World Housing Encyclopedia

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

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Stonework building with wooden timber roof

Report #	114
Report Date	17-01-2005
Country	IRAN
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
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Important
This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John A. Martin & Associates, Inc. or the participants' organizations.

Summary

Stonework buildings are a common type of rural construction in many parts of Iran (Figure 32). It is widely used in the mountainous areas because of the ease of attaining the building material. More than 71,000 stonework buildings were built in 1968-1972 in comparison to 54,000 brick masonry buildings in these years [1]. Unfortunately these buildings are often found in highly seismic parts of Iran (see maps on WHE webpage for Iran). Buildings of this

type are up to two stories high, with height/width aspect ratio on the order of 0.3-0.5. The building materials consists of stone, wood, mud mortar and straw. The major elements of these systems are stonewalls which carry both gravity and lateral loads. These walls consist of stone or stone ballast with mud mortar and straw. For reasons of thermal insulation the thickness of these walls is not less than 50 centimeters (usually 70 centimeters). Details of wall are shown in Figures 11 to 20. The roof includes wooden joists and a set of secondary joists which are plastered with a thick layer of mud (Figures 21 and 22). Different views of this kind of building are shown in Figures 1 to 3. Also a typical building view, plan and layout are shown in Figures 4 to 10. Weak points of this construction type are: the presence of a heavy roof; inadequate behavior of the walls under out-of-plain forces (Figures 23 and 24); poor shear capacity of the mortar; inadequate connection between roof and walls; inadequate connection between intersecting walls; and lack of diaphragm action in floors and roof where the roof elements (wooden beams) do not work together in earthquakes and may collapse (Figures 25 and 27). In general, this kind of structure is frequently used as a house and stable in mountainous villages, but its earthquake performance is not acceptable. Any proper rehabilitation techniques may save many people's lives.

1. General Information

Buildings of this construction type can be found in most villages in the mountain regions of Alborz and Zagros (Figure 32). This type of housing construction is commonly found in rural areas.

This kind of building is not practiced in major cities but only in rural cities and mountainous villages. The major reason for the popularity of this form of construction is that in mountainous regions, stone mines are easily accessible. Two kind of stones are used in these stonework buildings: 1-Rubble stone, a by-product of the mining industry (Figure 12). 2-Carcass stone, which comes from riverbeds (Figure 11).

This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. .

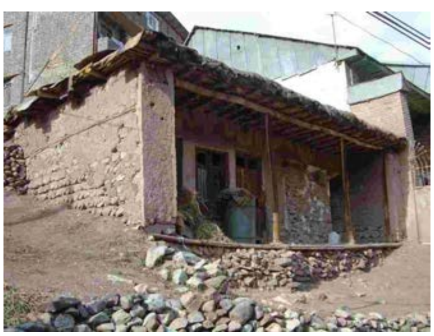
Figure 1a: Typical Building View [3]

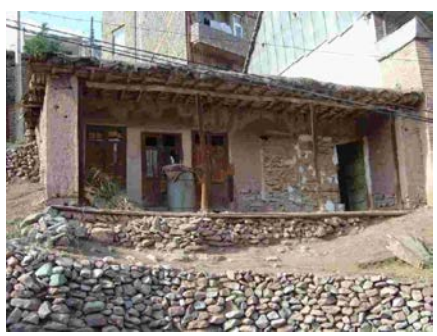
Figure 1b: Typical Building View [3]


Figure 2a: Typical Building Wall View [3]


Figure 2b: Typical Building Wall View [3]


Figure 3: Typical Building Roof View [3]


Figure 4: View of common stone masonry house type

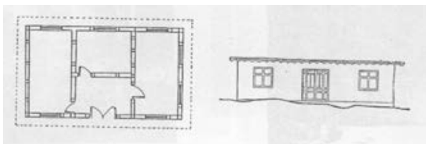

Figure 5: Elevation and a Plan of a Typical Building [7]

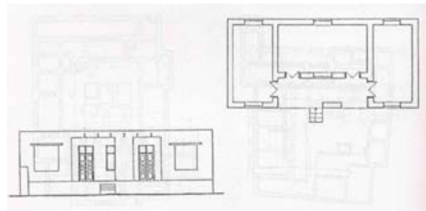

Figure 6: Elevation and a Plan of a Typical Building [7]

