STONE MASONRY IN CLAY MORTAR with GABION BANDS

GABION BANDS

An Alternative to timber bands for Rural Stone Masonry in Mud Mortar (SMM)
Conservationtech Consulting: www.conservationtech.com
Nepal page: www.traditional-is-modern.net/Nepal.html

Information provided by Randolph Langenbach in reply to the request by the DUDBC by emails from Dipendra Aryal, Civil Engineer, and Raju Neupane, Senior Divisional Engineer Dated 27 November 2016.

1. Base Shear Calculations for Stone Masonry with Mud Mortar

In order to respond to your request for calculations, we have undertaken the following simple computation to arrive at a typical base shear for a Stone Masonry with Mud Mortar (SMM) building, before analyzing the benefits of the addition of Gabion Bands or ring beams of any other material, including reinforced concrete (RC) or timber. Considering a masonry wall height of 9'-0" including the parapet wall with a thickness of 1.5', the PLF (pound per linear foot) resistance of the unreinforced stone masonry segment at the base of the structure would be:

For a code based working stress shear capacity of "Natural Stone Masonry", a value of 4 psi (lbs. per square inch) can be found in the 1982 (USA) Uniform Building Code. A calculation of the shear force (V) pounds per lineal foot can be arrived at:

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1) (Working stress shear capacity of "Natural Stone Masonry"(4 psi) * (Width of wall (1.5 ft) * (144 sq.inches per foot) - / - (divided) Shear equation constant (1.5) = **576 PLF (Pounds per Lineal Foot)**

2) Then, to account for friction between the stones, a conservative coefficient of friction for clay mortar against stone masonry = μ =0.25 of weight of the stones, thus:

   - Weight of the Wall = 150 Pounds per Cubic Foot * wall thickness of 1.5 FT * (Wall Height of 9 FT) = **2025 LBS weight of wall** (disregarding window openings) based on height of 9 height.

   - Weight of wall of 2025 lbs * 0.25 μ Coefficient of friction= **506.25 PLF**

3) **TOTAL LATERAL LOAD RESISTANCE:** = 576 PLF +506 PLF = **1082 PLF**

Per **NBC 108: 1994** Site Considerations for Seismic Hazards all site selections for this structure must be:

- A minimum of 500m from the surface trace of a known fault;
- Not located in the plains of eastern Terai due to the liquefaction potential;
- Located within the guidelines of figure 3.2 to protect against landslide dangers;
- Located appropriately to avoid damage caused by flooding.

NBC 105: 1994 - Seismic Design of Buildings In Nepal

Seismic Loads:

	Wall Span:	Long		Short
	H	2.4384	m	2.4384
	D'	9.7536	m	6.7056
Section 7.3:	T1	0.070269		0.084748
Figure 8.2:	Z	1.1		
Table 8.1:	I	1		
Figure 8.1:	C	0.08		0.08
Table 8.2:	K	4		
Section 8.1.1:	Cd=	0.352		0.352
Section 10.1:	V=	Cd x Wt		

4) Seismic load from wall weight contribution only, per linear foot of wall:
   0.352 * 2025 LBS = **713 PLF**

5) Taking the Total Lateral Load Resistance (3), and subtracting the Total Seismic Load (4)
   1082 PLF – 713 PLF = **369 PLF**

Therefore, one would observe that there is 369 PLF to accommodate loads directed from elsewhere in the structure to the primary shear walls.

The evidence from the destruction of large numbers of rural SMM houses in the 2015 earthquakes would support a finding that even with conservative numbers in this calculation to show the lateral load resistance of SMM without any anti-seismic resilience measures, the resilience of some of these structures was probably lower than even these calculations indicate.

The evidence from these earthquakes points to two important reasons for this effect: First, very few of the rubble stone walls in the rural houses were bonded with stones that crossed through the wall to tie the inside and outside layers of masonry together. Worsening the risk, the collar joint between the outside and inside layers was very often filled with smaller stones, gravel, and an excess of mud mortar.

Second, the gable end walls of the houses were not tied to the floor(s) and the ties of the joists resting on the sidewalls of the structures did not extend through the walls to adequately tie the walls together for the floors to work as diaphragms. In many villages, there were examples of SMM houses which did remain standing with varying amounts of damage that show that better quality stone masonry work, together with stronger connections between the floors and walls, does appear to have been critical for their survival.

