Build Back Better -

Bhatar

Background and Rationale

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Abstract

Bhatar is a traditional construction system consisting of stone masonry walls reinforced with horizontal timber ladder-beams, which combine to resist and dissipate the energy and stresses induced during an earthquake.

This document describes the background and rationale of the *bhatar* system, including:

- History and development.
- Needs assessment and context (including climate, cost and culture).
- Impact assessment (including environmental and socio-political).
- A detailed discussion of the structural components and characteristics of the *bhatar* system, plus commentary on the challenges of undertaking reliable structural calculations, and the rationale for excluding vertical reinforcement. Common problems with modern *bhatar* construction are also presented.
- A discussion of the advantages and disadvantages of alternative construction types, including reinforced masonry, confined masonry, timber frame *dhajji* construction, and unreinforced stone masonry and *bhatar*-like structures, plus a comment on the opportunity for sustainable reconstruction.
- A proposed *bhatar* training strategy, which incorporates general community announcements, training workshops, and educational material.

These components confirm the critical need to provide timely and adequate advice to home builders on safe *bhatar* construction, especially in isolated rural areas of Pakistan where there is simply no viable construction alternative.

This document complements the simple manual, *Bhatar construction: Timber reinforced masonry. An illustrated guide for craftsmen*, which has been developed through a long process of field observations, research and stakeholder consultation across all levels, This information has been consolidated in this document: *Build Back Better – Bhatar: Background and Rationale.*

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1 Background and history

Bhatar is a traditional construction system consisting of stone masonry with horizontal timber reinforcement bands. This type of construction has been extensively used in Turkey, Afghanistan, Pakistan, India and Nepal for many centuries. Studies by Hughes[1] and Langenbach[2] describe the long history of *bhatar*-style construction, and its resilience to the effects of earthquakes.

Such evidence can be seen in historic and contemporary *bhatar* constructions in the north of Pakistan. These include high-profile heritage sites like Baltit Fort and Besham Fort (Figure 1), as well as numerous houses and commercial buildings in the areas affected by the October 2005 earthquake.

Although there is a strong tradition of *bhatar* in Pakistan, in recent times the fine skill in *bhatar* construction has diminished. This may be attributed to rapid population expansion, 'forgotten' memory of the threat of earthquakes, and a tendency towards the use of so-called 'modern' materials (fired brick, cement and steel). These factors have combined to produce poor workmanship and mixed constructions, with many of the critical details of traditional *bhatar* construction missing from new buildings.

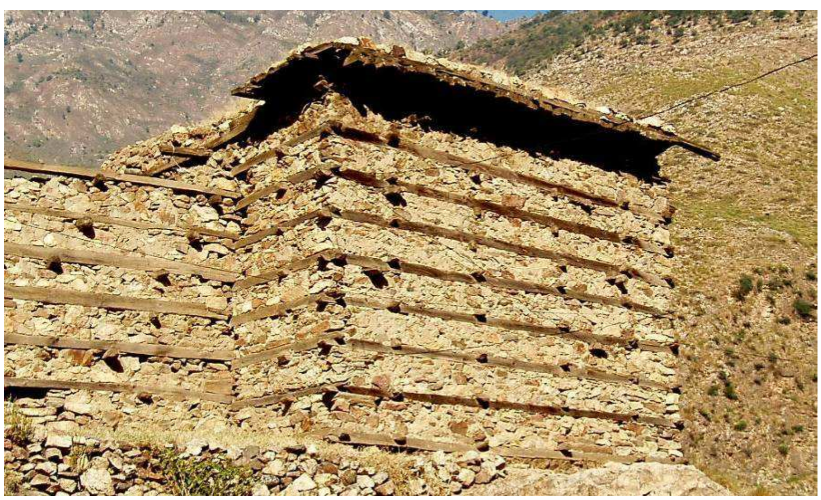

Figure 1. Besham Fort, NWFP, Pakistan (c. 1750).

[1] Hughes, R. (2005) *Vernacular Architecture and Construction Techniques in the Karakoram*, In Karakoram: Hidden Treasures in the Northern Areas of Pakistan. (Stephano Bianca, ed.) Torino: Umberto Allemandi & C. for The Aga Khan Trust for Culture, 99-132.

[2] Langenbach, R. (2007) *Guidelines for preserving the earthquake-resistant traditional construction of Kashmir,* UNESCO, New Delhi, 154p.

