World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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HOUSING REPORT
Stone masonry residential buildings

Report #	138
Report Date	26-05-2007
Country	PAKISTAN
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
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Summary

In the Northern part of Pakistan, which mostly consists of mountainous terrain and where building stones are more abundantly available than any of the alternate building material, people commonly construct single story stone masonry buildings for residential purpose. A variety of building typologies are in use. An approximate distribution of common types of such buildings is:- Stone masonry houses without mortar with earthen roof (Fig 1a). 10% Stone masonry houses in mud mortar with earthen roofs (Fig 1c). 40% Stone masonry houses in cement mortar with earthen roof (Fig 1d). 10% Stone masonry houses in cement mortar with G.I.Sheet roof (Fig 1f). 30% Stone

masonry houses with R.C roofing (Fig 1g) 10%. Construction of houses in rubble stone masonry, in dry or in mud mortar, was most common and was generally practiced in the past in these areas. It is still in practice in most construction. Presently, among all, about 50% of the buildings are of this type. In new construction mud mortar is steadily being replaced with cement mortar. Wall thickness in all cases usually varies from 1 to 1 ½ ft. Roofs are usually earthen and generally consist of thatch covered with mud/earth and supported on wooden beams (or logs) and rafters. Some time wooden columns are also provided beneath the beams along the walls or in between the walls to support the roofing. Wooden rafters, planks and G.I. sheets are also used in modern construction for roofing. Any particular or regular layout is not used for construction of these residential buildings. It varies depending on the available space. Size of the building also varies from a single room to more than one room as per requirement of the family (Figs 3a--3c). These structures are considered, from experience, to be strong enough to withstand the applied gravity loads, but their seismic performance has not properly been investigated and is believed to be vulnerable to earthquake of even moderate shaking, particularly when confining elements such as wooden columns are not used. In a typical type of construction, historically known to be well resistant to seismic effects, horizontal and vertical wooden members are provided in the walls. These horizontal and vertical members are inter-connected at corners and other locations through wooden nails. The remaining space of the wall is then built in stone masonry of any type. This type of construction was commonly practiced in remote North parts of this region in the past and is still in practice for improved seismic performance in some of the buildings (figs 5a--5e).

1. General Information

Buildings of this construction type can be found in the Northern mountainous parts of Pakistan where the percentage of this type of construction may exceed 80% of the total residential building stock. This type of housing construction is commonly found in both rural and sub-urban areas.

Stone masonry is basically general practice for residential building construction in both rural and urban areas. The form and type varies with locality. In cities however the new trend is to use RCC frame structures instead of stone masonry.

This construction type has been in practice for less than 100 years.

Currently, this type of construction is being built. It is not known exactly as to how long this construction type has been practiced. It is believed that this type has been practiced at least 200 years.

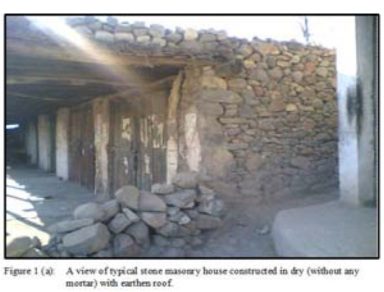

Figure 1: Typical stone masonry house, mud mortar with earthen roof.

Figure 2: Stone masonry without mortar under construction

Figure 3: View of typical stone masonry wall construction, with mud mortar

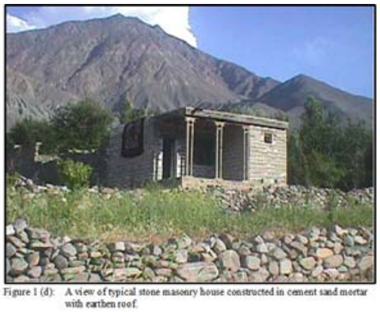

Figure 4: Typical stone masonry house constructed in cement sand mortar with earthen roof

Figure 5: Stone masonry house under construction with cement sand mortar with wooden truss and G.I.Sheet roof

