

# STONE MASONRY IN CLAY MORTAR with GABION BANDS

## GABION BANDS

Alternative to timber bands for masonry in mud mortar

A report submitted to the Nepal DUDBC by Randolph Langenbach,  
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Information provided by Randolph Langenbach in reply to the request by the DUDBC by emails from Pratik Pradhan & Ganesh Karmacharya dated 20 & 29 February respectively.



### INTRODUCTION

As explained in the original submittal, this is a proposal for the use of a particular construction technology, rather than the architectural or engineering design of a specific structure. The concept is guided by the need in Nepal - as well as in many other countries subject to earthquakes - to improve the safety of owner-built, non-engineered construction of rubble stone masonry structures laid with mud mortar. The 2015 earthquakes in Nepal demonstrated both the particular vulnerability of this kind of construction and its widespread use within the damage district, such that entire villages were sometimes flattened by the tremors. It is also common in rural areas throughout the rest of the country.

The effort to develop this particular technology and to seek its recognition by the DUDBC is guided by the underlying philosophy that for earthquake risk reduction to be successful, there must be public access to legally approved construction systems that are (1) easily understood by the non-engineering trained public, (2) based on traditional practices that can be easily taught to itinerant local masons and even owner-builders, and (3) not dependent on following complex construction procedures or mathematical calculations. In the earthquake areas of the United States and Canada this philosophical guideline is met by the simple fact that almost all small and even medium scale residential buildings – up to 6 stories in some areas – are constructed of stud-frame timber. Such timber construction has demonstrated resilience in earthquakes even when not engineered and of mediocre or poor quality construction. In much of the rest of the globe, where wood is not so plentiful, reinforced concrete construction has displaced traditional timber and masonry systems and has thus come to be understood as “modern” and erroneously perceived to be earthquake resistant, even when not engineered or constructed correctly.

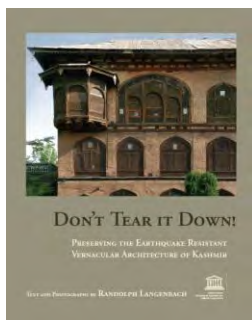
The Nepal Building Code (sections NBC 202 & 203), as well as Volume 1 of the DUDBC “Design Catalogue,” recognize the need in Nepal to accept and regulate the construction of houses built of masonry laid in mud mortar. Prior to the development of the Nepal Codes, India laid the groundwork for a code that recognizes non-engineered masonry construction, with the adoption in 1993 the Indian Standard (IS) 13828: “Improving Earthquake Resistance of Low Strength Masonry Buildings—Guidelines.” All of these are very important and worthwhile documents because they recognize and regulate what in most countries of the world is viewed as archaic forms of construction which would be illegal for new buildings.

As will be explained below, the **Gabion Bands** proposal is closely tied to the horizontal bands already recognized in all of these codes for seismic hazard reduction. The sections that follow are from the 20 February 2016 DUDBC request for more information.

### 1. Specifications:

The proposed Gabion Bands technology is best parsed into two parts for this discussion. First is the question of the effectiveness of horizontal bands as a collapse prevention system for masonry construction. Second is the question of whether the use of welded wire mesh or polypropylene geogrid can form a substitute for the use of timber or reinforced concrete for this purpose.

**Question (1)** Regarding the first question, as already noted the use of horizontal bands (ring beams) in both rubble stone and brick masonry is recognized in the Nepal Building Code. This comes from modern-day recognition of the effectiveness of horizontal reinforcement dating back more than two millennia, with evidence of timber bands found in Knossos, Greece, and the archeological site of the Minoan settlement of Thera, on the island of Santorini, Greece. This use extends through Ancient Rome and later construction. It has continued up to the present in Turkey and in the Himalayan regions in Kashmir and other parts of India, and also can be found in certain buildings in Nepal.



Their effectiveness in the 2015 Nepal earthquake can probably best be demonstrated by the survival in better condition of the 18<sup>th</sup> century portions of the Hanuman Dhoka Palace in Kathmandu when compared with the white 19<sup>th</sup> and 20<sup>th</sup> century wings which either lacked them, or, as found in one wing, they had rotted out because they were buried within the wall rather than visible on the surface where they could be inspected. An important feature of the 18<sup>th</sup> century wings was that the timber crosspieces that passed through the walls and extended out to the open air, so that their vulnerable end grain was not buried and thus subject to rot.

**See APPENDIX 1:** My research on the heritage of this construction system in Kashmir has been published in 2009 by UNESCO in the book ***Don't Tear It Down! Preserving the Earthquake Resistant Vernacular Architecture of Kashmir***. Please turn to APPENDIX 1 after page 9 below, to see the excerpts from this book which describes the timber-laced bearing wall system (called *taq* in Indian Kashmir, and *bhatar* in Pakistan). A copy of this book can be obtained

from UNESCO NEPAL. I was told that they have several copies, and if they are out, UNESCO NEW DELHI has confirmed to me that they have approximately 80 copies remaining.

**See APPENDIX 2:** For another scientific publication on the effectiveness of horizontal bands in rubble stone masonry construction, please turn to APPENDIX 2 for a synopsis of a paper “An experimental study of effectiveness of seismic and retrofitting measures in stone masonry houses” of shock table testing undertaken at the Indian Institute of Technology, Roorkee by Pankaj Agarwal and Shashi K. Thakkar, Department of Earthquake Engineering, IITR. These are colleagues at the same university as Professor Anand Arya, and all were involved in the drafting of the Indian Standard Building Code IS 13828, much of which is incorporated into the Nepal Building Codes. As explained in the text: “*The purpose of this study was to evaluate existing IS code [and by reference, also the NBC code] techniques of strengthening and retrofitting measures and to propose upgrading these methods to achieve better performance in earthquakes.*”

**Question (2)** The second question is whether the galvanized wire (GW) or polypropylene (PP) geogrid mesh is an adequate substitution for the timber or the reinforced concrete specified for horizontal bands in the Nepal and Indian Building Codes. The answer is based on empirical observations and data. The concept of the Gabion Band is to wrap a single course of masonry with GW or PP tied tightly for positive inelastic confinement. The GW mesh is intended to be welded straight wires, not chicken wire or the laced wire that can often be found to be used for gabion baskets used for retaining walls. This use of straight welded wire or polypropylene mesh forming a flat tube around the tightly wrapped stone will form a semi-rigid beam within the wall.

This is likely to perform better than the reinforced concrete bands shown in the NBC because earthquake experience has shown – particularly in Italy – that the rigidity of reinforced concrete bands can be less compatible with the flexibility of masonry walls – particularly of rubble masonry in mud mortar. The Gabion Bands will be better able to move together with the stone wall around them, yet they will resist the separation of the walls at the corners and along their length.

In conversations with Amod Dixit and Ramesh Guragain at NSET in August, the question of whether it would not be better to wrap the walls with the GW or PP was raised. I explained that I agreed that the wrapping of the walls in combination with through-wall ties has proven in a number of studies and shake table tests to be an excellent way of retrofitting existing structures, but the proposed Gabion Bands are designed to be done while a wall is constructed anew. For this the bands are more suitable because the installation of the bands is most compatible with the masonry construction sequence, as can be seen by the video here: <https://vimeo.com/142754836>. Wrapping of the wall cannot be done until the construction of the masonry wall is completed. In any case, NSET has done much good work on testing and training engineers to use bands in masonry construction, and has expressed support for the Gabion Band technology.

## 2. Practicality, (minimum quality assurance) and adaptability of the proposed new construction material.

In terms of practicality, the evidence to date is that the use of Gabion Bands may be the most practical of all the alternative methods to accomplish similar levels of seismic protection. The demonstration house construction project carried out and filmed for the TV documentary shown in the USA called *Himalayan Megaquake* was completed in the remarkably short period of four days from the initial demolition to the completion of the walls for a single room dwelling. The video at the link shown above demonstrates how the addition of the bands was easily incorporated into the otherwise normal work by the masons and owner-builders. No specialized training was necessary beyond the initial instructions.

The system is also designed to be easily adaptable to different situations, as only the wire encasement of the bands is the added step that differs from the normal non-engineered masonry house construction. In order to ensure a level of quality control to make the system suitable for wide-spread use, a simple graphic handbook or manual sheet should be created, so that the proper placement of the bands is carried out – particularly at the roof level so that there is a diaphragm at the top of the walls – which is needed regardless of the type of material used for bands. Please see the Handbook *Bhatar Construction, An Illustrated Guide for Craftsmen* shown and linked on page 7 below for an example of such a manual.



*left: House in Pakistan of bhatar construction being built after 2005 earthquake (photo by Tom Schacher for SDC). Right: Demonstration house with Gabion Bands at the Sunar Family Farm in Mankhu, Dhading District featured in TV documentary show Himalayan Megaquake.*

One demonstration of the practicality of Gabion Bands has been the growing interest from people involved with the construction of houses and schools in Nepal after the earthquake. I have heard from the Executive Director of an NGO “Nepal School Projects” ([www.nepalschoolprojects.ca/](http://www.nepalschoolprojects.ca/)), which had constructed approximately 90 schools in rural Nepal since 1975. She reported that over 90 % of their schools had collapsed or been severely damaged in the earthquake! Of all of the reconstruction technologies she had learned of, she is most interested in the Gabion Bands because of all of the attributes described above –

particularly because many of these schools are in remote villages where the importation of heavy materials necessary for RC construction is impossible.

Already underway are several other projects, one of which is being undertaken with the assistance of former Peace Corps volunteer, John Vavruska, at Chupar in Nuwakot District about 25 miles north of Kathmandu (photos below). In this site, he has secured polypropylene geogrid mesh instead of galvanized wire, and only recently, on 2<sup>nd</sup> of March 2016, he reported that *“The polypropylene Secugrid geogrid is easy to work with and has high tensile strength.”*



**Chupar School under construction with polypropylene Gabion Bands. (Photos by John Vavruska)**

Another colleague of Mr. Vavruska is providing assistance to another village named Halchok in the Kathmandu Valley. In both of these sites, they decided to use Gabion Band technology after selecting it as the best of all options for both the school buildings and the houses.

I have learned of another house that was inspired by the Mankhu demonstration project that has already been constructed and finished in Jiri a village of 7,138 people in Dolakha District in the Janakpur Zone of north-eastern Nepal by a group called “Solar Wanderkino Nepal.” This project was undertaken by Kshitiz Pradhan (Civil Engineer) and Awas Thapa (Documentary filmmaker). The two photographs below show that project in Jiri.



**New house with Gabion Bands in Jiri.**



### **3. Usefulness and Limitation of the proposed new building material and/or new construction technology.**

The best use is the rapid and economic reconstruction of rural houses of rubble stone with mud mortar that collapsed in the 2015 earthquakes. To find a technology that can make them significantly safer and resilient yet which requires only an additional construction material (rolls of wire or polypropylene) that can even be carried on one's back or on an animal for off the road sites, and that otherwise is based on the use the local materials from the collapsed structure, can make for a much faster and more effective earthquake recovery.

As for a limitation, one is that the GW or PP is visible on the exterior of the building, unless plastered, and thus for heritage structures or temples it may not be as suitable as timber. Also, for the galvanized wire the quality of the galvanizing is an issue, as eventually – depending on the quality of the galvanizing – the material can rust. Polypropylene is generally expected to have a longer life – perhaps 70 years, but even though it is intended to resist degradation from the sun, it must be plastered to gain the longest life without embrittlement from UV rays.

### **4. Production method and construction technology with its detail procedure of new material and technology.**

I believe that this is covered in comprehensive detail in the DUDBC Submittal of 26 November 2015. If not already in hand, this complete document can be downloaded from:

<http://www.traditional-is-modern.net/NEPAL/DUDBC/Conservationtech-GabionBands.pdf>

I also recommend the video posted above. (<https://vimeo.com/142754836>).

### **5. Standards and codes of practice used in Nepal or in foreign context regarding new building material and construction technology.**

Except for the substitution of galvanized wire or polypropylene geogrid, the Gabion Band technology is intended to be consistent with the requirements for horizontal bands in the Nepal Building Codes (NBC) 202 and 203. It is also consistent with the same provisions in the Indian

Building Code IS 13828:1993-reaffirmed 2008 “Improving Earthquake Resistance of Low Strength Masonry Buildings — Guidelines.”

**5.A: STRUCTURAL FLOOR DIAPHRAGM: Attic Floor and roof structure:** In addition to the installation of the bands within the walls, to make the bands (whether they be of timber or of wire or PP mesh) be most effective, the treatment of the connection of the attic floor and roof of each building must be done in a way that creates a securely connected diaphragm so that the building is held together like a box with a lid on it. Because of the shortage of time during the construction of the demonstration project in Mankhu, this top of the building was not completed, but it is described in the first Submittal to DUDBC (<http://www.traditional-is-modern.net/NEPAL/DUDBC/Conservationtech-GabionBands.pdf>) on pages 11 and 12. On page 12 of that report, an illustration from the DUDBC Design Catalogue Volume 1 from “*Stone Masonry with Mud Mortar SMM-1.I*” has been included which shows this correct treatment.

