"GABION BANDS": A Proposed Technology for Reconstructing Rural Rubble Stone Houses after the 2015 Nepal Earthquakes

By Randolph Langenbach,   27 August, 2015, updated 10 September, 2015
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Introduction: This idea for the use of galvanized welded wire mesh was conceived of in response to the April 25th Gorkha, Nepal Earthquake. The idea came to my mind and was first published only three weeks after the earthquake in response to the news reports and images showing what had proven to be an extremely vulnerable traditional form of masonry construction in rural Nepal. It is based on research on the history and effectiveness of the use of timber lacing in bearing-wall masonry construction in Kashmir and other parts of the world. These systems have repeatedly proven to be effective in reducing the risk of collapse in both historical and recent earthquakes.

Destroyed rubble stone houses. (web)

It is a type of construction which is already widely accepted in South Asia, and is in both the Indian and the Nepal Building Codes. The concept of using wire instead of timber is the result of unique circumstances in post-earthquake Nepal that have demanded alternatives to timber. I have given the term "Gabion Band" to this technology to refer to the common use of what are called 'gabion baskets' for retaining walls, and the use of the term "band" which is common in Nepal as a synonym for "ring beam."

Destroyed house in Gorkha District. (web)

By unique circumstance, this concept was refined and demonstrated in the construction of a house in the hillside village of Mankhu, in Dhading District. This opportunity to demonstrate the system came when the proposal came to the attention of Liesl Clark of Skydoor Films who was making a science documentary film for the WGBH TV program NOVA. The Gabion Band concept, and this very first house incorporating it in rural Nepal, is described below.

Collapsed house showing horizontally bedded rubble stone construction in Gorkha District. (web)

The Problem: Large numbers of the traditional stone houses in the rural areas of the earthquake damage districts in Nepal were heavily damaged or collapsed to the ground in the earthquakes. Sometimes whole villages were leveled. The construction generally is of a mixture of rubble stone and partially dressed stones. Some of what looks like a river rock rubble (meaning rounded from erosion by water flow), which is particularly vulnerable to collapse in earthquakes, has been used. While the roofs originally may have been covered with slate, now most of the roofs are of corrugated galvanized steel (CGI) sheets.

The most pressing question now presented after the devastation left by the earthquake, and the homelessness of a large part of the population, is what to do to 'build back safer" while still respecting the existing knowledge and skills of the local population to rebuild their houses themselves. In many of these areas, which are located remote from good road access, the only feasible forms of construction must use the locally available materials – mostly from the collapsed structures themselves. The problem therefore is most importantly how can we adapt the existing construction traditions, rather than import new systems, whether of reinforced concrete or of steel, or other manufactured and imported materials and systems.

Photos by Prem K. Khatry of school construction in Gorkha district.

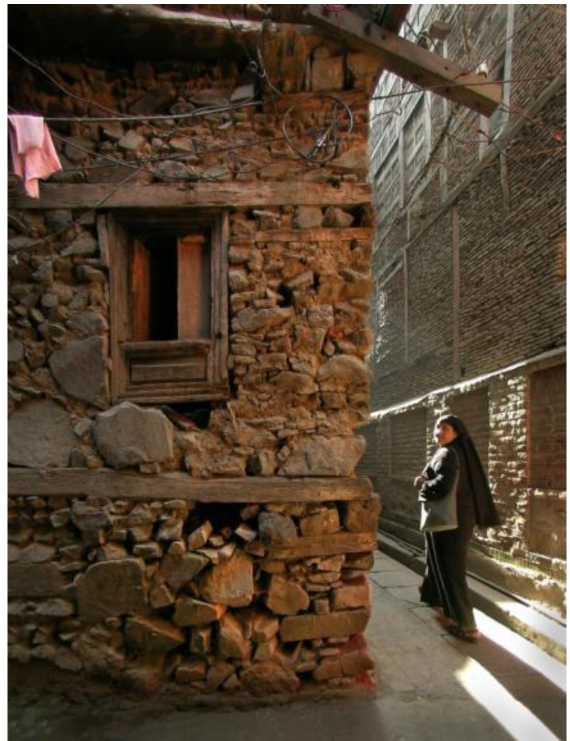
Thus people must be able to build their own houses out of the local stone, mud, and timber – with the stone and timber most likely coming from the ruins of their pre-earthquake home. Moreover, while trees do grow in these rural areas, sawn timber – particularly of construction quality heartwood – is in short supply, expensive, and often not available in long lengths.

