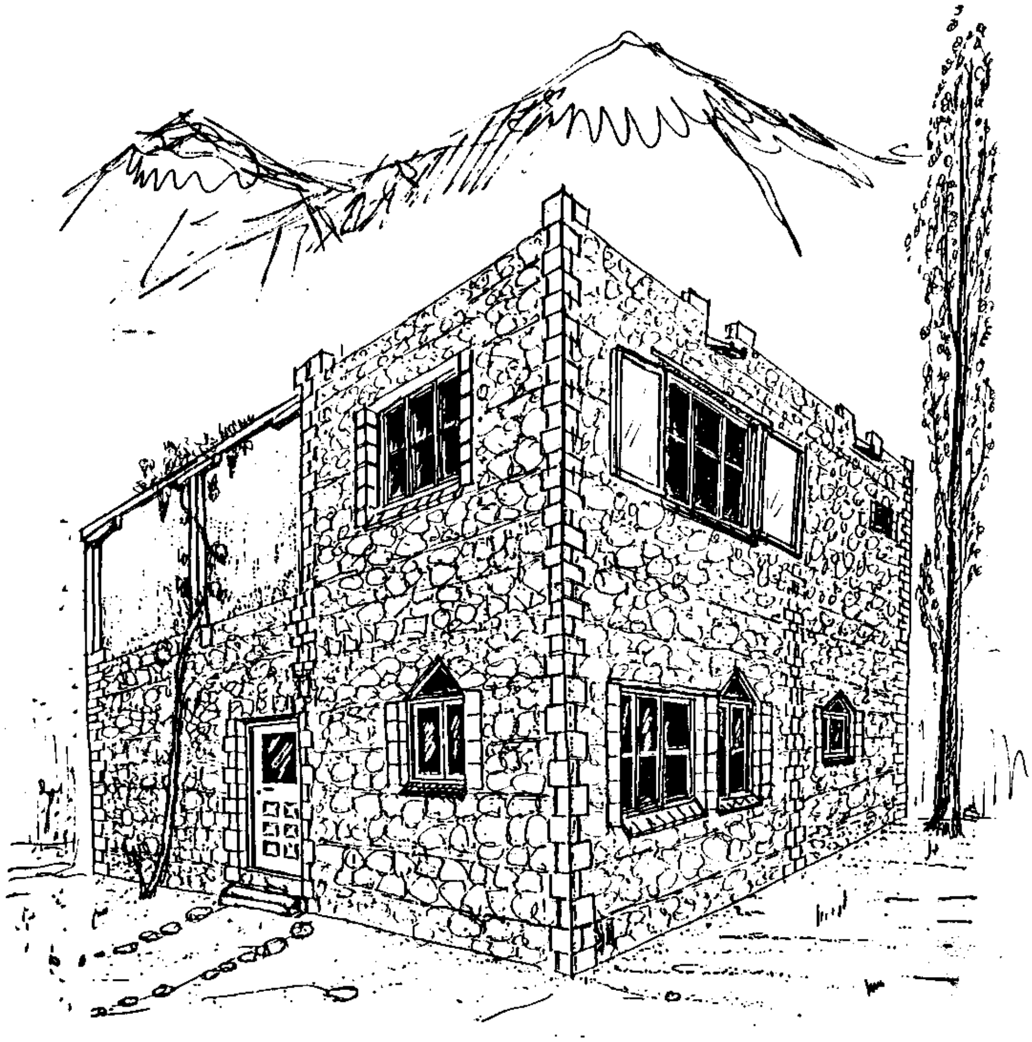
HUYS ADVIES

GALVANISED WIRE REINFORCEMENT (GWR) TECHNOLOGY

Earthquake Reinforcement for
Non-Engineered Stone and Earth Constructions
When Good Quality Reinforced Concrete is NOT an Option



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Abstract

Abstract: Earthquakes negatively affect many houses of low-income people due to poor material choice and construction techniques, especially in non-formal settlements and housing developments. In the remote village areas of high mountains such as the Himalayas and the Andes, the introduction of cement and steel reinforcement bars for reinforced concrete constructions is very costly and often unaffordable for the local villagers. Galvanised Wire Reinforcement (GWR) is an earthquake reinforcement for thick, non-engineered dressed and semi-dressed stone walls; adobe, cement and soil blocks; and rammed earth building constructions. In remote mountain areas, masonry with cement mortar is only marginally done due to the high cost of cement, sand and aggregates. The 2.3 mm knotted GWR provides lengthwise and crosswise reinforcement within the wall thickness and vertically along the borders of all openings, such as doors, windows and wall endings. The special advantage of the Hot-Dip Galvanised Wire is that it does not require a high concentration of cement in the concrete or cement mortar to prevent corrosion of the wires. Villagers can apply the reinforcement throughout the wall construction using only low cement mixtures, thus keeping the construction cost low. L-shaped and U-shaped cement blocks provide hollow space for the vertical reinforcement consisting of GWR strips folded upwards, facilitating construction and providing an aesthetic architectural design. The cement blocks can be cast on site using a simple to operate mould and hand compacting, also allowing low-cost production techniques. For ground-floor-only buildings, the GWR strips should be applied in every alternating course of stone or block masonry; thereby creating adequate stress reinforcement throughout the wall structure and having contact with all stones or blocks. For two-storey buildings, the reinforcement on the ground floor is increased.

Key words: mountains, remote, housing, earthquake reinforcement

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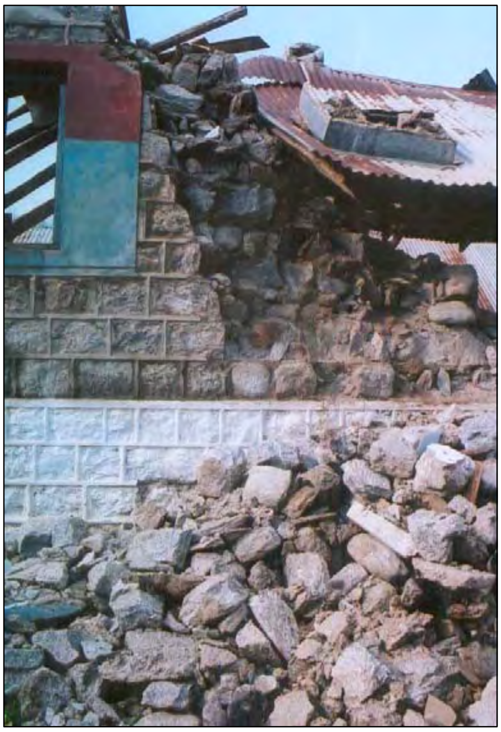
PREAMBLE

I. GWR versus Reinforced Concrete

Feedback has been obtained about the GWR technology from various sources, including sceptics who consider reinforced concrete beams in the walls to be the better solution. Given the same building plan, when the reinforced concrete is properly executed and the concrete quality is good and reinforced concrete framing is correctly realised around all openings, such constructions can resist larger earthquake forces than a similar building with GWR reinforcement.



However, the quality execution of concrete is the problem in remote villages, only to be resolved by rigorous training of masons and educating the house owners on the importance of reinforcing dressed stone walls. In addition, the quality of reinforced concrete in towns having road access is at best only half of the design strength and the reinforcement design is often faulty.

In both cases, the use of reinforced concrete beams and GWR requires symmetric building plans with sufficient shear walls and preferably a floor diaphragm.

The GWR is not meant to be a cheaper substitute for reinforced concrete, but it is a substantial improvement over non-reinforced dressed stone or adobe houses. In cases where the house owner has the finances and access to good quality reinforced concrete being applied correctly, the good quality reinforced concrete has the preference over GWR. However, this is seldom the case in remote mountain villages.

II. Durability of the GWR

A second feedback is on the durability of the GWR. In order to speed up the production of the wire-mesh, this was point welded and supplied from the factory in rolls (see picture). The point welds, however, destroy the galvanisation and corrosion will occur. Although it may take 20-30 years before this point-welded wire will corrode in a wet and abrasive environment (like the Gabion wire), this will last 40-60 years inside the walls and when dry much longer. Based on the corrosion of the point-welded material, this wire-mesh should have a hot-dip treatment after the welding.

The 2.3 mm knotted hot-dip wire (not the point welded) may obtain some micro cracks due to the bending of the knots, but it is far less affected by corrosion than the point-welded wire. Therefore, it will last much longer; in a dry wall environment 100 years is a fair estimate.

III. Durability of the GWR in Soil Mortar

The houses in the villages are commonly constructed in dry stone. Some "mason" the stone using clay soil.[1] This is because both cement/line and sand are unaffordable for these villagers. Sand is often as difficult to come by as cement because it often has to be collected a thousand meters lower at riverbeds. Non-galvanised steel will corrode in the porous cement mortar, but the hot-dip GWR will last for many years, especially inside the wall and protected from abrasion by the outside climate. The galvanised wire used in Gabions for outside road retaining walls, riverbeds and other infrastructure lasts more than 20 years in such highly exposed and abrasive environment, especially in riverbeds. Inside brick masonry (regularly moist), the galvanised wall anchors last between 50 and 100 years in European climates and longer in a dry environment. For this reason, the internal wall lifetime of the hot-dip GWR can be taken at 100 years in a dry mountain climate.

A problem may arise when hot-dip GWR is not used, but galvanised wire from unknown sources, such as imported wire from China. In such cases, it is advised to paint the knotted areas with corrosion protective paint after knotting the mesh. This of course will slightly increase the cost, but it can be easily undertaken at the village level.

In full adobe block walls, the many GWR length wires (two of 2.3 mm in all alternating layers = 8.3 mm^2) with the knots and the many cross wires is a far better distribution of stress resistance than two steel bars (two of Ø10 mm = 157 mm^2). Comparing the same steel amount (cost), 19 sets of wires is equivalent to just one set of steel Ø10 mm bars. These two steel bars do not provide any grip on adobe block walls and will separate when a force is applied. Knots and cross wires of the GWR ensure grip.

IV. Overall Building Strength

Comments were received about the overall building strength and strength of the GWR as compared to reinforced concrete bars. Placing the GWR in all alternating masonry layers will bring the wire into contact with all the stones of the wall construction. The bonding is lengthwise and across the wall. Especially dressed stone walls obtain substantial strengthening by the wire-mesh because the inside and outside faces of the walls become connected; see explanation in the text. The bonding between the wires and the surrounding stone or adobe construction is achieved by the cross wires and the knots between the perpendicular wires.

Earthquake forces may reach up to 0.25G (earthquake zone 3-4). In other words, the horizontal earthquake force is equivalent to 25% of the mass of the same construction. Although dry masoned stone walls have no internal horizontal stress force resistance, the correct placing of the GWR in the horizontal joints and the vertical framing around all the openings allows a stress force of at least 0.2G. This is more than sufficient for the estimated maximum earthquake force in ground-floor-only houses in a 50-100 year period in most earthquake areas. Reinforced concrete bars may sometimes resist much larger G forces, but it is the adherence between the bars and the surrounding concrete that determines whether the beam remains intact or not. In addition, the beam needs to adhere to the surrounding construction. After many earthquakes, one often sees reinforced concrete bars that have popped clean out of the concrete and the construction falling away from the beams.

The GWR works throughout the construction: 19 sets of 2.3 mm wires have the same steel section as one set of Ø10 mm bars. Twelve sets of wires have the same steel section as one set of Ø8 mm bars. Over-strengthening buildings with heavy reinforced concrete members is not useful as it also increases the weight of the construction and thereby increases the earthquake forces on the building.

[1] The word "mason" as used here refers to the building technique, not necessarily using cement or lime mortar in the joints.

1. INTRODUCTION

<u>Earthquakes and Remote Mountain Areas</u>

The western wing of the Karakorum Range of the Pakistan Himalayas, comprising the Northern Areas and Chitral, is under the influence of plate tectonics that culminate beneath Afghanistan. Earthquake movements are frequently registered in the entire area. A very large earthquake occurred in October 2005, leaving 75,000 people dead and destroying more than 100,000 houses. Building to withstand these tremors is therefore extremely important in saving human lives and minimising economic disaster. Road access to remote villages is often by donkey trail. Bringing cement, long concrete reinforcement bars, sand or aggregate is extremely difficult and expensive.

Not only the cost of making reinforced concrete is high, but generally the skills to make the reinforcement or to produce good quality concrete is greatly failing in remote mountain areas. Many of the collapsed houses in Kashmir and other earthquake areas show total failure in the concrete constructions because of poor design and poor concrete quality. To improve the situation, training of masons and awareness raising among house owners is of very high importance.

Lack of natural resources, such as timber, have affected the building practices over the last generation. This aspect, combined with rapid population growth, has resulted in a severe deterioration of building quality, especially in areas where no alternatives to traditional stone constructions have been developed. BACIP has introduced the Galvanised Wire Reinforcement (GWR), providing an economically feasible and technically sound method to reinforce traditional dressed stone, semi-dressed stone and soil block constructions <u>in remote mountain villages</u>.

<u>Non-Cement Mortar Masoned Semi-Dressed Stone and Rammed Earth Construction</u>

Galvanised barbed wire was first used in 1970 with the reconstruction of low-cost *bahareque* houses (timber frame, bamboo mats and soil plaster construction) in Guatemala by CARE. The use of wire-mesh in stone masonry was used by the author in the earthquake reconstruction programme after the devastating earthquake of 1982 in Dhamar, Yemen Arab Republic.[2] The galvanised wire-mesh technology was particularly suited for the horizontal reinforcement of 18" wide dressed stone walls. In the Dhamar reconstruction project, rolls of pre-manufactured <u>double</u> galvanised cattle fencing were used for rapid application. The openings in this wire-mesh ranged from 6 cm to 20 cm.

The central plateau of Yemen has good quality clays. Two to four-storey houses are traditionally built from rammed earth, having 2-3 ft. thick walls. Before casting and compacting a higher layer of rammed earth between a wooden formwork, a new strip of the cattle wire-mesh was laid from corner to corner. By doing so, a horizontal reinforcement was realized at 1 ft. vertical intervals, providing an even distribution of reinforcement throughout the walls. With the slimming of the walls, the cattle wire-mesh was cut in narrower strips, keeping the length wires along the sides of the wall about one inch from the external face.

<u>When Reinforced Concrete is Not an Option</u>

As indicated in the preamble, the GWR technology is not a cheaper substitute for good quality and slender reinforced concrete wall framing, but an option for people in remote villages having no access to finance or good quality reinforced concrete. New reinforcement methods are under development with flexible polypropylene and glass fibre mesh (netting) to overcome the possible doubts about the durability of the galvanised wire-mesh.

[2] Project financed by the Netherlands Directorate for International Cooperation (DGIS) and DHV Consulting Engineers, The Netherlands. The use of wire-mesh is common in reinforced masonry designs (burned brick).

2. EARTHQUAKE REINFORCEMENT TECHNOLOGY

The objective of the GWR is to provide internal stress resistance to walls lacking sufficient natural bonding to function as shear walls. Stress resistance is traditionally obtained with wooden tie beams laid in the walls. These tie beams need to be placed in short intervals. In modern building technology, iron reinforcement bars are applied by imbedding them in a layer of strong cement concrete. This "modern" building technique has a number of serious disadvantages when applied in remote mountain areas because the correct sand and stone aggregates are unavailable, cement is very expensive, and mixture and curing processes are often deficient. Improperly realised concrete constructions become an additional earthquake hazard in themselves due to their massive weight.