**School Buildings:** This is particularly important that this floor diaphragm and secure roof connections be done for school buildings because the room sizes are larger, making the walls more vulnerable to out of plane overturning that cannot be resisted by the Gabion Bands alone. Unlike houses, horizontal attic floors are often not needed and thus there is only a roof with open trusses, and the roof is very light because now instead of traditional use of slate, it is clad with GCI sheets. It is recommended for school classroom buildings that at least a structural membrane be added below the roof – perhaps useful also for storage – that can serve to secure the walls to form the “box top” effect of having a diaphragm similar to that shown for houses.

The effectiveness of the Gabion Bands is based on the existence of overburden weight from the masonry itself, so that a short wall of masonry above the attic floor structure is very important to holding that floor structure in place to serve as a diaphragm. It is thus also important to be sure that all walls are connected to that floor, and not just the two opposite bearing walls. Please see **APPENDIX 3, UNESCO BOOK** page`58- Section: 3.6.1 Floor-Level Ring Beam for more information on this subject in reference to the Indian and Nepal Building Codes.

**5.B: VERTICAL REINFORCEMENT: Concerns about vertical reinforcement shown in NBC 202 and 203:** One provision in each of these NBC codes which concerns me is the requirement for vertical reinforcements in the corners of the buildings and at other wall intersections for several reasons: (1) they are hard to execute during the construction process in a way that will not rapidly deteriorate – that is to rot, if they are timbers or bamboo poles or rust if they are steel reinforcing rods, and (2) they will be incompatible with the load-bearing masonry walls which must be allowed to settle and shift naturally without the transfer of loads to vertical structural members embedded in the walls such that their full overburden weight is partially removed from the wall, and (3) it will fail to work as intended in the event of future design level or greater earthquake by causing disruption to the surrounding masonry in mud mortar during the earthquake. This third point is based on empirical observations of earthquake damage in Turkey to buildings that had vertical elements in otherwise unreinforced rubble stone masonry walls where the stones fell away revealing the embedded timbers and remained intact on either side.

Please turn to **APPENDIX 3** after page 9 below for more material on this subject and an excerpt from the UNESCO book that explains the reasons for this concern in greater detail. I have placed this material in the appendix because the acceptance of the Gabion Bands technology is not dependent on the presence or absence of vertical reinforcement. The use of the Gabion Bands does NOT prevent the inclusion of vertical reinforcement as described in the code. The recommendations made here and in Appendix 2 are in addition to the Gabion Band proposal because they apply to all banded construction, including that which is already fully described within the NBC codes.

**External vertical reinforcement alternative that is easily compatible with Gabion Bands:** If vertical reinforcement is desired or necessary because of conditions as described by Professor Arya, my recommendation is that the Gabion Bands be tied together at the corners of the walls on the exterior and interior with vertical wires (or polypropylene rope). This has the considerable advantage of avoiding the internal corrosion of the masonry with the concrete sheathed steel rebar, or the considerable risk from the use of a wooden or bamboo rod that will quickly rot away unseen and unmaintainable.

#### **6. Used in similar EQ prone areas as Nepal or Not. (If yes submit photo evidence.)**

As mentioned above, the use of banded (ring beam) construction with timbers for masonry buildings has been found throughout the Middle East and South Asia with examples dating back centuries, even millennia. Today it continues to be used in parts of Turkey, Iran, Afghanistan, Pakistan, and India. As mentioned above, it is recognized in the Indian as well as the Nepal building codes. (See [www.conservationtech.com](http://www.conservationtech.com) for published papers on this subject. Perhaps the most detailed and comprehensive, with many photographic illustrations is this one: From “[Opus Craticium](#)” to the “[Chicago Frame](#)”: [Earthquake-Resistant Traditional Construction](#)” published in the [International Journal of Architectural Heritage](#) in 2007.

The most dramatic recent example of the adoption of timber banded construction known in Pashtun as *bhatar*, together with the other traditional timber and masonry construction system known Kashmiri as *dhajji* and in English is “half-timber”, is in Pakistan after the 2005 Kashmir earthquake. The Kashmir earthquake killed approximately 80,000 people, with most of the casualties in Pakistan. After the earthquake, the Government of Pakistan’s reconstruction commission and engineering arm “ERRA” (Earthquake Recovery and Reconstruction Authority) was given the mandate to determine the rules for the engineering design of houses which would be considered to be “compliant” and thus eligible for financial assistance from the Government. The head of this program was in Nepal on 8 October for a meeting of the **Shelter Cluster Nepal** where he described this program, which was recorded in the “*Recovery and Reconstruction Working Group Meeting Minutes*”:

*General Nadeem explained that in Pakistan the Government initially focused on confined masonry for reconstruction but then realised that the vernacular typologies used by many of the earthquake communities were more appropriate in many areas, and could be constructed in an earthquake resilient manner so this was then included*

in the programme. These minutes can be downloaded here:

[https://www.sheltercluster.org/sites/default/files/docs/lessons\\_learned\\_and\\_experience\\_sharing\\_pakistanaceh\\_8th\\_october\\_2015.pdf](https://www.sheltercluster.org/sites/default/files/docs/lessons_learned_and_experience_sharing_pakistanaceh_8th_october_2015.pdf)

This description in the “Minutes” understates the extraordinary impact of this acceptance of traditional construction – including rubble masonry construction with timber bands known as *bhatar*. UN-HABITAT has confirmed that by 2009, 150,000 new homes had been constructed in either *dhajji* or *bhatar* construction in northern Pakistan. For many of the people who lost their homes in the earthquake, government support of this construction provided the only viable option for many people because they lived remote from roads in a mountainous area of Pakistan, not unlike the rural citizens of Nepal in the heart of the damage district of the 2015 earthquakes. This program was described in the International Federation of Red Cross and Red Crescent Societies “*World Disasters Report 2014*,” Chapter 5, page 132.

<http://www.ifrc.org/Global/Documents/Secretariat/201410/WDR%202014.pdf>. (Together with Maggie Stephenson, who is now in Nepal, I was an invited co-author of parts of this IFRC document. My thanks are to Maggie Stephenson of UN-HABITAT and Tom Schacher of SDC for the data on the reconstructions in Pakistan as well as the opportunity to visit the damage district and to meet with ERRA in 2006.)



General Nadeem said that one of the successes of the Pakistan Government program was that the international NGOs joined forces with the government to provide trainings to local masons and even home owners so as to improve the quality of the traditional masonry construction to make it more resilient, moving away from the earlier plan to require reinforced concrete block construction as the only compliant typology. As part of this training, ERRA, jointly with SDC, FRC, A&D, and UN-HABITAT published a Manual on *bhatar* construction, authored

by Tom Schacher of SDC, which can be seen here: [http://www.archidev.org/IMG/pdf/Battar-handout\\_English-07-06-04.pdf](http://www.archidev.org/IMG/pdf/Battar-handout_English-07-06-04.pdf). This stands as a good example of what can be produced in Pakistan to be used to ensure high quality Gabion Band construction with locally taught owner-builders and masons.

**7. Structural calculation addressing following checks should be provided for the load bearing masonry structure and required seismic force should be as per NBC 105 or relevant IS code.**

Since this proposal is for a modification to the construction of many different buildings, and is focused on improving the performance of a construction system – rubble stone masonry – that is so widely varied building to building, it would be misleading to attempt to provide calculations as justification. In addition, rather than NBC 105 “*Seismic Design of Buildings in Nepal*,” Gabion Band buildings are subject to NBC 203: “*Guidelines for Earthquake Resistant Building*

*Construction: Low Strength Masonry.*” This latter code provides an empirical process to regulate and improve the design and construction of non-engineered buildings.

The question of relevance of calculations arose in Pakistan after the Kashmir earthquake of 2005. In the same report quoted above on page 5, Dominic Dowling, PhD structural engineer, who analyzed *bhatar* construction – where the only difference is the use of timbers rather than Gabion Bands – came to the following conclusion, which also applies here in Nepal with Gabion Band construction:

*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 behaviour 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.*

If the Gabion Bands proposal is accepted by the DUDBC, my intention is to pursue further research into the system by establishing a project to undertake both engineering research and longevity research into the life of the galvanized wire and polypropylene geogrid. Possible affiliated NGOs include Builders without Borders and the Earth Island Institute. Expressions of interest in undertaking shaking table tests and other engineering testing of the system have already come from Middle East Technical University in Ankara, Turkey, and also the University of Nevada in Reno, Nevada, USA.

**8. References for data used in structural calculation such as properties of building material if any (ensuring the validity of data eg. authentic international journal, codes of practice etc.)**

Again, since the only difference proposed is the use of wire encased stone for the bands instead of timber or RC, the design approach is that specified for NBC 203. For a paper from research on the use of polypropylene bands in India for the jacketing of masonry buildings (“bands” here refers to single strands of polypropylene, not ‘bands’ that mean ring beams in the buildings), please go to: [http://ascelibrary.org/doi/abs/10.1061/\(ASCE\)CF.1943-5509.0000733](http://ascelibrary.org/doi/abs/10.1061/(ASCE)CF.1943-5509.0000733) to see the paper “*Improving Seismic Performance of Masonry Structures with Openings by Polypropylene Bands and L-Shaped Reinforcing Bars*,” by Sanket Nayak<sup>1</sup> and Sekhar Chandra Dutta.

**9. Geometrical shape and size of the building and rooms should be as per NBC. eg. Span limitation, shape, storey and sizes of opening etc.**

Nothing in the Gabion Bands technology should conflict with any of these provisions within the Nepal Building Codes that apply to the construction undertaken.

**10. Assurance of quality and standard of the new building materials & technology in Nepalese context.**

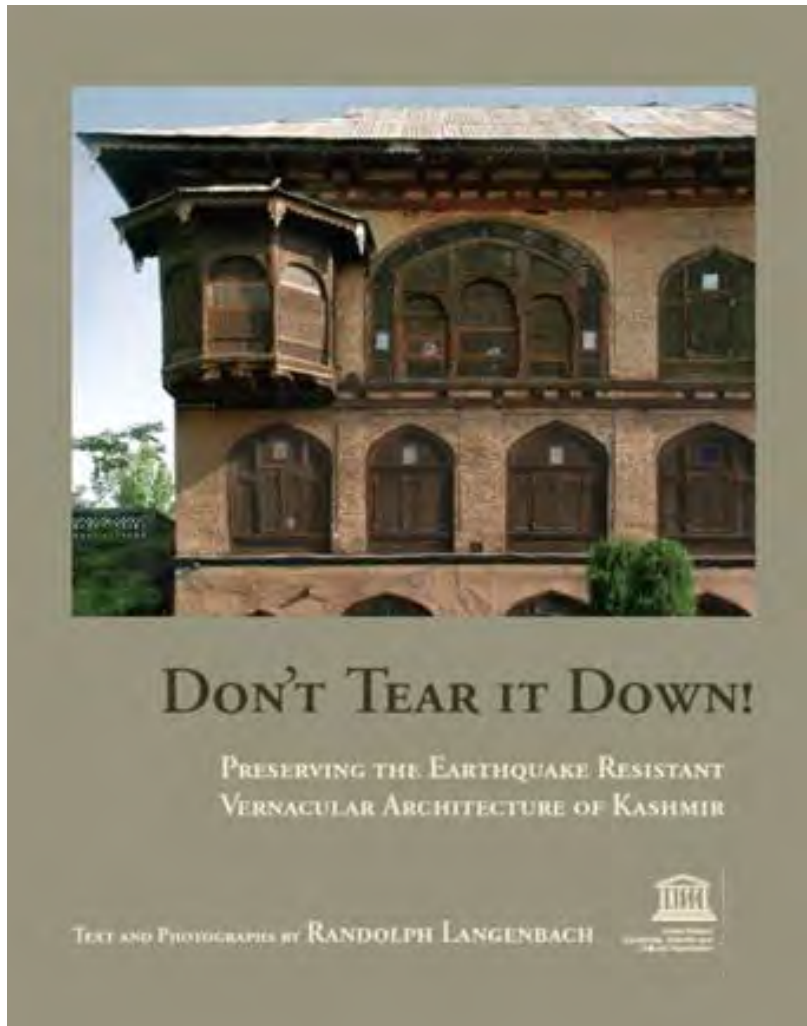
The simplicity of the Gabion Bands technology also means that quality control issues should be manageable. The one new material associated with this technology is the galvanized wire or polypropylene geogrid. At this stage, both the galvanized steel wire and polypropylene appear to be suitable and reasonably long lasting, with the steel wire protected by galvanizing from rusting and the polypropylene protected from UV embrittlement by solar blocks within the plastic.