The school shown being constructed in photos by Prem K. Khatry shown in the photo on the right is being done with a degree of masonry expertise, and that the walls consist of flat stones that are roughly dressed (the term "dressed" in stone masonry means tooled and shaped so that the stone can be properly bedded in horizontal layers or 'courses'). The mortar is clay without added lime (and thankfully, no Portland cement). The walls appear to have rubble cores between the inside leaf and outside leaf, each of which are one stone thick). Almost all of these rural rubble stone houses completely lack bond courses, as such would result in walls which are not smooth. The roofs are constructed with rafters resting on the walls and a ridge beam that is often not well attached to the stone gables at either end.

A Proposed Solution: Before arriving in Nepal, a communication from a colleague in Australia, Catherine Forbes, brought to my attention two items: (1) Fencing wire is available in these mountain villages, and (2) Gabion confined rock is frequently used for retaining walls along roads, etc. This information has lead to the proposal of a solution that may be remarkably, even deceptively, simple, inexpensive, and not requiring either heavy manufactured materials or sophisticated engineering or construction training, all of which fit with the guiding philosophy behind the seeking of a solution to the problem of safe construction in rural Nepal, where resources are limited, and access to many sites is only on foot.

Photos from web of gabion basket retaining wall (above). The photo below shows how inconspicuous the wires can be if the basketing is of only a single layer of stone.

The "Gabion Bands" concept consists of the installation of a single course of stone wrapped in galvanized welded wire mesh at designated points in the vertical height of the wall. Stainless steel would be even better for longevity, but practicality demands that the wire be galvanized. (The wire mesh for the gabion bands is best if it is a straight wire, not the diagonal woven wire often seen used for gabion retaining walls in Nepal.) If durable wire is not easily obtained, an alternative material that may even last longer and be equally effective (but which may require more NGO work to set up a distribution network) is polypropylene geogrids – the kind of product used for earth stabilization in road building, etc. This has been used for the banding of stone buildings in China as reported in the EERI World Housing Encyclopedia tutorial on Stone Masonry construction (http://www.world-housing.net/tutorials).


Historic house in Sringar, Kashmir showing timber bands in rubble stone construction. (Photo by author)

The basic objective is to turn these individual stone courses into bands (ring beams). These bands would be overlapped and strongly connected in the corners, and would extend around the building, and be placed in any stone masonry interior cross-walls as well. In effect, each of these ring beams is like a long thin gabion basket which runs continuously without a break around the entire dwelling. Within each floor of the dwelling, there would be a band above the foundation at the base of the walls, below the floor level of the ground floor. About one meter up from that would be a band at the window sill level. This band is the only one that will not be continuous, as it must be interrupted by the doorways. Above that, is a band just above the window lintels, and then at the level of the 2nd story (or at the roof level for one story houses), there is a band just below the roof structure or above and below the joists which hold the attic floor. If the house is two stories, then the joists for the 2nd story, and the attic floor, are sandwiched between bands.


A 19th century timber-laced rubble stone fort in Northern Pakistan near epicenter of 2005 earthquake that killed 89,000 people. It survived with very little damage despite having been abandoned and unmaintained for half a century! (Photo by author)

The common Nepali stone houses have double-pitched roofs with gables, so it is recommended as part of this system that an attic floor be installed so that the top of the masonry walls are connected to an effective floor diaphragm. Also, above that level, a short continuation of the stone wall, capped by another band, is recommended under the roof so that the masonry walls of the house have sufficient overburden weight to make for an effective resistant connection with the attic floor diaphragm. The joists and beams which hold the floors should penetrate through both leafs of masonry preferably with the traditional pegged connection to the front porch and with pegged connections to the gabion band above and below the timbers.