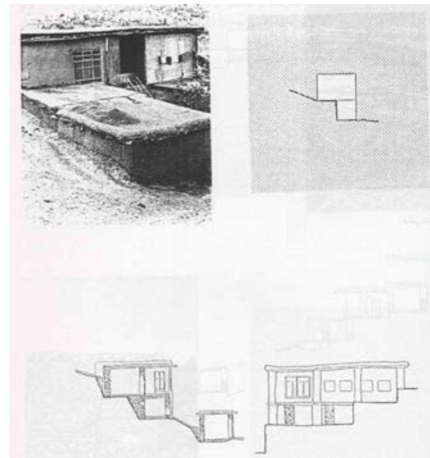

Figure 7: Elevation of a Typical Building [7]

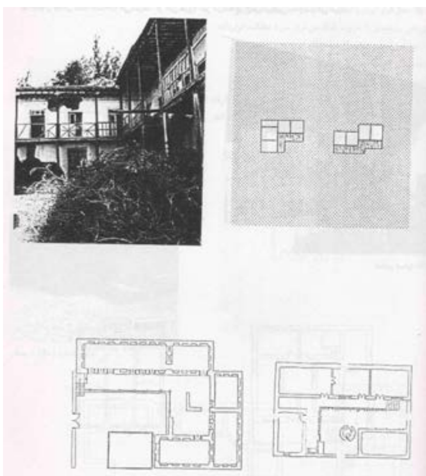

Figure 8: View and Plan of a Typical Building [7]

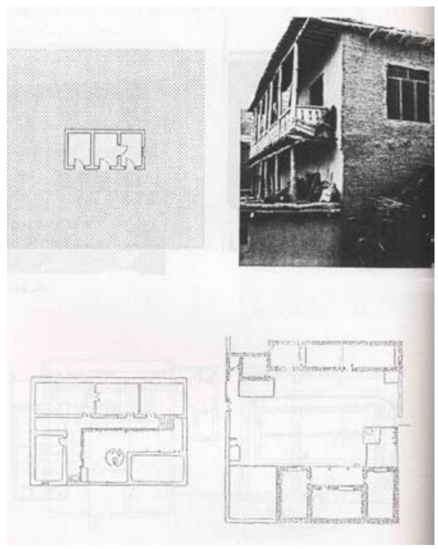

Figure 9: View and a Plan of a Typical Building [7]

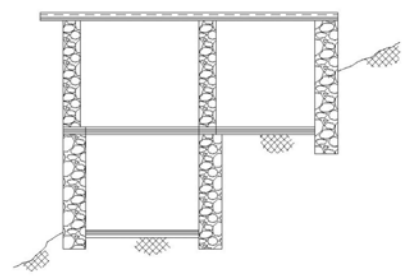

Figure 10: Two story stone masonry house on a slope

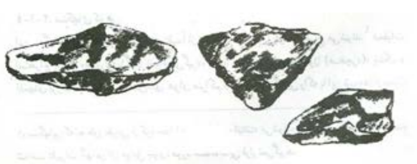

Figure 11: Carcass Stone [1]

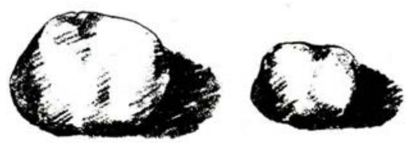

Figure 12: Rubble Stone [1]