Like timber, which is subject to rot and insect attack, the issues of longevity will define the need for maintenance over time, but in considering these lifespan issues, it is important to understand that even at a point where damage has been sustained from exposure and decay, the later undertaking of a retrofit based repair is entirely possible without having to dismantle the masonry wall. This is advantageous when compared with the use of steel rebars in reinforced concrete bands because, when they are not galvanized and when the cement cracks and they do rust, they can disrupt the masonry far more than the wire mesh. Moreover, the repair of a wall where the Gabion Bands may have rusted is far more feasible and easier to undertake than attempting to repair cracked and broken RC bands with heavily rusted reinforcing bars.



## APPENDIX 1:

EXCERPTS on *taq* timber-laced masonry bearing wall construction from:



Published in 2009 by UNESCO, New Delhi



*TAQ*: TIMBER-LACED MASONRY  
BEARING WALL CONSTRUCTION

*Taq* construction is a composite system of building construction with a modular layout of load-bearing masonry piers and window bays tied together with ladder-like constructions of horizontal timbers embedded in the masonry walls at each floor level and window lintel level. These horizontal timbers tie the masonry in the walls together, thus confining the brick mud or rubble stone of the wall by resisting the propagation of cracks. The masonry piers are almost always 1 to 2 feet square and the window bay/alcove (*taqshe*) 3 to 4 feet in width. The *taq* modular layout defines the Kashmiri house size measurements, i.e. a house can be 3 *taq* (window bays) to 13 *taq* in width. In Pakistan, timber-laced masonry is known by the Pashto word *bhatar*.



*DHAJJI DEWARI*: TIMBER FRAME WITH  
INFILL MASONRY CONSTRUCTION

*Dhajji dewari* is a timber frame into which one layer of masonry is tightly packed to form a wall, resulting in a continuous wall membrane of wood and masonry. The term is derived from a Persian word meaning “patchwork quilt wall”. The frame of each wall consists not only of vertical studs, but also often of cross-members that subdivide the masonry infill into smaller panels, impart strength and prevent the masonry from collapsing out of the frame.

*There are a number of other types of wood frame and wood wall vernacular construction types that can be found in Kashmir on both sides of the Line of Control, but these are not covered in this volume. For more information on these and other subjects related to this book, please see [www.traditional-is-modern.net](http://www.traditional-is-modern.net).*



1.1a 18th- or early 19th-century canal shop house alongside what was once the Mar Canal in Srinagar. This building survived the 1885 earthquake. The timber lacing has held this structure together despite extensive differential settlement. Note that the windows are not lined up vertically: this feature would not be structurally possible had the walls not been reinforced with timbers.



1.1b Taq building on the bank of the River Jhelum. The fact that this bearing wall masonry structure can be held up on three poles is a testament to the effectiveness of the timber lacing. The shoring poles are supporting the structure under the three main beams that support the joists, two of which are embedded in the front and back masonry walls.

## I.1. TAQ CONSTRUCTION

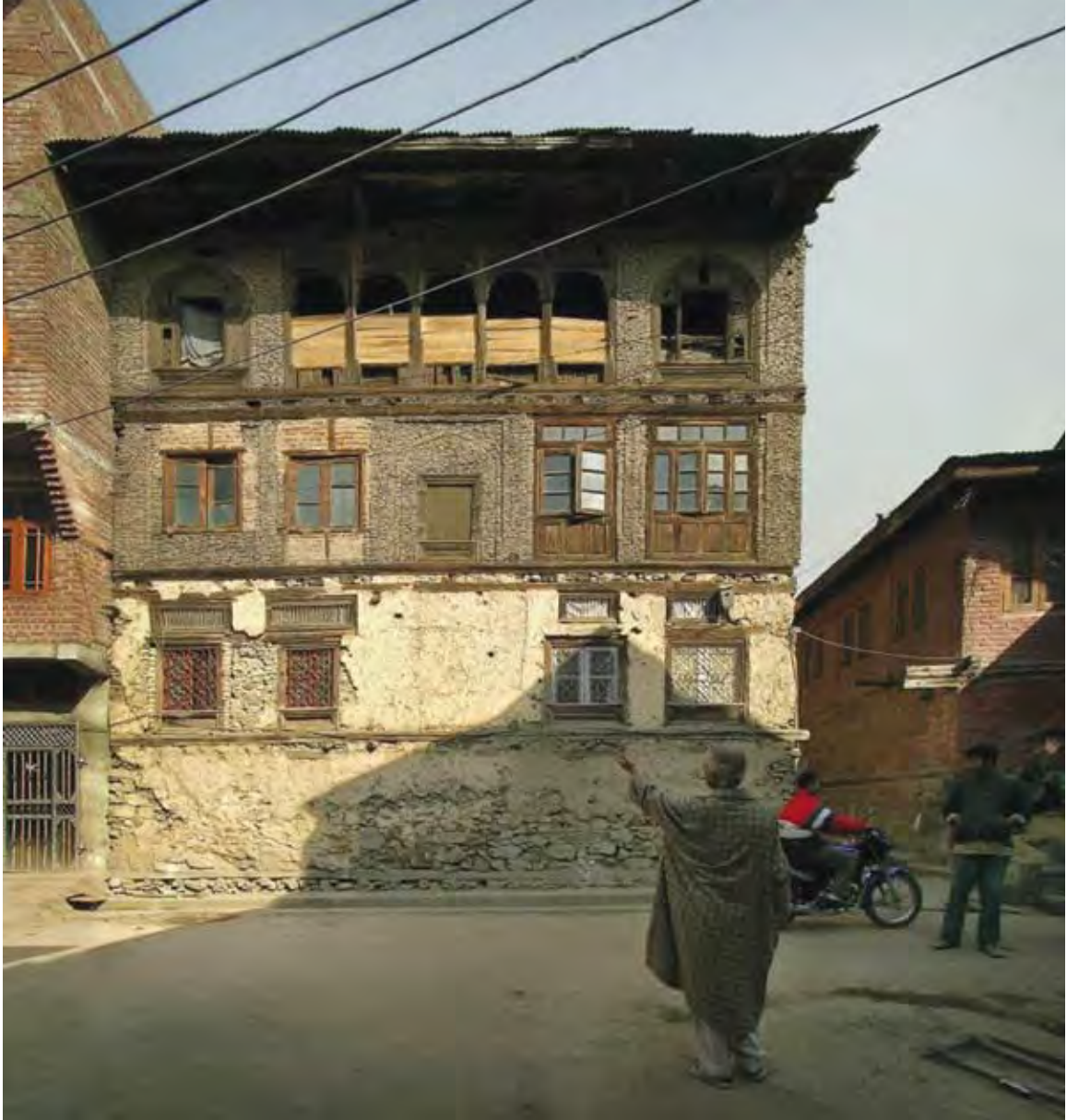
*A combination of wood and unreinforced masonry laid on weak mortar gave [taq] buildings the required flexibility. The wooden bands tied the mud mortar walls and imparted ductility to an otherwise brittle structure. Built by masons, who had no formal degrees in structural engineering and architectural design, these structures stand today as the epitome of human creative instincts. Yet, these buildings continue to fascinate modern-day engineers... Tragically, however, rarely does this learning translate into constructions based on such masterly designs.*

Sr. Sudhirendar Sharma, Development Analyst & Ashoka Fellow  
Ashoka Changemakers, 2005

Taq construction is a bearing wall masonry construction with horizontal timber lacing embedded into the masonry to keep it from spreading and cracking. It is usually configured with a modular layout of masonry piers and window bays tied together with ladder-like constructions of horizontal timbers embedded in the masonry walls at each floor level and window lintel level. The masonry piers are thick enough to carry the vertical loads, and the bays may either contain a window, or a thinner masonry wall as required by the floor plan and the building's orientation. The ladder-like sets of timber beams (*ker*) laid into the exterior and interior faces of the walls are connected together through the wall either by the floor beams (*veeram*) and joists or short connector pieces (see Figure 1.1h for a view of similar construction in Ahmedabad where the connector pieces are visible). These horizontal "ladder bands" are located at the base of the structure above the foundation (*das* or *dassa*), and at each floor level and at the window lintel level.

The face bricks traditionally used during the 19th and early 20th centuries were small in size, rough-surfaced, and hard-fired (Figure 1.1f). They are known as Maharaji bricks because the Maharaja of the Dogra period (1846–1947) monopolized their production. They served as the weather-resistant skin over sun-dried brick (known locally as *khaam seer*) or rubble made up of broken bricks laid in clay mortar (Hamdani, 2006).

There is no specific name in Kashmiri to identify this timber-laced construction method itself, but the closest name used to describe it is *taq* because this is a name for the type of buildings in which it is commonly found. *Taq* refers to the modular layout of the piers and window bays, i.e. a five-*taq* house is five bays wide. The masonry piers (*tshun*) are almost always 1½-2 feet (45-60 cm) square, and the bays are approximately 3-4 feet (90-120 cm) in width. Because this modular pier and bay design and the timber-laced load-bearing masonry pier and wall system go together, the name has come to identify the structural system as well.



*1.1c Taq construction in Srinagar. The symmetrical layout of windows is characteristic of taq and it is from this that the name of the construction system is derived.*

An important factor in the structural integrity of *taq* is that the full weight of the masonry is allowed to bear on the timbers, thus holding them in place, while the timbers in turn keep the masonry from spreading. The spreading forces can result over time from differential settlement – or in an instant in an earthquake. The overburden weight of the masonry in which the timbers are embedded serves to “pre-stress” the wall, contributing to its resistance to lateral forces.

The best early account of the earthquake performance of *taq* construction maybe the one by British traveller Arthur Neve, who was present in Srinagar during the earthquake of 1885 and published his observations in 1913:

*“The city of Srinagar looks tumbledown and dilapidated to a degree; very many of the houses are out of the perpendicular, and others, semi-ruinous, but the general construction in the city of Srinagar is suitable for an earthquake country; wood is freely used, and well jointed; clay is employed instead of mortar, and gives a*



1.1d House under demolition showing how the masonry wall of taq is subdivided into panels where the light shows through between the wall panel and the half-demolished pier.



1.1e Photograph taken in the 1980s showing a building under demolition with taq timbers visible at the window lintel level and at the floor level. The floor joist can be seen to penetrate the wall where it is sandwiched between the exterior runner beams.

*somewhat elastic bonding to the bricks, which are often arranged in thick square pillars, with thinner filling in. If well built in this style the whole house, even if three or four storeys high, sways together, whereas more heavy rigid buildings would split and fall.” (Neve, 1913)*

One most unusual element in the Kashmiri *taq* system is the existence of a deliberately unbonded butt joint between the masonry piers and the wall and window panels that can be seen in Figure 1.1d – a seemingly irrational detail which one would think would weaken the building wall in an earthquake. Nevertheless, it is a common, yet distinctive, feature in many (though not all) *taq* buildings. This joint divides the masonry walls into piers that are physically separate from the layer of masonry surrounding the windows or spanning the bay where there are no windows.

This system, with the timber tie beams together with the masonry subdivided into piers and panels, was most likely invented to avoid diagonal tension cracks from differential settlement of the foundations on the soft soils of the former lake bed that would otherwise have



1.1f View of the mid-19th century Jalali Haveli in Srinagar showing Maharaji bricks. Maharaji bricks, common in the 18th to early 20th centuries, were shaped without the use of a wooden mold and thus are of varying length and about 1 inch (2.5 cm) in thickness.

disrupted the masonry, as can be seen in Figure 1.1g. It may also have evolved as a construction sequencing method, allowing the early completion of the roof, which rests on the piers, before the rest of the walls and interior was completed. In barns and the top storey on rural houses, the space between the piers is left open when the floor is used as a hay loft.

In earthquakes, the value of these joints in the masonry is more questionable. From a positive standpoint, the separation of the panels of masonry serves as a crack stopper, and the avoidance of settlement cracks reduces the likelihood that the wall would be weakened by them before an earthquake, but subdivision of the wall into panels would seem to make it less resistant in an earthquake than if the masonry panels were bonded to the piers. In fact when one examines the actual construction of the masonry common in the older houses, with its amorphous clay- and rubble-filled cores (Figure 1.1j), the crack-stopping control joints are probably effective in reducing the negative effects that these cores would otherwise have if they were not limited to discrete elements. The timber ladder bands and timber floors bridge across the joints, keeping the individual piers from separating and the house from breaking apart.

*Taq* construction has largely gone out of use in Indian Administered Kashmir for new construction, but in Pakistan's Northwest Frontier Province, however, new buildings with *bhatar* and *cator* and cribbage construction continue to be constructed, particularly since the 2005 earthquake focused renewed interest on the seismic resistance of these systems – especially in preference to plain rubble stone without timber lacing, which had been commonly used in rural areas until the earthquake. In addition, *bhatar* has been successfully reintroduced into remote areas of Pakistan Administered Kashmir after the earthquake (see Figures 3.3i & 3.3j and 5.5h & 5.5i).



1.1g Photograph taken in the 1980s in Srinagar of an unreinforced masonry building without timber lacing, showing how soil subsidence is causing the structure to come apart.