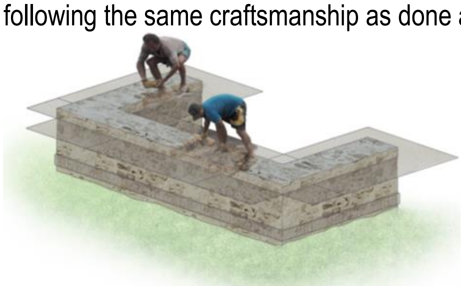
The Construction Sequence: One may think that the proposed system will be complicated to build and require extensive training, but in the demonstration house in Mankhu, it proved to be quite simple and fast. The only material that was added to what otherwise was traditional masonry construction was the wire mesh. The only tools that were needed were pairs of pliers which could also snip the wire, and a hammer to help shape it around the stones.

The process proceeded as follows:

(1) At the level of a band, one would simply unroll the fencing wire along the partially completed stone wall, overlapping it if the role runs out and pieces must be joined together.

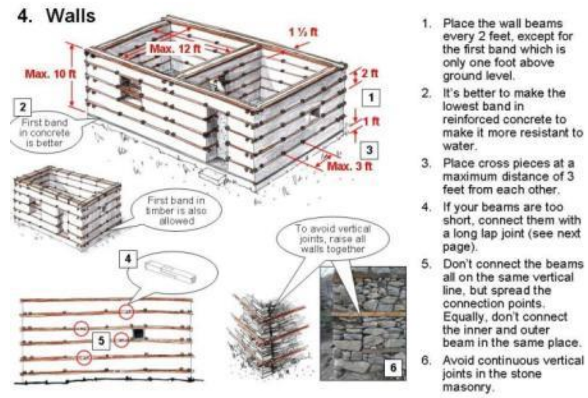
(2) Trim the ends of the wire so that the sides and ends can be wrapped over the next single course of stone with the corners interlocked.

(3) Add one more course (single layer) of stone masonry in mud mortar following the same craftsmanship as done already.

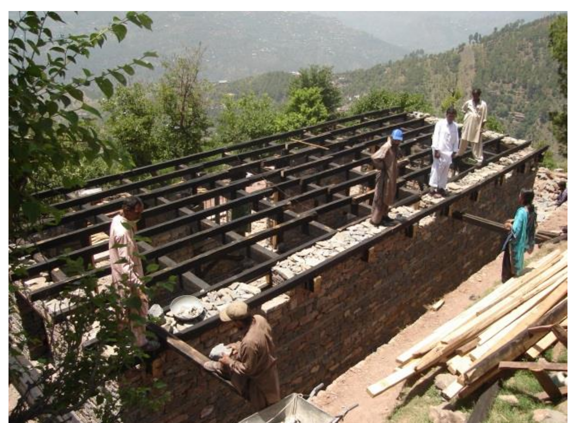


(4) Bend the wire up and over this new layer of masonry, so that that one course of stone is inside a tube of wire tightly drawn and wired together.

(5) Then, carry on until the next band with the stone masonry work. At the roof or 2nd story floor level, be sure to secure the floor beams and joists to the band.



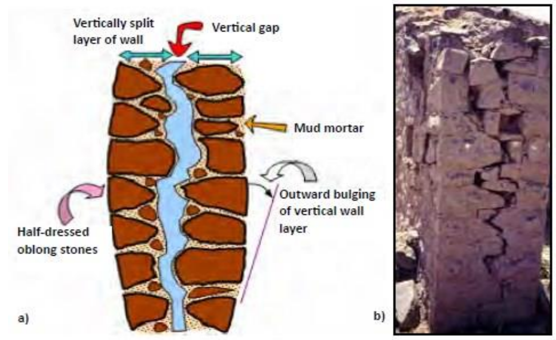
Page from manual for timber-laced construction produced for the Government of Pakistan after 2005 earthquake for when they approved this timber-laced construction for new buildings. The gabion bands proposed here are intended to work the same way. (Manual by Tom Schacher of SDC)



Examples of new building being constructed with timber bands in Pakistan after the 2005 earthquake. The gabion bands proposed here would lay into the wall and overlap in a similar way, as well as secure the wall to the floor diaphragm as seen in the bottom view. (Photos by Tom Schacher (top) & Jean Schmidt for CRAterre (bottom))

The advantages of this system: There are a number of advantages of this proposed system over alternatives, such as the jacketing of the whole building with wire mesh.