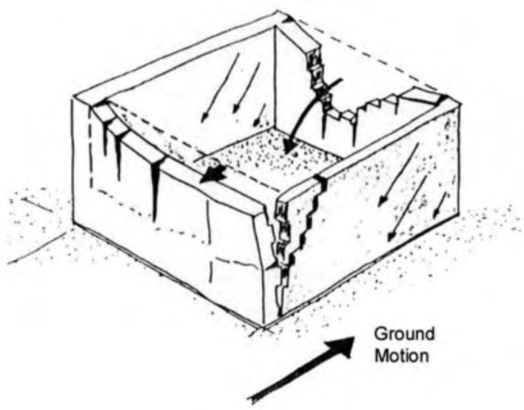
The amount of reinforcement required is determined by the expected earthquake forces; these are directly related to the mass of the construction (weight). The expected horizontal forces caused by an earthquake can be derived from a standard earthquake code.[3] This force varies from 20-30% of the mass of the construction. For public buildings, a multiplier of 1.25 or 1.5 is used, depending on its importance. These values are used for low-rise buildings up to four storeys.

Well masoned houses with tie beams, floor diaphragms and consisting of no more than two storeys with proper distribution of doors and windows are usually strong enough to withstand minor earthquakes. In general, these houses are non-engineered, meaning that no special calculations are made.

Non-masoned and non-reinforced houses will fail in any major earthquake and cause numerous casualties, as well as great economic loss. For non-masoned (non-bonded masonry) houses to be earthquake resistant, the following is required:

a. Rectangular cut stones that are fully supported by lower stones.
b. Minimal one through-stone per square meter of wall.
c. Floors and roof beams anchored into the walls in two directions, making diaphragms.
d. Openings that are at least one meter away from the junctions of the walls.
e. Short freestanding wall lengths (without cross walls) and low unsupported walls.

The diagram below shows the effect of an earthquake on a room made in masonry that does not have any stress capacity.[4]

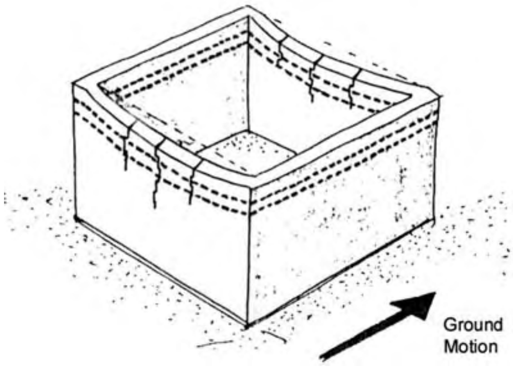


[3] The American ACI 318 and the Indian Earthquake code are rather similar in their calculation methods.
[4] Sketches on pages 4-6 are copied from Indian Earthquake Research Institute documents, 1976.

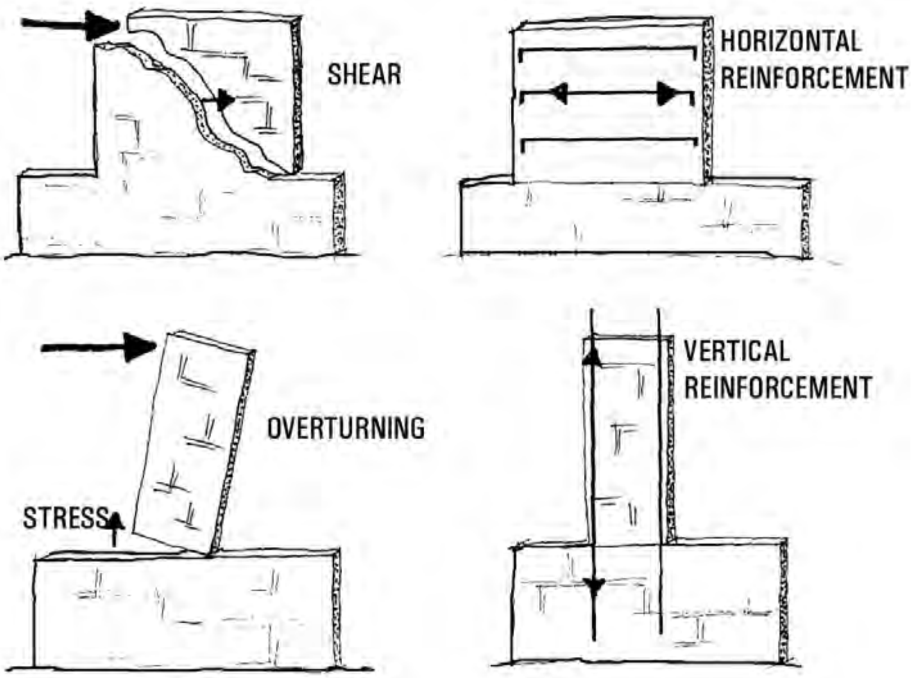
The effect of simple stress reinforcement in the higher parts of the wall is illustrated right.

The better the stress reinforcement is embedded in the wall and distributed over the higher part of the wall, the less cracks will appear in the unsupported central part.

GWR or reinforced concrete tie beams provide such a distributed stress reinforcement in semi-dressed stone or soil block constructions.



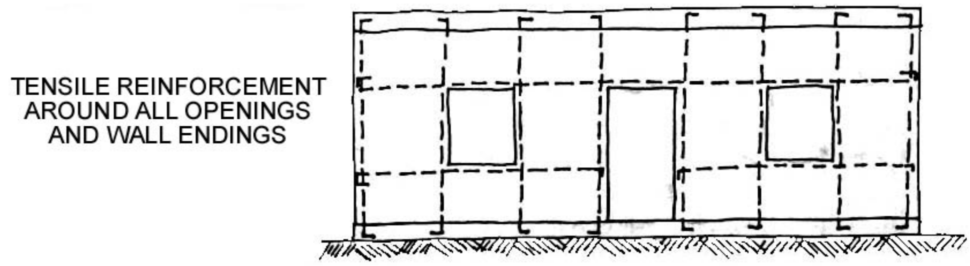
The four diagrams below give an idea of the shear forces in small wall sections, such as those between doors and windows. With the occurrence of an earthquake, diagonal cracks will appear in the walls as indicated in the first diagram. To withstand the horizontal forces, stress reinforcement should be brought into the wall in several layers, crossing the diagonal line of failure (second diagram). The third diagram shows the overturning of a narrow wall section. Here stress reinforcement needs to be placed vertically as indicated in the last diagram. C-shaped and L-shaped cement blocks at wall endings and corners provide room for placing such vertical reinforcement.



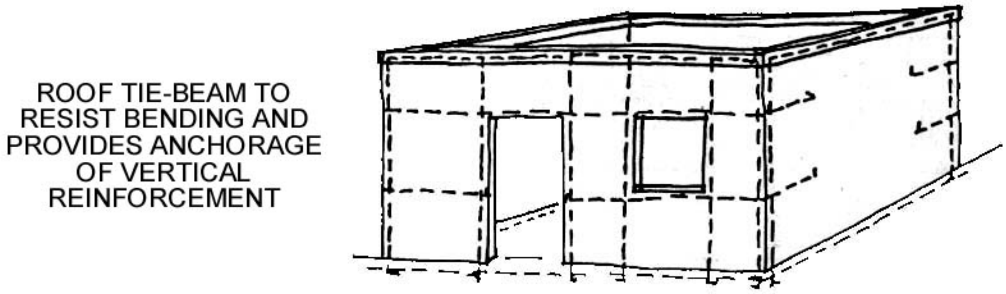
LOCATION OF HORIZONTAL AND VERTICAL SHEAR REINFORCEMENT

The combination of the above two principles of wall reinforcement requires narrow wall sections to be fully framed along their outside borders. With the use of C- and L-shaped blocks, slender stiffener columns can be integrated with the extremities of the walls, connecting the foundation to the upper tie beams.

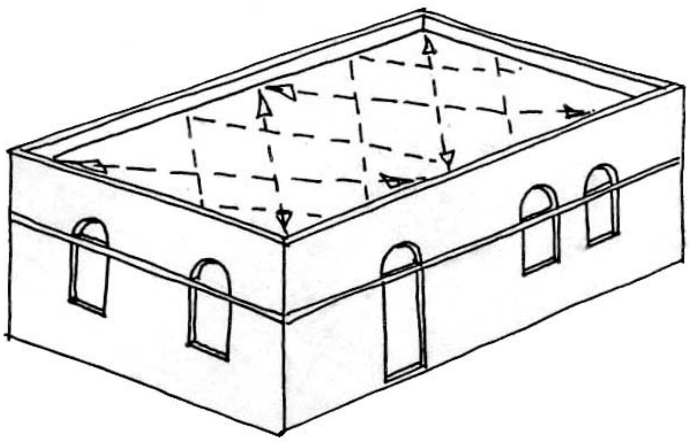
The schematic presentation of such a reinforcement pattern is present in the sketches below.



When the above reinforcement pattern is combined with a tie beam reinforcement in the top of the wall, it will provide an overall reinforcement pattern as indicated in the sketch below.



The stability of a house not only depends on the reinforcement of individual wall sections, but on the overall coherence of the construction as well. Long walls need to be supported with either reinforced buttresses or anchored cross walls. All floor and roof beams need to be properly anchored into the wall tie beams to create floor/roof diaphragms that function in all horizontal directions. In addition, all inside walls need to be anchored into this floor/roof diaphragm.



The method of reinforcement described can be used for one or two-storey buildings without load bearing reinforced concrete columns. However, the higher the building, the greater the amount of reinforcement required in the lower walls. For buildings with a few storeys, the strength of the shear walls in the lowest part of the building should be more than in the top floors.

The window and door openings should be distributed in the façade in such a way that sufficient wall segments (piers) remain to form shear wall sections. For non-engineered constructions, the total cross section of piers in the lower floor walls should increase with the height of the building (see page 8). When a two-storey building is planned, but will be built in stages, the amount of piers and internal wall reinforcement should conform to that higher design of the future.

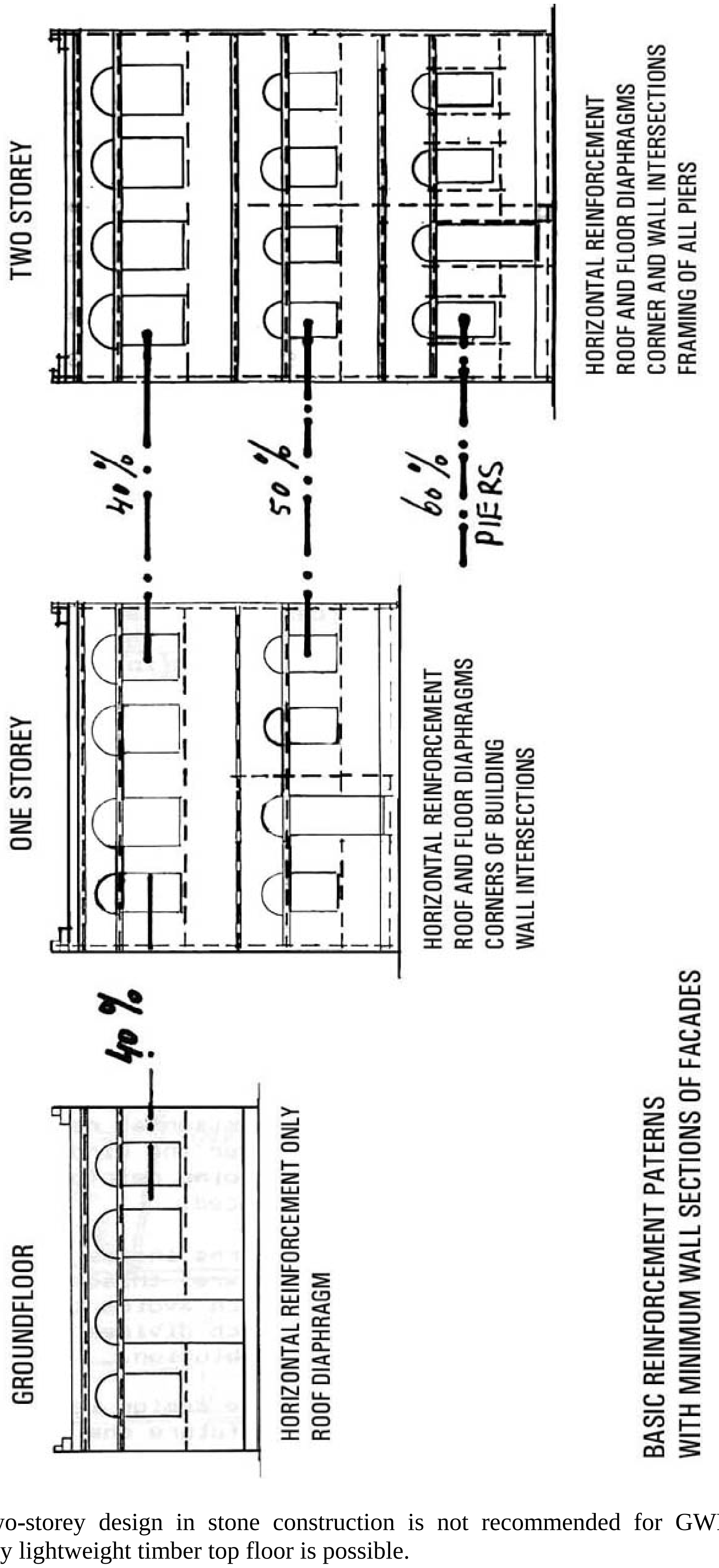
Earthquake disasters occur when a storey is added on top of a ground floor construction that was not designed for additional floors. This is aggravated when shear walls on the ground floor are eliminated to make room for shops.

The quality control of house construction in villages depends entirely on the knowledge of the house owner. Building advice should give general rule-of-thumb guidelines to ensure sufficient safety to withstand earthquakes. These guidelines must be understood by both the house owner and the locally available skilled labourers. Some guidelines found in earthquake building codes are:

- No window or door opening should be made within one meter of the corners of the building.
- When the width of a wall section between openings is smaller than its height (piers), the vertical sides of these wall sections need to be reinforced.
- The piers next to a door or window opening should have a minimum width equal to half the height of that opening. For example, if the door opening is two meters high (6 ft.), the pier should be minimum one meter (3 ft.) in width.
- When numerous window openings are required, it is better to make one large opening with a strong shear wall, rather than several small openings with many piers. Depending on the design, reinforced columns can be considered instead of several piers.
- For the top floor, where there will be no future construction above, the cross section of the shear walls should be a minimum of 40% of the original wall section (without the openings).
- For the floor where there will be only one floor constructed above, the cross section of the shear walls should be a minimum of 50% of the original wall section (without the openings).
- For the floor where there will be two floors constructed above, the cross section of the shear walls should be a minimum of 60% of the original wall section (without the openings).
- When the openings in the lowest floor of a three-storey building consist of more than 30% of the original wall construction, then reinforced column constructions need to be realised.
- For buildings higher than three storeys, engineering calculations should be made.
- The above-indicated percentages can be taken over the entire wall section of the floor only where both the inner and outside walls have a fully integrated network of linked up tie beams, floor and roof diaphragms.
- When horizontal or vertical loads are applied on walls, good bonding from face to face of the wall should avoid internal separation.