2 Needs assessment

The *bhatar* system has been developed over many centuries, taking into account the local context and needs, including climate, cost and culture. These factors are still relevant in current times, especially in remote and traditional regions. In spite of the variety of construction alternatives, there is little doubt that *bhatar* will continue to be the construction form of choice for these isolated rural communities. This highlights the importance of providing adequate guidance and support to ensure proper *bhatar* construction.

2.1 Climate

Bhatar is commonly used in high altitude regions where temperatures range from -15℃ to +40℃. In the winter, snowfalls of s everal feet are also common. The *bhatar* walls and flat earth roof have high thermal mass, which serves to regulate the temperature, thus reducing internal heat during summer, and cold during winter (which also reduces fuel heating costs). A well-plastered *bhatar* wall resists water penetration from rain and accumulated snow.

2.2 Cost

In isolated and mountainous areas, material transport costs can be prohibitive. In the aftermath of the October 2005 earthquake, the cost of ‘modern’ materials (cement, steel, concrete blocks, fired bricks) significantly increased. Even simple materials such as sand and gravel are not locally available and must be processed and transported from distant locations. This factor, coupled with the low income levels in these regions, mean that an affordable housing solution is necessary.

2.3 Culture

Bhatar is a well-established technique, linked with the cultural identity of the population. *Bhatar* houses are locally preferred because the solid, thick walls provide security (resist penetration of bullets) and thermal comfort. The typical flat earth roof provides a practical space which is used for agricultural purposes (drying crops) and social gatherings.

3 Impact assessment

3.1 Environmental

The *bhatar* technique is considered to be an environmentally sound form of construction. Indeed, timber is one of the most sustainable building materials available, and the other materials required (stone and soil) are plentiful in the regions of interest, and have minimal environmental impact.

In the earthquake affected areas, timber salvaged from damaged houses is considered to be sufficient to supply the needs for new *bhatar* construction, especially with a significantly reduced amount of timber in the roof in the proposed guidelines. Training in improved *bhatar* construction also provides an opportunity to educate local communities about deforestation, reforestation and sustainability.[3]

'Modern' materials (e.g. cement, steel and fired-bricks) have very high embodied energy[4], especially in isolated rural areas, where materials must be transported in multiple stages over difficult terrain (e.g. by truck, jeep and foot/donkey). In consideration of the overall environmental impact, the *bhatar* technique is the most appropriate option in such regions.

3.2 Socio-political

In recent times, it has been widely reported that the *bhatar* technique is on the verge of being officially approved. Many affectees have been awaiting this confirmation prior to commencing construction of their houses. It is anticipated that further delays, or non-approval of the technique will result in substantial unrest in the affected areas.

[3] Refer to Page 11 of the bhatar booklet *Bhatar construction: Timber reinforced masonry. An illustrated guide for craftsmen.*

[4] "Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery." (http://www.greenhouse.gov.au/yourhome/technical/fs31.htm)

4 *Bhatar* system

4.1 Structural components

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

<u>Stone masonry:</u>

The stone masonry walls are generally 18+ inches wide, built with dry-stacked stone masonry. Walls are constructed using two rows (wythes) of stones which are slightly inclined towards the centre of the wall. This configuration can sustain very high compressive loads, due to the orientation of the stones which interlock when subjected to vertical loads. Through-stones (across the full width of the wall) interconnect the wythes, and reduce out-of-plane delamination of the wythes (a common problem with poorly constructed stone masonry walls). Corner stones provide stronger links at the corners and avoid continuous vertical joints.

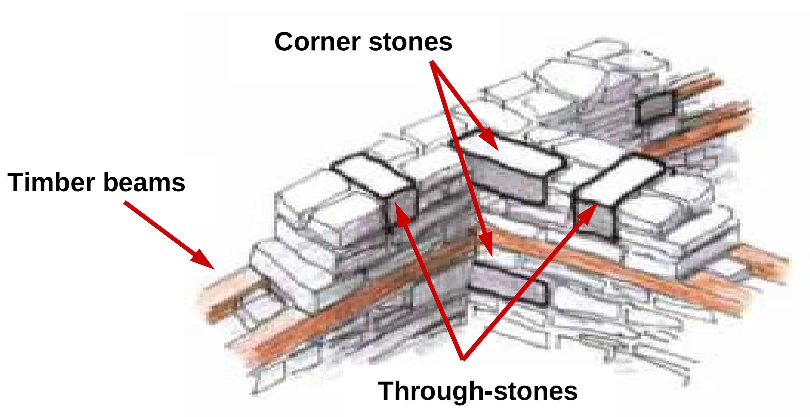

Figure 2. Stone masonry wall with through-stones and corner stones.