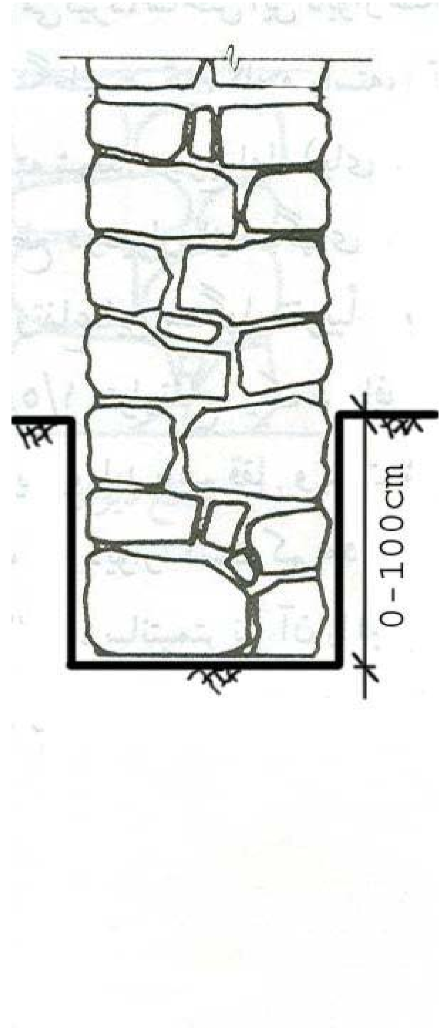

Figure 13: Stone Walls Foundation

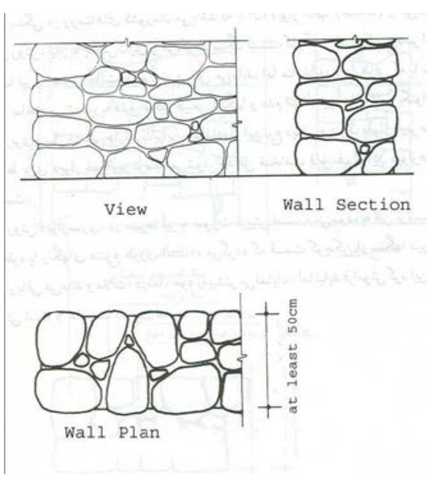

Figure 14: Walls with Rubble Stone [1]

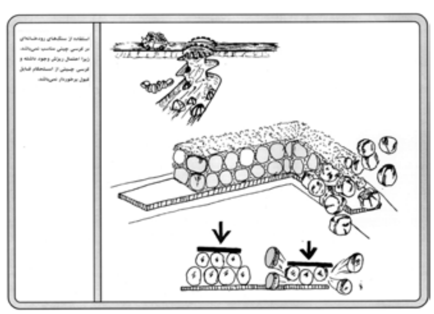

Figure 15: Seismic Behavior of Rubble Stone [9]

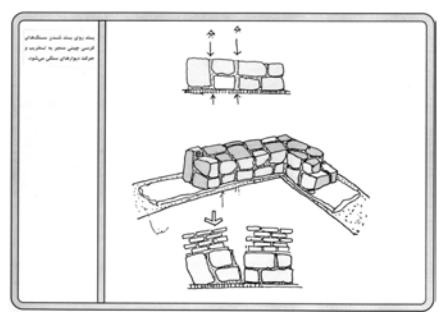

Figure 16: Seismic Behavior of Carcass Stone [9]

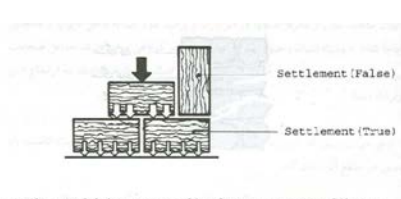

Figure 17: Stone Settlement [1]

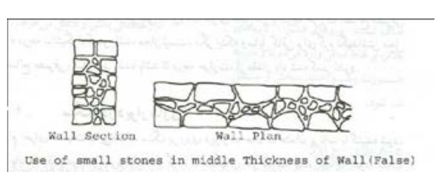

Figure 18: Vulnerable Walls (Buckling of outer stones) [1]

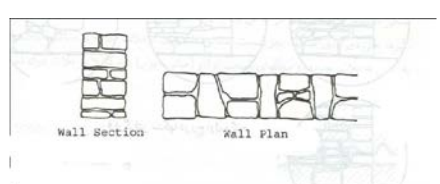

Figure 19: Adequate walls [1]

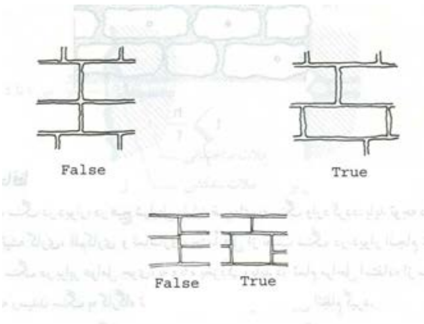

Figure 20: Stone Units Arrangements [1]