1.1h View of partially demolished 18th- or 19th-century dwelling in Ahmedabad, Gujarat, with timber lacing like that found in Kashmir. This view shows the cross-pieces that tie the inside and outside runner beams laid into the masonry wall together. (A view of the peg holding one of these crosspieces is shown in Figure 2.3.3a.)

## TAQ TIMBER BANDS

1.1i A model showing the typical “ladder bands” of timber runners and crosspieces found embedded in the masonry walls in traditional *taq* construction. At the floor levels, the joists run through the wall, and another pair of runner beams rests on top of the joists. At the window lintel level, shown in between, the timbers are tied together with cross pieces like those that can be seen in the Ahmedabad example in Figures 1.1h & 2.3.3a.



1.1j This detail of the corner of an abandoned house in Srinagar shows the historic masonry in *taq* construction well. The hard-fired Maharaji bricks are only the external skin. The interior is random rubble of clay and low-fired bricks. The stout timber lacing consists of two layers of runner beams with the joists sandwiched in between. The ends of the joists can be seen between the runner beams in the facade on the right.

With this amount of clay and random rubble, one would expect the earthquake performance of these structures not to be good, so the timber lacing undoubtedly is critical to the reported good performance. Had a section like this been broken off the corner of an unreinforced masonry building with no timbers to stop its progression, the collapsed section might have extended all the way to the roof.



### 3.2 THE EARTHQUAKE RESISTANCE OF TAQ CONSTRUCTION

Returning to the Indian side of Kashmir, one of the most important of the post-earthquake reconnaissance reports was published by EERI. This report was written by Professors Durgesh C. Rai and C. V. R. Murty of the Indian Institute of Technology, Kanpur and published in December 2005 as part of EERI's *Learning from Earthquakes* report on the Kashmir earthquake. The quotations below from the authors were based on observations made during the first several weeks after the earthquake. Describing *taq* construction, which they observed in the damage district on the Indian side of the Line of Control, Professors Rai and Murty observed:

*In older construction, [a] form of timber-laced masonry, known as Taq has been practised. In this construction large pieces of wood are used as horizontal runners embedded in the heavy masonry walls, adding to the lateral load-resisting ability of the structure. ...Masonry laced with timber performed satisfactorily as expected, as it arrests destructive cracking, evenly distributes the deformation which adds to the energy dissipation capacity of the system, without jeopardizing its structural integrity and vertical load-carrying capacity. (Rai and Murty, 2005)*

It is interesting to compare their observation with that of Professors N. Gosain and A.S. Arya after an inspection of the damage from the Anantnag Earthquake of 20 February 1967, where they found buildings of similar construction to Kashmiri *taq*:

*The timber runners...tie the short wall to the long wall and also bind the pier and the infill to some extent. Perhaps the greatest advantage gained from such runners is that they impart ductility to an otherwise very brittle structure. An increase in ductility augments the energy absorbing capacity of the structure, thereby increasing its chances of survival during the course of an earthquake shock. (Gosain and Arya, 1967)*

These two reports are separated by almost 40 years. Gosain and Arya ascribe a kind of ductile behaviour to the timber-laced masonry and even say that the timbers “impart ductility” and augment “energy absorbing capacity”, while Rai and Murty use the term “energy dissipation capacity” to describe the same phenomenon. The different ways of describing this behaviour simply reflect changes in terminology, as the word “ductility” is more scientifically correct when used to describe an attribute of a single material rather than that of a combination of materials; but the basic phenomenon remains the same, and other noted scholars have made similar observations in other countries. In Turkey in 1981, Professor Alkut Aytun credited the bond beams in that country with “incorporating ductility to the adobe walls, substantially increasing their earthquake resistant qualities”, and illustrated his point with a



3.2a Photo by Turkish Professor Alkut Aytun showing a two-storey brick house with timber bond beams spanning the ground rupture from the 1970 Gediz earthquake in western Turkey. In the caption to this image, he observes that this shows the effectiveness of timber bond beams for both fired or unfired brick masonry (Aytun, 1981).



3.2b The side of a timber-laced masonry building near Uri after the 2005 earthquake: The quake caused the cracking of the modern rigid cement plaster from the otherwise non-destructive shifting of the underlying timber-tied masonry.

photo of a house that spanned the fault rupture in the 1970 Gediz earthquake, where the timber lacing held the masonry bearing wall together despite approximately 50cm of vertical ground displacement (Aytun, 1981) (see Section 2.2.4).

The concept of ascribing ductility to a system composed of a brittle material – masonry – is a difficult one for many modern engineers. While a steel coat hanger is ductile, which can be seen when it is bent beyond its elastic limit, a ceramic dinner plate is brittle. So how can masonry, which on its own is inarguably made up of brittle materials, as shown in Figure 2.2.4a, be ductile? Rai and Murty in 2005 avoided the use of the term “ductile” probably because the materials in *taq* are not ductile and do not manifest plastic behaviour. However, what makes timber-laced masonry work well in earthquakes is its ductile-like behaviour as a system. This behaviour results from the energy dissipation because of the friction between the masonry and the timbers and between the masonry units themselves.

This friction is only possible when the mortar used in the masonry is of low-strength mud or lime, rather than the high-strength cement-based mortar that is now considered by most engineers to be mandatory for construction in earthquake areas. Strong cement-based mortars force the cracks to pass through the bricks themselves, resulting in substantially less frictional damping and also rapidly leading to the collapse of the masonry. Arya made this difference clear when he said: “Internal damping may be in the order of 20%, compared to 4% in uncracked modern masonry (brick with Portland cement mortar) and 6%-7% after the masonry has cracked.” His explanation for this is that “there are many more planes of cracking...compared to the modern masonry” (see Section 2.2.3).

The difference between cement mortar and weaker traditional mortars made of mud or hydrated lime has been a significant issue in the field of building conservation for many years, but the debate over the efficacy of the weaker mortars has been different in areas where earthquakes are a risk. As can be seen in this quotation concerning premodern masonry construction in the United States, there are attributes to mortar other than compressive and tensile strength that are even more fundamental to the long-term stability and conservation of the masonry:

*It is essential to distinguish between hard and soft mortars. The use of lime-sand mortar ... was soft enough to furnish a plastic cushion that allowed bricks or stones some movement relative to each other... A cushion of soft mortar furnished sufficient flexibility to compensate for uneven settlement of foundations, walls, piers and arches: gradual adjustment over a period of months or years was possible. In a structure that lacks flexibility, stones and bricks break, mortar joints open and serious damage results. (Harley McKee, 1973)*

In areas subject to earthquakes, engineers have often sought to specify strong cement-based mortar. However, in the larger earthquakes, the strength of the mortar ceases to be helpful once the walls begin cracking, as they inevitably do in a strong earthquake. It is then that the “plastic cushion” and other attributes described by Harley McKee become more important. Perhaps most important is that the masonry units – the stones or bricks – be stronger than the mortar so that the onset of shifting and cracking is through the mortar joints, and not through the bricks. Only then can the wall shift in response to the earthquake’s overwhelming forces without losing its integrity and vertical bearing capacity. With timber-laced masonry, it is important to understand that the mortar is not designed to hold the bricks together, but rather to hold them apart. It is the timbers that tie them all together. The benefits of energy dissipation are gained from the non-destructive friction and cracking that can take place in a masonry wall that is surrounded and thus confined by the timber bands.

Professors Rai and Murty also point out that the timber lacing “arrests destructive cracking” in the masonry walls. This phenomenon may have been understood as far back as in ancient Rome, if not earlier, where concrete walls were constructed with horizontal bands of brick that extended through the walls subdividing the concrete. Crack-stopping masonry construction technology can also be found in medieval construction in Istanbul, with similar bands of brick in the Theodosian walls which still exist around the oldest part of the city. Each of these bands is called a *hatıl*, (plural *hatıllar*) the Turkish term still used to identify the horizontal timber ring beams in masonry that were commonly used throughout the Ottoman Empire, the cultural influence of which may be in part responsible for the *cator*, *bhatar*, and *taq* construction found in Pakistan and India. (For illustrations of the Turkish examples, see Langenbach, 2007a.)

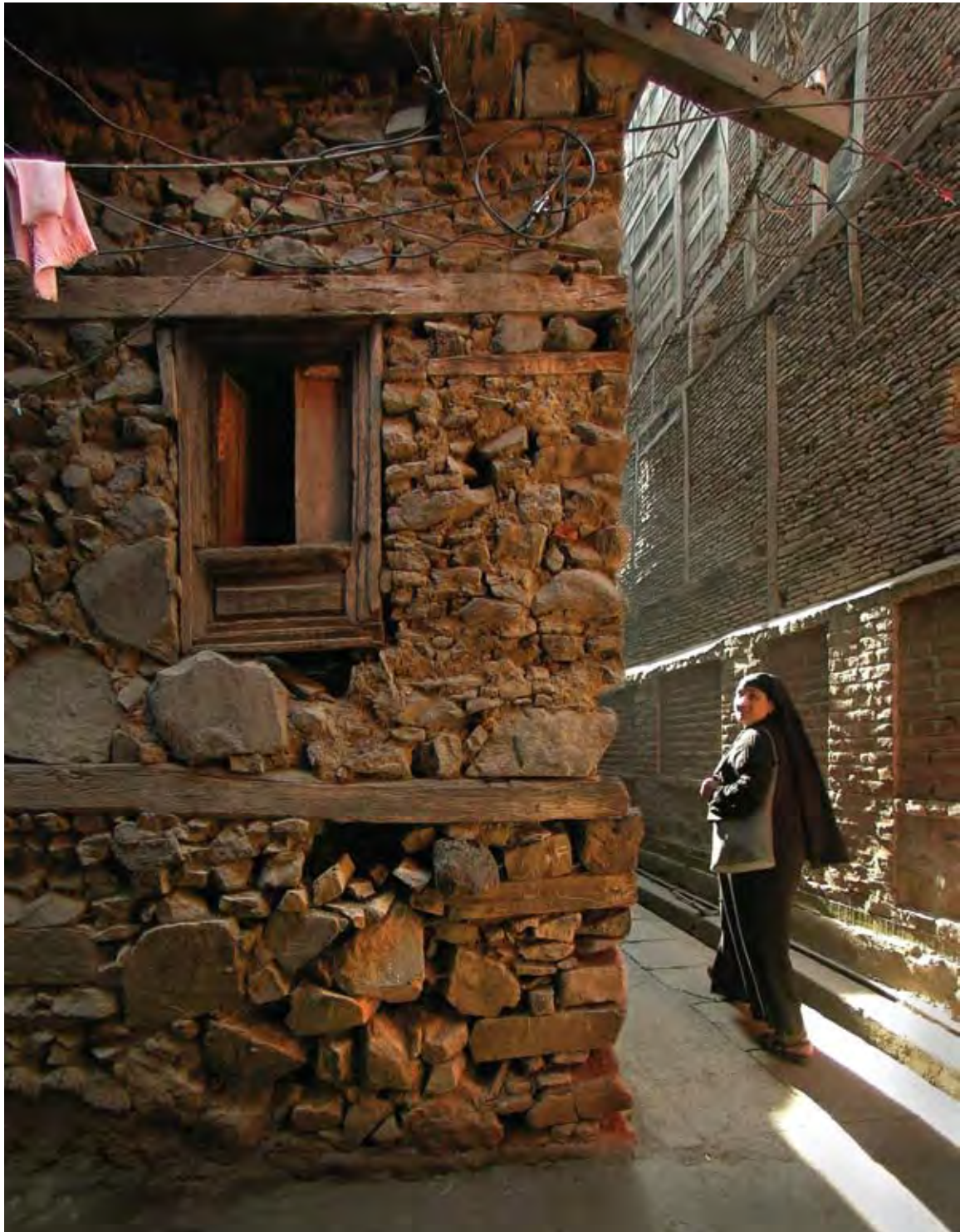


### 3.3 TAQ TIMBER LACING IN CODES AND GUIDELINES

3.3.1 INDIA: Although not identified by their Kashmiri names, both the *taq* and *dhajji dewari* systems have been recognized and adopted into several of the Indian Standard National Building Codes. Dr Anand S. Arya, a principle author of the Indian building codes, undertook research at IIT-Roorkee on the construction systems and was influential in their inclusion into the Indian Standard code. He has reported that “timber runners” (the horizontal timbers laid into masonry walls like those in *taq*) were introduced into the code for non-engineered construction in 1967.

In 1980, timber ring beams of the same kind of ladder-like configuration as are illustrated in the Indian Standard codes were described and illustrated in the internationally recognized document

3.2c & d In Ahmedabad, this timber lacing in the 17th-century “Old Haveli” of the Dwarka Dheesh Mandir is treated as a part of the architectural ornament. This and many other timber-laced bearing wall and timber frame with infill structures in Ahmedabad did well in the 2001 earthquake, with no collapses of occupied structures and no deaths. By contrast, many nearby reinforced concrete buildings, almost all of which had been constructed during the most recent decade, collapsed.