In some cases a weak mud or lime mortar is used, although this often reduces the quality of masonry because less care is taken in the placement of the stones. The use of cement-based mortar is not advocated because it results in a stiff connection which diminishes the capacity of the structure to dissipate energy through friction generated between the stones.

Timber *bhatar* bands

The *bhatar* bands are continuous timber ladders which are laid in the stone masonry wall at two feet vertical spacing. The ladders consist of two longitudinal timber beams (3" x4") with timber cross pieces (3" x 4") at three feet horizontal spacing (Figure 3). The ladders are crossed and connected at the corners (Figure 4).

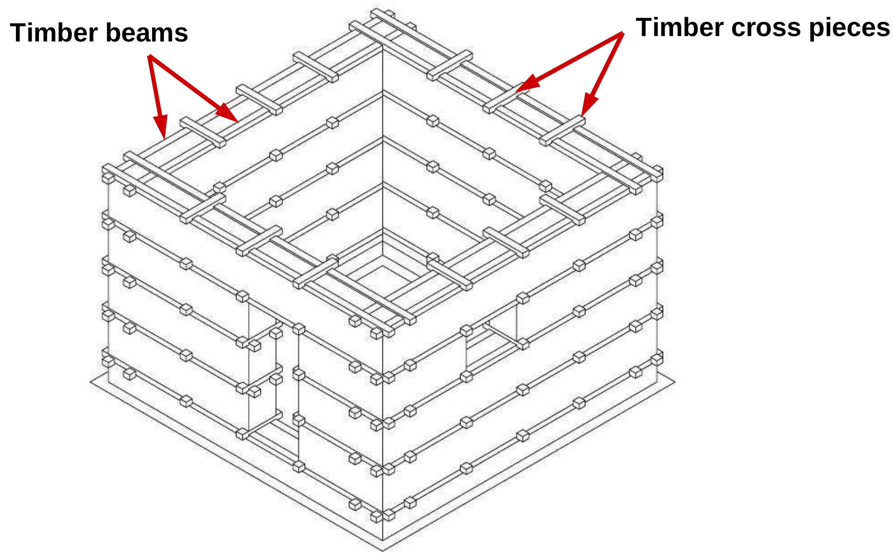

Figure 3. *Bhatar* band configuration, including timber beams and cross pieces.

Figure 4. Configuration of *bhatar* bands and stone masonry.

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 (about the vertical axis) is provided by the horizontal timber elements (strong tensile capacity), which are embedded in the wall. In this sense, the *bhatar* bands provide a similar structural function as reinforced concrete beams/bands in reinforced or confined masonry.

2. Resistance to out-of-plane bending and overturning (about the horizontal axis) is provided by the inherent stability of the walls (with a height-thickness ratio commonly ranging from 4 to 6)[5].

3. Resistance to in-plane and out-of-plane shear forces is provided by the inherently high friction in the system, again a feature of the width, weight and configuration of the walls (described below).

4. Resistance to vertical corner cracking (the most common and critical damage pattern in unreinforced masonry walls) is provided by the interconnected *bhatar* bands at the corners, which ensure a strong connection between orthogonal walls.

5. Resistance to delamination of the masonry walls (another common damage pattern in two wythe unreinforced masonry walls) is provided by the *bhatar* bands, plus inclusion of through-stones, which serve to tie together both wythes of the stone masonry.

6. Resistance to cyclic loading is provided by the timber elements (which possess excellent tensile and elastic characteristics), and the friction within the stone masonry.

[5] See <Tolles, E.L., Kimbro, E.E., Webster, F.A. and Ginell, W.S. (2000) Seismic stabilisation of historic adobe structures, The Getty Conservation Institute, Los Angeles, California, 158p.> for a detailed discussion of stability of stout masonry walls.

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 co-efficient 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.

The configuration of horizontal timber ladder-beams have been included in international standards for earthquake resistant construction, including the IAEE *Guidelines for earthquake resistant non-engineered construction*[6] and the Indian Standard IS13828:1993 *Improving earthquake resistance of low strength masonry buildings – guidelines*[7]. Inclusion in these guidelines demonstrates the acceptance of the proposed reinforcement system.

