Design Requirements of the Recommended Minimum Building Standards of the ACI 318.

"Every structure shall be designed and constructed to resist minimum total lateral seismic forces assumed to act non-concurrently in the direction of each of the main axes of the structure in accordance with the following formula:

The total horizontal force **V = I.K.CS.W** in which formula:
I = The importance of the building (house = 1, public/school/clinic = 1.5, etc.)
K = The type of construction (box = 1.33 or space frame = 1.0)
CS = The soil condition (rock, sand, clay and other)
W = The total mass or dead weight of the building or building component."

The CS factor is composed of: (1) a fundamental elastic period of vibration C of the building in seconds and related to the height of the structure, and (2) a site-structure resonance factor S. The C factor for small buildings (less than four storeys) does not exceed 0.12. The S factor is T/T_s and in between 1.5 (largest) and 1.0 (smallest). The CS factor for small buildings does not exceed 0.14, whether the soil is firm or soft.

The building sites of the villages on the Dhamar, Maghrib Ans and the Ma'bar plateau were either on rock outcrops or on the loess deposits. These loess deposits included alluvial silts, sands and gravel, and formed a rather firm soil. At deeper levels on the plateau, lacustien deposits (lake originated) with high clay content were found. Due to continuous pumping for irrigation water, the ground water table was rather low and liquefaction of the soil was not easily considered. Actually the only place where the water table was rather high was in Risaba where the groundwater level was about 4 meters below field level and descending rapidly.

TOTALLY DESTROYED STONE-BUILT VILLAGE ON A ROCK OUTCROP

The above means that for small buildings built on soft soil or rocks, no large difference in calculations exist according to the ACI and Uniform Building Code. On the other hand, we saw considerably more damage in the houses which were built directly on the rock. Observations in the two different parts of the earthquake-affected area (the plateau and the mountains) showed that many of the mud wall or adobe constructions had less damage than the dry piled cut-face stone structures.

Four main reasons for this difference might be given;

- The major difference of damage is explained by the loose and technically inadequate rock constructions (explained above) that do not have internal coherence, but a huge mass. The total building mass of a loam construction is estimated at 30-50% less than the traditional cut-face stone constructions.
- The soft, thick alluvial subsoil in Ma'bar possibly absorbed some of the vibrations.
- The vibrations in the epicentre, right under the plateau, were more vertical as compared with building locations at 30 to 40 km away being more horizontal. The earthquake had a shallow focus of about 10 km under the plateau.
- The mud construction or adobe has more elasticity and coherence than the dry piled cut-face stone structures.

It is evident that more advantage is gained by (1) reducing the total mass of the building and (2) improving the quality of the masonry work, than with precise analysis of the soil or site conditions.

To simplify the whole calculation, we took the CS factor at its highest recommended level of 0.14 for small buildings. The resulting horizontal force V on residential buildings then is 0.20 or 20% of the total mass of the building (or component) as the horizontal force on the building section immediately below; the quality of the site can be disregarded in non-engineered low rise constructions.

Building Code Development

In Yemen Arab Republic (1985), a general building code needs to be drawn up, even if its application can only be gradual over a long period of time. Such a code should consist of two parts:

- A general part which includes recommendations on site conditions, height and shape of the buildings and general reinforcement patterns for non-engineered construction, self-help construction and building contractors. This general part should be extensively illustrated with schematic drawings and photographs of good practices. In particular, the advantages and disadvantages of dressed stone constructions should be elaborated upon.
- Another more technically specific part, which should include the specific international codes and specifications related to reinforced concrete constructions and constructions higher than three floors. This second part, also based on the ACI Code and Uniform Building Code, has to be both translated and adapted to the Yemeni situation and its ways of quality control.

The proposed code should have a strong educational function and people should realize that the use of such a code is for their own protection and benefit. The code should be presented using different educational methods for the different population groups to be addressed and become an integral part at each formal education level. The more complex parts and the civil engineering should be taught at the poly-technical schools and universities, whilst the popular interpreted versions will be required for education at the primary, lower technical schools and vocational training centres.

NEW CONSTRUCTION TECHNOLOGY REALIZED BY
THE SELF-HELP RECONSTRUCTION PROJECT

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