In traditionally built houses without the traditional wood framing, the above-indicated conditions seldom exist.

The following drawing gives a schematic presentation of the information provided above.

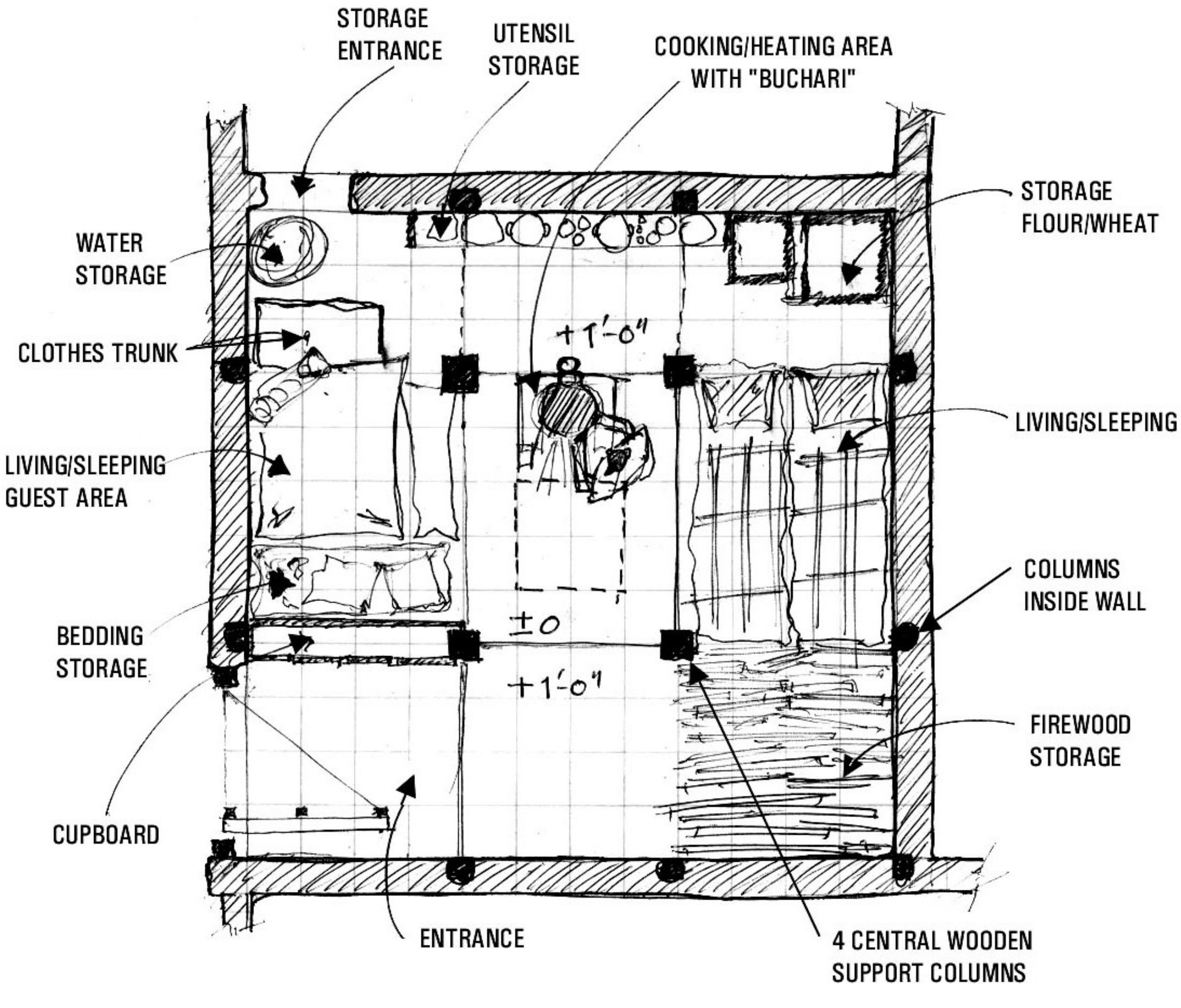


Note: The two-storey design in stone construction is not recommended for GWR technology. However, a very lightweight timber top floor is possible.

3. TRADITIONAL DRY STONE CONSTRUCTION

Traditional houses in the Northern Areas of Pakistan use four to seven heavy wooden columns in the centre of the room, supporting massive roof beams and having in-filled stone walls on the periphery. These dry stone (non-cemented) exterior walls often have internal wooden posts supporting the heavy roof construction. The roof consists of tree trunks, branches, twigs, grass, birch bark and various layers of clay soil. Adjacent to the central living area, various stores are built having a solid wall construction (no window openings). The only light comes through a central opening in the roof, doubling in function as a smoke outlet.

In the event of a major earthquake, the pillared construction would remain standing, but periphery non-masoned walls would eventually fall out of their framing. If the walls of the adjacent rooms (stores) fail to withstand the earthquake, the pillars would topple sideways causing the whole massive roof to collapse, burying the inhabitants under the heavy roof and rubble.



LAYOUT OF THE TRADITIONAL HOUSE IN THE NORTHERN AREAS OF PAKISTAN

Reducing the overall mass of the roofs of traditional houses will substantially reduce the earthquake risk and the possibility that the roof collapses. New roof waterproofing and thermal insulation remains necessary for the lighter reconstructed roofs.

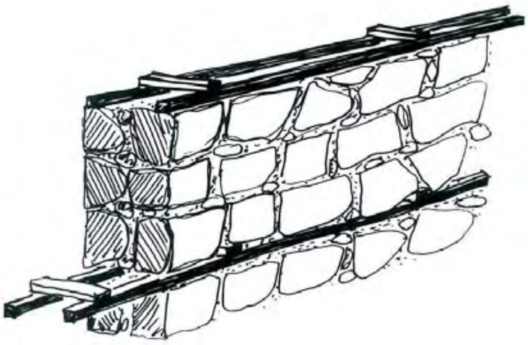
TRADITIONAL HOUSE ~ COLUMNS JUST MANAGE TO KEEP THE HEAVY ROOF UP.
WITHOUT THE REMAINING BRACING WALLS, THE STRUCTURE WILL COLLAPSE FURTHER.

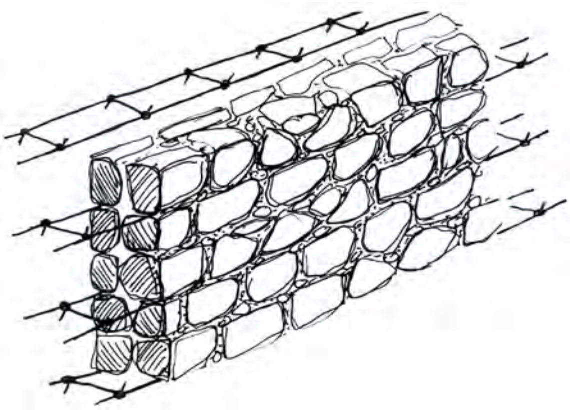
In the past, a wooden tie beam construction was made in the length of the wall consisting of two parallel (fruit tree) wood sections connected to each other with short sleepers. In some cases, these lengthwise wooden strips have been applied in the corners of the walls only.

The population growth has created a high demand for new construction and this has led to an over-exploitation of available forests for building materials and firewood. The result is the non-availability of fruit trees for construction and scarcity of quality wood for the traditional house design with the central columns. The limited hardwood available in the market is unaffordable for wall reinforcement. In the absence of an alternative, villagers are constructing walls without any reinforcement. This makes all such houses highly vulnerable to earthquake jolts and does not allow for the building of two-storey houses.

The GWR replaces the traditional wood reinforcement in dry wall stone masonry and increases the number of layers for better distribution of the stress reinforcement.

OLD BUILDING WITH TRADITIONAL WOODEN TIE BEAMS





LATERAL WALL REINFORCEMENT ~ TRADITIONAL METHOD AND NEW GWR SOLUTION

Modern dressed and semi-dressed stone constructions have particular disadvantages in relation to earthquake movements. The worst are stone constructions with nicely cut-face stonework.

a. Earthquake forces are directly related to the mass of the construction. Traditional 18-20" (46-50 cm) dressed stone walls generate tremendous earthquake forces that can only be resisted with either very strong or very stable constructions. Non-masoned stone construction has neither of those two characteristics.

b. Traditional stone walls are composed of two lines of semi-dressed stones (inner and outer faces). Small pointer stones are used throughout the construction (both on the inside and outside faces) to balance the stones vertically in the façade of the wall. When some of these pointer stones fall out due to erosion or vibration, the wall becomes unstable and eventually will bulge and collapse.

PHOTO LEFT: CROSS-SECTION OF TRADITIONAL WALL SHOWING LACK OF BONDING BETWEEN FACES, BUT WITH THE USE OF A LARGE AMOUNT OF CEMENT MORTAR AND PLASTER.
PHOTO RIGHT: TRADITIONAL WALL, THE TOP IS HELD IN PLACE BY THE ROOF.

c. For a straight uniform finish of the façade, the stones are dressed to even height. The stones are cut backwards from the cut-face into a conical shape so they can be easily aligned. The façade stones are supported inside the same wall with roughly cut stones, rubble and clay. Cut-faced stones will resist some vertical vibrations, but the inside of the wall is compressible. The result will be a rotation of the cut-face stones, breaking them loose from the inner wall. This will cause the cut-face stone wall to fall away in an earthquake (see sketch next page).

COLLAPSED AND FALLEN AWAY

d. To provide binding between the inner and outer wall faces, through-stones need to be placed at intervals of minimum one meter every other layer, thus providing about one tie per square meter wall. This is still insufficient to withstand many tremors over a long period of time. These walls, if not masoned with cement mortar, will come apart.

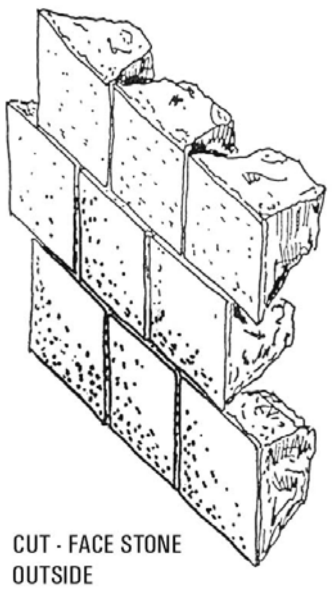
e. In many government buildings (schools, police posts) the cut-face stone walls are additionally beautified with raised cement joints. The amount of work and cement of these building is very high, while technically these constructions are potential death traps during an earthquake.

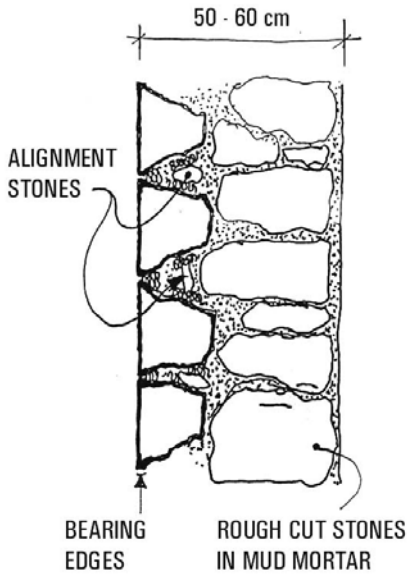
EXAMPLE OF POLICE POST WITH CUT-FACE STONE WALLS AFTER AN EARTHQUAKE

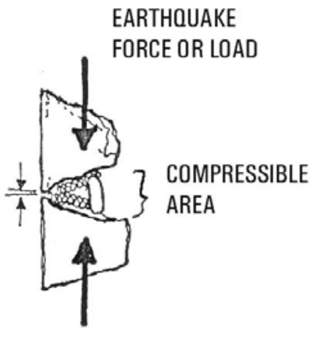
f. When the 18" two-stone wall is masoned with cement mortar for additional strength and bonding between the two faces, large amounts of mortar are required (30% of wall volume). When steel reinforcement bars are masoned into this cement work, the quality of the cement mortar covering the steel bars is often inadequate. Consequently, the steel reinforcement bars corrode and destroy the construction in the long term.

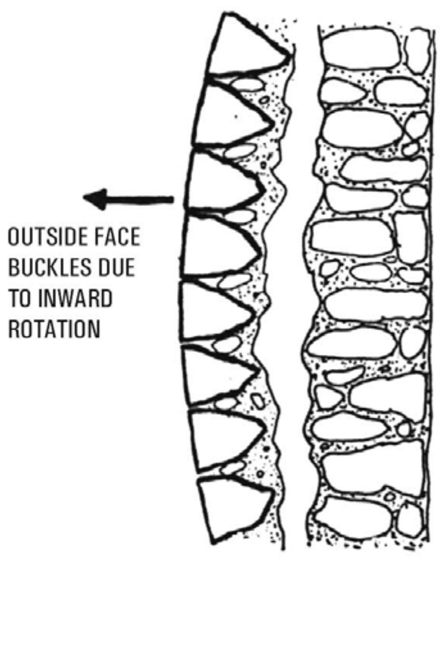
g. Steel reinforcement bars embedded in natural stone masonry are always over-dimensioned in relation to their adherence to the stones around them. Many thinner reinforcement wires or GWR provide a better spreading of the stress resistance throughout the construction.

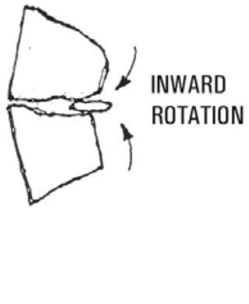
The sketches below depict the above-indicated problems.











4. GALVANISED WIRE REINFORCEMENT

The GWR technique provides a simple, cost-effective solution for making stone or adobe houses better resistant to earthquakes. Although binding of stone walls with cement mortar is the best method for making dry stone masonry more earthquake resistant, the disadvantages of using cement mortar in the remote mountain villages outweigh the advantages for many inhabitants:

- Cement is costly, heavy and difficult to carry, making transport additionally expensive.
- For loose stone construction, a large quantity of cement mortar (30% of stone volume) is required.
- Reasonable sand quality is required for the cement mortar. Not all riverbeds have the quality and quantity of sand required, and those that do often are located at considerable distance from the villages, often more than 1000 m lower.

Considering the above problems in the remote mountain villages, a reinforcement technique is required that can be applied in:

1. Dry stone masonry using stabilised mortar only.
2. Construction of soil block walls.
3. Adobe and rammed earth constructions.
4. Masoned constructions in which stones, bricks or cement blocks are used.

Steel bars used to reinforce masonry constructions require strong cement-sand mortar (minimum 1:4) or concrete (1:2:3). When the concrete or mortar quality is poor, steel reinforcement bars will eventually corrode and break the surrounding masonry by expansion of the corrosion.

The GWR does not require masonry with strong cement-sand mortar (only 1:10) and can be used in dry stone construction or adobe walls without the immediate danger of corrosion of the wires. Corrosion protection is adequate with double galvanisation, such as used for barbed wire and fencing wire. Point-welded wire requires post-welding galvanisation.