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 (as described in Section 1).

[6] IAEE, International Association for Earthquake Engineering (1986) *Guidelines for earthquake resistant non-engineered construction*, IAEE, Tokyo, 158p.

[7] BIS, Bureau of Indian Standards (1993) *Indian Standard IS13828: Improving earthquake resistance of low strength masonry buildings – guidelines,* BIS, New Delhi, 13p.

4.4 Vertical reinforcement:

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).

Vertical reinforcement is not traditionally used in *bhatar* constructions in the NWFP region of Pakistan. 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[8]. This feature introduces discontinuities within the structure, thus reducing the overall seismic capacity.

Vertical timber posts are often included in *bhatar* constructions to provide additional support to the roof structure, especially in large rooms. These timber posts are independent of the walls, and are not considered to provide vertical reinforcement *per se*, to the *bhatar* walls.

[8] Dowling, D.M., Samali, B. and Li, J. (2005) *An improved means of reinforcing adobe wall units – external vertical reinforcement*, Proceedings of SismoAdobe 2005, Lima, Peru, 16-19 May 2005.

4.5 Common problems

In recent times, the fine skill of *bhatar* construction has been gradually reduced. Since the October 2005 earthquake, new *bhatar* houses have been built to replicate the traditional style, however important details are often missing. Common problems in new *bhatar* constructions include:

1. Absence of strong connections between timber elements (beam-cross piece connections, beam-beam connections at corners, and beam-beam lapped connections, Figure 5).

2. Poor quality stone masonry, consisting of rounded stones, and/or missing through-stones or corner stones (Figure 5).

3. Poor alignment of beam-beam lapped connections creating vertical planes of weakness (Figure 5).

4. Use of mixed techniques, such as half-*bhatar*, half-concrete houses, which introduce discontinuities and inconsistencies in dynamic response.

These defects significantly compromise the structural integrity of *bhatar* houses. Considering that affected populations in isolated areas will invariably build back using the *bhatar* technique, it is most important that these common problems are addressed, and the skill in *bhatar* construction is renewed.

Figure 5. Common defects in modern *bhatar* constructions: poor connection between timber elements, poor alignment and connection of beam laps, and lack of through-stones.

5 Alternative construction types

A number of alternative construction types exist for the reconstruction of earthquake affected houses. These include reinforced masonry, confined masonry and timber-framed *dhajji* construction (all of which have been approved as part of the ERRA reconstruction policy), plus unreinforced stone masonry and *bhatar*-type constructions, which have been historically used in the affected regions. Since the earthquake, the 'Build Back Better' reconstruction approach has focused on improving the quality of materials and the quality of construction (with emphasis on the use of 'modern' materials and techniques). In remote areas, however, much of the effort and funds have been directed towards the acquisition of such materials (with high transport costs), with less resources directed to construction quality. This has led to an abundance of unsafe and non-compliant houses, with mixed and misunderstood construction systems of very poor quality and limited structural capacity.

5.1 Reinforced masonry / confined masonry

Reinforced masonry and confined masonry constructions consist of stone, fired brick or concrete block masonry with vertical and horizontal reinforcing elements (steel bars and concrete). Promotion and training in these techniques have led to acceptable results in areas where there is good vehicular access. In remote regions where access is difficult (and often only possible using a combination of jeep and donkey) the transport of substantial quantities of materials is a significant problem. (In excess of 20 tonnes of materials are required for the construction of a standard 12 ft x 12 ft reinforced/confined masonry house). Furthermore, there is a lack of skill and experience in the use of 'modern' materials in these regions. These factors combine to produce large stocks of very unsafe new houses which will be unlikely to resist future major earthquakes. Some of the common construction deficiencies include:

1. Poor quality concrete, due to a reduction of cement content, use of locally available sand (which may be high in clay, silt and organic compounds), reduction or absence of gravel, and lack of proper curing.

2. Inadequate beams and columns, due to a reduction of member size, and/or reduction or absence of steel reinforcement.

3. Poor quality masonry construction, including insufficient brick/block alignment, very thin mortar joints, and low strength mortar.

4. Use of mixed construction techniques, which introduce weaknesses and differential structural responses during ground shaking.

5. Misunderstanding of principles and techniques of 'modern' construction, including quality of materials, quality of workmanship, and connections details.