Figure 6: Stone masonry house with dressed stones in cement sand mortar with RCC roof

Figure 7: A wooden column in the center of a room, in addition to the main stone masonry walls, is provided to support roof gravity load

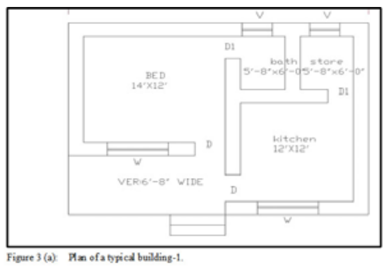

Figure 8: Plan of a typical building

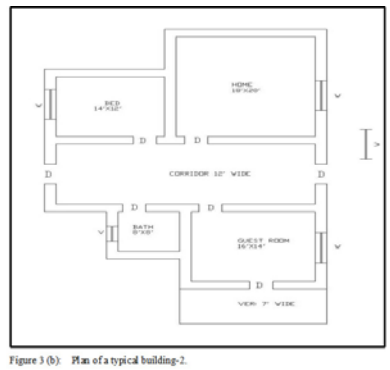

Figure 9: Plan of a typical building-2

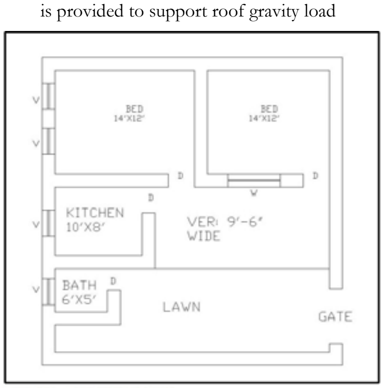

Figure 10: Plan of typical building-3

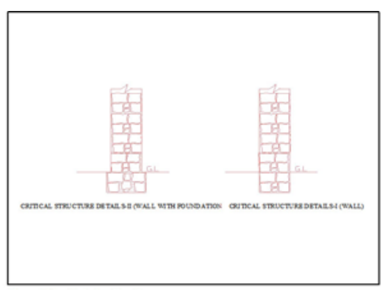

Figure 11: Typical wall section

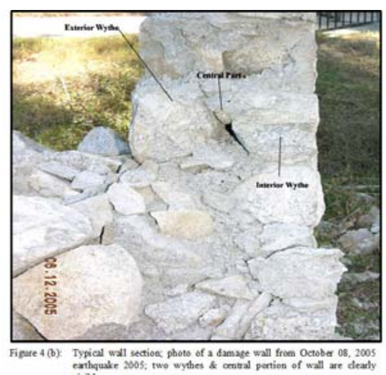

Figure 12: Damaged wall from October 8 2005 earthquake. Two wythes and central portion of wall are clearly visible.

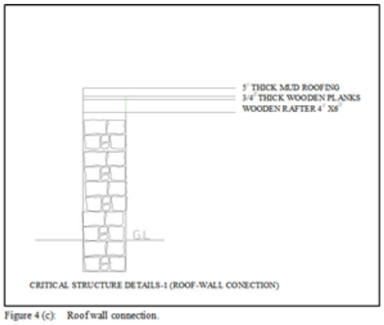

Figure 13: Roof wall connection

Figure 14: An old house with wooden seismic bands

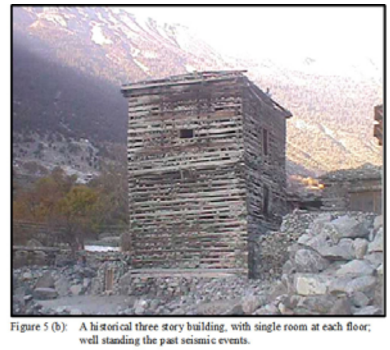

Figure 15: A historical three story building, with single room at each floor; well standing the past seismic events

