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
Earring system (Shekanj) in dome-roof structures with unreinforced brick and adobe materials

Report #	118
Report Date	26-05-2007
Country	IRAN
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in mud/lime mortar
Author(s)	Nima T. Bekloo
Reviewer(s)	

Summary

This building structure derives its name from the four earrings that are constructed at the four corners of a rectangular building at the spring level of dome roof. This structural system was developed due to the lack of of wood and stone. It was widely constructed more than 3

thousand years ago, after the invention of the dome-roof structures in the Old Persian Empire (Ashkanian & Sasanian). The main problem with the dome-roof building was to transform the rectangular or polygonal plan of the group of walls into the circular plan at the spring level of dome roof. They used to construct the first row of dome and then construct another row on top of previous one with a little offset closer to the center of the dome circle and so on. That was too difficult to construct. This system was invented to resolve this problem. In this system, once the walls were constructed, four earrings (shekanj) built upon four corners of walls intersections, and then it was much easier to build a dome over these. It is an ideal system to resist vertical and gravity loads and transform them into horizontal and shear loads. For lateral loads, domes behave like trusses and distribute the load to the other parts of the structure creating a perfect load path.

1. General Information

Buildings of this construction type can be found in throughout the Persian Empire, except places near the sea. This type of housing construction is commonly found in both rural and urban areas.

This building type is more common in old and traditional cities.

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

Currently, this type of construction is being built. This construction system is, now-a-days, rarely constructed. These are mostly constructed in areas of low population density in the middle of the desert (Kavir) or in small towns where construction materials such as steel, cement are not abundantly available.