5.2 Timber frame *dhajji* construction

Dhajji is a traditional form of construction in the AJK region of Pakistan, which consists of a timber lattice framework with tightly packed in-fill stone masonry. This technique has been largely rejected in NWFP for a variety of cultural and practical reasons, including:

1. No prior use of this technique. The *dhajji* system relies on good joint detailing and carpentry skills, which are not commonly found in NWFP.

2. Perception that *dhajji* houses are not secure from intruders, based on the thin 4" walls being unable to resist outside aggression, including penetration by bullets.

3. Climatically inappropriate in regions of high snow fall and large temperature variations.

5.3 Unreinforced stone masonry and *bhatar*-like structures

In remote areas, where people have very little or no source of income, they will invariably reconstruct their houses using locally available materials and traditional techniques. In the earthquake affected areas there is a widespread mistrust of unreinforced stone masonry, and renewed interest in *bhatar* construction. However, many of the fine skills in *bhatar* construction have been lost in recent times, so a variety of *bhatar*-type houses are being built which lack many of the key seismic elements (as described in Section 4.5

above). These houses present a significant danger in future earthquakes, and highlight the need for proper training and support.

5.4 Sustainable reconstruction

The earthquake reconstruction process in Pakistan provides an opportunity for sustainable action. In addition to the immediate focus on housing reconstruction (under the banner of 'Build Back Better') is the opportunity to provide long-term improvements in housing construction practices. The memory of the earthquakes is still relatively fresh in the minds of those affected, and this presents an ideal context for the promotion of earthquake safe construction techniques. The construction guidelines issued and money allocated to affected families as part of the ERRA reconstruction framework has resulted in unprecedented, rapid construction using so-called 'modern' materials (cement, steel, fired brick). This approach has produced both positive outcomes (general achievement of the 'Build Back Better' philosophy), as well as negative outcomes, including a lack of understanding of the principles of 'modern' construction, and a loss of skill in traditional construction techniques. These negative aspects have a long-term impact, especially in rural areas, where resource limitations mean that future construction will revert to low-cost and traditional techniques, the skill in which is being progressively lost.

6 *Bhatar* training strategy

The objective of the proposed *bhatar* training program is to improve the standard of *bhatar* construction in rural areas of earthquake-affected Pakistan, especially in NWFP where there is a strong tradition of *bhatar* construction. The key activities and resources for effective *bhatar* training include:

1. General community announcements, confirming the official status of *bhatar* construction, as well as outlining the process and key requirements to ensure safe and compliant construction. This may take the form of media announcements, billboards and information flyers.

2. Training workshops incorporating elements of simple theory and background, combined with practical demonstrations and hands-on training. Training will be tailored to the specific requirements and experiences of different stakeholders (including partner organisations, compliance inspection teams, technical experts, master trainers, field technicians, masons and home-owners). This process will be based on the existing programs related to training in confined masonry, reinforced masonry and *dhajji* construction.

3. Educational material, consisting of construction booklets and posters, which describe the key features of the system, and serve to supplement the detailed training workshops described above. The *bhatar* construction manual, *Bhatar construction: Timber reinforced masonry. An illustrated guide for craftsmen*, is an example of this type of educational material. This manual has been developed through a long process of field observations, research and stakeholder consultation across all levels.

Figure 6. Hands-on *bhatar* training workshop.

7 Summary and conclusions

Bhatar is a traditional construction system consisting of stone masonry walls reinforced with horizontal timber ladder-beams, which combine to resist and dissipate the energy and stresses induced during an earthquake.

The *bhatar* system has been developed over many centuries, taking into account the local context and needs (including climate, cost and culture).

Bhatar structures have a proven capacity to resist the lateral loads generated during an earthquake. This resistance is provided by the inherent stability of the walls, the tensile capacity of the timber elements, and the dissipation of energy through friction between the stone masonry and timber bands. These mechanisms combine to ameliorate common damage patterns of unreinforced masonry walls (e.g. vertical corner cracking and delamination of masonry walls).

In spite of the variety of construction alternatives, there is little doubt that *bhatar* will continue to be the most appropriate construction form in isolated rural communities. This highlights the importance of providing adequate guidance and support to ensure proper *bhatar* construction. The earthquake reconstruction process in Pakistan provides both the opportunity and the framework to address this issue and support building back better with *bhatar*.