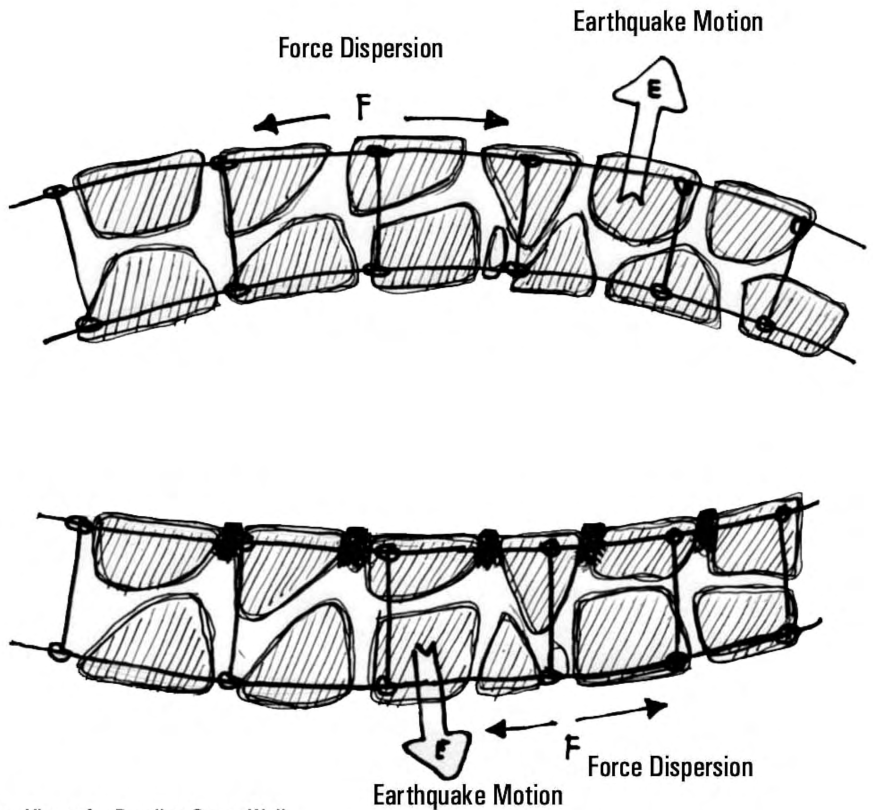
Good adherence between the wires and the wall is necessary. To achieve this adherence, a long ladder-like strip is made from galvanised wire. The many knots and cross wires grip the surrounding stone construction or adobe masonry at regular intervals (1 ft.). To give the cross wires more grip, the extensions of the cross wires are wound over the length wire (see annexe).

The amount of light sand-cement mortar required to fix the cross wires between the stones is considerably less in comparison to other masoned constructions. Less cement mortar results in considerable material and financial savings. Stabilised cement mortar is a large improvement over mud masonry and avoids wind and rain erosion in the joints.

The GWR works best when the reinforcement is placed along the faces of each wall. Thick walls are heavier, but in a thicker wall, the distance between the wires is also increased and the increased moment-arm of the reinforcement will be more resistant to bending.

An earthquake motion perpendicular to a wall will bend the wall between the supporting cross walls. With the GWR inside the outer faces of the wall, stress forces will be applied to the reinforcement, resisting the bending force. The alternating forces of an earthquake make the wires work in alteration.

To improve resistance against compression, the open spaces between the stones of both faces need to be pointed with cement mortar. Cement mortar is needed because the outside face is subject to wind and rain erosion.



Plan View of a Bending Stone Wall
showing where the GI Wire takes tension and the stones pointed with cement mortar take the compression.

WARNINGS:

GWR is not a substitute for the framing of all wall sections in good quality slender reinforced concrete or lack of shear walls in the house design.

When the GWR is fitted into a poorly masoned wall construction or laid between improperly cut or round stones that do not fit tightly around it, the GWR will not make the wall much stronger.

The GWR in itself does not make the wall earthquake resistant. It is only in combination with good masonry and stone cutting that it greatly enhances the earthquake resistance. Framing of all openings and wall endings is necessary.

The GWR resists only the stress forces and not the compression. The compression forces need to be taken care of by good quality stone work and well positioned shear walls. The GWR in the walls should be linked at all the junctions.

A wall of rubble before an earthquake will be a pile of rubble after an earthquake – with GWR or not. GWR is no superglue.

5. GWR TECHNIQUE

The GWR technique is very simple and straightforward to apply in any wall construction, be it stone, cement blocks, adobe, compacted soil block or rammed earth walls. The GWR needs to be placed in courses from the foundation to the roof tie beams. The GWR should be placed in alternating layers in non-masoned dressed stone walls to ensure that all stones are connected to the GWR.

The GWR strips can be pre-manufactured, point welded, extra galvanised and supplied in rolls in a few standard sizes. Winding the cross-wire extensions can be done quickly on site using a small hollow tube tool.

Width of GWR

The width of the GWR depends on the type of building materials, as follows:

- Adobe and Soil Block Walls: For 16-inch wide walls – 14-inch wide GWR
For 12-inch wide walls – 10-inch wide GWR

- Semi-Dressed Stone Walls: Traditionally 18-inch wide – 16-inch GWR with light cement mortar in the joints (1:10)

- Cement Block Walls: Hollow 6-inch cement blocks are preferably used in light wall constructions, providing stability and some thermal insulation. For the 6-inch hollow cement block walls, 5-inch wide GWR is recommended.

Factory Point-Welded Wire Strips

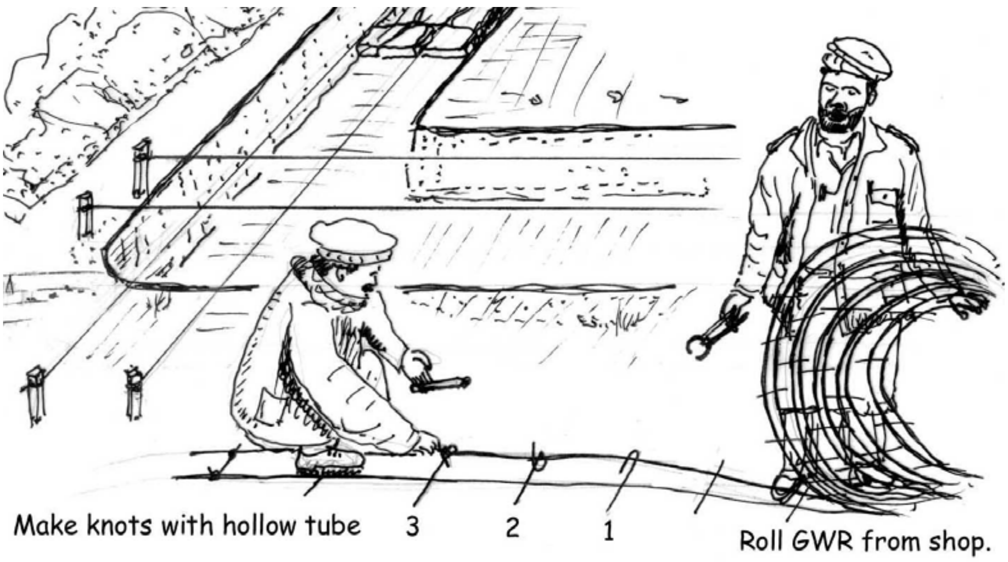
When the wire strips are factory point welded, pre-manufactured rolls of 100-200 m can be marketed in the same way as rolls of barbed wire. The cross wires should be thinner (2 mm) than the length wires (2.5 mm) because the point-welding process will reduce the thickness (strength) of the length wire. For hand-knotted wire, 2.3 mm wire should be used. The cross wires (2 mm) are straight and stick 2 inches out from the length wires. The point-welding process needs to be carefully controlled so that the actual section of the length wire will not reduce to less than 2 mm. The wire-mesh needs post-welding hot-dip galvanisation. The GWR can be rolled to facilitate transport (200 m = 10 kg).

Requirement for a Core House

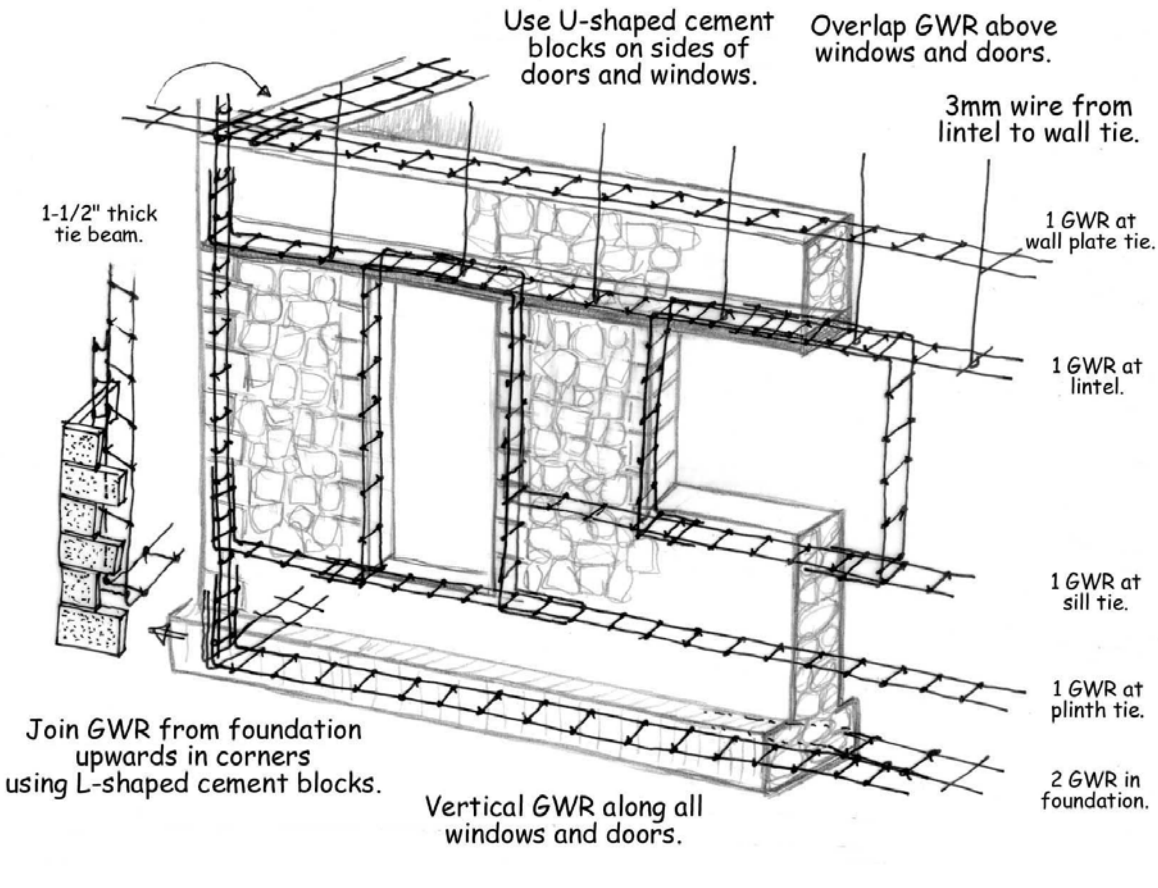
Minimal 400 m (20 kg) is required for a ground-floor-only 50 m^2 core house. Each layer in a 50 m^2 core house requires 50 m length of GWR. An earthquake-resistant ground-floor-only house requires minimum seven layers of GWR: 2 x foundation, 1 x plinth, 1 x windowsill, 1 x half way the window, 1 x lintel and 1 x roof tie. In addition, vertical reinforcement is recommended along all door and window frames, overlapping above the openings (see next page). For buildings that will have a second storey in the future, the amount of wires should be increased to 11 layers.

On Site Application

The GWR is unrolled at the building site and cut to length. This length is longer than the wall sections to allow overlap and anchorage to the next section. The mason who applies the GWR in the walls is required to wind the 2-inch extension twice around the main wire or to joining GWR sections. This winding will enhance the friction and adherence in adobe constructions and with a little cement mortar on the winding, it will greatly enhance the linkage with semi-dressed stone constructions. The metal winding tool is about the size of a thick ballpoint pen.



As indicated in Chapter 2, shear wall reinforcement requires vertical reinforcement to be at the ends of the walls and along all window and door openings. The GWR needs to be folded upwards at the corners of the walls and along the doors and windows. The upward folded GWR will meet other GWR sections coming from lower layers. The overlapping strips of vertical GWR form the vertical wall reinforcement.

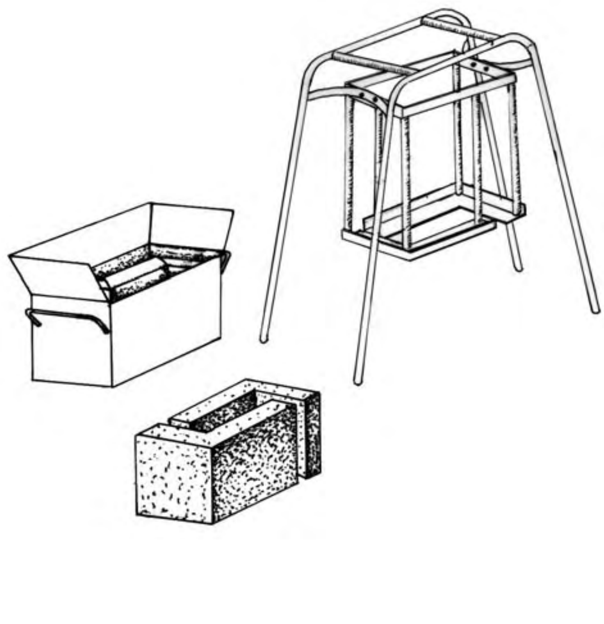


L-shaped and C-shaped cement blocks have been designed for easy masonry work and for casting slender concrete columns. These cement blocks are placed in the wall corners and along the sides of door and window openings. The cement blocks have four important advantages:

1. With the placement of the cement blocks, straight vertical edges are first masoned upwards at all corners and allow easy in-fill of the cut-stone masonry. A string is stretched between the raised corners. This saves substantial time in masonry work.
2. The vertical GWR can be pulled upwards in the space between the cement blocks and the stone masonry. The cement blocks will function as formwork allowing easy filling of the space between the blocks and the stone wall with light mortar and small stones.
3. When concrete is cast for the wall-framing columns, no formwork is required. The filling with concrete should be done after every two layers masoned.
4. The architecture obtained by the combination of the corner cement blocks and cut-stone in-fill work is aesthetically very appealing (see sketch on the cover page).

Various moulds can be used for making the C- and L-shaped cement blocks. One manual type of mould is described below – the rack mould. Large quantities of good quality cement blocks can be rapidly made with this mould.

The rack mould consists of a 2 mm sheet metal mould (open at both the top and bottom) and a rack with a compacting angle iron fitted to it. The mould is placed on a flat, sanded cement floor and filled to the rim with fairly dry aggregate cement mortar (8:1). The rack is then lifted over the mould and set down with force onto the mortar in the mould, compacting the mortar. An additional amount of mortar mix is added to the mould and the compacting with the rack is repeated. Once firmly compacted, the mould is lifted while the rack holds the freshly compacted cement block down. When the mould is free from the freshly cast block, the mould and rack together are further lifted and placed aside to make the next block. The mould may not be tapered inside, otherwise it cannot be lifted.