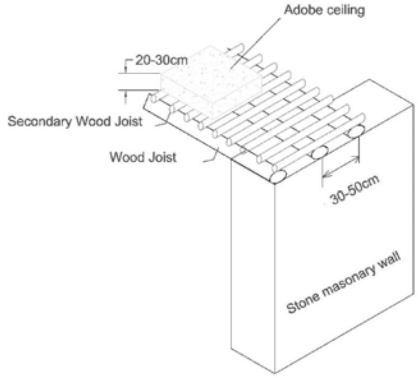

Figure 21: Typical Detail of Connection between Wall and Roof

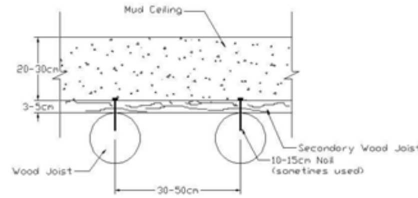

Figure 22: Roof Details (using secondary wood joists)

Figure 23a: Typical external walls damage in Firoozabad-Kagoor earthquakes [3]

Figure 23b: Typical external walls damage in Firoozabad-Kagoor earthquakes [3]

Figure 24a: Typical internal walls damage in Firoozabad-Kagoor earthquakes [3]

Figure 24b: Typical internal walls damage in Firoozabad-Kagoor earthquakes [3]

Figure 25: Typical roof damage in Firoozabad-Kagoor earthquakes [3]

Figure 26a: Typical roof damage in Firoozabad-Kagoor earthquakes [3]

Figure 26b: Typical roof damage in Firoozabad-Kagoor earthquakes [3]

Figure 27: Total collapse of stonework building in Firoozabad-Kagoor earthquakes [3]

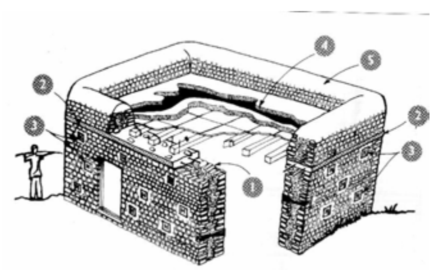

Figure 28: Retrofitting components

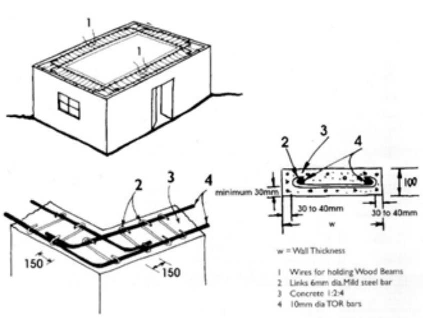

Figure 29: R.C. Band bellow Roof Beams

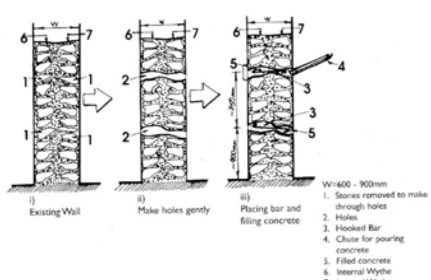

Figure 30: Providing R.C.

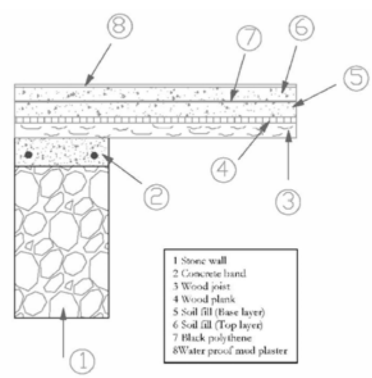

Figure 31: Polythene sheet placements

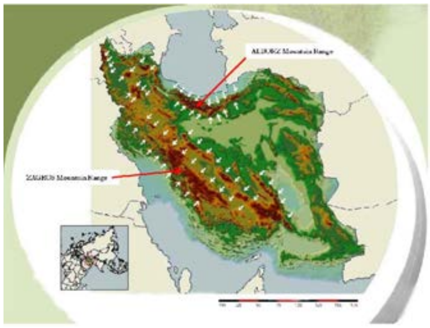

Figure 32: Distribution of Stonework Buildings in Iran

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They share common walls with adjacent buildings. Usually they are constructed side by side and there is no distance between them

2.2 Building Configuration

A typical plan of this kind of building is shown in figure 3. Most windows are about 120X120 centimeters and doors are 200X100 centimeters.