(1) The jacketing is designed to improve existing buildings, while this is designed to be integrated into the construction of new buildings.
(2) The Gabion Bands require less training and skill to be installed.
(3) If the 'gabion' bands are done with wire fencing that has a reasonably open pattern, the bands will be inconspicuous, and the overall appearance of the dwelling will be as before, but they will still be visible enough to demonstrate to the owners and their guests that the building is seismically safe. Also, if there is breakage or deterioration of the band, it will be visible, and can be addressed as a maintenance item.
(4) The stone masonry gabion bands are flexible, and of the same nature as the material into which they are place – such that there is material compatibility – something which cannot be said of reinforced concrete ring beams.



This illustration is from **A Tutorial: Improving the Seismic Performance of Stone Masonry Buildings**, by Jitendra Bothara and Svetlana Brezv, published by EERI, 2011. Available as a free PDF on the web at http://www.world-housing.net/. It explains one of the principle vulnerabilities suffered by typical mud mortared rubble stone construction in Nepal. The uneven stone laid without bond courses is subject to rapid collapse from high frequency earthquake vibrations. This happens in particular because the smaller stones and mud in the center of the wall compresses which causes the outer leafs to separate and collapse. (Co-author Jitendra Bothara, SE, is from Nepal.)

One point needs to be reiterated. If one thinks that because the stone gabion band is good, then a reinforced concrete band must be better, there is substantial earthquake experience now to indicate that this is not true. In the 70's and 80's, reinforced concrete ring beams in stone buildings – particularly in Italy – were accepted practice – but subsequent earthquakes have repeatedly proven that this was a bad idea. Because of their rigidity, when an earthquake caused the stone wall above and below to vibrate and undulate, the rigid band separated from the stones and even sometimes walked out of the structure, carrying away everything that was above it.

The gabion stone bands will move with the wall as it undulates and vibrates, and if some stones below should come loose and fall, it serves to stop the progress of the cracks. It can also bend and thus remain bearing upon the stonework of the remaining wall, which is essential to damp out the vibrations and keep the masonry under compression so as to resist the lateral forces and high frequency vibrations of the earthquake.

And finally, in response to an email from Catherine Forbes saying "*An engineer here has proposed concrete bands*" shaped and moulded to the stones above and below, asking if that may "*resolve some of the issues you raise in your report with the use of concrete bands?"* My response is that this "gabion" proposal is built on a fundamental philosophical point that construction in this part of the world <u>must</u> be based on the use of the local materials of recycled stone and timber with newly dug local mud from the site itself, with nothing added that cannot be hand carried to the site or loaded onto a pack animal. A cement concrete ring beam cannot be said to conform to this criteria in any respect.

In fact, it is instructive to ask oneself if it is practical to carry the bag you see in my attached picture on the top of one's head – up a steep slope, and over a dirt path which is sometimes many kilometers long – and then go back for another one. Follow that with the bags of sand and aggregate. Only then can you mix concrete at the site. Ask the same question about the rebar – which as you see in the next picture in this yard is not even deformed bar. Then when one gets all this to the site, can you really rely on the local people knowing what to do with it properly?

The third picture is of a man carrying one of our purchased rolls of wire – a 50 foot length. It took about 2.5 rolls of this to do the house you see in my report. The tools to cut and bend it could be carried in a fanny pack.

Mankhu Demonstration House: As mentioned, this opportunity to demonstrate this proposed earthquake hazard mitigation strategy for rubble stone rural houses was sponsored by the filmmakers for a PBS (WGBH) NOVA documentary on the Nepal earthquake. The village identified as a site for this demonstration house was the village of Mankhu in Dhading District – high on the mountain side of what here are identified as the foothills of the Himalayan Mountains.

A family cluster of homes was found at the village where all the houses at the site had collapsed and one structure with its foundations intact, but which could be quickly prepared for a one-story one room demonstration home was found and the family was willing for it to be used – and as it turned out excited to be able to get this home rebuilt for the young sister and brother who had lived in it before it had collapsed.