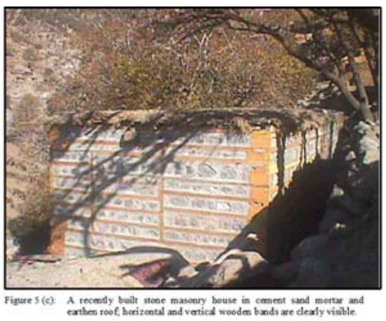

Figure 16: A recently built stone masonry house in cement sand mortar and earthen roof; horizontal and vertical wooden bands are clearly visible

Figure 17: Inner close view of building in previous figure (fig 5 c)

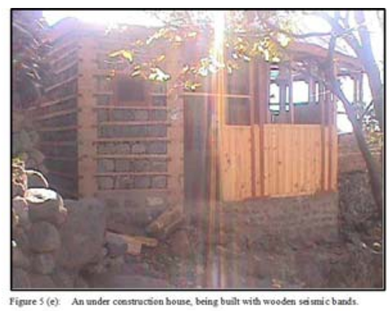

Figure 18: A house under construction, being built with wooden seismic bands

Figure 19: Typical corner failure of a stone masonry house in mud mortar with earthen roof; Pakistan earthquake of October 08, 2005

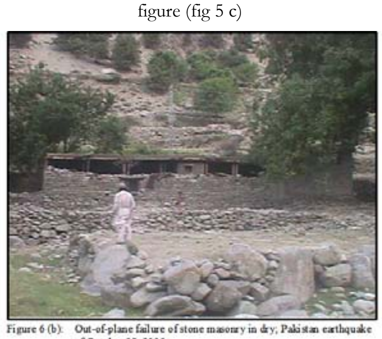

Figure 20: Out-of-plane failure of stone masonry with no mortar; Pakistan earthquake of October 08, 2005

Figure 21: Gable wall failure: Pakistan earthquake of October 08, 2005

Figure 6 (d): Debris of buildings collapsed due to lateral thrust in addition to seismic forces. Note a building in the background with rigid diaphragm is still standing; Pakistan earthquake of October 08, 2005.

Figure 22: Debris of buildings collapsed due to lateral thrust in addition to seismic forces. Note a building in the background with rigid diaphragm is still standing; Pakistan earthquake of October 08, 2005

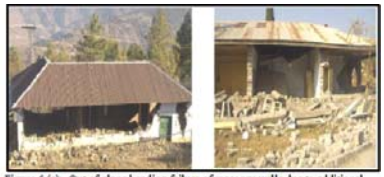

Figure 6 (e): Out of plane bending failure of masonry walls due to additional thrust from roof trusses; Pakistan earthquake of October 08, 2005.

Figure 23: Out of plane bending failure of masonry walls due to additional thrust from roof trusses; Pakistan earthquake of October 08, 2005

Figure 6 (f): Slippage of top course of masonry; Pakistan earthquake of October 08, 2005.

Figure 24: Slippage of top course of masonry; Pakistan earthquake of October 08, 2005

Figure 7 (a): Seismic strengthening technique; Column repaired after the earthquake.

Figure 25: Seismic strengthening technique; column repaired after the earthquake

Figure 7 (b): Seismic strengthening techniques; Column repaired after the earthquake.

Figure 26: Seismic strengthening techniques; column repaired after the earthquake

Figure 7 (c): Seismic strengthening techniques; Horizontal and Vertical wooden bands introduced after the earthquake.

Figure 27: Seismic strengthening techniques; horizontal and vertical wooden bands introduced after the earthquake

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They share common walls with adjacent buildings. A typical separation distance between buildings cannot be specified. Sometimes there may be no separation while in isolated dwellings, separation distance may be up-to ½ km or even more.) When separated from adjacent buildings, the typical distance from a neighboring building is 0-500 meters.