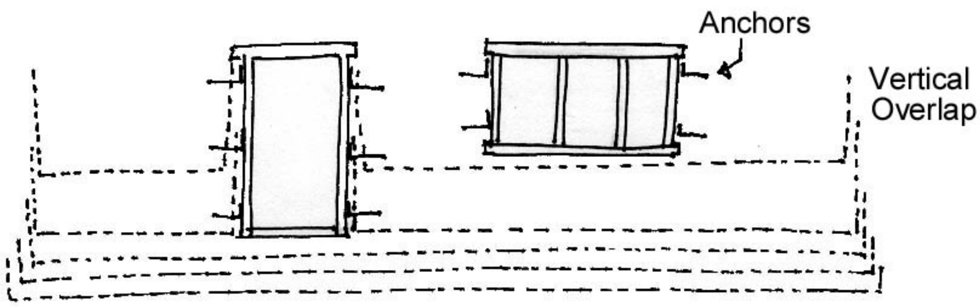
6. BUILDING A HOUSE

Foundation

Traditional houses constructed on slopes often have high foundations built in rough stone masonry. The space inside the foundation is frequently used as cattle sheds or storage for fodder and firewood. Although this basement may not be sophisticated enough for living quarters, the walls have to bear the superstructure as it will receive the first horizontal impact by an earthquake jolt.

Depending on the soil type and boulders in the subsoil, reinforcement of the foundation is important to prevent any settlement cracks in the higher walls. The GWR needs to be applied in every layer of the foundation and cover its whole width. For wide foundations, wide GWR strips are used or several strips can be joined lengthwise, overlapping each other.

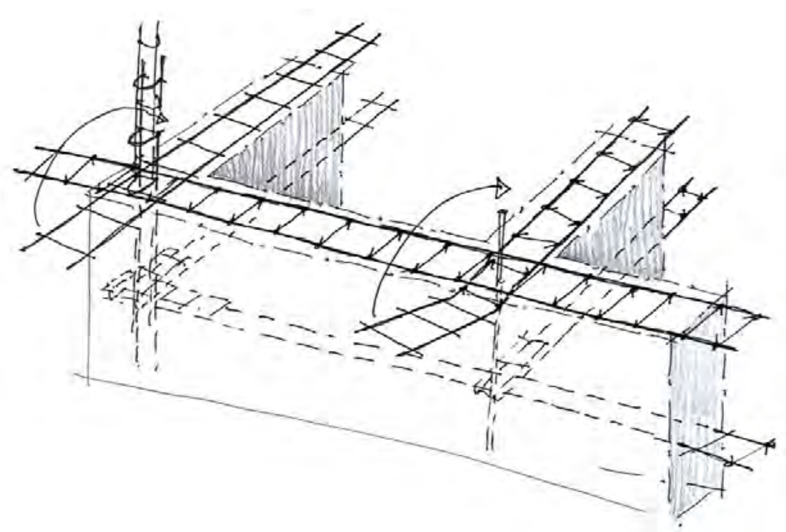
To provide anchorage for the vertical wire reinforcement at the wall ends, several GWR strips are bent upwards at the corners, overlapping for 1-2 ft. to create the corner columns. This vertical reinforcement will run upwards inside the C- and L-shaped cement blocks.



IN FOUNDATION, IN EVERY LAYER

Wall Junctions and Corners

The horizontal GWR is folded over at the corners to make a turn or folded over the cross strip; thus anchoring one wall to the other. This applies to corners and T-junctions.

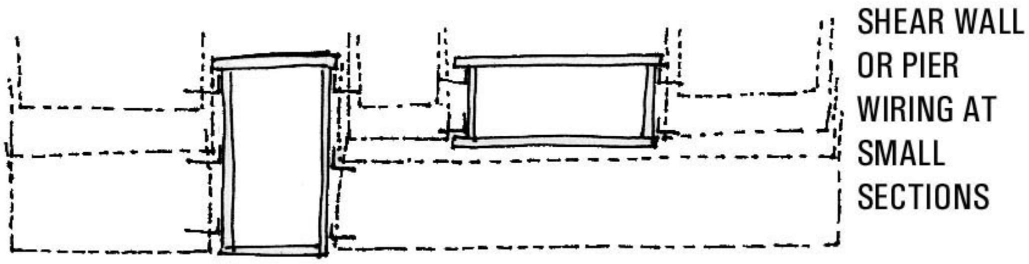


Window Sill

Apply one GWR strip under all window openings. This will be part of the shear wall reinforcement.

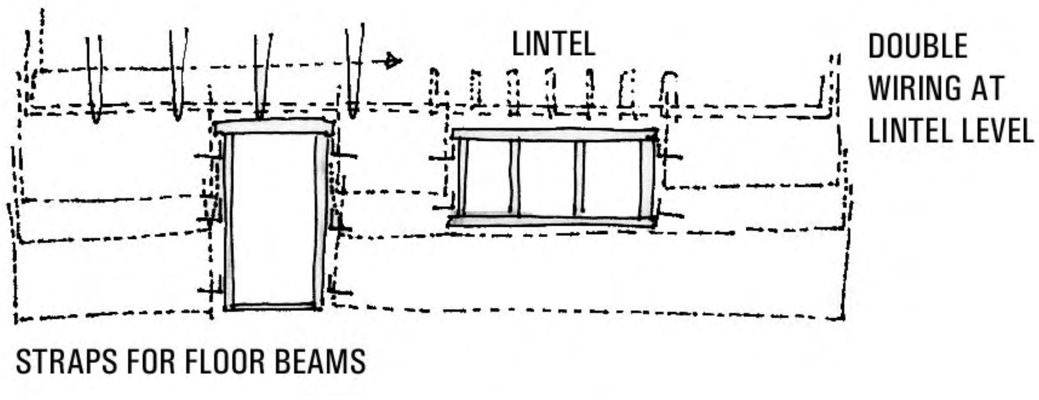
Shear Walls

Between wall ends and openings, shear wall reinforcement needs to be applied. When the wall sections are narrower than the height, pier reinforcement has to be created. Shear wall reinforcement consists of several layers of GWR over the height of the wall section and the bent-up ends of the wall reinforcement into the vertical columns. Pier reinforcement is created by doubling or tripling the vertically folded-up GWR strips along the sides of the doors, windows and wall ends, thus making reinforced columns.



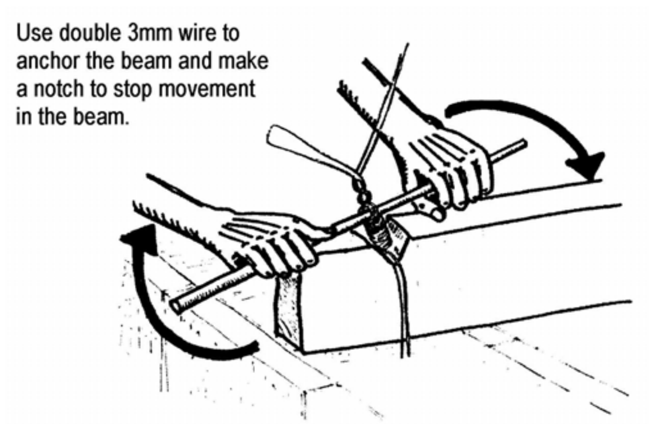
Door and Window Lintel Tie Beams

All door and window lintels need to be connected throughout the building; also over inside walls. For doors and windows lintels, the GWR is doubled, depending on the span, and loops of 3 mm wire are attached to the GWR at short intervals. The 3 mm wire loops are hooked into the GWR and between the hoops, a solid line of stones or cement blocks is masoned as pressure zone.

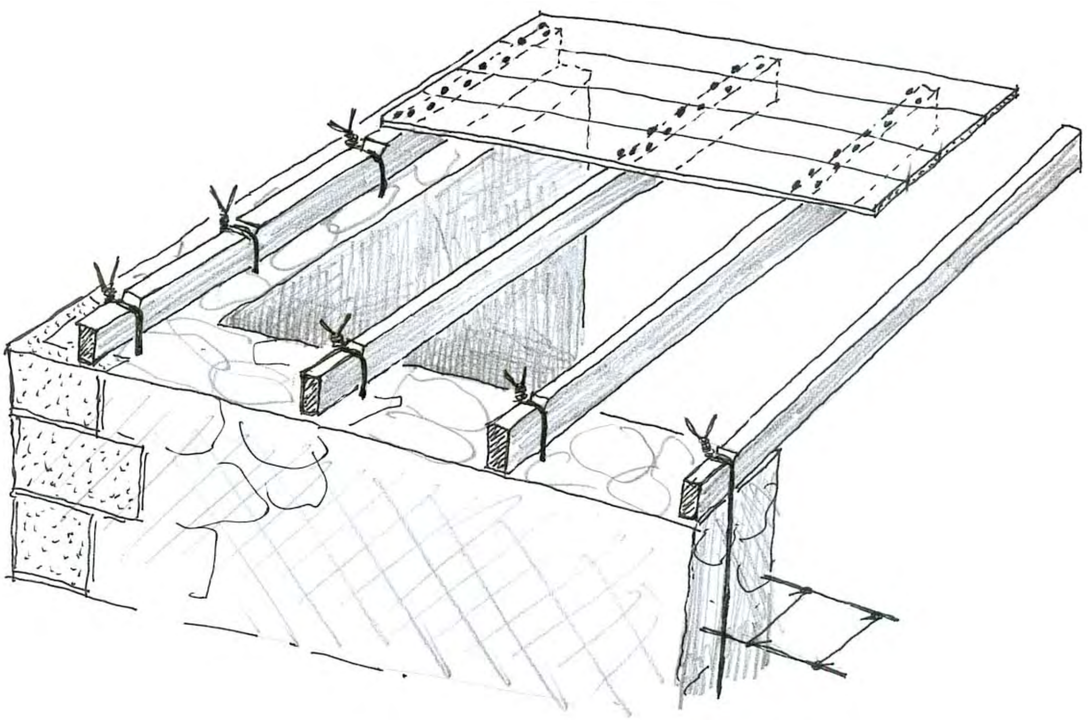


Floor / Roof Beams – Diaphragms

Starting at the door and window lintel level, a 3 mm galvanised wire is hooked into the GWR to provide anchorage for floor and/or roof beams and wall plates. The beams need to be notched over the middle of their supports. The two ends of the 3 mm wire are tied down over the notches to avoid that (in case of a major earthquake) the beams slip out of these anchors. The floors and the roof should form a diaphragm with all walls, providing full bracing at every floor level and the roof.



The 3 mm wire straps are tied together over the notches in the floor beams. To provide a connection between the wall running parallel to the floor beams and the floor beams themselves, a wall beam is tied onto the parallel wall. The flooring or roofing is nailed to this wall beam and also over all the floor beams; thus creating an integral floor diaphragm.



Invisible Inside Walls

The GWR is invisible in the finished traditional stone construction, thus preserving the traditional architectural appearance of the building. Inside, the GWR links the inner face and outer face together and connects the inner and outside walls of the building at all corners and at various levels.

Slimming of Walls

Slimming of the walls is recommended for one-storey houses (ground floor plus one) in order to reduce the weight. The storey should be as light as possible, for example using light cavity walls. Some traditional houses have the upper storey made of wattle and clay fixed in a timber framework. GWR is not recommended for two (or more) storey buildings in stone construction.

Thermal Insulation

For higher altitude mountain areas, thermal insulation of the houses is important for comfort and firewood saving. In this case, a three parallel wire GWR strip should be applied (see page 29).

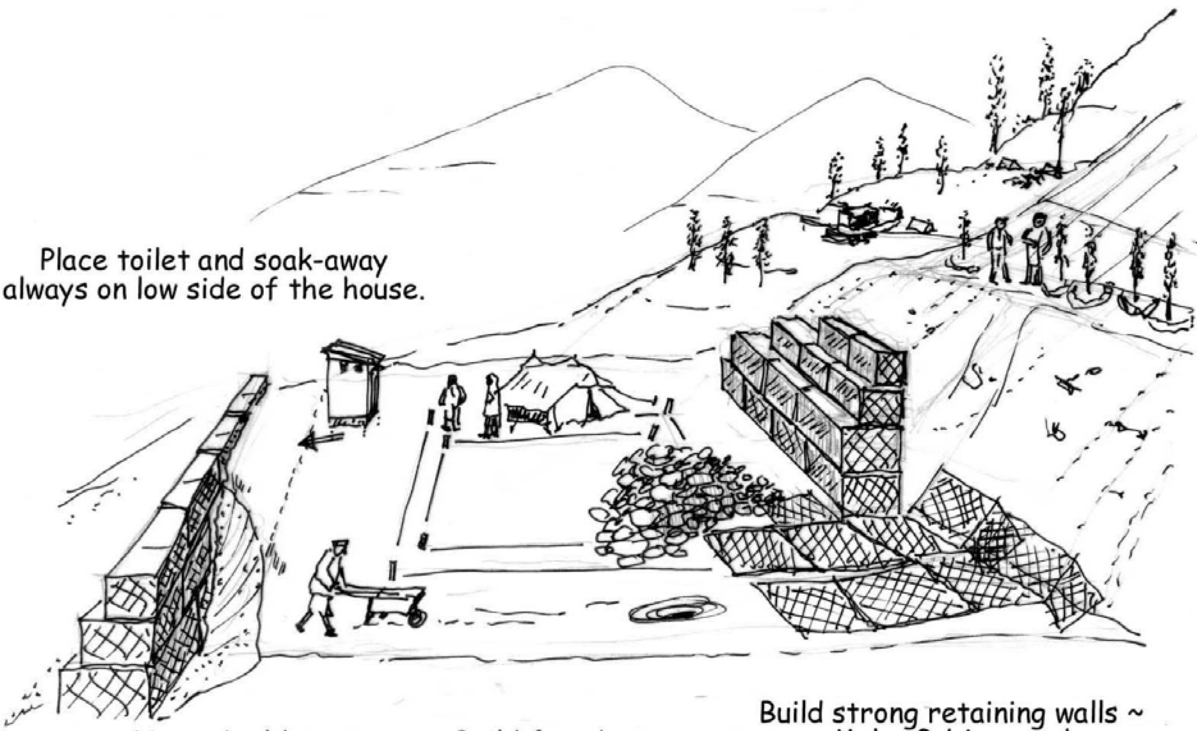
7. CONSTRUCTION DETAILS

<u>Choose or Develop a Safe Site</u>

Collect and make rectangular cut stones.

Do not use round or egg-shaped stones.

Plant trees to stabilize slope.



Place toilet and soak-away always on low side of the house.

Never build near or on infill soil.

Build foundation on solid ground.

Build strong retaining walls ~ Make Gabions and fill with rubble and round stones.