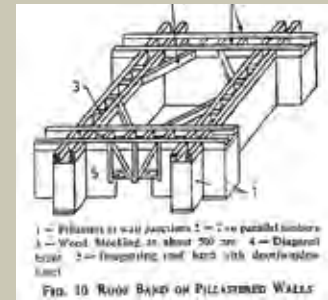
*3.2e While most taq buildings in Srinagar are constructed of fired brick, the lower storeys of this large house are of stone and do not observe the modular window bay layout from which the term taq is derived. Timber-laced stone construction is more common in Baramulla and the surrounding rural mountain areas further to the west.*

published by the International Association of Earthquake Engineering based in Japan. This document was revised in 1986 by an international committee composed of Teddy Boen from Indonesia, Yuji Ishiyama from Japan, A. I. Martemianov from the USSR, Roberto Meli from Mexico, Charles Scawthorn from the USA, Julio N. Vargas from Peru and Ye Yaoxian from China, and re-published under the title *Guidelines for Earthquake Resistant Non-Engineered Construction*. The committee was chaired by Professor Anand Arya from IIT-Roorkee, India. (Arya et al, 1986). (The National Information Center of Earthquake Engineering (NICEE) in Kanpur has now made it available on the web in Hindi and in English.) The same concepts also have been recognized in the Turkish codes as early as 1972 (Aytun, 1981), and in the Nepal Building Code, which was drafted in 1994.

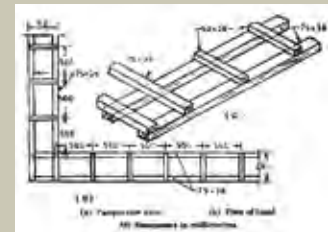
The most recent Indian codes date from 1993. A modified form of *taq* construction can, as mentioned above, be found in the Indian Standard Building Codes *IS 13827: Improving Earthquake Resistance of Earthen Buildings – Guidelines*, and *IS 13828: Improving Earthquake Resistance of Low-Strength Masonry Buildings – Guidelines*. Low-strength masonry “includes fired brick work laid in clay mud mortar and random rubble; uncoursed, undressed or semi-dressed stone masonry in weak mortars; such as cement-sand, lime-sand and clay mud”. (The inclusion of the word “guidelines” in the titles of these codes is emblematic of the fact that for the most part, building codes in India remain advisory documents, rather than mandatory rules, and also a recognition of the fact that these particular codes address types of rural construction for which it would be difficult to enforce mandatory rules in any case.)

After the 2005 Kashmir earthquake, the Government of India, Ministry of Home Affairs gave further recognition of variants of the traditional Kashmiri systems by including them in their publication that followed the earthquake, *Guidelines for Earthquake Resistant Reconstruction and New Construction of Masonry Buildings in Jammu and Kashmir State* (Arya and Agarwal, 2005). The two 1993 codes and the 2005 post-earthquake manual all specify that seismic bands (also known in English as tie beams, ring beams or bond beams) are recommended for use in new masonry construction. The timber versions of these bands shown on page 14 of the 2005 *Guidelines*, and in *IS 13828*, Section 8 are very similar to what has existed in *taq*, *bhatar*, and *hatil* timber-laced construction for centuries.

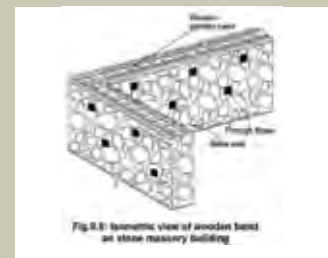
*IS 13827* for earthen buildings, Section 11.1 specifies that “two horizontal continuous reinforcing and binding beams or bands should be placed, one coinciding with lintels of door and window openings, and the other just below the roof in all walls in seismic zones III, IV, and V.” This code specifies that these bands be made of timber. For thin walls, a single timber may be used with diagonal corner braces, but for thicker walls, two timbers are to be laid on either side of the wall and connected with short pieces. In *IS 13828* for low-strength masonry, the use of timbers is specified as an alternative to the use of



(1) Illustrations from *IS 13827* showing timber lacing recommended for earthen buildings.



(2) Illustration from *IS 13828* showing timber lacing recommended for low-strength masonry buildings.



(3) Illustration from 2005 *Guidelines for Earthquake Resistant...Masonry Buildings in... Kashmir* showing recommended use of timber bands in stone masonry buildings.



3.3b Traditional bhatar construction in the Swatt Valley town of Behrain used to stabilize a rounded random rubble stone wall construction which otherwise is extremely at risk in earthquakes.



3.3c Early 20th-century fort in Besham, Pakistan after the 2005 earthquake, showing how the collapse of this dry-laid rubble stone wall was prevented by the timber lacing. This demonstrates the effectiveness of the timber tie beams (bhatari) in holding the earthquake-damaged rubble stone wall together.



3.3d Training of craftsmen and owner-builders in a rural area of Pakistan Administered Kashmir. Photo by SDC.

a continuous band of reinforced concrete. The placement of the seismic bands is the same as in *IS 13827*.

The sizes of the timbers for the reinforcing bands specified in both codes, which range from 2" x 3" (50 x 75mm) to 3" x 6" (75 x 150 mm), are smaller than those used historically. For the *taq* houses, the sizes were probably dictated by the difficulty of cutting timber into boards before the arrival of power saws, and the need for timber thickness for the scarf joints that pre-date the use of metal straps. Today, connections can be accomplished with steel hardware and nails, and the timber can be efficiently sawn into boards at a sawmill. This may be the rationale for the smaller dimensions. (It should be noted that conformity with the smaller dimension makes the notching together of the timbers difficult to accomplish, and relying on nails which eventually rust may not be adequate if an earthquake should occur years later.)

3.3.2 PAKISTAN: The recognition and adoption of timber-laced masonry construction has followed a different and more recent trajectory in Pakistan where the worst effects of the 2005 Kashmir earthquake resulted in a humanitarian crisis that required creative solutions to the problem of housing construction in remote rural areas. The Government of Pakistan reported that approximately 75,000 people were killed and 70,000 injured in Northern Pakistan, including Pakistan Administered Kashmir, and 600,000 houses and 6,298 schools were destroyed (ERRA, 2006). On the Indian side of the Line of Control, 1,350 were killed and 6,300 injured.

Immediately after the earthquake, the Government of Pakistan established the Earthquake Reconstruction and Rehabilitation Authority (ERRA) to “facilitate the rebuilding and repair of damaged infrastructure, including housing, roads, bridges, government buildings, schools and hospitals”. (ERRA, 2007) There were and continue to be two important mantras that guide the activities of this organization, as well as the associated international organizations that have come to provide aid in the earthquake-stricken areas of Pakistan. The first is “build back better” and the second is that the housing rebuilding process would be “owner-driven”.

Although not always achieved, the “build back better” goal is a fundamental goal of disaster rebuilding efforts in general, but the “owner-driven” concept has turned out to be of crucial importance. What it means is that the objective was not for the government or NGOs to come in and provide the rebuilt housing, but rather only to provide training and funding for the owners themselves to rebuild their own housing on their own

properties. The government retained responsibility for the inspection to allow only approved earthquake resistant construction to receive financial assistance (ERRA, 2007 and [www.erra.gov.pk](http://www.erra.gov.pk)). This may not seem noteworthy except that throughout the world there are many examples of enclaves of culturally insensitive identical houses built after earthquakes where the houses are lined up in military-like rows, such as those described in Section 4.4 (see also Langenbach and Dusi, 2006c). ERRA wisely resisted pressure by some donors and NGOs which wanted to undertake the construction directly. In 2007, General Nadeem Ahmed, former Deputy Chairman ERRA, who supported and maintained the owner driven policy and ensured it was responsive to field needs and community priorities, was awarded the UN-HABITAT scroll of honour. UN-HABITAT has reported that the “owner-driven” practice in Pakistan has resulted in a massive broad base of new skills and knowledge, as well as the relearning of forgotten crafts.

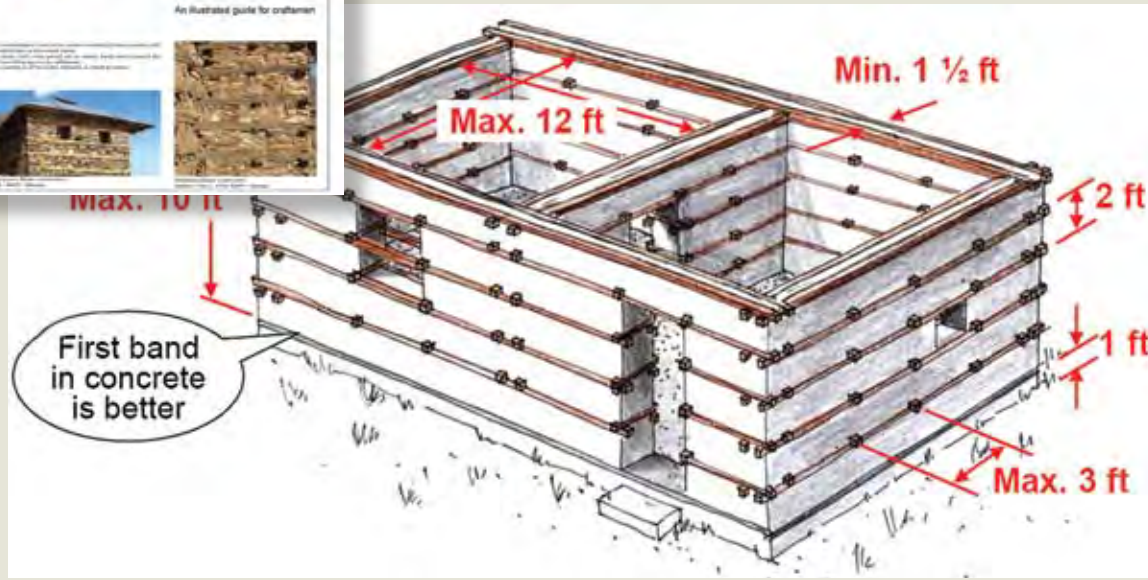
In Pakistan, a major contribution in support of ERRA was made by teams fielded by the Pakistan Poverty Alleviation Fund and the National Rural Support Programme (NRSP). The international organizations include UN-HABITAT, the Swiss Agency for International Development and Cooperation (SDC), the National Society for Earthquake Technology, Nepal (NSET), Architecture & Développement, France (A&D), the French and Belgian Red Cross, and over 60 other NGOs. These organizations provided major assistance in setting up training centres in the damage district and carrying out the trainings of carpenters and masons as well as owner-builders (see Figures 3.3d, 3.3e and 3.3f). In the case of UN-HABITAT, a major portion of the staff contribution was made by Kashmiris, including Sheikh Ahsan Ahmed, S. Habib Mughal and Hamid Mumtaz, who supported the approval of traditional construction.

Government endorsement of traditional techniques was not immediate, however. In May of 2006, only seven months after the earthquake, ERRA published a manual designed to establish a government-approved standard for earthquake-resistant construction that would be considered “compliant” and thus eligible for financial reimbursement from the government. This document, *Guidelines For Earthquake Resistant Construction Of Non-Engineered Rural And Suburban Masonry Houses In Cement Sand Mortar In Earthquake Affected Areas*, specified the type of reinforced masonry that would be eligible for government assistance.

As the post-disaster rebuilding process proceeded, the rigid adherence to the one construction typology presented increasing problems as the relief efforts moved from the urban areas into increasingly remote rural areas. As was reported in the ERRA 2007 Environmental Assessment (ERRA, 2007), “Of the total housing stock, 84 percent was damaged or destroyed in Pakistan Administered Kashmir and 36 percent was damaged or destroyed in NWFP [North



3.3e, f & g Views of a training workshop on bhatar construction for local masons in Battagram, Pakistan, in spring and summer 2007, prepared by the French Red Cross with Architectes et Développement. Photos by the French Red Cross.



3.3h Drawing from the training manual *Bhatar Construction, an Illustrated Guide for Craftsmen*. This manual was created by Swiss Architect Tom Schacher of SDC and published by the Government of Pakistan for use in the training of rural craftsmen for the reconstruction of earthquake-damaged homes. Source: Tom Schacher and ERRA, Government of Pakistan.

West Frontier Province]. The affected houses were predominantly rural, with urban units accounting for only 10 percent of the total. Much of the rural housing was located on steep slopes difficult to access.” A requirement that government assistance be limited to reinforced masonry with cement mortar would mean that the materials would have to be transported deep into the countryside where sometimes there were no roads to meet this requirement (see Figure 3.3k). As a result, many of the families rendered homeless began rebuilding destroyed rubble masonry houses using traditional timber-laced masonry.