2.3 Functional Planning

The main function of this building typology is single-family house. Usually this kind of building is used for living but sometimes when the building is located at the foot of a slop, the ground storey has less surface area than the top one and is used for depot reservoir or as a stable. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. In one-story buildings there is just one door and in two-story buildings there is one door in front of building and another one behind the building.

2.4 Modification to Building

Usually there is no modification.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
	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	☐
		7	Brick masonry in mud/lime	

Masonry	Unreinforced masonry walls		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)	☐
			Stud-wall frame with	

		41	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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is confined masonry wall system. The roof of the building is constructed with joists spaced at 20-50 centimeters which transfer loads from the roof to the walls (500-600 kilogram per square meter) and then walls transfer loads to the ground directly. Wall thickness is between 45-70 centimeters. These walls have no foundations.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is confined masonry wall system. Walls carry the inertia forces produced by the roof mass. These loads must be transferred from the walls to the ground by in-plane behavior of the walls, but usually there is no proper path for adequately transferring these seismic loads to the ground in stonework buildings. Floors and roofs do not work as rigid diaphragms and there is rarely connection between the roof components (joists and secondary joists). Heavy floors and roofs are supported on walls without any connection (Figure 21). These deficiencies may cause separation and collapse of roof components as shown in Figures 25 and 26: 1- Walls collapse under out of plane loads. 2- Improper arrangement of stone units may cause buckling of outer stones in walls (Figures 15, 18 and 23a). 3- Walls collapse because of poor shear capacity of mortar; also there is not enough cohesion between stone units and mud mortar.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 0 and 0 meters, and widths between 0 and 0 meters. The building has 1 to 2 storey(s). The typical span of the roofing/flooring system is 3-4 meters. The typical storey height in such buildings is 2.5-3 meters. The typical structural wall density is none. .

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	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	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)	☐	☐
	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	☐	

Timber			☐
	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	☑	☑

The roof includes wooden joists and a set of secondary joists which are plastered with a thick layer of mud (Figures 21, 22 and 3).

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	☐

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

Typically there is one family per housing unit that may sometimes include grandparents.

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)	☐

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)	☐

Because this kind of building is placed in mountainous areas, the owners of them are usually peasants or shepherd. In each housing unit, there are no bathroom(s) without toilet(s), 1 toilet(s) only and no bathroom(s) including toilet(s).

Usually toilet is placed outside of housing unit. .

4.4 Ownership

The type of ownership or occupancy is renting and 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)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	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	☐	☑	☐
Wall openings	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 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)	☐	☑	☐
Additional Comments	The roof consists of a mud-straw mix about 20-30 centimeters thick, which makes the roof very heavy. The walls are not connected together or to the roof with adequate connections. There are no tie beams or columns in these buildings. The walls do not have enough strength to resist out-of-plane forces. The mortar also has inadequate strength. Usually these buildings are placed on steep slopes in mountainous areas which have a high potential for landslides.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	The combination of stone and mortar has low tensile and shear strength, especially for out-of-plane seismic effects. Sometimes openings such as walls and windows reduce the strength of the bearing walls. The perimeter walls are not sufficiently connected at the corners, and behave as separate elements, which causes damage in the wall corner connections.		During earthquakes in the mountainous regions of Iran, there is extensive damage and many casualties in these buildings due to wall collapses. Figures 23 and 24 show typical damage of stone walls from earthquakes.
Frame (columns, beams)	No Frame exists.	No Frame exists.	No Frame exists.
Roof and floors	Usually they consist of heavy materials that behave as flexible diaphragms in earthquakes, which undermines the connections between the stone walls and the diaphragm. Also there is not a tie beam for integrity.		After wall failure, the heavy roof generally collapses. Figures 25 and 26 show evidence of this phenomenon.
Other			

Total collapse of this kind of building occurred during several past earthquakes in Iran. Figure 27 shows one of these catastrophes.