If Bands been included in the construction of these buildings, there is much evidence not only from the earthquakes in Nepal that such massive collapses would have been avoided, but also from earthquakes in Turkey in 1999 and in 2000, in Gujarat, India in 2001, and in the 2005 Kashmir earthquake in both India and Pakistan. In fact, some rural houses in Nepal were constructed with timber bands. In one case in Mankhu, in a recent interview of the 85 year old grandfather who constructed it, he said this resulted from post-earthquake recommendations after the earthquake of 1934. That house survived the 2015 earthquake with very little damage.

2. Contribution of the GABION BANDS to the Seismic Resilience of the Stone Masonry with Mud Mortar (SMM) buildings

To provide a meaningful Building Code related calculation specific to the use of Gabion Bands, one has to know what, if any, calculations were used in the existing Nepal Building Codes for the bands which are currently specified in the *"…Rules of Thumb…"* for SMM construction. The Gabion Bands are a change only in the material to be used for the bands from that shown in the Code, but they do not represent a significant modification of the seismic function or performance of the bands in SMM construction. Just as with the timber bands, they (1) provide a tensile reinforcement of the walls, (2) a tie between the walls at the corners that is even stronger than that provided by timber bands, and (3) a bond between the inside and outside layer of the stone masonry walls themselves, which are otherwise often are totally lacking in bond courses or bond stones.

To learn if such calculations exist, it is best to turn to the principle international firm responsible for the <u>Nepal Building Codes</u> related to structure and seismic resistance was the firm of BECA International Consultants Ltd., in Wellington, New Zealand. The "Team Leader" for many of these codes, including NBC the code that is most relevant to SMM construction, <u>NBC #202: Mandatory Rules of Thumb for Load Bearing Masonry</u> is Engineer Richard Sharpe of BECA.

Richard Sharpe, in a 25 November 2016 reply to the question about calculations, has said that:

> *"…our draft NBC work did not try to quantify the good-practice recommendations for informal structures. That applies also to the recommended "horizontal ladder" bands so commonly promoted. We all know intuitively and by experience that these concepts improve significantly seismic resilience if they are constructed reasonably in*

compliance with the concepts." He goes on to say: *"In my view, it would be inappropriate to insist on explicit calculations to justify these concepts being endorsed by a government authority… I still endorse the idea of gabion bands being an instinctively beneficial form of seismic resilience."*

Another citation that is relevant to the issue of calculations is a report by Earthquake Engineer for UN-HABITAT Dominic Dowling, PhD, on the Pakistani ***"Bhatar"*** structural system which uses bands of timber, similar to that which is already recognized by the Nepal Building Code. His observation under the heading of "*Structural Calculations"*, dated June 2007, is:

> *"Because of the inherent variability and complexity of the individual materials, component interactions and forms of construction, it is not possible to accurately calculate or model the structural behavior of the bhatar system. As the* bhatar *system relies on structural stability and energy dissipation rather than strength characteristics, standard calculation techniques appropriate for dynamic analysis of engineered structures have limited validity when applied to bhatar construction. Of greater value is the vast amount of empirical data available from post-earthquake reconnaissance, and historic evidence.*
>
> This quote can be found on page 50 of the Appendix 1 of the Second Submittal to the DUDBC of Gabion Bands.

Engineer Dominic Dowling goes on to say: *"The combination of dry-stacked stone masonry and timber bhatar bands provides strong resistance to seismic forces. Key structural characteristics include:*

1. *Resistance to out-of-plane bending (about the vertical axis) is provided by the horizontal timber elements (strong tensile capacity), which are embedded in the wall. In this sense, the bhatar bands provide a similar structural function as reinforced concrete beams/bands in reinforced or confined masonry.*
2. *Resistance to out-of-plane bending and overturning (about the horizontal axis) is provided by the inherent stability of the walls (with a height-thickness ratio commonly ranging from 4 to 6)* [The Gabion Band construction is about 4.5 on average.].
3. *Resistance to in-plane and out-of-plane shear forces is provided by the inherently high friction in the system, again a feature of the width, weight and configuration of the walls (described below).*
4. *Resistance to vertical corner cracking (the most common and critical damage pattern in unreinforced masonry walls) is provided by the interconnected bhatar bands at the corners, which ensure a strong connection between orthogonal walls.*
5. *Resistance to delamination of the masonry walls (another common damage pattern in two wythe unreinforced masonry walls) is provided by the bhatar bands, plus inclusion of through-stones, which serve to tie together both wythes of the stone masonry.*
6. *Resistance to cyclic loading is provided by the timber elements (which possess excellent tensile and elastic characteristics), and the friction within the stone masonry.*

