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
Four arches (Char taaqi) with dome-roof structures, and unreinforced brick and adobe materials.

Report #	117
Report Date	26-05-2007
Country	IRAN
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in mud/lime mortar, with vertical posts
Author(s)	Nima T. Bekloo
Reviewer(s)	

Summary

The 'Four arches' or Char Taaqi (in Persian) derives its name from the four arches that connects tops of four timber or masonry piers enclosing the space. It is an equilateral architectural unit consisting of four arches or short Barrel vaults between four corner piers, with a dome over the central square; this square and the lateral bays under the arches or barrel vaults together constitute a room of cruciform ground plan. This structural system developed about 2500 years ago, after earring system in the Old Persian Empire (Sasanian age). Main goal of this building system was to create wide openings at four side of the structure. This building system was used for special places that carry high population like fire temple (place where Persians worshiped the Fire God), mosque, bazaar and other public places. This is not that difficult to built a dome over four arches. Further, dome structures are ideal for large span structures against gravity loads as it transforms them into horizontal and shear loads. In addition, for lateral loads, domes behave like a truss and distribute the load to other parts of the structure developing a perfect load path. This construction system has been considered, the most prominent structural system in traditional Iranian architecture. These are basically monumental buildings developed close to desert where there was not enough construction materials that could take tensile stresses.

1. General Information

Buildings of this construction type can be found in all parts of the Persian Empire, especially next to the desert (Kavir). This type of housing construction is commonly found in both rural and sub-urban areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is not being built. This construction system was common in the past for monumental building structures.

Figure 1: Typical building (shrine in Aqda, province of Yazd).

Figure 2: Another typical building (this is a Niasar fire temple, constructed approximately 0 A.D., in the village of Niasar, near Kashan in the province of Isfahan).

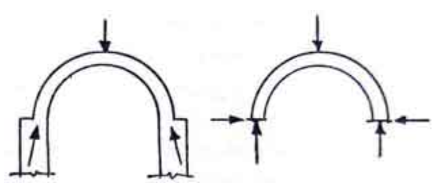

Figure 3: Perspective Drawing Showing Key Load-Bearing Elements

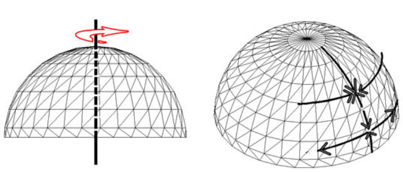

Figure 4: Perspective Drawing Showing Key Load-

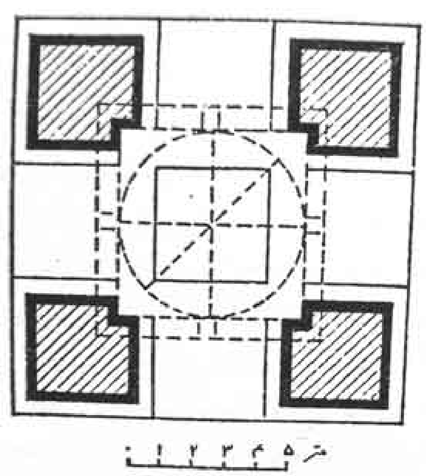

Figure 6: 1- Cracks in the dome-roof (it may not

Bearing Elements

Figure 5: Plan of a Typical Building

have been caused by an earthquake). Photo from Kerman bazaar, in the city of Kerman.

Figure 7: 2- Vertical crack on thick column (pier). This is from a structure built around 0 A.D. in the city of Bam, province of Kerman.

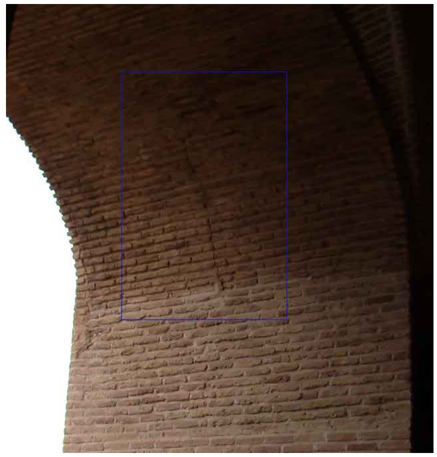

Figure 8: 3- Collapse of the structure due to non ductile materials (Bam earthquake, 2003, IRAN) This is the Kerman bazaar in the city of Kerman.

Figure 9: An Illustration of Key Seismic Features and/or Deficiencies. This is a building built around 0 A.D. in the city of Bam, province of Kerman.

Figure 10: Roof opening for natural light because of lack of electricity in the past . This is the Ganjali khan bath in the city of Kerman.

Figure 11: Modification and strengthening technique of arches. This is the Toqrol Tower, built around 400 A.D., in the city of Ray, province of Tehran.

Figure 12: The holes that carry the timber tie beams to prevent slipping the roof. This building is located in the city of Aqda, province of Yazd.

Figure 13: Modern structure based on principles of older Persian architecture. This is Azadi Square, built in the 1970's, in the city of Tehran.

Figure 14: Section. Building built around 0 A.D. in Bam, province of Kerman.

Figure 15: A Samanian king's house in Bukhara

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. These are mostly free standing buildings. However, sometimes when these are built in the middle of other buildings (as intersection), there is no gap between adjacent buildings When separated from adjacent buildings, the typical distance from a neighboring building is 0 meters.

