GALVANISED WIRE REINFORCEMENT (GWR) TECHNOLOGY

Earthquake Reinforcement for Non-Engineered Stone and Earth Constructions

Engineer Sjoerd Nienhuys
Jaffna, Sri Lanka
February 2006 (Update of July 2004)
Abstract

Galvanised Wire Reinforcement (GWR) can be used as earthquake reinforcement for non-engineered dressed and semi-dressed stone walls, adobe, soil block and rammed earth building constructions. In remote mountain areas masonry with cement mortar is only marginally done (or not done at all) due to the high cost of the cement, sand and aggregates. Traditional 18" (45cm) thick stone walls have a very loose internal structure horizontally (lengthwise and across) and vertically. While in the past hardwood tie-beams were used to provide bonding, durable wood has become scarce and expensive. The GWR provides reinforcement both lengthwise and crosswise within the wall thickness and vertically along the borders of all openings. L-shaped and C-shaped cement blocks provide space for the vertical reinforcement, facilitating construction and providing an aesthetic architectural design. GWR is simple to apply and low cost in material and transport. Several GWR strips can be used for lintel reinforcement. GWR with three length wires is used to make thermally insulating cavity walls.

Table of Contents

1. INTRODUCTION ................................................................................................................... 1
2. EARTHQUAKE REINFORCEMENT TECHNOLOGY ............................................................. 2
3. TRADITIONAL DRY STONE CONSTRUCTION ................................................................... 7
4. GALVANISED WIRE REINFORCEMENT ........................................................................... 12
5. GWR TECHNIQUE ................................................................................................................. 14
6. BUILDING A HOUSE ............................................................................................................ 17
7. CONSTRUCTION DETAILS .................................................................................................. 20
8. RESUME .............................................................................................................................. 27
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.

BACIP is a project of the Aga Khan Planning and Building Services, Pakistan. The programme was financed by PAK-SID, a collaborative venture between the Canadian International Development Aid (CIDA) and the Aga Khan Development Network. In addition, the cost of the Programme Director was financed by The Netherlands Directorate General for International Cooperation (DGIS).

Edited by: Doreen Nienhuys

Drawings, sketches and photographs by:
Mubarak Ahmed (BACIP) ~ sketches on pages 11, 21, 22a and 23.
Indian Earthquake Research Institute documents (1976) ~ sketches on pages 2-4.
Sjoerd Nienhuys ~ all other drawings, sketches and photographs

**********

Aga Khan Planning and Building Service, Pakistan (AKPBS,P)
300/2 Garden East, Behind Ismaili Garden Jamatkhana
Karachi 74550, Pakistan
akpbs@akpbs.org
bacip1@glt.comsats.net.pk
www.akdn.org

Sjoerd Nienhuys
Caritas-Hudec
14 Mathew’s Road, Deogu Street
Jaffna, Sri Lanka
smienhuys@sltnet.lk

**********

The views expressed in this report are those of the author and not necessarily shared by the Aga Khan Planning and Building Services, Pakistan. This report may be copied and/or reproduced, giving due acknowledgement to the author.
1. INTRODUCTION

Earthquakes and Remote Mountain Areas
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 by donkey trail. Bringing cement, long concrete reinforcement bars sand or aggregate is extremely difficult and expensive.

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 in remote mountain villages.

Non-Masoned Semi-Dressed Stone and Rammed Earth Construction
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. 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 double galvanised cattle fencing were used for rapid application. The openings in this wire-mesh ranged from 6cm to 20cm.

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 is laid from corner to corner. By doing so, a horizontal reinforcement is realized at 1 ft. vertical intervals, providing an even distribution of reinforcement throughout the walls. With the slimming of the walls, the wire-mesh is cut in narrower strips, keeping the length wires along the sides of the wall about one inch from the external face.