At this stage, individuals from the NGOs with their Pakistani colleagues had a chance to examine the various forms of traditional construction that had done well in the earthquake and which were already being copied by the survivors for new construction to replace their destroyed rubble stone homes. Together, they began to work with ERRA and NESPAK to establish ways to broaden the compliant construction types, first to accept *dhajji* construction and then later to accept *bhatar*. One of the difficulties, as reported by UN-HABITAT, was the fact that *dhajji* and *bhatar* construction had not been the subject of engineering research and no generally accepted analytical tools had been developed for it. In an effort to provide some professional credibility for the systems, UN-HABITAT prepared the report shown in Figure 3.3l in which their engineering consultants state, “Because of the inherent variability and complexity of the individual materials...it is not possible to accurately calculate or model the structural behaviour 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” (see sidebar on page 50 for more excerpts). This explains why many engineers, including those representing the World Bank and other donor agencies have difficulty accepting traditional construction.

With the support of Army personnel who could see the practicality of using the local vernacular in the mountain areas and the urgency of the need for disaster assistance funding in this historically volatile region, *bhatar* was approved by ERRA in July 2007. While overseeing a programme covering the construction of 630,000 new and repaired houses, Waqas Hanif, the ERRA Programme Manager for Rural Housing, came to embrace both *dhajji*



and *bhatar* and thus was key in ensuring both were approved as compliant. Despite the effort that it took, architect Tom Schacher observed that “the readiness of the engineering consultants to the government to review their dogmas and approve construction practices hitherto unknown to them and for which they often didn’t have the required scientific evidence was extraordinary.” (Schacher, 2008)

This history in Pakistan is significant for a number of reasons. Not only has the earthquake made it clear to the government and affected citizens alike that there is a need for more structurally sound and earthquake resistant construction, even in rural areas, it has also served to bring urbanized and university-educated architects and engineers into contact with the culture and indigenous building crafts characteristic of the rural regions. Most had long identified non-engineered traditional masonry construction of all types as archaic and unsuitable for contemporary living, particularly in an earthquake area, but after such a devastating earthquake, they could witness for themselves what survived and what failed. The interaction between the foreign humanitarian technical support teams both with the local engineers and government officials and the local population was crucial in what actually became a creative two-way technology transfer. Before either *dhajji* or *bhatar* could be adopted, both the foreign and the Pakistani professionals had to jettison their pre-existing prejudices to accept and improve upon premodern systems that were taught to them by the local people themselves. This stands as a remarkable example of openness, creativity, and acceptance at all levels.



3.3i & j Completed building with *bhatar* following the Pakistani government-endorsed guidelines constructed by SDC as a demonstration of approved *bhatar* detailing. Photos by Tom Schacher, SDC.



3.3k Cement blocks for housing reconstruction being moved by footpath to a remote site. Source: ERR4, 2007.

## NEW BHATAR BUILDINGS IN PAKISTAN



5.5h A new house with cator and cribbage timber lacing. The Balti word cator has the same meaning as the Pashto word bhatar. The regional difference is to have the extra reinforcement provided by the cribbage in the corners. This house was constructed for the former owner of the historic Altit Fort by the Aga Khan Cultural Services Division. Photograph by Tom Schacher, Swiss Agency for Development and Cooperation (SDC).



5.5i This new barn of bhatar with dry-laid stone masonry construction is in a mountain village near Battagram (in Gari Nuwab Said) in the Northwest Frontier Province of Pakistan. The site is remote from the road, one hour by car, then another half-hour by foot away from Battagram, making reinforced concrete construction impossible. Photograph taken in 2007 by Tom Schacher, Swiss Agency for Development and Cooperation (SDC).

### 3.6 A COMPARISON OF KASHMIRI TRADITIONAL CONSTRUCTION WITH THE PROVISIONS OF THE INDIAN BUILDING CODES

While the early recognition of the value of these traditional systems and their inclusion in the codes is significant, it is important to note some of the differences and missing elements in the codes when compared with the best examples of Kashmiri traditional construction. This section is not intended to be comprehensive, but to draw attention to details that are distinct attributes of traditional construction and of critical importance to good performance in earthquakes.

It is important to remember that codes are intended to be minimum standards, so that the absence of a particular detail from any code does not mean that the code is deficient for its purpose, or that the detail itself should not be considered as a way of improving building performance beyond that of the minimum.

3.6.1 FLOOR-LEVEL RING BEAM IN *TAQ* AND *DHAJJI* CONSTRUCTION: *IS 13827*, *IS 13827*, *Earthen Buildings* and *IS 13828*, *Low-Strength Masonry* deal with bearing wall masonry, and the timber section of *IS 4326* which includes “brick nogged timber frame construction”. Interestingly, all of these codes lack detailing of how the joists would be connected to the walls in multi-storey construction. *IS 13828* allows for construction of up to three complete storeys with a flat roof, or two storeys plus an attic in a pitched roof, but the illustrations and details showing the placement of the horizontal reinforcing bands show only one storey plus roof. For bearing wall masonry, the seismic bands in all of these codes are only shown as they would be for locations where the floor joists do not supplant the short connector pieces. In both the code sections on brick nogged construction and on timber frame construction, the method of connecting the floor joists securely to the walls is not illustrated or discussed.

As a result, the important feature of *taq* constructions where the floor joists extend through the wall between the timber runner beams embedded into the wall is missing from these codes. It is also missing from the 2005 *Guidelines for Earthquake Resistant Reconstruction and New Construction of Masonry Buildings in Jammu & Kashmir State*, which is based on those codes and allows two-storey plus attic gable construction in its provisions. This floor-to-wall connection detail is one of the most effective earthquake-resistant features of the *taq* and *dhajji dewari* systems. It



3.6.1 a, b & c Photographs showing construction details of *taq* buildings. The one on the far left shows the front wall perpendicular to the joists in a *taq* building, showing how the joists are sandwiched between the timber bands. The second shows how the secure connection of the joists to the front wall bridged the earthquake-collapsed rubble-stone side wall. The third show a *taq* building partly demolished, exposing the timber lacing in the wall parallel to the joists.

is essential for holding the building together and thus enabling the upper-floor and attic floor to work as diaphragms and resist the outward collapse of the exterior walls.

**3.6.2 CORNER VERTICAL REBAR IN TAQ CONSTRUCTION:** In *IS 13828*, low-strength masonry is defined as masonry laid in lime-sand or mud mortar. The code specifies that for this type of masonry a steel reinforcing rod should be placed vertically in the corner of the masonry walls, penetrating through the masonry and seismic bands from the foundation to the roof. It states: “Bars in different storeys may be welded or suitably lapped”.

Of course, the traditional *taq* buildings which meet the definition of “low-strength masonry” were devoid of steel reinforcing or vertical reinforcing of any kind. The question that arises, therefore, is whether this added steel is a critical improvement over the traditional method of reinforcing only with horizontal timbers. While the vertical steel may seem to be only a small addition in the overall total scheme, it represents a large conceptual difference in the way that the building is structured not only to resist earthquake vibrations, but also to settle and move over time, as it must be allowed to do.

In a newly constructed one- or two-storey house, if well constructed with cement or cement-lime mortar, and with other steel reinforcement in the masonry, vertical rebars in the corners may very well raise the threshold at which the shaking would trigger damage; but the question of whether the construction will in fact be done well is a very important concern, and the code approves the use of clay mud mortar for both brick and stone masonry. In the fine print of *IS 13828*, the weak mortar and the existence of voids in rubble stone masonry is recognized by the recommendation that these vertical bars be embedded in a sheath of concrete by placing a “casing pipe” around them and lifting the casing as concrete is poured into it so as to confine the concrete to the area around the bar.

When this corner vertical reinforcement is understood for what it is – as a series of thin reinforced concrete columns arranged deep in the fabric of the load-bearing masonry walls of the one-to-three-storey house – one can see that the building that is being constructed is no longer truly a bearing wall building. This is because these tall thin columns with their steel cores cannot move and compress over time in a way compatible with the stone or brick laid in mud mortar that surrounds them. Instead, the steel bar has a different coefficient of expansion than the surrounding masonry, and, together with its concrete jacket, it cannot compress as the masonry and mud mortar around it shifts and compacts over time. Thus, it may gradually take a larger percentage of the overburden loads as the masonry and the mortar compress. This can gradually disrupt the masonry in the corner of the building.



Fig 11.1: Essential Internal Elements in Buildings for Earthquake Safety

*3.6.1d This illustration from Ministry of Home Affairs Guidelines for Earthquake Resistant ...Masonry Buildings in Jammu & Kashmir State, by A.S. Arya, shows “seismic bands” as recommended for a two-storey building conforming to the Indian code. The seismic bands are important, but while much attention is given to vertical reinforcement of the corners (see Section 3.6.2), nothing is said about tying the floors to the walls through the floor-level bands. The floors are of major structural importance in earthquakes, and are critical to keeping a building from coming apart.*



*3.6.1e This is a section view of the house, the oblique view of which is shown in Figure 1.2d. This view provides the unique opportunity to see the entire dhajji structural system at its most basic pre-industrial level. Few of the timbers have been sawn or shaped, and many are thus curved to the shape of the trees from which they came. The floor joists, which run from left to right, can be seen where they penetrate the exterior façade on the right between the top plate of the frame from the floor below and the bottom plate of the frame of the floor above.*

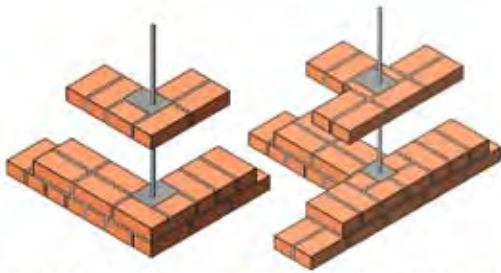


Fig.11.6: Recommended joint details with the vertical reinforcement at corner of brick masonry walls

3.6.2a Illustration from Ministry of Home Affairs Guidelines for Earthquake Resistant ...Masonry Buildings in Jammu & Kashmir State, by A. S. Arya. This kind of detail is recommended in the Indian Standard Building Codes and other documents, but its long-term efficacy is questionable (see Section 3.6.2).



3.6.2b This example of rusting steel demonstrates the expansion that occurs when the iron converts to an iron oxide (rust). The force of this on surrounding materials is sufficient to break any masonry or concrete cover.

In the event of an earthquake, the interface between this long thin column of the single steel bar in the concrete jacket can then be a zone of weakness in the critically important corners of the building because the column interferes with a proper strong bond pattern for the corner masonry between the timber bands.

In addition, cement is also incompatible with the mud mortars or weak lime mortars that are allowed in this same code. In the presence of moisture, the soluble salts in cement migrate out and crystallize, causing efflorescence that will gradually destroy the masonry and break down the surrounding mortar. Thus there is a significant danger of a rapid deterioration of the masonry walls. Moisture easily penetrates low-strength masonry. Normally this is not destructive, but when steel is introduced, the steel can rapidly become corroded in areas where the concrete sheath is cracked or inadequately filled when poured. This is inevitable in spite of the concrete sheath because the quality and consolidation of the concrete are likely to be compromised by the need to pack it into the small pocket, or even, in the case of rubble stone construction, pour it into the small casing tube.

The potential problems with this kind of detail are magnified by the code language that states that successive bars are to be “welded or lapped”. Welding of steel reinforcing is dangerous, yet illustration no. 11 in the code shows a bar in a tube that is too small to accommodate the lapping of two bars with sufficient space for protective concrete cover. Welding changes the molecular nature of the steel, potentially causing brittle fracture of the rebar. It also can cause rapid corrosion because of changes to the electrical potential in the steel. Enlarging the tube to accommodate the lapping of each successive rebar will displace even more masonry, while failure to fully accommodate the lap with adequate concrete cover over it, and the off-centre bar above and below the lap will lead to rapid corrosion because of inadequate protection by the concrete.

It is important also to recognize that placement of both the rod and concrete jacket are skilled trades that are more advanced and less widely known than those of those of timber and mud-mortar masonry construction. Welding is an even more specialized skill. In most environments where the population continues to build using the traditional technology of low-strength earthen, stone, or brick masonry, it is unlikely that their knowledge encompasses proper safe construction in reinforced concrete, especially for such small components in what otherwise is a timber and masonry construction project. As a result, the inclusion of the vertical rebar in the code brings

with it the substantial risk that, if executed in the field, the rural builders will only succeed in making their walls weaker, rather than stronger – even while adding substantially to the cost of the project.

Suffice it to say that if steel reinforcing had been available and used in the walls of the 19th- and early 20th-century *taq* houses, or for that matter the dome of the Pantheon in Rome, completed in AD 125 (Figure 5.2c), the bars would long ago have rusted, causing the walls to burst. Steel expands to many times its original dimension when converted from steel to iron oxide (rust), a process which exerts tremendous force onto confining materials (Figure 3.6.2c). Few of these buildings would be restorable today had this been done.

