World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Unreinforced Masonry Building : Brick masonry in mud/lime mortar, with vertical posts

Report#	117
Last Updated	
Country	Iran
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Reviewers	,

Important

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General Information

Building Type:	Unreinforced Masonry Building : Brick masonry in mud/lime mortar, with vertical posts
Country:	Iran
Author(s):	Nima T. Bekloo, NA
Last Updated:	
Regions Where Found:	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.
Summary:	The 'Four arches' or Char Taaqi (in Persian) derives its name from the four arches thatconnect the tops of four timber or masonry piers enclosing the space. It is an equilateralarchitectural 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 barrelvaults together constitute a room of cruciform ground plan. This structural system developedabout 2500 years ago, after the earring system in the Old Persian Empire (Sasanian age). The maingoal of this building system was to create wide openings at four side of the structure. Thisbuilding system was used for special places that carry high population like fire temple (placewhere Persians worshiped the Fire God), mosque, bazaar and other public places. It is notthat difficult to built a dome over four arches. Further, dome structures are ideal for large spanstructures against gravity loads as it transforms them into horizontal and shear loads. Inaddition, for lateral loads, domes behave like a truss and distribute the load to other parts ofthe structure developing a perfect load path. This construction system has been considered the most prominent structural system in traditional Iranian architecture. These are basicallymonumental buildings developed close to the desert where there was not enough constructionmaterials that could take tensile

	stresses.
Length of time practiced:	More than 200 years
Still Practiced:	No
In practice as of:	Unknown
Building Occupancy:	Institutional housingOther
Typical number of stories:	1
Terrain-Flat:	Typically
Terrain-Sloped:	Occasionally
Comments:	This construction system was common in the past formonumental building structures.

Features

Plan Shape	Square, solidRectangular, solid
Additional comments on plan shape	This building is square in the plan. This type of building has also been constructed with other plan shapes as wellhowever, then the name would be different.
Typical plan length (meters)	7-30
Typical plan width (meters)	7-30
Typical story height (meters)	7-20
Type of Structural System	Masonry: Earthen/Mud/Adobe/Rammed Earth Walls: Mud wallsMasonry: Earthen/Mud/Adobe/Rammed Earth Walls: Adobe block wallsMasonry: Earthen/Mud/Adobe/Rammed Earth Walls: Rammed earth/pile constructionMasonry: Unreinforced Masonry Walls: Brick masonry in mud/lime mortarMasonry: Unreinforced Masonry Walls: Brick masonry in mud mortar with vertical posts
Additional comments on structural system	Lateral load-resisting system: The lateral load-resisting system is huge masonry piers connected by the arches at the topand the dome-roof system.Gravity load-bearing system: The vertical load-resisting system is earthen walls: huge masonry piers connected by the arches at the top and the dome-roof system.

Gravity load-bearing & lateral load-resisting systems	Plaster of paris was one of the materials that was used for the mortar.
Typical wall densities in direction 1	>20%
Typical wall densities in direction 2	>20%
Additional comments on typical wall densities	The typicalstructural wall density is more than 20 %. 15% to 30%.
Wall Openings	Large openings are provided in all four sides in between huge pierslocated at the corners. Sometimes an opening is also provided in the roof for natural light. These are usually around 50cm in diameter.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Some modifications could have been made in the roof opening and the shapes of the arches over time. The roofopenings could have been made smaller or larger, and the arches modified as shown in figures.
Type of Foundation	Shallow Foundation: Wall or column embedded in soil, without footingShallow Foundation: Rubble stone, fieldstone isolated footingShallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	
Type of Floor System	Wooden beams or trusses and joists supporting heavy flooring
Additional comments on floor system	Vaulted Masonry; The construction materials have no ductility. With building it in vault form, the forces distribute on surface.
Type of Roof System	Masonry roof, unknownVaulted masonry roofShallow-arched masonry roofEarthen roof, unknownVaulted earthen roofRoof system, other
Additional comments on roof system	Vaulted Masonry; The construction materials have no ductility. With building it in vault form, the forces distribute on surface.
	These buildings do not share common walls with adjacent buildings; theyare mostly free standing

Additional comments section 2	buildings. However, sometimes when these are built in the middle of other buildings (as intersection), there is no gap between adjacent buildings. This building type was used as public places like temples, mosques, street or bazaar, intersections, public baths, ormaybe sometimes as house of an important person because with this technique the house could be constructedbigger and higher. In a typical building of this type, there are no elevators and no fire-protected exitstaircases. Depending on the building function, there could be up to four exits on all four sides.