Plaster or Cavity Wall
A GWR strip can be made with three length wires. Two wires consist of the main wall reinforcement, while the third external wire is used to create a cavity wall. Cavity walls create thermal insulation whereby comfort is enhanced and firewood savings realised. Especially in the desert climates and high altitudes, such as on the Yemen plateau, Pakistan, North India, Nepal, Tibet, China and Mongolia, cavity walls are economically and thermally efficient.

---

1 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, or when the bonding is exceeded by an earthquake jolt. Stress resistance is traditionally obtained with wooden tie-beams laid in the walls. In modern building technology, iron reinforcement bars are applied by imbedding them in a layer of 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 code2. 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. Oenings 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 capacity3.

---

2 The American ACI 318 and the Indian Earthquake code are rather similar in their calculation methods.
3 Sketches on pages 2-4 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.

The combination of the above two principles of wall reinforcement requires that narrow wall sections need to be fully framed along their outside borders. With the use of L-shaped and C-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 or piers remain to form shear wall sections. For non-engineered constructions, the total section of piers in the lower floor walls should increase with the height of the building. 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 those buildings that are 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.
GROUND FLOOR

HORIZONTAL REINFORCEMENT ONLY
ROOF DIAPHRAGM

ONE STOREY

HORIZONTAL REINFORCEMENT
ROOF AND FLOOR DIAPHRAGMS
CORNERS OF BUILDING
WALL INTERSECTIONS

TWO STOREY

HORIZONTAL REINFORCEMENT
ROOF AND FLOOR DIAPHRAGMS
CORNER AND WALL INTERSECTIONS
FRAMING OF ALL PIERS

BASIC REINFORCEMENT PATTERNS
WITH MINIMUM WALL SECTIONS OF FACADES
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.
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.
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" (46-50cm) 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 and size. 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.

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.

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 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.

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.

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.

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 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 page 15).

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.
WARNING:

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 stronger.

The GWR in itself does not make the wall earthquake resistant. It is only in combination with good masonry and/or stone cutting that it greatly enhances the earthquake resistance.

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.

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, double 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-Produced Point-Welded
When the wire strips are factory point-welded, pre-manufactured rolls of 100-200m can be marketed in the same way as rolls of barbed wire. The cross wires should be thinner (2mm) than the length wires (2.5mm). The point-welding process needs to be carefully controlled so that the actual section of the length wire will not reduce to less than 2mm.

Double Galvanisation after Welding
The cross wires (2mm) are straight and stick 2 inches out from the length wires. After the welding process, the wire strip needs to be double galvanised conform the treatment for good quality barbed wire. The GWR can be rolled to facilitate transport (200m = 10 kg).

Requirement for a Core House
Minimal 400m (20 kg) is required for a 50-m² core house. Each layer in a 50-m² core house requires 50m length of GWR. An earthquake-resistant ground-floor-only house requires six layers of GWR: 2 x foundation, 1 x plinth, 1 x windowsill, 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).

On-Site Application
The GWR is unrolled on 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 sections of the GWR. 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. These cement blocks are placed in the wall corners and along the sides of door and window openings. The cement blocks have three 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. 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-shaped 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 2mm 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-shaped and L-shaped cement blocks.

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 3mm wire are attached to the GWR at short intervals. The 3mm 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 3mm 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 3mm 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 3mm 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 its 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**
For two-storey buildings, a slimming of the walls is recommended for the highest storey in order to reduce the weight. The top 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.

**Thermal Insulation**
For higher altitude mountain areas, thermal insulation of the houses is important for comfort and firewood saving. If this case, a three parallel wire GWR strip should be applied (see page 26).
7. CONSTRUCTION DETAILS

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.
FOLD THE ENDS OF THE GWR STRIPS UPWARD TO CREATE VERTICAL REINFORCEMENT
WHEN 10MM 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 3mm 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.

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 thermal insulation material to increase its insulation property.

Over the plastic foil (3), a ½" 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 and stones.

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 3mm 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.

The application of this technology will allow a first or second storey, provide greater ability to withstand earthquakes and increased personal safety of the occupants. With large earthquake impacts, the cross wires 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.

**********************************