Ultimately, traditional construction typologies generally work best if one understands and thus maintains the integrity of each particular system rather than mixing it with potentially incompatible modern elements. This is particularly true for those traditional systems which have demonstrated structural attributes that have significantly reduced risk from different natural hazards such as earthquakes. The mixing of modern technologies, such as steel reinforcement inside a masonry wall, with traditional technology, such as the horizontal timber lacing in a low-strength masonry bearing wall, can radically change the behaviour of that wall in a way which can destroy the positive attributes of the older technology without effectively engaging the new. This is exactly what happened in Bam, Iran, where many of the houses collapsed during the 2003 earthquake, killing over 30,000 people. Almost all of these houses which collapsed were relatively new. Most had been constructed with unfired clay brick walls but had steel beams supporting heavy jack arch roofs of fired brick. These roofs were extremely rigid and strong, but lacked mechanical attachments to the unfired brick masonry walls, so they fell off the walls and crushed the occupants.

**3.6.3 HEIGHT OF TIMBER-LACED MASONRY BUILDINGS, INCLUDING *TAQ* AND *DHAJJI DEWARI*:** The timber construction section of Indian Standard code *IS 4326* begins with the statement that “timber has a higher strength per unit weight and is, therefore, very suitable for earthquake resistant construction”. This positive comment is followed by a surprising restriction: “timber construction shall generally be restricted to two storeys with or without the attic floor”. This is despite the fact that this type of combined construction has been common in many parts of the world for centuries, and has withstood earthquakes throughout the seismically active East European, Anatolian, and Central Asian regions. If timber is so suitable for earthquake resistance, is it not reasonable to ask: Why should timber and masonry buildings be limited to either one or two storeys? Two storeys is far less than what is allowed in other countries, including the United States, where timber construction even up to five storeys is



*3.6.3a A once splendid five-storey house of taq construction along side the Rainawari canal, Srinagar. These large houses in the Rainawari area are constructed on the very soft soils of what was once the middle of Dal Lake. The timber lacing is essential to their stability, and their age and durability demonstrates that multi-storey buildings of masonry and timber can be safely built.*



*3.6.3b A five-storey (including attic level) taq building and four-storey dhajji dewari building in the commercial centre of Srinagar. These and many others in Srinagar may be reminiscent of the kinds of buildings which astonished Kalhana in 1148, Tímúr in 1398 and Dughlat in 1540.*

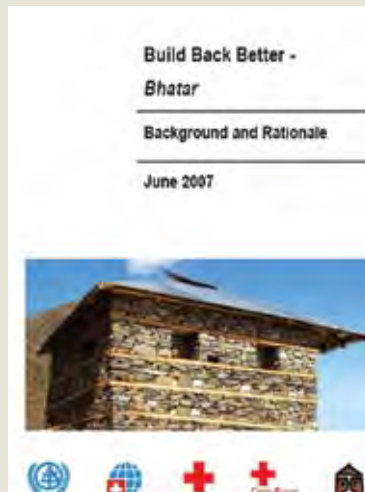


3.6.3c *The Gargoo Residence in Bulbul Lankar, Ali Kadal, Srinagar. This house is four storeys plus attic in taq construction, with a stone base and brick upper storeys. Photo by Akshay Kaul.*

common, and where historically it was often higher (see Figures 3.6g and 3.6h). If fire is the concern, the brick infill in brick nogged timber construction tends to slow down the spread of fire compared with the 100% timber construction with pocket walls that is common in North America. If maintained, wooden structures can last for hundreds of years (see Figures 5.5a & 5.6e).

On the issue of building height, it is worth noting the early observations quoted in the previous chapter from 1398 by Tímúr who observed that the buildings in Srinagar were “all of wood” and “they are four or five storeys high” (Elliot, 1867) and the other by Mirza Haider Dughlat (1540) who remarked on the “lofty...five storeys high buildings of fresh-cut pine” (Bamzai, 1994). If 16th-century timber buildings could exceed five storeys before there was modern firefighting apparatus, then why only two storeys now?

In any case, as remote as the older buildings in Srinagar and Baramulla seem from those that are illustrated in the Indian Standard Building Codes, it is still important to understand that these older buildings are part of a living tradition. The reason why the elements of their construction are in these codes is that certain scientists and engineers, with a knowledge of more than only steel and concrete, recognized aspects of these premodern systems as earthquake-resistant long before the 2005 earthquake. Perhaps it is now time to consider embracing the use of traditional materials and systems more widely and wholeheartedly, so that the full benefits of sustainable and environmentally less destructive construction practices can be obtained.



3.3l This report was produced by UN-HABITAT for the Pakistan Government.

### ENGINEERING RESEARCH AT IIT-ROORKEE



3.3m & n Full-size models of rubble stone low-strength masonry houses, 3.3m with seismic bands, and 3.3n the same construction but without seismic bands. Both were tested on the IIT-Roorkee shock table. Source: Agarwal et al, 2002.

## A STRUCTURAL ENGINEERING REVIEW OF WHY BHATAR PERFORMS WELL IN EARTHQUAKES

EXCERPTS FROM: *BUILD BACK BETTER – BHATAR: BACKGROUND AND RATIONALE*, BY, DOMINIC DOWLING PHD, ENGINEER, PIERRE-YVES PERE, ARCHITECT, FRENCH RED CROSS, AND PIERRE PERRAULT, ENGINEER, BELGIAN RED CROSS, FOR UN-HABITAT, JUNE 2007.

**4.1 Structural Components:** The *bhatar* system consists of stone masonry walls reinforced with horizontal timber ladder-bams, which combine to resist and dissipate the energy induced during an earthquake....

**4.2 Structural Characteristics:** 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 is provided by the horizontal timber elements... embedded in the wall... a similar structural function as reinforced concrete beams/bands in reinforced or confined masonry.
- (2) Resistance to out-of-plane... **overturning**... is provided by the inherent stability of the walls with a height to thickness ratio commonly ranging from 4 to 6.
- (3) Resistance to ... shear forces is provided by the inherently high friction in the system.
- (4) Resistance to vertical corner cracking (the most common and critical damage pattern in unreinforced masonry walls) provided by the interconnected *bhatar* bands at the corners.
- (5) Resistance to delamination of the masonry walls... is provided by the *bhatar* bands...
- (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.

The fundamental principle of the *bhatar* system is dissipation of energy through friction (shear). Physical bonds exist between the different components, so the shear capacity of the structure is proportional to the coefficient of friction between adjoining elements (stone-stone and stone-timber), the cross-sectional area of the wall, and the gravitational load. For *bhatar* structures, all of these factors are inherently present (dry-stacked stone masonry, interlocking timber elements, and wide and heavy walls) so the capacity for dissipation of energy through friction is very high.<sup>10</sup>

**4.3 Structural Calculations:** 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 behaviour 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.

## APPENDIX 2:



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### A summary of article

**“An experimental study of effectiveness of seismic and retrofitting measures in stone masonry houses”**

**by Pankaj Agarwal and Shashi K. Thakkar,  
Department of Earthquake Engineering, IITR, Roorkee, India,**

**from *European Earthquake Engineering* 16(3) 2002.**

**A summary of article “An experimental study of effectiveness of seismic and retrofitting measures in stone masonry houses”, by Pankaj Agarwal and Shashi K. Thakkar, Department of Earthquake Engineering, IITR, Roorkee, India, from *European Earthquake Engineering* 16(3) 2002.**

Stone masonry is one of the most traditional and oldest materials of construction in hilly and rural parts of India. Past earthquakes that have occurred in the Indian subcontinent particularly Uttarkashi, 1991, Killari, 1993, and Chamoli, 1999 reveal that the root cause of devastation is the collapse of stone masonry houses. Therefore, the earthquake resistance of such construction should be enhanced. Strengthening and retrofitting are the two most vital issues for minimizing disaster. Strengthening implies incorporation of earthquake resistant features in the structural system of a newly constructed building that improves its seismic resistance by increasing strength and ductility.

We carried out a series of tests on full-scale single storey random-rubble stone masonry models under progressively increased intensity of shocks on a shock-table facility. The purpose of this study was to evaluate existing IS code techniques of strengthening and retrofitting measures and to propose upgrading these methods to achieve better performance in earthquakes.

**Models for strengthening and retrofitting measures**  
Six stone masonry models in random rubble are tested on a shock-table facility to study the effectiveness of codes providing for earthquake resistance measures. One model is built in a traditional way without any strengthening measures while the other models featured gradually increasing strengthening arrangements like roof, lintel and sill bands, and corner reinforcement. Two damaged models are retrofitted by combinations of two different techniques.

**Design and Construction of Model**

The model is single storeyed one room house measuring 2900x2600x2700mm and thickness of walls is 400mm constructed in random rubble stone masonry. The layout plan and section of the model is given in Figs. 1 and 2

The method of strengthening recommended in IS code is based on the following concepts:

- Need of integral action,
- Strong and ductile connections between walls, roof elements and foundations,
- Improvement in strength for out-of-plane bending,
- Strengthening of weaker sections by steel, timber or reinforced concrete and
- Improving the strength of mortar and quality of construction and insertion of bonding elements.

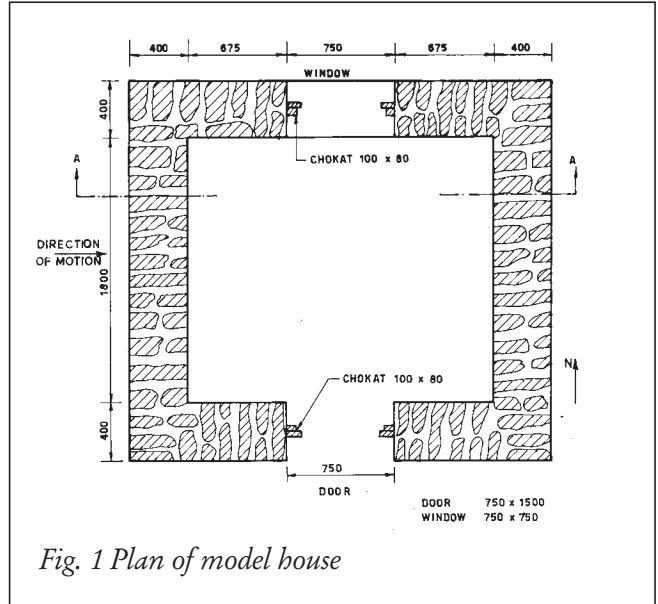


Fig. 1 Plan of model house

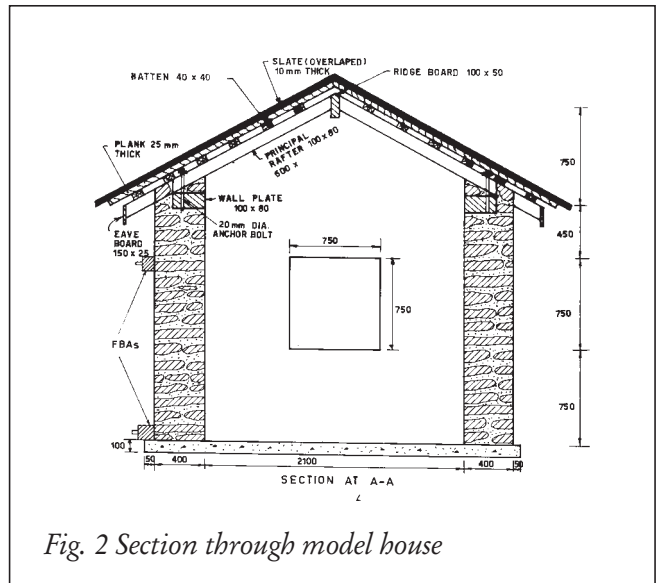


Fig. 2 Section through model house

The Indian Standard Code IS: 13828: 1993, *Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines* furnishes the details of strengthening measures. The function and brief description of each strengthening measure are summarized as follows:

**Mortar:** The stone masonry of random rubble or dressed stone type should be constructed in cement-sand (1:6), lime-sand (1:3) or clay-mud of good quality.

**Wall Dimensions:** The height and length of the wall should be less than 3m or 5m respectively. The wall thickness should not be larger than 350mm and inner and

outer wythe interlocked with bond stones. The bond stones (through-stones) of full-length equal to wall thickness should be used in every 600mm lift at not more than 1.2m horizontally.

**Wall Openings:** Door and window openings in walls reduce their lateral load resistance and hence should preferably be small, not more than 40% of wall area, and placed centrally. If openings do not comply with the code, they should be strengthened by reinforced concrete lining with 2 high-strength deformed bars of 8mm diameter.

### Seismic strengthening features

The building should be strengthened by horizontal bands or bond beams at critical levels and vertical reinforcing bars at corners and junctions of walls. The bands form a horizontal framing system, which transfers the horizontal shear, induced by the earthquakes from the walls normal to the direction of shaking to structural walls parallel to the shaking, and it also connects all the structural walls to improve integral action. In combination with vertical reinforcement, they improve the strength, ductility and energy dissipation capacity of masonry walls. Fig. 3 shows the details of horizontal bands at the level of the roof, lintel and sill. Fig. 4 furnishes the details of providing the vertical reinforcement in stone masonry.