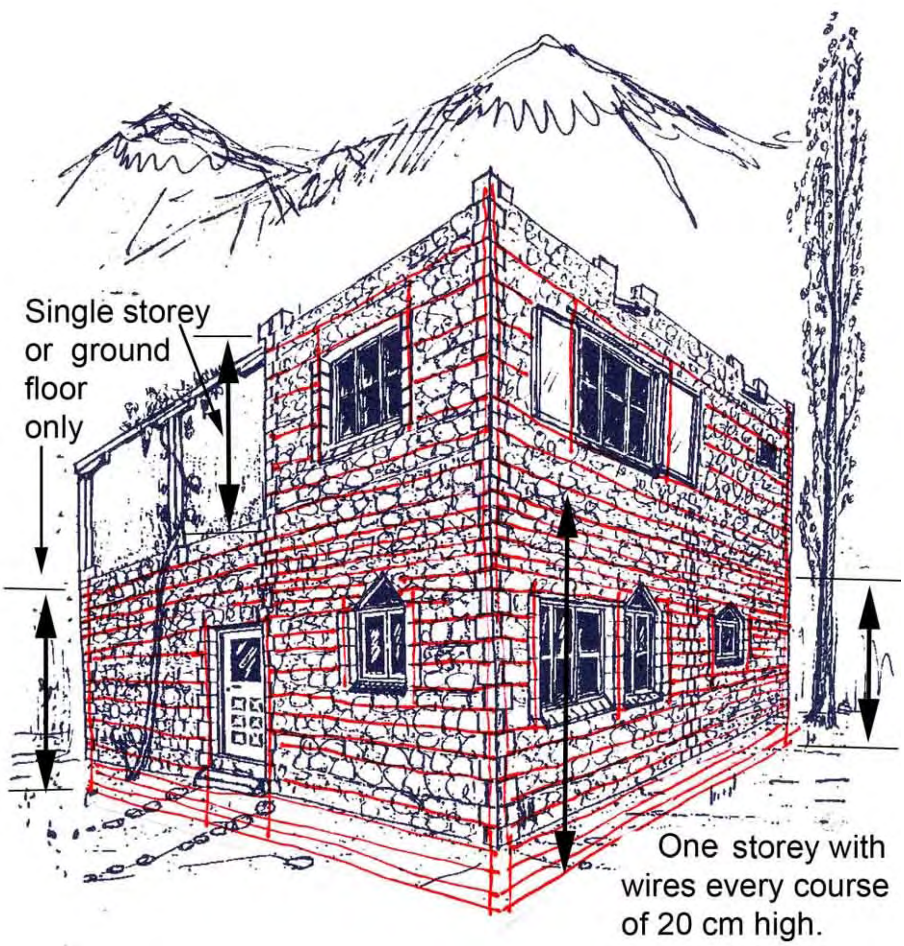
Distribution of GWR in Ground-Floor-Only and One-Storey Buildings

For ground-floor-only buildings, a minimum of one GWR wire-mesh in every alternative layer is recommended. This way all the stones or blocks will have contact with the wire-mesh and it creates lengthwise and crosswise reinforcement. The crosswise reinforcement binds the two faces of the wall together.

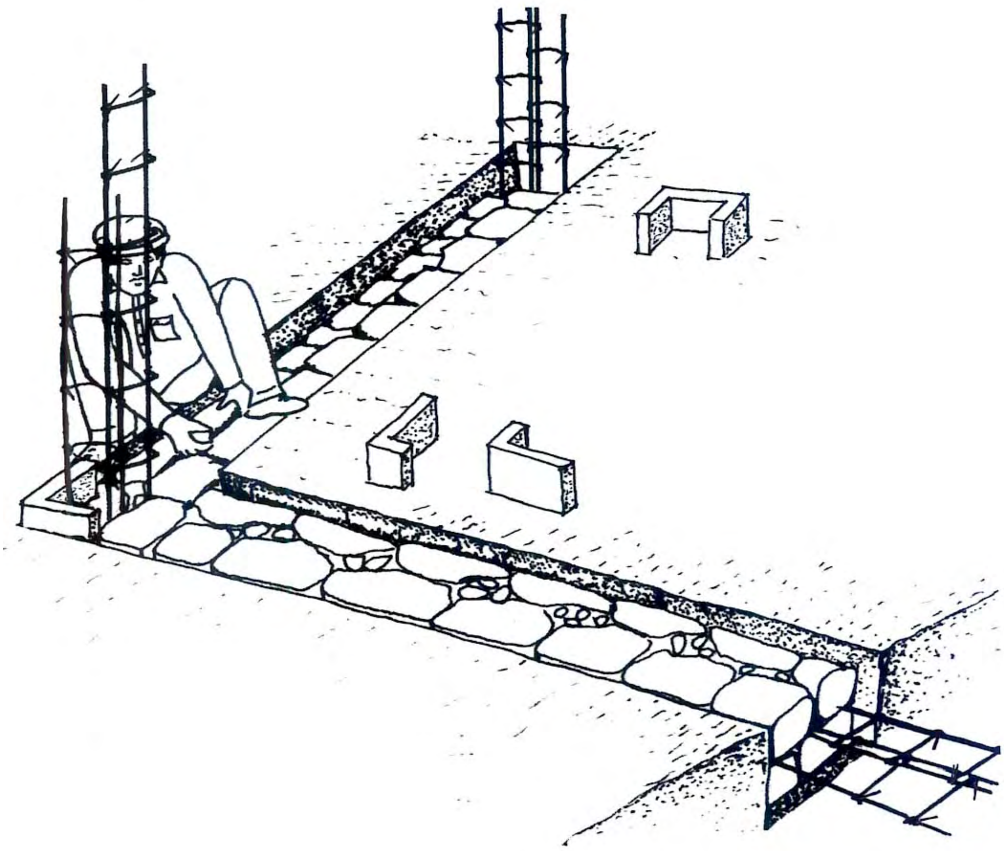
However, if an additional storey is added, the possible earthquake load on the ground floor walls will increase because of the additional weight of the first storey, especially if built in stone or other heavy materials. Therefore, building an additional storey lightweight is essential.

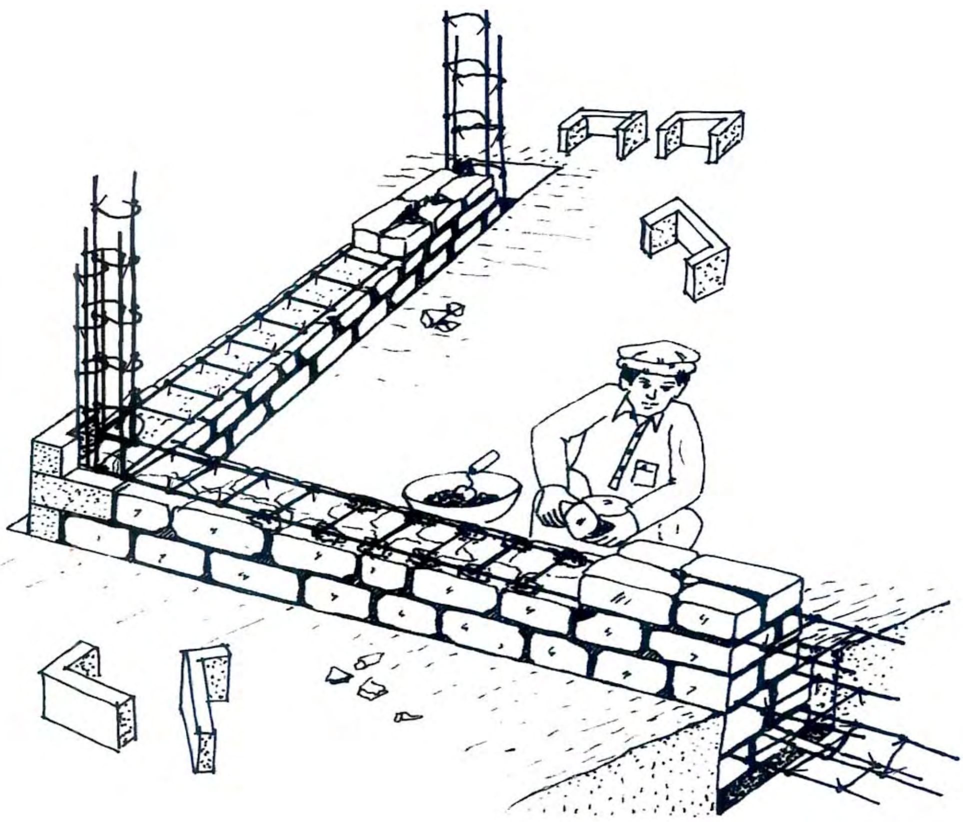
Assuring sufficient internal and external shear walls and full connection of the cross walls to their perpendicular walls, as well as a floor diaphragm being properly connected to all four outside walls, will strengthen the building for a first storey.

By increasing the number of wire-mesh reinforcement layers in the ground floor section, the building strength will also increase. When a one-story house is planned for the future, it is recommended to increase the reinforcement in the ground floor. Every 20 cm high course of the stone or block walls should have GWR reinforcement.[5] For the walls of the added storey, one GWR wire-mesh every alternative layer is adequate.

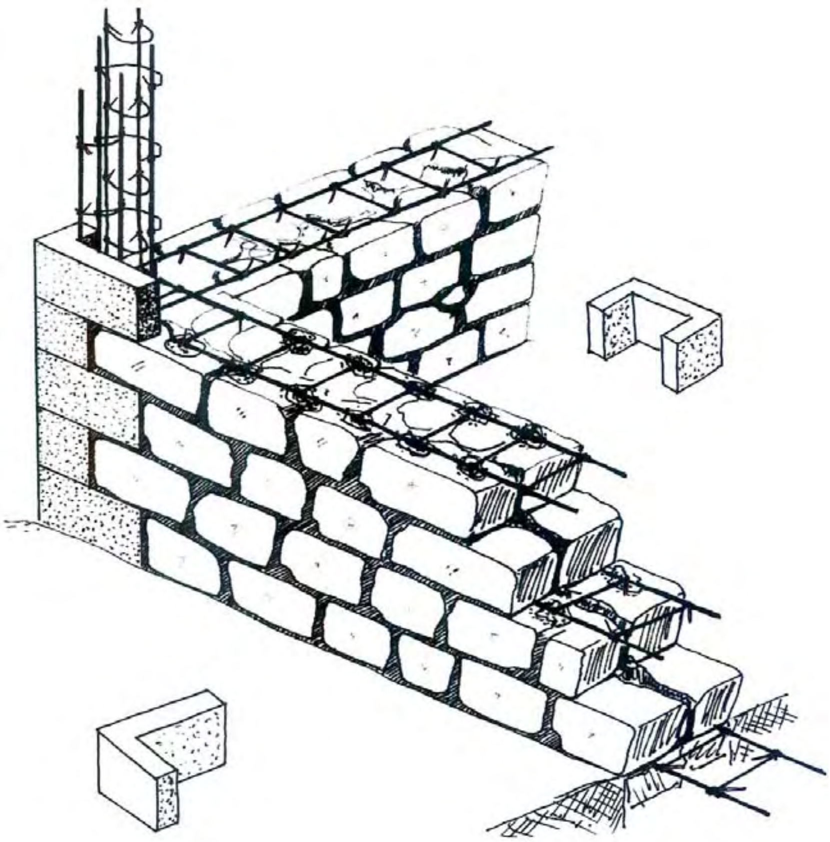


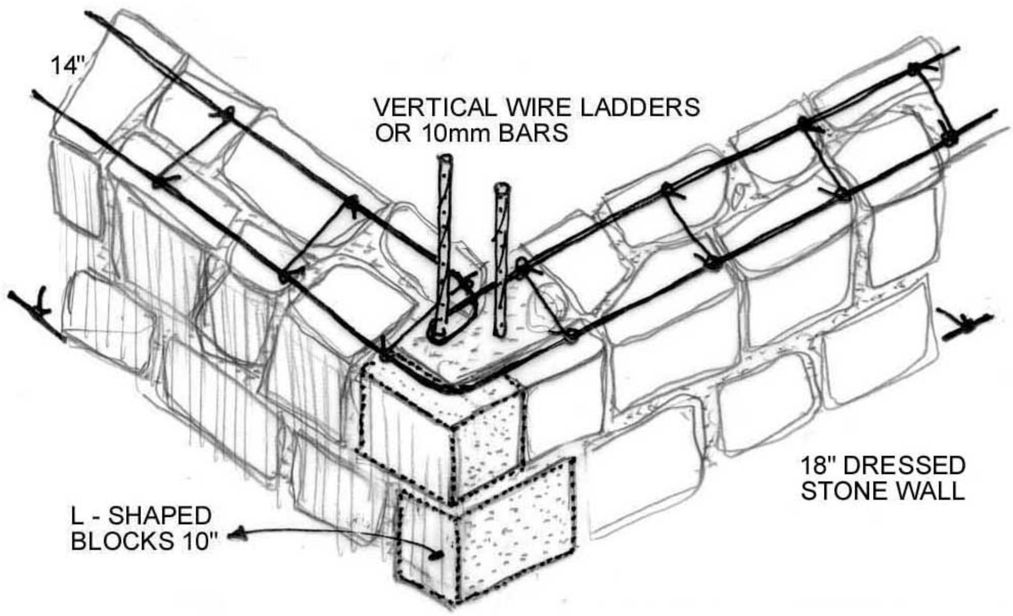
[5] The stones or blocks should have a height of 20 cm. Using very small stones is not advised with this technology.