2.2 Building Configuration

Variable configurations are used to suit requirements. Rectangular buildings are most common practice. L-shape is also constructed. In some cases isolated rooms on 2 or 3 sides of an open terrace are constructed for a single housing unit. Usually one door and one or two windows in each room are provided. In present day practice standard size doors (3 ft x 7 ft) and windows (3 x 4 to 6 x 4 ft) are provided. In past practice small doors and windows were used. Doors up-to 4 ½ ft height and windows of 1 x 2 to 2 x 2 ft were commonly used in traditional houses in the remote northern part of this region. A small opening (usually 1 x 1 ft size) in the roof was also provided for the purpose of both lighting and fire smoke ventilation.

2.3 Functional Planning

The main function of this building typology is single-family house. Normally used for single or joint families consisting of families of real brothers or paternal cousins. In a typical building of this type, there are no elevators and no fire-protected exit staircases. The main opening provided for the purpose of access to the room is the only mean of escape in these buildings.

2.4 Modification to Building

Generally these houses are not modified. Additional rooms are constructed horizontally when so required.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Dressed stone masonry (in lime/cement mortar)	
	Adobe/ Earthen Walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block walls	
		6	Rammed earth/Pise construction	
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	
		8	Brick masonry in mud/lime mortar with vertical posts	
		9	Brick masonry in lime/cement mortar	
		10	Concrete block masonry in cement mortar	
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	
		12	Clay brick masonry, with concrete posts/tie columns and beams	
		13	Concrete blocks, tie columns and beams	
	Reinforced masonry	14	Stone masonry in cement mortar	
		15	Clay brick masonry in cement mortar	
		16	Concrete block masonry in cement mortar	
Structural concrete	Moment resisting frame	17	Flat slab structure	
		18	Designed for gravity loads only, with URM infill walls	
		19	Designed for seismic effects, with URM infill walls	
		20	Designed for seismic effects, with structural infill walls	
		21	Dual system – Frame with shear wall	
	Structural wall	22	Moment frame with in-situ shear walls	
		23	Moment frame with precast shear walls	
	Precast concrete	24	Moment frame	
		25	Prestressed moment frame with shear walls	
		26	Large panel precast walls	
		27	Shear wall structure with walls cast-in-situ	
		28	Shear wall structure with precast wall panel structure	

Steel	Moment-resisting frame	29	With brick masonry partitions	
		30	With cast in-situ concrete walls	
		31	With lightweight partitions	
	Braced frame	32	Concentric connections in all panels	
		33	Eccentric connections in a few panels	
	Structural wall	34	Bolted plate	
		35	Welded plate	
Timber	Load-bearing timber frame	36	Thatch	
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	
		38	Masonry with horizontal beams/planks at intermediate levels	
		39	Post and beam frame (no special connections)	
		40	Wood frame (with special connections)	
		41	Stud-wall frame with plywood/gypsum board sheathing	
		42	Wooden panel walls	
Other	Seismic protection systems	43	Building protected with base-isolation systems	
		44	Building protected with seismic dampers	
	Hybrid systems	45	other (described below)	

The most popular practice is to use rubble stone masonry in mud mortar or with out mortar (dry masonry) with wooden roofs, with or without using wooden columns to support roofing.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). The masonry walls and wooden columns, if provided, act as load bearing elements. The walls and wooden columns in turn transfer the load to the ground either directly or through the foundation.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The lateral load resisting system consists of masonry walls and wooden columns also contribute, if they are provided.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 8 and 15 meters, and widths between 5 and 12 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 3.5 meters. The typical storey height in such buildings is 3.2 meters. The typical structural wall density is more than 20 %. 15% - 25%.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted		
	Composite system of concrete joists and masonry panels		
	Solid slabs (cast-in-place)		
	Waffle slabs (cast-in-place)		
	Flat slabs (cast-in-place)		
	Precast joist system		