The photographs on the right show the progress of the project from the initial demolition of the ruins to a common height, and the reconstruction of the house with the welded wire-mesh bands (ring beams). Below you can see the laying out and cutting of the wire mesh to size, and then in the 3rd, 4th, and 5th pictures on the right, the laying out and wrapping of the bands is visible. The corners are interlocked by wrapping the ends of the two bands back onto themselves such as both bands form a single ring around the corners of the structure.

The wrapped band can be seen in the picture below. When the house is completed, this wire band can be plastered with mud plaster. In the photograph below that, the family and team of masons from the community is shown who built the house, which was completed as a shell in just 4 days. The roof is shown as it was placed only temporarily on the structure during the documentary filming, but the intention is to install it permanently on timber rafters, and perhaps in the future to add a second story.

In addition to the installation of the bands, the wire mesh was used to fabricate a beam with stones inside so to span the corner to support a simple chimney, and so to address the usual problem found in many houses where the kitchen stove is an open fire filling the kitchen with smoke.

The photo on the left shows the Sunar family members and the masons from the community who constructed the house. The young man in the center with the brown shirt is Ram Sunar, who will live in the house.

As the walls of the house neared completion, the heavens marked this remarkable project at the moment with a rainbow.

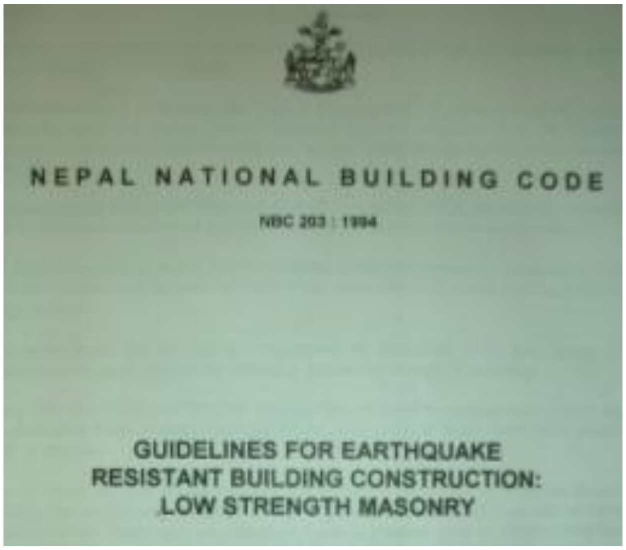
Acknowledgements: This house building project was carried out from 16 to 19 August, 2015. The owner / occupant of the house is Ram Sunar, and we thank the Sunar family for the opportunity to undertake and film this project at their family property. Also they and their neighbors who were the masons for the project are to be credited with the construction of the house, with guidance only on the fabrication of the bands and some other details such as the chimney. Randolph Langenbach was assisted on the site by two volunteers from Nepal with background in environmental science and engineering: Dipendra Gautam and Lakpa Sherpa of Kathmandu, so thanks go also to them for their generous time, effort and guidance.

Thanks also go to Scott MacLennan and Her Farm who arranged for and gave us housing and meals over the course of the project.

Of course credit for the filmmaking project that made this house building project possible goes to Leisl Clark of Skydoor Films and to WGBH, Boston, Massachusetts, USA for the production of the science documentary for the TV show NOVA.

The house shell shown here was built in 4 days. The roof shown is only placed on it temporarily – as the wood framing for the permanent roof is still to be installed. The family also plans to rebuild the 2nd room onto the foundations that are visible to the right.

The cost of the wire consumed in the construction of this one room structure was approximately 15,000 NPR (about $150 USD)


NEPAL NATIONAL BUILDING CODE

NBC 203 : 1994

GUIDELINES FOR EARTHQUAKE
RESISTANT BUILDING CONSTRUCTION:
LOW STRENGTH MASONRY

The Nepal National Building Codes 202+203+204 for Bearing-Wall Masonry, Low Strength Masonry and for Earthen Construction all feature bands either of timber, bamboo or steel for seismic resistance.