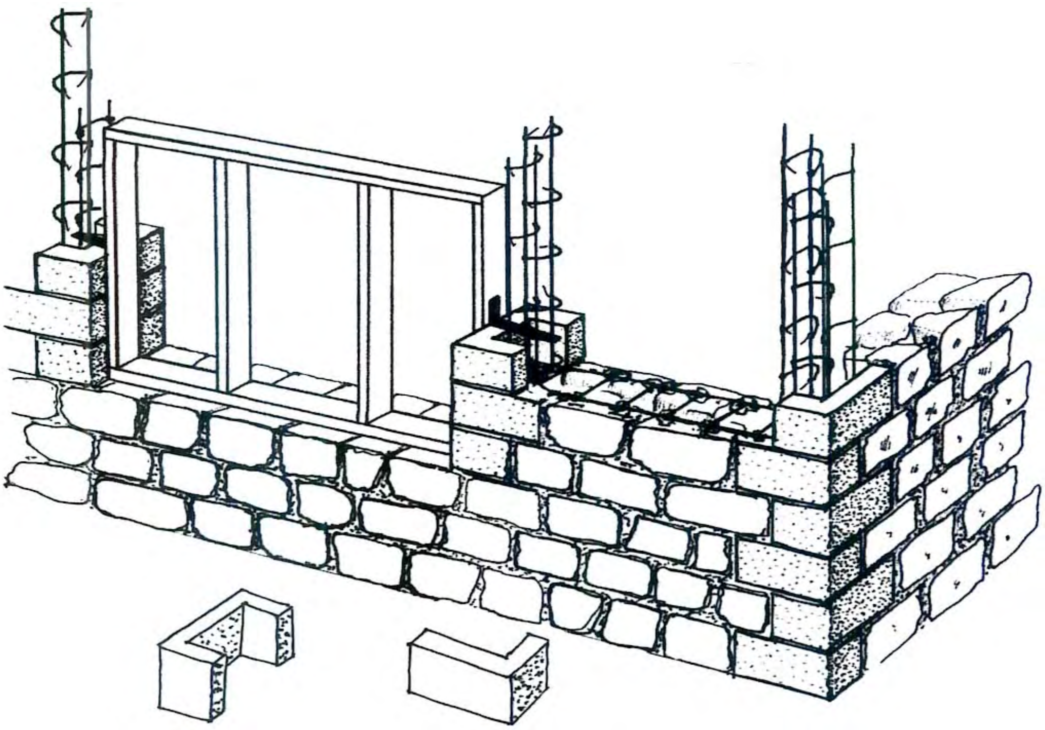


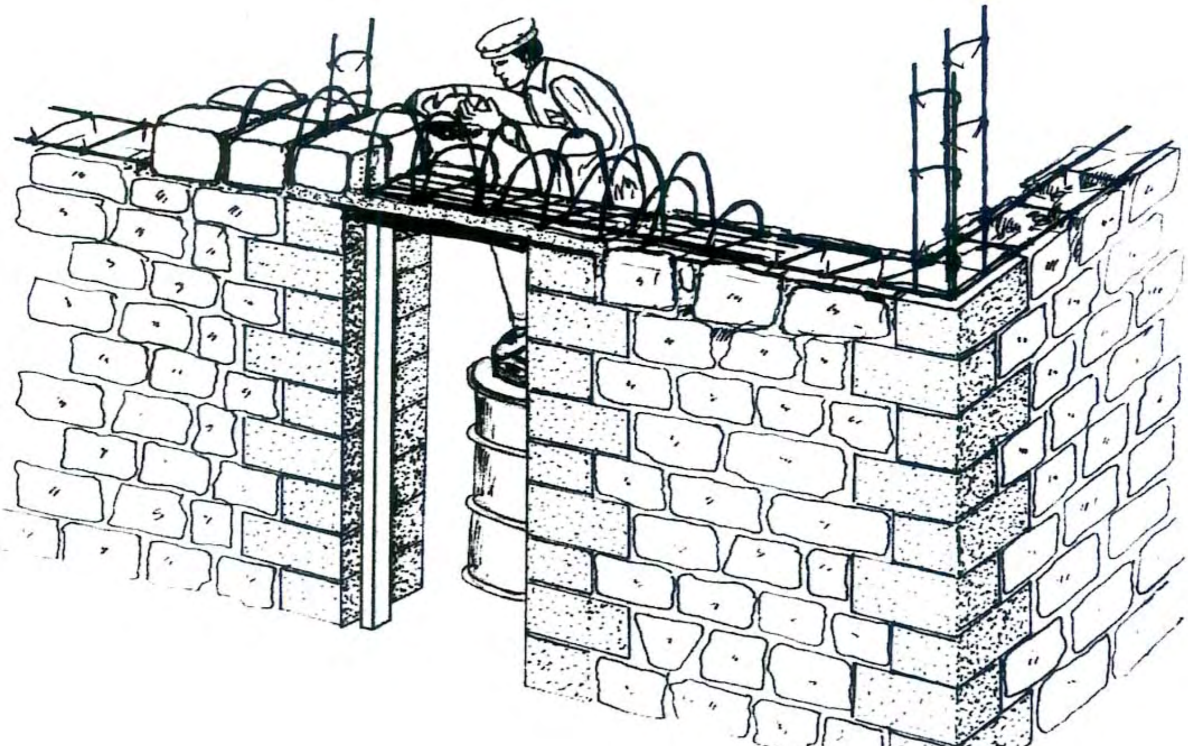
FOLD THE ENDS OF THE GWR STRIPS UPWARD TO CREATE VERTICAL REINFORCEMENT



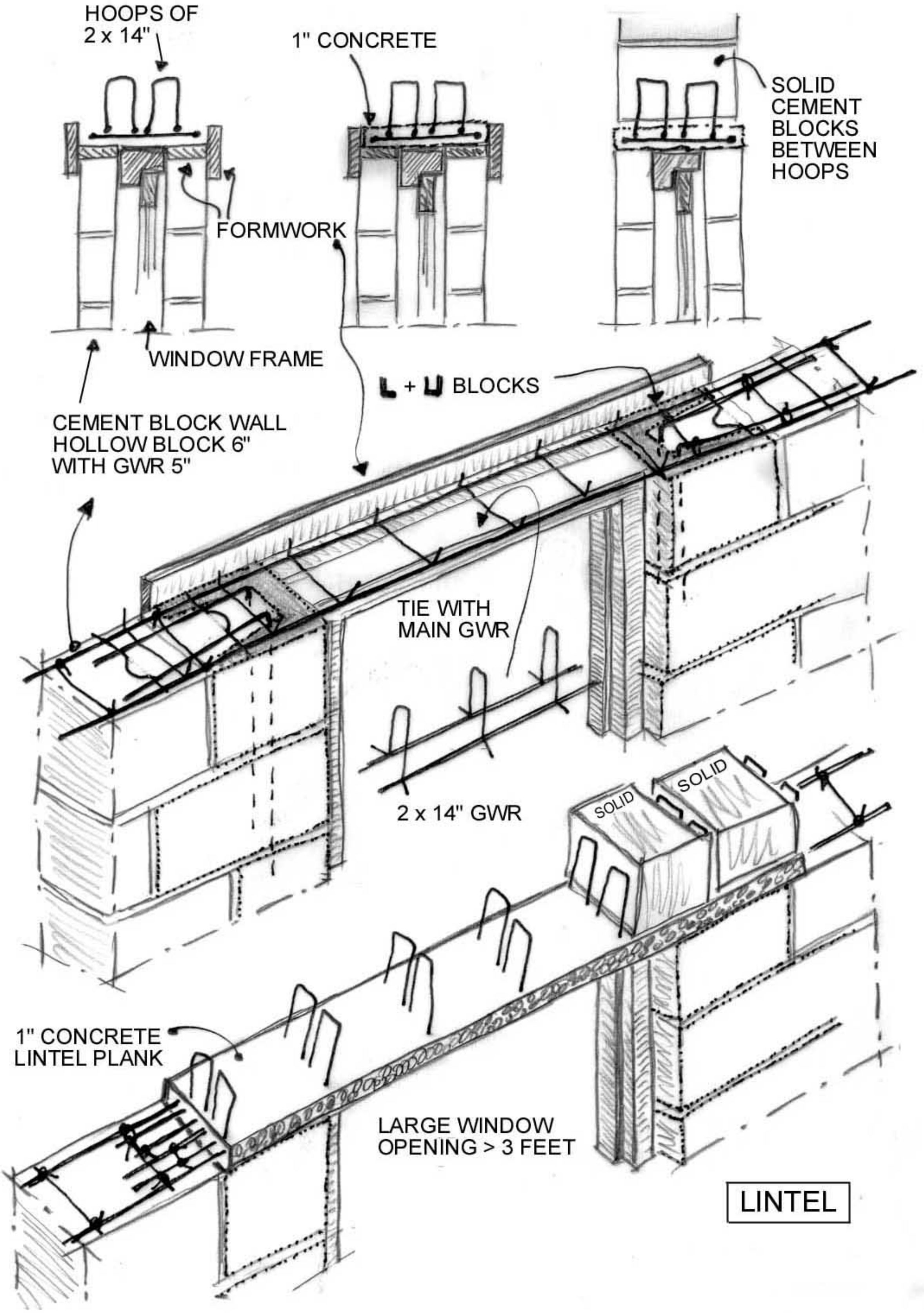


WHEN 10 MM IRON BARS ARE USED IN THE STIFFENER COLUMNS,
GOOD QUALITY CONCRETE (1:2:3) SHOULD BE USED TO AVOID STEEL CORROSION

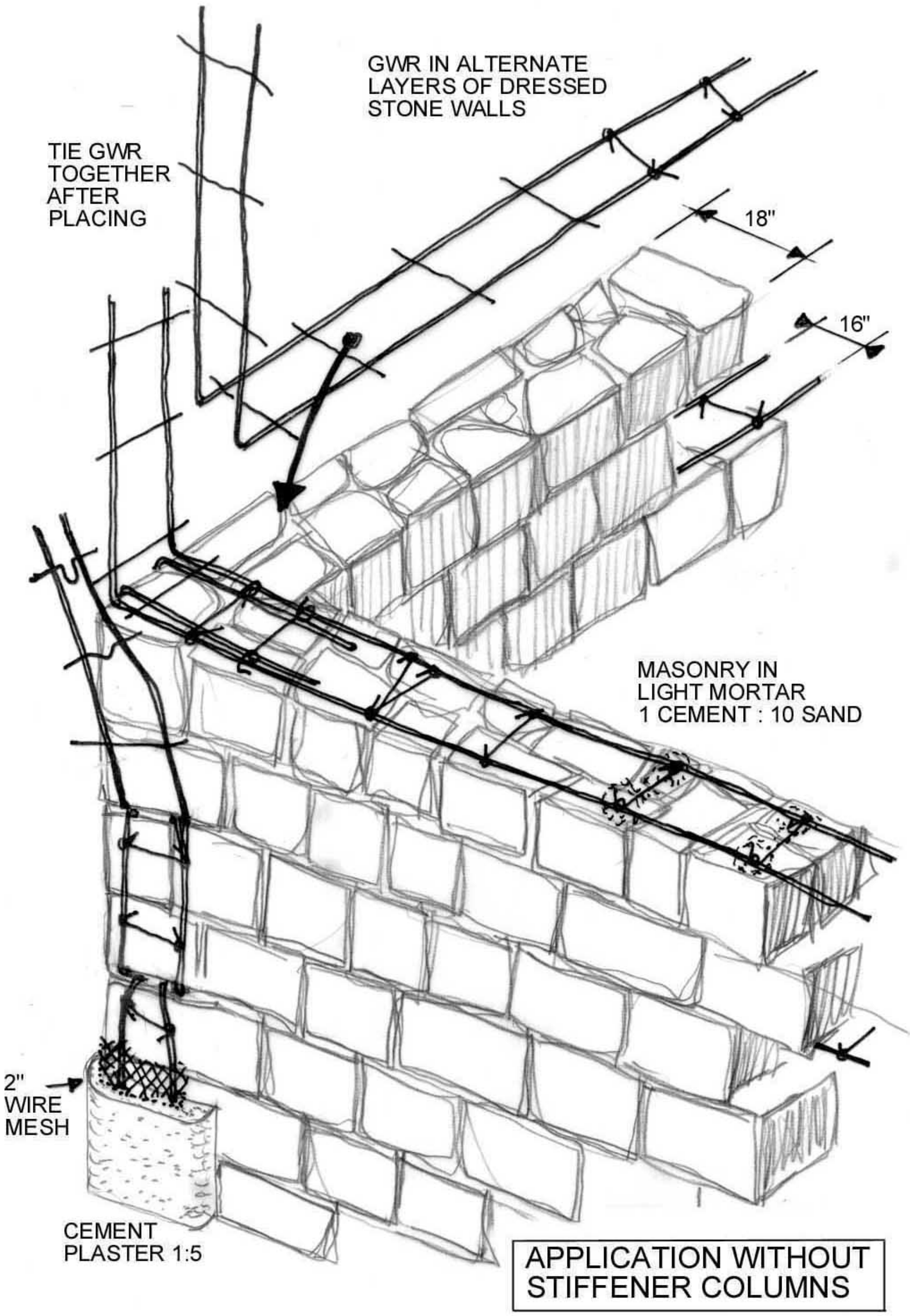




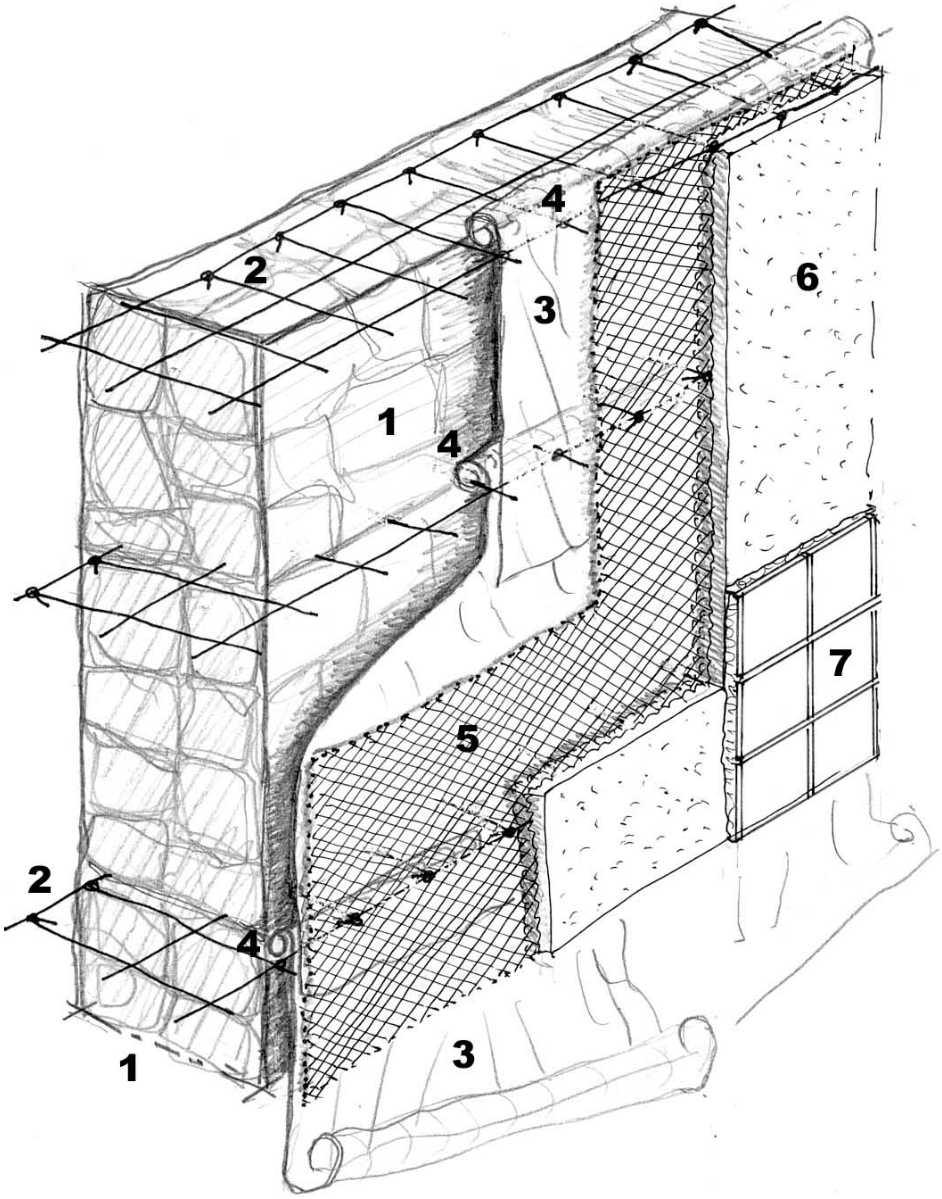
SOLID BLOCKS ARE MASONED WITH CEMENT MORTAR (1:4) BETWEEN THE HOOPS
TO FORM THE PRESSURE ZONE OF LINTELS



LINTELS CAN BE MADE OF 2" CONCRETE IN COMBINATION WITH GALVANISED 3 MM HOOPS



VERTICAL GWR CAN ALSO BE APPLIED OUTSIDE THE WALLS AND
COVERED WITH EXPANDED METAL MESH AND PLASTER (1:4)



Cavity Wall Construction

Stone masonry (1) with GWR strips (2) consisting of three length wires from which one wire extends 2" out from the stone wall. In cold climates, the cavity wall needs to be made on the interior side of the outside walls of the building. Thermal insulation should be applied on the inside stone face by means of one or more reflective foils. The number of reflective foils depends on the altitude.