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
1985	Ardabil	5.8	VII
1990	Manjil	7.6	
1992	Lordekan	5	VII

2004	Firoozabad	6.3	

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Stone.	Unknown		
Foundation	No foundation			
Frames (beams & columns)	No frame			
Roof and floor(s)	Joists with mud mortar and straw	Unknown		

6.2 Builder

The builder lives in this construction type.

6.3 Construction Process, Problems and Phasing

First, the ground is excavated with a width of 80-100 centimeters and a depth of 50-100 centimeters for the wall perimeter. Next, the walls are constructed from bottom of this cavity. On rare occasions, a wooden column is used at the intersection of stone walls. Wooden beams are then placed on top of walls at a 20-50 centimeter spacing distance. The top surface of the beams is covered with thinner wooden beams or board(plank). Finally the roof is plastered with mud in two separate stages to achieve a total thickness of 20-30 centimeters. The construction of this type of housing takes place in a single phase. Typically, the building is originally not designed for its final constructed size. There is no special design & drawings for this kind of construction.

6.4 Design and Construction Expertise

This kind of building is constructed by people lacking formal construction expertise. Sometimes expert bricklayers build these buildings with some special architectural features in the walls and roof but they are not certified. Engineers or architects are not present in the design/construction of this housing type.

6.5 Building Codes and Standards

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

6.6 Building Permits and Development Control Rules

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

These buildings are old. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

per m2 of built-up area expressed using a currency used in the region, and, if possible, an equivalent amount in $US in the brackets e.g. 200 Rs/m2 (5 $US/m2).

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.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

CONTINUED: This step can be started from bottom towards top of wall after two days of casting the ceiling level band. a- Select points where "through" stones will be installed at horizontal and vertical distances of about 1 meter apart, with 50 cm horizontal stagger. b- Remove the mud plaster from the surface exposing the stones. Remove the mud mortar around the stone to sufficient depth gently, not violently, so as to expose the stone on all sides. c- Loosen the stone up and down by means of a small crowbar, so that the other stones of the walls are not disturbed. Pull out the stone slowly, holding it by both hands. d- Remove inner material gradually so that a 75 mm (3") sized hole can be made in the wall. A bigger hole is not needed. e- Locate position of the opposite stone on the other face of the wall. Remove the stone slowly same gentle process. f- The hole made through the wall will be bigger in size on both faces and narrower inside resembling a dumbbell shape. It does not matter if the hole is inclined instead of being horizontal. g- Place concrete of 1:24:4 mix to fill half the depth of the hole from both sides and place 8mm diameter hooked mild steel bar through and fill the hole completely. h- Cure for 14 days by sprinkling water on the exposed surfaces on both sides. FINISHING THE ROOF AND PARAPETS PROCEDURE) Step FOUR Re-laying the roof on the band 1- Lay the wooden joists and where found necessary, the Ferro-cement channels, on separate rooms as far as possible. 2- Hold these elements to the R.C. band at ceiling level by the wires projecting out of the band (see step two). 3- Build the stone walls to the required height. 4- Affix the wooden planks to the wooden joists with nails. Step FIVE (Figure 31) Finishing the roof The following suggestions are not essential to retrofitting scheme but are desirable for achieving good water proofing of the roof and parapets so that rain water ingression into the walls is prevented. This will maintain the dry strength of mud mortar in the walls. a) Finish the roof by using water proof non-erodible mud plaster as evolved by the CBRI, given below: Cutback is prepared by mixing bitumen 80/100 grade kerosene oil and paraffin wax in the ratio of 100:20:1 for 1.8 kg of cutback, 1.5 kg bitumen is melted with 15 grams of wax and this mixture is poured in a container having 300 ml kerosene oil with constant stirring till all ingredients are mixed. This mixture can now be mixed with 0.03 cubic meters of mud mortar for application as plaster. A plaster thickness of 20-25 mm is suggested. b) The stone parapet top and the walls can be finished on the inside face by using galvanized chicken wire mesh held to the wall by means of nails and plaster over using mud plaster or cement sand 1:6 mix. The galvanized mesh should pass through the space between wooden frames and the walls.

8.2 Seismic Strengthening Adopted

8.3 Construction and Performance of Seismic Strengthening

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