In Pakistan, durable timber was more available and affordable for reconstructions after the 2005 Kashmir earthquake than in many rural areas in Nepal after the 2015 earthquakes. This list of attributes of timber bands applies almost completely also to that for Gabion Bands. In the case of #1 above, timber would allow for less bending than Gabion Bands, but if tightly wrapped around a single stone course, the Gabion Bands is almost as stiff. This was demonstrated when the same technology was used to make a beam to hold up a hearth for a smoke hood over kitchen stove in the house constructed in Mankhu shown in the DUDBC submittals. All the other points apply equally to Gabion Bands. The points about the value of friction to the earthquake resistance are especially pertinent, as the Gabion Bands will allow the stones to move but stay together, unlike reinforced concrete bands, which have shown a tendency in the earthquakes to bridge over sections of the walls that have fallen out from beneath them, as seen in the photo below. The Gabion Bands will more likely remain bearing onto the courses below, which then is more likely to hold the stones in place.

School building in Banakhu, Kavre District showing stone fallen out from beneath RC band. The building was destroyed, and subsequently demolished. *Photo by: Jeet Bahadur, Banakhu*

It is also important to note that the process of installing the bands results in a good number of extra cut off pieces of the geo-mesh material, all of which can be installed into the wall under courses of stone in between the bands, just as shown in NBC 203: Low Strength Masonry on Page 47, Figure 10.8(d). Such reinforcement will further make up for the lack of through bond stones, and add to the energy dissipation produced by friction between the stones.

The example of Pakistan is particularly relevant to Nepal, because the earthquake there in 2005 caused ten times the number of fatalities as those in Nepal in 2015, and most of these fatalities were in buildings with a combination of stone and reinforced concrete. After two years of an effort by the Pakistan government to promote reinforced concrete construction in rural areas where the materials could not be obtained or carried in, the rubble stone with timber bands *bhatar* construction was approved. Since that date, UN-HABITAT has estimated that as many as 100,000 new houses have been constructed using this traditional technology.

3. Lintel Band Bending Strength Issue

To answer the query about the *"Load calculation above lintel, so that the strength of Lintel can bear the applied load – Checking means for bending of lintel band"* there appears to be confusion about where the Gabion Bands are intended to be placed. Unlike timber bands, they are not designed or intended to replace the wooden framework of the windows or the doors, but rather, will be located above and below that framework. The lintel band thus does not span the window and door openings without support. It is designed to sit on the lintels of the door and windows themselves. I have seen much evidence that tightly wrapped bands can span openings with little sagging, but that is not their purpose when placed in the stone walls of the buildings. The wooden framework of the windows and doors is intended to completely serve that purpose.

It is also important to note that the lintel band is never intended to be at the top of the wall. It is followed by more stonework, with additional bands below and above the joists which hold the attic floor for houses of one story plus and attic. The very top of the wall must extend up above the floor of the attic before it meets the roof (not unlike as shown on page 12 of the original Submittal (available at www.traditional-is-modern.net/nepal.html). This is important, as the safety and resilience of the banded masonry construction depends on enough overburden weight above the joists to make the attic floor work well as a diaphragm.

4. The Importance of the Non-Engineered building provisions of the Nepal Building Code

Dr. Amod Dixit, the Executive Director / Chief of Party (COP), Program for Enhancement of Emergency Response (PEER) / National Society for Earthquake Technology - Nepal (NSET) presented a paper at the 6th International Disaster and Risk Conference IDRC Davos 2016 in which he says:

> *"Developed in 1994, the Nepal Building Code (NBC) addresses the full range of locally prevalent construction types, including non-engineered indigenous structures. Most buildings in Nepal are built by owner-builders or local tradesmen…In the absence of basic regulatory capacity, the Nepalese code development team chose to set realistic objectives for the design of technical standards and guidance materials. For simple, small-scale construction, the code proposed technical guidance as "rules of thumb," assuming that simple but essential structural details could be checked by non-specialist staff of municipal building departments."*

In his cover letter, Dr. Dixit says that *"Currently, about 80% all buildings being built in the urban and urbanizing areas of Nepal belong to the category of* "Mandatory Rules of Thumb" *or the* "pre-engineering approach"*. Thanks to such differential approach, the process of improving seismic performance of buildings by the process of* "Building Code Implementation" *has been conspicuously successful in Nepal."*

The Gabion Bands technology is fully intended to contribute to the improvement of the safety of rural construction, especially where road access is limited or non-existent, and thus where the <u>only</u> option that the home owner-builders can avail themselves of to provide a measure of safety in the event of another earthquake must be something that can be carried on their backs, as is possible with the wire or polypropylene geo-mesh. Gabion Bands may be the one technology that can serve that need.