Fig. 3 Detail of horizontal band

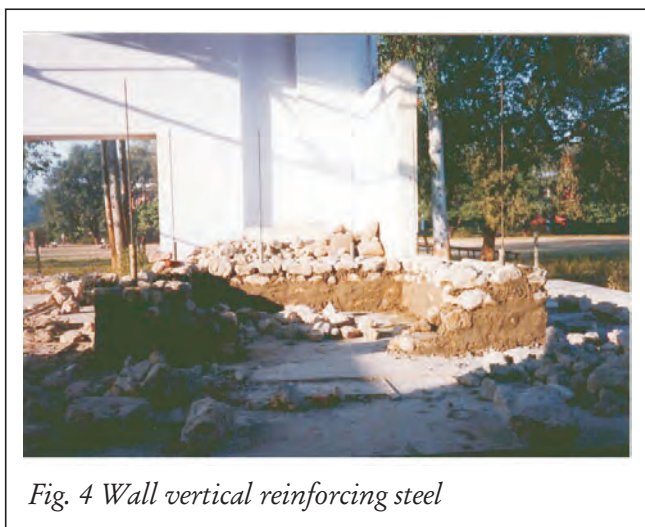


Fig. 4 Wall vertical reinforcing steel

### Shock table tests on models

The facility consists of following components:

- Railway track,
- Shock table,
- Dead-load wagons or striking wagons,
- Winch mechanisms to pull wagons

The loaded wagons are placed on the track on both sides of the shock table. One of the loaded wagons is allowed to roll down the gentle incline, impact through springs and thus drive the shock table into collision with the other dead-load wagon. The general arrangement of the shock table and its signature of shock are given in Figs.5 and 6.

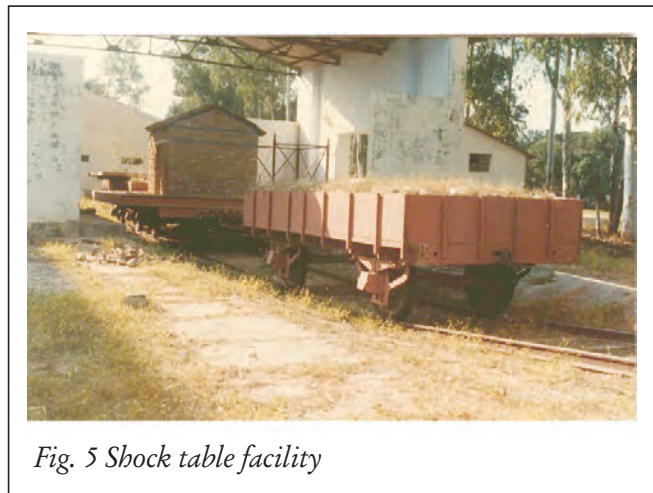


Fig. 5 Shock table facility

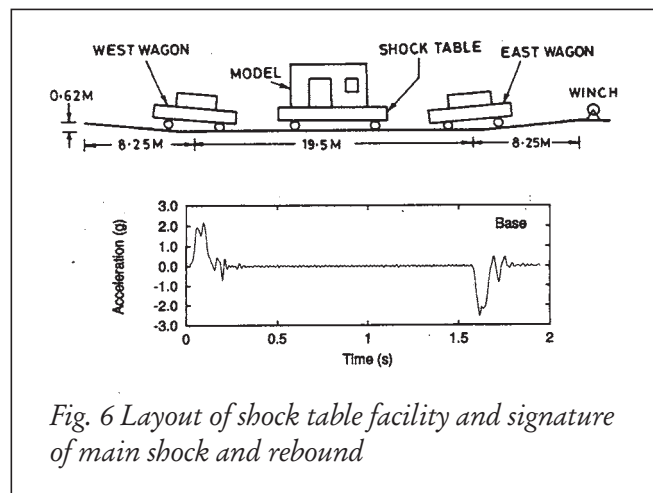


Fig. 6 Layout of shock table facility and signature of main shock and rebound

Shock test results are shown in Figs. 7 to 10.

### Conclusions

Through the number of tests are too few to make generalized conclusions about the behaviour of stone masonry building under earthquake type motion, some important conclusions can be made on the shock response of stone masonry models and are highlighted below:

- Code provisions are effective in reducing the damage mainly above lintel level. Brittle shear failure in wall piers still occurs but can be



*Fig. 7 Partial collapse below lintel band*



*Fig. 8 Positive action of bands reduces damage sharply*

reduced by providing an additional horizontal band, preferably at sill level. The vertical reinforcement at the corner of the model, in combination with horizontal bands increases the strength of the model as well as reduces cracking at corners.

- The provision of a seismic band at lintel level is the minimum requirement to prevent the collapse of the house in random rubble stone masonry models made in mud or cement sand mortar. The mere use of rich mortar without any other earthquake resistance measure is not adequate to prevent collapse of structures.
- The injection of cement grout in localized damaged areas can restore the original strength and stiffness. The scheme of repair involving stitching of corners of walls avoids delamination of walls during shock test.
- The external binding scheme of retrofitting is effective for increasing the strength beyond that of the original system, as cracks in the retrofitted models occur in new positions instead of the regions of previous cracks. The introduction of external horizontal tie bars helps reduce further cracking because of the ties

of the walls behaving similarly as a band and are capable of resisting bending moment due to out-of-plane vibration of the wall. Moreover, external binding with welded wire mesh in damaged region not only increases the lateral resistance of the wall but also prevents shear and flexure failure of the models.

- The acceleration pattern along the height of the model generally shows that prior to cracking the acceleration at the top of the model is higher than that at the base but after cracking the acceleration at the top of the model is smaller than that at the base of the model. It is also observed that after cracking of the model the ratio of roof to base acceleration decreases in successive shocks for the same model. This indicates that the damaged lower portion of the model functioned as a kind of base-isolator that prevented the propagation of energy into the upper portion.

For a full copy of the paper, please contact the author at: [panagfeq@iitr.ernet.in](mailto:panagfeq@iitr.ernet.in)



*Fig. 9 Unstrengthened house of cement-sand mortar*

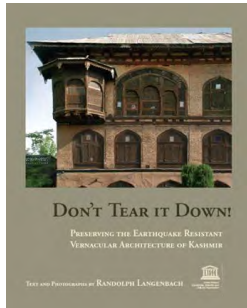


*Fig. 10 Unstrengthened house constructed with mud mortar*

## APPENDIX 3:

### 3.A: FLOOR DIAPHRAGM TIES

EXCERPTS From



Page 58 showing the **BUILDING CODE COMPARISON** dealing with traditional *taq* construction:

#### A Comparison of Kashmiri Traditional Construction with the Provisions of the Indian Building Codes

While the early recognition of the value of these traditional systems and their inclusion in the codes is significant, it is important to note some of the differences and missing elements in the codes when compared with the best examples of Kashmiri traditional construction. This section is not intended to be comprehensive, but to draw attention to details that are distinct attributes of traditional construction and of critical importance to good performance in earthquakes.

It is important to remember that codes are intended to be minimum standards, so that the absence of a particular detail from any code does not mean that the code is deficient for its purpose, or that the detail itself should not be considered as a way of improving building performance beyond that of the minimum.

**Floor-Level Ring Beam in *Taq* and *Dhajji* construction:** *IS 13827*, *IS 13827*, *Earthen Buildings* and *IS 13828*, *Low-Strength Masonry* deal with bearing wall masonry, and the timber section of *IS 4326* which includes "brick nogged timber frame construction". Interestingly, all of these codes lack detailing of how the joists would be connected to the walls in multi-storey construction. *IS 13828* allows for construction of up to three complete storeys with a flat roof, or two storeys plus an attic in a pitched roof, but the illustrations and details showing the placement of the horizontal reinforcing bands show only one storey plus roof. For bearing wall masonry, the seismic bands in all of these codes are only shown as they would be for locations where the floor joists do not supplant the short connector pieces. In both the code sections on brick nogged construction and on timber frame construction, the method of connecting the floor joists securely to the walls is not illustrated or discussed.

As a result, the important feature of *taq* constructions where the floor joists extend through the wall between the timber runner beams embedded into the wall is missing from these codes. It is also missing from the 2005 *Guidelines for Earthquake Resistant Reconstruction and New Construction of Masonry Buildings in Jammu & Kashmir State*, which is based on those codes and allows two-storey plus attic gable construction in its provisions. This floor-to-wall connection detail is one of the most effective earthquake-resistant features of the *taq* and *dhajji dewari* systems. It is essential for holding the building together and thus enabling the upper-floor and attic floor to work as diaphragms and resist the outward collapse of the exterior walls.



3.6.1 a, b & c Photographs showing construction details of taq buildings. The one on the far left shows the front wall perpendicular to the joists in a taq building, showing how the joists are sandwiched between the timber bands. The second shows how the secure connection of the joists to the front wall bridged the earthquake-collapsed rubble-stone side wall. The third show a taq building partly demolished, exposing the timber lacing in the wall parallel to the joists.

## 3.B: VERTICAL REINFORCEMENT

My criticism of vertical reinforcement in rubble masonry walls is also shared by Dominic Dowling, PhD Structural Engineer for UN-HABITAT, Pierre-Yves Pere, Architect, Reconstruction IC Coordinator for French Red Cross, Pakistan, and Pierre Perrault, Engineer and Construction Delegate for the Belgian Red Cross, Pakistan in their 2007 report on *bhatar* construction in Pakistan after the 2005 earthquake. The same can be said for Gabion Band construction, as well as other timber laced construction in Nepal.

*Vertical reinforcement is commonly provided in structures to resist out-of-plane bending and overturning, and in-plane and out-of-plane shear forces. In the case of bhatar structures, vertical reinforcement is not necessary because these forces are resisted by the combination of wide, heavy walls, and horizontal timber elements (as described above). ...*

*Inclusion of a continuous vertical connection between the timber bhatar beams reduces the capacity of the system to dissipate energy through moderate lateral movement of the stone and timber elements. The vertical reinforcement will also carry some gravity loads of the structure, thus reducing compression in the walls, further decreasing the important friction between the stone elements and timber beams.*

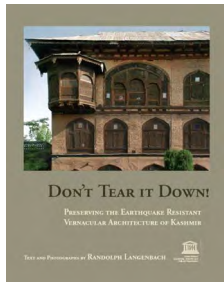
*Research has shown that vertical timber reinforcement embedded within masonry walls has a tendency to cause damage to structures, even during low intensity ground motion, due to the differential response between the flexible timber elements*

and the stiff masonry walls. This feature introduces discontinuities within the structure, thus reducing the overall seismic capacity.

The full report can be found at: [http://www.traditional-is-modern.net/LIBRARY/PAKISTAN-reconstruct/07\(06-29\)DOWLING-Bhatar.pdf](http://www.traditional-is-modern.net/LIBRARY/PAKISTAN-reconstruct/07(06-29)DOWLING-Bhatar.pdf)

As a further note on the topic of the vertical reinforcement, after leaving Nepal in August I met with emeritus professor Anand Arya in New Delhi, who at the age of 85 still goes to work each day at the Habitat Centre. He is the co-author of the Indian Building Codes and also the Nepal Building Codes. When I asked him about the vertical rebars in stone masonry and expressed my concerns, he said that the reason for it was the possibility of flexural behavior of the masonry walls in certain buildings where the walls were tall and not so wide such that flexural rocking behavior would be expected. In these instances, I recommend that the external tying of the Gabion Bands with wires and cables can address this concern, without the risk of the problems described in the UNESCO pages above.

EXCERPTS showing the **BUILDING CODE COMPARISON** dealing with traditional *taq* construction:



Page 59 showing the **BUILDING CODE COMPARISON** dealing with traditional *taq* construction:

**3.6.2 Corner Vertical Rebar in *taq* construction:**

In *IS 13828*, low-strength masonry is defined as masonry laid in lime-sand or mud mortar. The code specifies that for this type of masonry a steel reinforcing rod should be placed vertically in the corner of the masonry walls, penetrating through the masonry and seismic bands from the foundation to the roof. It states: “Bars in different storeys may be welded or suitably lapped”.

Of course, the traditional *taq* buildings which meet the definition of “low-strength masonry” were devoid of steel reinforcing or vertical reinforcing of any kind. The question that arises, therefore, is whether this added steel is a critical improvement over the traditional method of reinforcing only with horizontal timbers. While the vertical steel may seem to be only a small addition in the overall total scheme, it represents a large conceptual difference in the way that the building is structured not only to resist earthquake vibrations, but also to settle and move over time, as it must be allowed to do.



Fig. 11.1 Essential Internal Elements in Buildings for Earthquake Safety

3.6.1d This illustration from Ministry of Home Affairs Guidelines for Earthquake Resistant ...Masonry Buildings in Jammu & Kashmir State, by A.S. Arya. Shows “seismic bands” as recommended for a two-storey building conforming to the Indian code. The seismic bands are important, but while much attention is given to vertical reinforcement of the corners (see Section 3.6.2), nothing is said about tying the floors to the walls through the floor-level bands. The floors are of major structural importance in earthquakes, and are critical to keeping a building from coming apart.