Structural concrete	Hollow core slab (precast)		
	Solid slabs (precast)		
	Beams and planks (precast) with concrete topping (cast-in-situ)		
	Slabs (post-tensioned)		
Steel	Composite steel deck with concrete slab (cast-in-situ)		
Timber	Rammed earth with ballast and concrete or plaster finishing		
	Wood planks or beams with ballast and concrete or plaster finishing		
	Thatched roof supported on wood purlins		
	Wood shingle roof		
	Wood planks or beams that support clay tiles		
	Wood planks or beams supporting natural stones slates		
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles		
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls		
Other	Described below		

Rammed Earth . Rammed earth floors in traditional houses and PCC floor in modern houses are normally practiced. Occasionally wooden floor are also constructed in special rooms (i.e. sitting rooms for guests or room used for storage of house commodities etc.). Wooden covered with mud and earth.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	
	Rubble stone, fieldstone isolated footing	
	Rubble stone, fieldstone strip footing	
	Reinforced-concrete isolated footing	
	Reinforced-concrete strip footing	
	Mat foundation	
	No foundation	
Deep foundation	Reinforced-concrete bearing piles	
	Reinforced-concrete skin friction piles	
	Steel bearing piles	
	Steel skin friction piles	
	Wood piles	
	Cast-in-place concrete piers	
	Caissons	
Other	Described below	

Walls are directly supported on soil without footings in traditional practice. Wooden columns are directly rested on a stone block of comparatively larger size which in turn rests on soil. In modern practice a regular step footing (one or two steps) is provided on plain concrete bedding.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

A single family or an extended family typically occupies one house or housing unit. The number of inhabitants in a family (single or extended) in most cases exceeds 10.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	
b) low-income class (poor)	
c) middle-income class	
d) high-income class (rich)	

Roughly about 20% of the population falls in the category of very poor, 65% poor and 15% middle class. 1% among middle class may be approximately rated as rich.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	
4:1	
3:1	
1:1 or better	

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	
Personal savings	
Informal network: friends and relatives	
Small lending institutions / micro-finance institutions	
Commercial banks/mortgages	
Employers	
Investment pools	
Government-owned housing	
Combination (explain below)	
other (explain below)	

Residential buildings are constructed by personal savings in most cases. Relatives and friends contribute in cash, kind, labour and materials in deserving cases. In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

One bathroom is usually provided with each housing unit particularly for use of female members. Providing latrine in the housing unit is not general practice in rural areas. Open fields in the vicinity of houses are used for the purpose. In the present day practice latrine/bathroom are constructed in the new houses. In cities one or two bathrooms and latrines are constructed as per requirement of the family. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	
outright ownership	
Ownership with debt (mortgage or other)	
Individual ownership	
Ownership by a group or pool of persons	
Long-term lease	
other (explain below)	

The houses are owned as common property of the family and are legally divided among the owners/heirs in accordance with the general rule of law practiced, whenever families are separated. The ownership of the house is thus transferred but remains within the family. Therefore the ownership can be categorized as "owned outright".

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		True	False	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.			
Building Configuration	The building is regular with regards to both the plan and the elevation.			
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.			
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.			
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.			
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.			
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);			
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.			
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps			
	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross			

Wall openings	walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.			
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).			
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).			
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)			
Other				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Poor quality of mud, excessive thick mud joints, and poor quality of construction.	Wooden horizontal bands and vertical wooden posts within the walls	In-plane shear and out-of-plane failure of walls
Frame(Columns, Beams)	N/A	N/A	N/A
Roof and Floor	Parts of the roof are not properly connected so each part acts independently without any integrity.		Collapse
Other			

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *A: HIGH VULNERABILITY (i.e., very poor seismic performance)*, the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is *A: HIGH VULNERABILITY (i.e., very poor seismic performance)*.