2.2 Building Configuration

This building is square in the plan. This type of building has also been constructed with other plan shapes as well however, then the name would be different. Large openings are provided in all four sides in between huge piers located at the corners. Sometimes an opening is also provided in the roof for natural light. These are usually around 50 cm in diameter.

2.3 Functional Planning

This building type was used for public places like temples, mosques, street or bazaar, intersections, public baths, or may be sometimes as house of an important person, because with this technique the house could be constructed bigger and higher. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Depending on the building function, there could be up to four exits on all four sides.

2.4 Modification to Building

Some modifications could have been made in the roof opening and the shapes of the arches over the time. The roof opening could have been made smaller or larger, and the arches modified as shown in figures.

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	☐
			Concrete block masonry in	

		16	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)	☐

Plaster of paris was one of the materials that was used for the mortar.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is earthen walls. Huge masonry piers connected by the arches at the top and dome-roof system.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Huge masonry piers connected by the arches at the top and dome-roof system.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 7 and 30 meters, and widths between 7 and 30 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 3-15 meters. Typical Plan Dimensions: The building plan size depends on the building function (intersection, mosque?). The plan dimensions may vary, but in overall the structure have a regular plan. Typical Story Height: It depends on the building function. Typical Span: single span for the single roof. The typical storey height in such buildings is 7-20 meters. The typical structural wall density is more than 20 %. 15% to 30%.

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. With building it in vault form, the forces distribute on surface.

3.6 Foundation

Type	Description	Most appropriate type
	Wall or column embedded in soil, without footing	☑
	Rubble stone, fieldstone isolated footing	☐

Shallow foundation	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 5-10 housing unit(s). Not applicable as these were used as public space. Each dome-roof provides cover to one large platform at ground level. The number of inhabitants in a building during the day or business hours is more than 20. The number of inhabitants during the evening and night is 5-10. These buildings had been uses as public buildings so the number of inhabitants depended upon the population area it served.

4.2 Patterns of Occupancy

Public places, for small to large population.

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)	☑

Economic Level: The ratio of price of housing unit to the annual income can be 1:1 for middle 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)	☑

Governors from taxes. Or people of an area gathered and built -for example- a public bath or mosque. In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) induding toilet(s).

Usually no bathroom provided. .

4.4 Ownership

The type of ownership or occupancy is outright ownership, ownership by a group or pool of persons and others.

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)	☑

It is public building owned by the governor or people of the area.

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	NA			

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Wall	N/A	N/A	N/A
Frame (columns, beams)	Constructed of low strength brittle materials, the structural elements are unreinforced.	well defined load path, high rigidity	diagonal cracks more often in mortar, shear and tensile failure at the column bottom
Roof and floors	Constructed of low strength brittle materials, heavy in weight, the roof is unreinforced, opening in the roof, large span	well defined load path, perfect distribution of forces and stresses	No significant damage except that caused by column failure

Other	No second seismic system like tie beams	NA	Crushing of brick material

This type of structure has continuous load path like concrete columns with concrete shell connecting the columns at the top, except that bricks and mortars do not have that material properties.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *B: MEDIUM-HIGH VULNERABILITY (i.e., 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 *C: MEDIUM VULNERABILITY (i.e., moderate 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
2003	Bam	6.5	VIII

As stated above this type has been constructed thousands years ago, hence there must have been many other earthquakes especially the historical ones that affected these buildings. However, information in not 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

As stated earlier, this type was usually built for public uses. May be in the past, the labors lived in the building temporarily who built it.

6.3 Construction Process, Problems and Phasing

Experienced persons, master builders and may be some 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 not designed for its final constructed size.

6.4 Design and Construction Expertise

There were no academically qualified engineers or architects and no standard codes for design of this type of building structures were available. These might have been 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 is a historic building typology and is not anymore being constructed nowadays, except for creating the past architecture of Persia. 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, Owner(s) and others. sometimes the governor maintains the building.

6.8 Construction Economics

Approximately US$70-80 /m2. 5-15 persons for about 6-12 month depending on the size of the building.

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 is based on the value of the building. Depends on the owner capital demand, usually for every US$5000 additional cover, it costs about US$6 /year added to fire insurance. That is what the insurance company quotes, however, these structures are now parts of the governors? properties. So these.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
No shear wall	add a shear wall to the system by filling between the arches.
Damages in load path (columns)	1. add a shear wall to the system by filling between the arches. 2. embed some materials to maintain the column.

opening in roof	Strengthening all around the opening.
heavy weight	Remove the heavy weight materials of the roof and replace them with light new materials.
large span	Constructing some horizontal tie beams (timber, cable or steel bar).
Unreinforced arch	Reinforcing of the arch by prestressed with cable or steel bar at spring level

The construction materials used in these buildings do not comply with the Iranian codes.

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?

They are used for both issues.

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?

Government.

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

NA.

Reference(s)

1. History of engineering in Iran
   Farshad,M.
   Balkh Publications 1997
2. Iranian retrofitting provision for existing buildings : Section 7 - Masonry structures and infills
   IIEES
3. Iran insurance co., http://www.iraninsurance.ir
4. Earthquake Engineering Theory and Applications
   Moghaddam,H.
   Farahang Publication 2002
5. Siamak Ahi webblog, http://chaartaagh.blogspot.com/

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)

Save page as