A thick plastic foil (3) is hung on the extended cross wires. At every horizontal line of cross wires, strips of plastic are placed or the end of the plastic sheet (4) is placed against the wall. This is to stop vertical air circulation between the plastic foil and the wall. This space can also be filled with EPS thermal insulation material to increase its insulation property.

Over the plastic foil (3), a ½" x ⅓" galvanised expanded metal mesh (5) is attached to the extended cross wires and the ends of the cross wires folded back. The expanded metal mesh is primed with sand-cement slurry of a mixture 1:1 to improve adherence of the plaster. A layer of plaster (6) is applied to the expanded metal mesh and pressed slightly into it. For bathrooms, tiles can be applied to the wall (7).

8. RESUME

With the pre-fabricated GWR, various widths and lengths of reinforcement can be easily applied in all types of stone masonry construction, even in the most remote mountain village. Because the GWR is double galvanised, only light cement mortar is used for enhancing contact between the GWR knots, cross wires and stones. It is estimated that the GWR will last up to 100 years within dry wall constructions without losing much of its strength due to possible corrosion.

The GWR technology should include the following:

- Instruction manual in its use and application and how to plan a building on a safe site.
- Manufacturing, delivery and installation of the C and L block-making equipment.
- Availability of the different widths of GWR in local shops, together with guidelines.
- Availability of 3 mm wire and cutting tools for making lintels and floor ties.
- Assembling instructions for complicated structural designs, such as for lintel constructions.

The use of stress reinforcement alone does not necessarily guarantee better earthquake-resistant housing; it is the combination of the stress reinforcement placed in the correct way and within good stone work. The GWR is not a magical addition, eliminating other precautions such as good masonry and anchoring of walls. Improved housing is a product of proper material use, workmanship and building site technology. The earthquake resistance of the building is only improved with a correct application of the GWR, including the framing of all wall sections.

The application of this technology will provide greater ability of a house to withstand earthquakes, increase personal safety of the occupants and allow for an additional storey when reinforcement is applied in all layers of the ground floor walls. With large earthquake impacts, the cross wires will hold the stones in two horizontal directions and absorb the impact. The coherence of the construction will be maintained with the framing of all wall sections, the tie beams and floor diaphragms.

The technology also greatly enhances the strength of adobe or rammed earth constructions. These rammed earth constructions exist in many countries regularly affected by earthquakes, such as Turkey, Afghanistan, Iraq, Iran, Pakistan, India, Nepal, Tibet, Mongolia and China, as well as in many Andean countries, such as Columbia, Ecuador, Peru and Bolivia.

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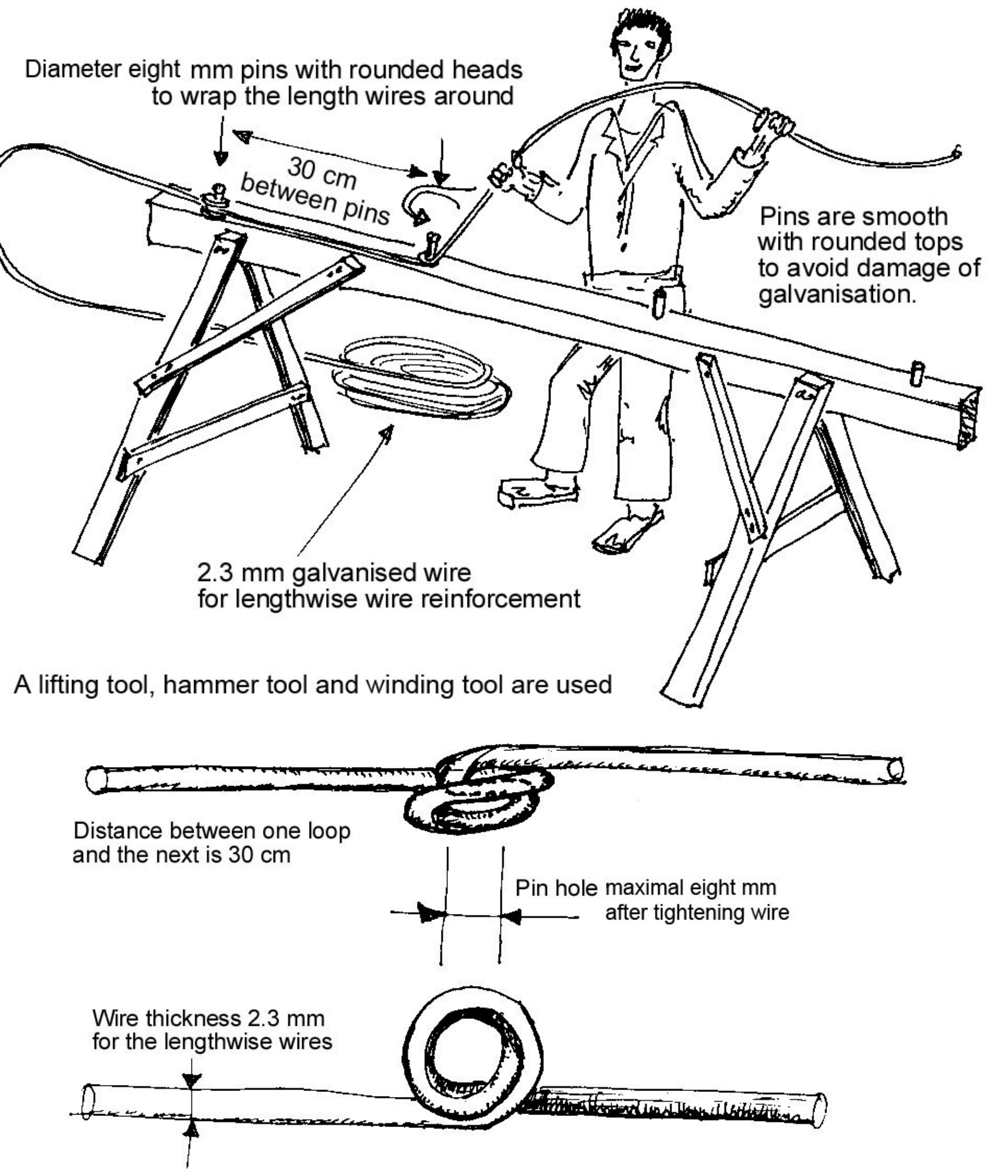
ANNEXE – HAND MAKING THE WIRE REINFORCEMENT

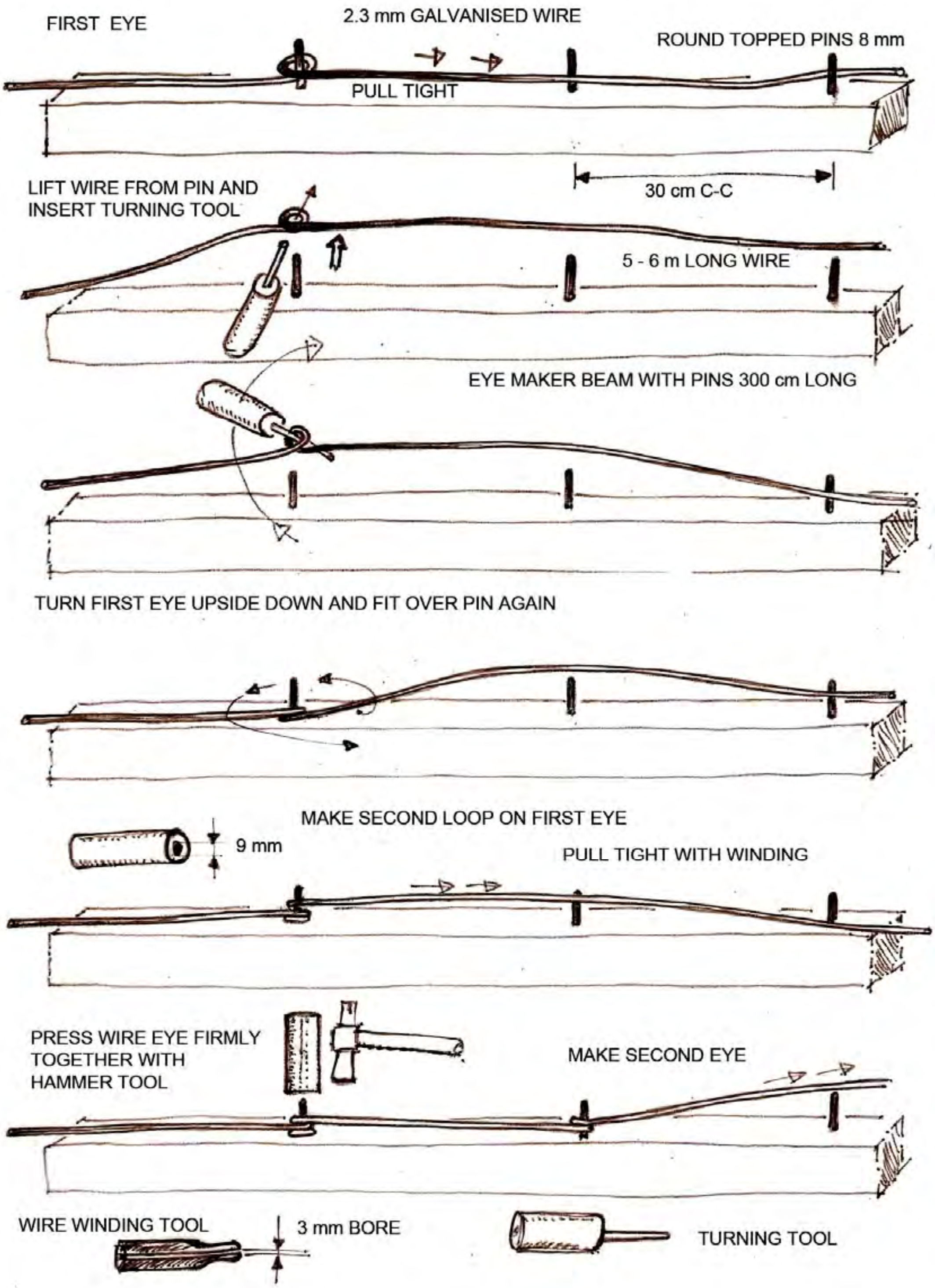
It is recommended that the GWR be factory welded and galvanised post welding. Rolls of GWR can be made available with the user manuals at the BACIP Resource Centres.

The GWR can also be hand manufactured according to the following description, ensuring that the eye is made in such a way that when a stretch force is applied on the wire, it cannot be pulled open, but tightens instead. Because of the over and under loop of the length wire, making the eyes requires the correct technique. Rolls of 5-6 m long wire-mesh can be made, corresponding to the most common lengths of the walls, including a connection/anchoring length for vertical or horizontal anchorage.



As an alternative to post-knotting stretching of the 5-6 m of newly made wire ladder, the open (remaining) space inside the eyes of the knot (the eye) can be filled with one or two hairpins of the same 2.3 mm GI wire. The ends of these hairpin wires are also wound around the main wire using a winding tool having a 3 mm hollow core and a rounded nose.

Making the length wires with the 8 mm eyes at every 30 cm interval can be done by hand using a beam with pins. After making and tightening the first eye, the wire is turned and a second loop is made and tightened. The double loop is pressed together with a hammer tool fitting over the pin.

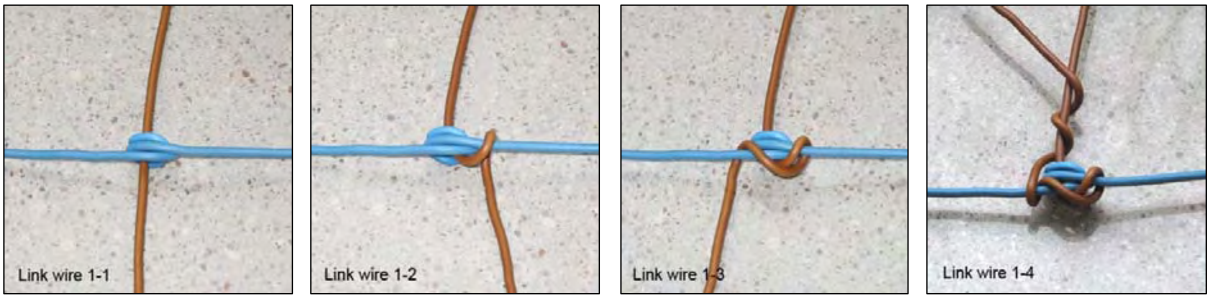


The length wires can be prepared in large quantities and in different length depending on the wall length of the construction, taking the anchoring length into consideration. The cross-link wires need to correspond with the width of the stone, adobe or cement block wall construction.

MAKING OF CROSS LINKS IN GWR

The making of the cross links at every 30 cm interval is shown below from three different angles. The horizontal wire (2.3 mm, blue) has the 8 mm diameter eye. The cross link wire comes from above (2.3 mm, brown). The cross-link wire sticks about 15 cm (6") through the main wire to make the connection.

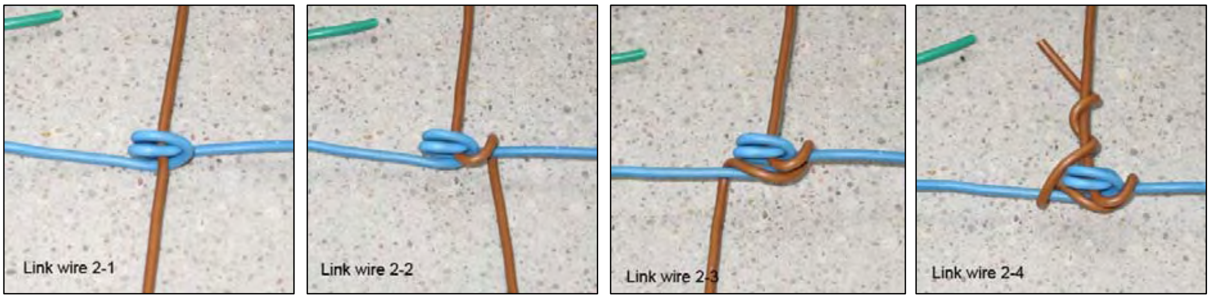
EXAMPLE A



The cross-link wire is first wound with a loop around one side of the main wire, then with a second full loop around the main wire again on the other side of the eye, and then again wound around itself.

EXAMPLE B

The same working method is applied, but now the eye in the main wire is shown from the other side.



First wind the link wire around one side of the main wire, then around the other side. This way the link wire cannot be pulled out of the main wire and develops a knot that can be masoned into the stone, cement block or adobe wall.

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ACKNOWLEDGEMENT

During the development of this technology in 1999-2001, Sjoerd Nienhuys was Technical and Programme Director of the Building and Construction Improvement Programme (BACIP). He was assisted by Ahmed Saeed Shaikh, Deputy Director, and Qayum Ali Shah, Manager Field Operations, who built his own house using this technology.

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