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1972	Sept.13. Hamaran (Hindu Kush)	6.3	VIII*
1974	Dec. 28. Pateen Valley (Hindu Kush)	5.9	VII*
1981	Sept. 12. Darel Valley (Hindu Kush)	6.1	VII*
2002	Nov. 01 Raikot Valley (Himalayas)	5.3	VI*

2002	Nov20 Raikot valley (Himalayas)	6.5	VIII*
2005	Oct 08 Muzafarabad (Himalayas)	7.6	IX-X

An earthquake of Magnitude Mw = 7.6 occurred on October 8, 2005 at 08:50 am local time causing damage and casualties over an area of 30,000 km2 in the N-W.F.P. province of Pakistan and parts of Pakistan administered Kashmir. The main event was followed by more than 978 aftershocks of Magnitude Mw = 4.0 and above, till October 27, 2005. The epicenter of the main earthquake was located at latitude of 34° 29' 35" N and longitude of 73° 37' 44" E. The focal depth of the main earthquake was determined to be 26 km (USGS). This was the deadliest earthquake in the recent history of the sub-continent with more than eighty thousand casualties, two hundred thousand injured, and more than 4 million people were left homeless. The adverse effects of this earthquake are estimated to be more than those of the tsunami of December 2004. The major cities and towns affected were Muzafarabad, Bagh and Rawlakot in Kashmir and Balakot, Shinkiari, Batagram, Mansehra Abbotabad, Murree and Islamabad in Pakistan. A significant number of casualties and injuries in the affected regions were associated with the total collapse of single story unreinforced stone masonry buildings. The stone masonry walls consisted of irregularly placed undressed stones, mostly rounded, that were laid in cement sand, mud mortar or even dry in some cases.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Stone, mud mortar, cement sand mortar		In case of cement mortar 1:8 to 1:10 is used	No experimental work has been done for determination of mechanical properties of such type of stone masonry.
Foundation	Stone, mud mortar, cement sand mortar		In case of cement mortar 1:8 to 1:10 is used	No experimental work has been done for determination of mechanical properties of such type of stone masonry.
Frames (beams & columns)				No experimental work has been done for determination of mechanical properties of such type of stone masonry.
Roof and floor(s)	Wood, earth			No experimental work has been done for determination of mechanical properties of such type of stone masonry.

6.2 Builder

Usually the owner himself is the builder and typically lives in the same building.

6.3 Construction Process, Problems and Phasing

In most cases the owners arrange material at site. Skilled labour (mason, carpenters etc) and unskilled labour are engaged to do the work on daily wages or lump-sum basis. Walls are generally constructed of stone laid dry, or in mud and rest on soil directly usually at a shallow depth (1-2 ft) without a foundation. A wooden roof rests directly on walls. To add to the stability wooden columns below beams are occasionally provided. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. Construction takes place over time according to the availability of resources.

6.4 Design and Construction Expertise

Design is not practiced. Skilled labourers for each component of the work are expert in their job through experience and practice. The owner hires these expert 'skilled labourers' to carry out the construction work. No role for either Engineers or Architects.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

No practice or attempt is made to enforce building codes.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules.

Building development control rules do not exist and therefore are not enforced so anyone can construct any type of residential building. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s). Maintenance is usually not required. In the case where any damage occurs, it is repaired. When the building reaches its serviceable life, it is dismantled and reconstructed.

6.8 Construction Economics

2400 - 5400 PRs/m2 (40 - 90 $US/m2). 2 to 5 man-days of skilled labour (mason, carpenter etc) and 8 to 12 unskilled labour will be required per m2 of this type of construction.(i.e. if 4 skilled and 10 unskilled labours are engaged to construct a house of this type with 100 m2 cover area they will complete it in 2 to 4 months.).

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. No earthquake insurance is available.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

The area is seismically very active. Earthquake in the past have caused damage in different localities. Being scattered, far-flung, and mountainous no documentation of such type of damage in the area is recorded and available. No defined retrofit (or strengthening) practice is known except only making a stronger component than that damaged in the earthquake through reconstruction or new construction, fig 7 (a) though 7 (c).

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?
No design method is practiced. The trend is to make stronger components than those damaged previously.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
NA.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

NA.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
NA.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
NA.

Reference(s)

Author(s)

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