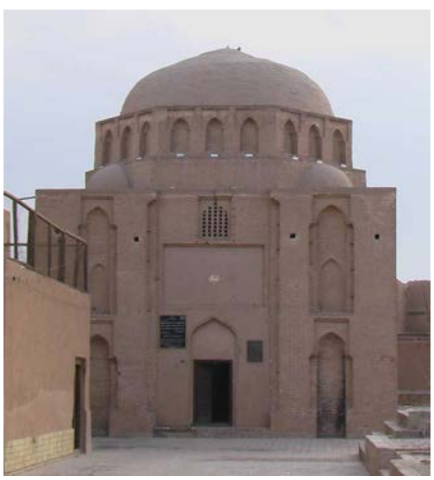

Figure 1: Typical Building

Figure 2: Key Load-Bearing Elements

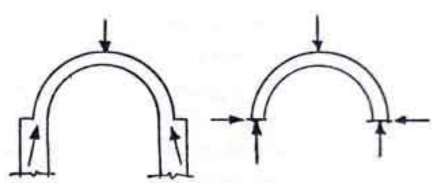

Figure 3: Key Load-Bearing Elements

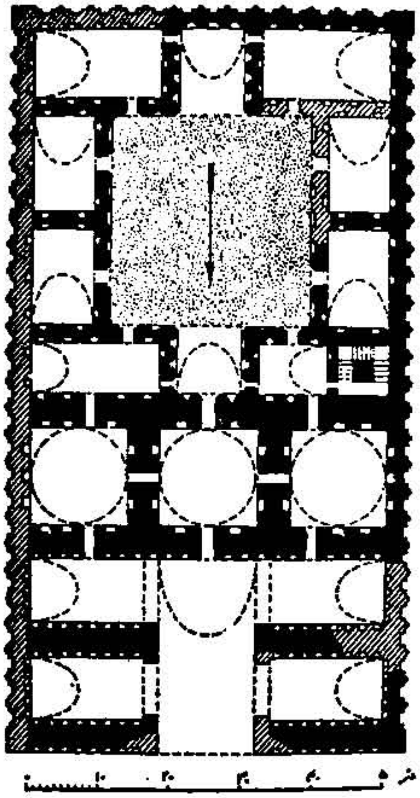

Figure 4: Plan of a Typical Building

Figure 5: Critical structural details

Figure 6: Critical structural details

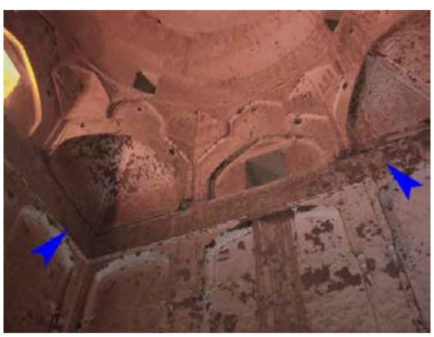

Figure 7: Critical structural details

Figure 8: Critical structural details

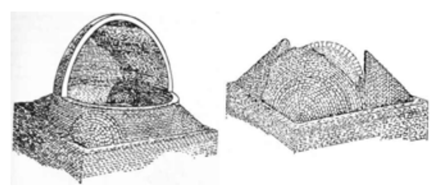

Figure 9: Critical structural details

Figure 10: Critical structural details

Figure 11: Key seismic feature

Figure 12: Typical earthquake damage

Figure 13: Typical earthquake damage

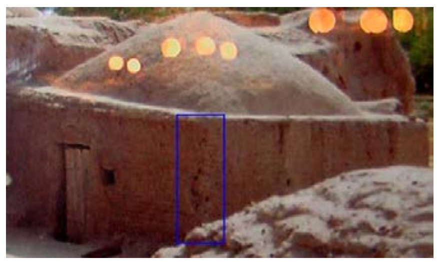

Figure 14: Typical earthquake damage

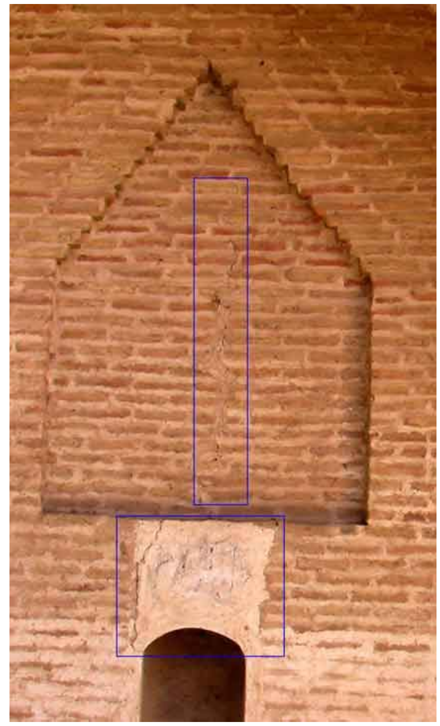

Figure 15: Illustration of seismic strengthening technique

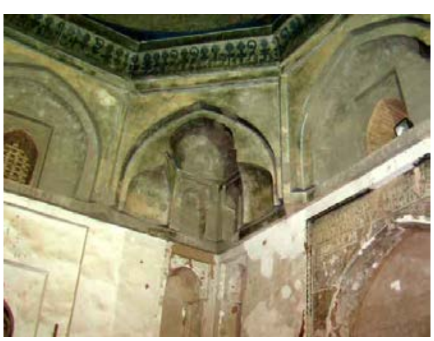

Figure 16: Inside view of the earring

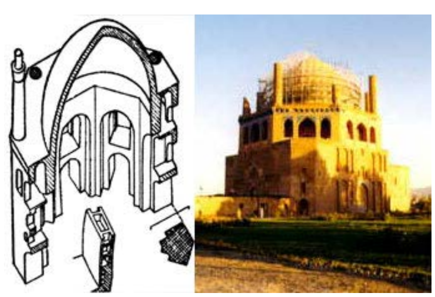

Figure 17: Soltanieh dome, Zanjan, IRAN (this dome was built without earring)

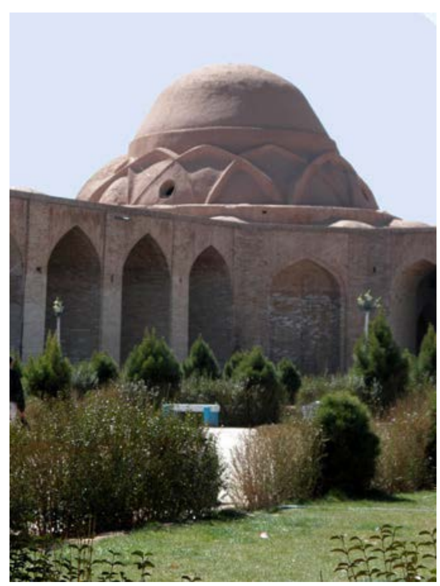

Figure 18: Earring over polygonal section (Kerman, IRAN)

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They share common walls with adjacent buildings. Most of the time, this building type sits in a group without any separation distance between them

2.2 Building Configuration

Building configuration in plan is often rectangular or octagonal, or sometimes even polygon with more arms. Due to its load bearing system, it does not have many openings. The openings are usually less than 30% of wall area. Sometimes openings are also provided in the roof as well. These are usually around 50 cm in diameter.

2.3 Functional Planning

The main function of this building typology is single-family house. Sometimes (especially in the old times) the whole family (including relatives) lived in a large rectangular with one common entrance. They might have used same courtyard, kitchen and service, but slept in separate rooms. One kind of these building type was known as four Eyvan (Balcony). In a typical building of this type, there are no elevators and no fire-protected exit staircases. Usually there was only one exit in this building type.

2.4 Modification to Building

Because the structural system is the load bearing system, it is possible only to modify some small openings.

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	☐
			Stone masonry in cement	

	Reinforced masonry	14	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)	☐

1. Sometimes walls and dome of the buildings constructed with mud mixed with pebbles as well. 2. Nowadays some people use cement based mortar as well.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is earthen walls. Load bearing walls and dome-roof system.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. Load bearing walls and dome-roof system.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 5 and 20 meters, and widths between 5 and 20 meters. The building has 1 to 2 storey(s). The typical span of the roofing/flooring system is 5-20 meters. Typical Plan Dimensions: The typical plan dimension depend on the building function (residential, barn, mosque etc). The dimensions may vary, but over all the structure have a regular plan shape. Typical Story Height: The storey height depends on the building function (residential, barn, mosque etc). Typical Span: Single span for the single roof. The typical storey height in such buildings is 4-20 meters. The typical structural wall density is more than 20 %. 20% to 40%.

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)	☐	☐
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	☑	☑

The construction materials have no ductility. By building it in vault form, the forces are distributed on the surface.

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	☐

NA.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). One unit in each building. One large room is covered by one dome-roof. 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 less than 5. NA.

4.2 Patterns of Occupancy

Houses of this type are mostly occupied by a single family.

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)	☐

Nowadays very small number of people live in this type of building. Economic Level: The ratio of price of housing unit to the annual income can be 1:1 for poor class families.

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)	☐

NA. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and no bathroom(s) including toilet(s).

As stated in section 2.4 when the whole family lived together, they shared the same bathroom and latrine. .

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)	☐

NA.

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	These are special type of structures which are not covered by National Building Code			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Constructed of low strength brittle materials, the structural elements are unreinforced, walls are large and heavy	Well defined load path, high rigidity, continues bearing (Shear) walls	Vertical and diagonal cracks in walls, more often along mortar joints
Frame	NA	NA	NA

(columns, beams)			
Roof and floors	Constructed of low strength brittle materials, heavy in weight, the roof is unreinforced, opening in the roof, slipping of the roof over walls large span,	well defined load path, perfect distribution of forces and stresses	No significant damage except that caused by wall damage especially when walls under the dome slip leaving the dome roof without any support
Other	Not enough distance between adjacent buildings, no second seismic system like tie beams,	NA	Crushable brick material, weak mortar band

This type of structure has continuous load path like concrete shear walls with concrete shell at top that connects the walls However, present building is constructed of extremely weak and brittle materials. Once cracked, the materials start crumbling.

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

As stated above this type has been constructed thousands years ago, so there must be many other earthquakes especially historical ones that affected these buildings. However, no exact information is available.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick & adobe	40-120 kg/cm2	20x10x10 ? 50x50x20 cm	Varies from places and ages
Foundation	Brick & stone	40 ? 150 kg/cm2	Not much bigger than the walls	Varies from places and ages
Frames (beams & columns)	NA			
Roof and floor(s)	Brick & adobe	40 ? 120 kg/cm2	20x10x10 ? 50x50x20 cm	Varies from places and ages

6.2 Builder

Yes, the builder lives in the house. Traditionally every body has a co-operation in construction their own home.

6.3 Construction Process, Problems and Phasing

It is basically owner built construction where experienced persons, master builders and may be some local contractors with help of labors built the structure, with shovel, hack, float and other old construction equipment. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

There were no academically qualified engineers or architects and no Standards for design of this type of building structures were available. These are constructed by empiricism or experimentation. However, it is still a issue of research. There are no academically qualified engineers or architects for this type of buildings.

6.5 Building Codes and Standards

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

NA.

6.6 Building Permits and Development Control Rules

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

This type can only be seen in small villages and old towns nowadays. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder and Owner(s). Often, the whole family work together for the maintenance of the building.

6.8 Construction Economics

Approximately US$ 80. For construction of an average size of house, 4-8 persons work for about 6 month.

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is available. Earthquake insurance is included in fire insurance and it?s based on the value of the building. It depends on the owner capital demand. usually for every US$ 5000 additional cover, it costs about US$ 6 /year added to the fire insurance.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Not enough distance between adjacent buildings	For buildings with different heights: 1.Destroy some common part of the adjacent walls to reach distance of 1% wall height. 2. Join all the buildings in an area to make them behave as a one single structure.
Damages in load path (exterior walls)	1. Add a shear wall to the system. 2. Embed some materials to maintain the wall. 3. Filling the cracks by plaster, cement?
Opening in roof	Strengthening all around the opening by wood or steel bars.
Heavy weight	Remove the heavy weight materials of the roof and replace them with light new materials.
Large span	Build some tie beams to make spans smaller.
Slipping the roof over the walls	Connect dome base with timber to prevent slipping.

Iranian codes stated that they are not suitable for monuments.

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.

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

Both intervention options have been used. They are used for both matters.

8.3 Construction and Performance of Seismic Strengthening

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

No.

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

Owner, local masons without any no academic background in engineering.

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

NA.

Reference(s)

1. History of engineering in Iran
   Farshad,M.
   Iranian code of practice for seismic resistant design of buildings Std.2800, BHRC 2005, Section 3 unreinforced masonry structures, Balkh Publication 1997
2. Iran insurance co., http://www.iraninsurance.ir
3. Iranian retrofitting provision for existing buildings, Section 7 masonry structures and infills
   IIEES
4. Iranian code of practice for seismic resistant design of buildings Std.2800, BHRC 2005, section 3 unreinforced masonry structures

5. Earthquake Engineering Theory and Applications
Moghaddam,H.
Farahang Publication 2002

6. Persians masters of empire
Researches group
Time Life Book Publication

Author(s)

1. Nima T. Bekloo, NA
No.24 St.18 velenjak ave.TehranIran, Tehran 1985743337, IRAN
Email:poosad@gmail.com FAX: (9821)-22171696

Reviewer(s)