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: Brick & stone	Wall: Characteristic Strength- 40-120 kg/cm2Mix Proportion/Dimensions- 20x10x10 - 50x50x20 cmVaries from places and ages
Foundations	Brick & stone	Characteristic Strength- 40-150 kg/cm2Mix Proportion/Dimensions- Not much bigger than the wallsVaries from places and ages
Floors	Brick & stone	Characteristic Strength- 40-120 kg/cm2Mix Proportion/Dimensions- 20x10x10 - 50x50x20 cmVaries from places and ages
Roof	Brick & stone	Characteristic Strength- 40-120 kg/cm2Mix Proportion/Dimensions- 20x10x10 - 50x50x20 cmVaries from places and ages
Other		

Design Process

Who is involved with the	

Who is involved with the design process?	ArchitectTechnologistBuilderOther
Roles of those involved in the design process	There were no academically qualified engineers or architects and no standard codes for design of this type of buildingstructures were available. These might have been constructed by empiricism or experimentation. However, it is still atopic of research.
Expertise of those involved in the design process	There are no academically qualified engineers or architects for this type of buildings.

Construction Process

Who typically builds this construction type?	MasonBuilderOther
Roles of those involved in the building process	Experienced persons, master builders and maybe some contractors with help of laborers built the structure.
Expertise of those involved in building process	
Construction process and phasing	Tools/equipment typically used: shovel, hack, float and other old construction equipment.The construction of this type of housing takes place in asingle phase. Typically, the building is not originally designed for its final constructed size.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	No
Applicable codes or standards	
Process for building code enforcement	

Building Permits and Development Control Rules

Are building permits required?	No
Is this typically informal	Yes

construction?	Yes
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	This is a historic building typology and is not being constructed anymore, except for creating the pastarchitecture of Persia. Building permits are not required to build this housing type.

Building Maintenance and Condition

Typical problems associated with this type of construction	Since These types are ancient, sometimes they clash with urban developement
Who typically maintains buildings of this type?	BuilderOwner(s)Other
Additional comments on maintenance and building condition	Sometimes the governormaintains the building.

Construction Economics

Unit construction cost	Approximately US$70-80 /m2.
Labor requirements	5-15 people for about 6-12 month depending on the size of the building
Additional comments section 3	

An Illustration of Key Seismic

Roof opening for natural light

Featuresand/or Deficiencies. This is a building built around0 A.D. in the city of Bam, province of Kerman.

because oflack of electricity in the past . This is the Ganjalikhan bath in the city of Kerman.

Socio-Economic Issues

Patterns of occupancy	Public places, for small to large population. Each dome-roofprovides cover to one large platform at ground level.
Number of inhabitants in a typical building of this construction type during the day	>20
Number of inhabitants in a typical building of this construction type during the evening/night	10-20
Additional comments on number of inhabitants	
Economic level of inhabitants	Middle-income classHigh-income class (rich)
Additional comments on economic level of inhabitants	Economic Level: The ratio of price of housing unit to the annual income can be 1:1 for middle class families.
Typical Source of Financing	Personal savingsInformal network: friends or relativesGovernment-owned housingOther
Additional comments on financing	Government from taxes or people of an area gathered and built -for example- a public bath or mosque.
Type of Ownership	Own outrightOwned by group or poolOther
Additional comments on ownership	It is a public building owned by the government or people of the area.
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	Earthquake insurance is included in fire insurance and it is based on the value of thebuilding.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 ofthe governors' properties.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	Yes
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
2003	Bam

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	As stated above this type has been constructed thousands years ago, hence there must have been many otherearthquakes especially the historical ones that affected these buildings. However, information in not available.
Additional comments on earthquake damage patterns	Overall damage patterns observed in past earthquakes for this type of construction included crushing of brick material and:(frame): diagonal cracks more often in mortar, shearand tensile failure at the column bottom (roof and floors): No significant damage except that causedby column failure(other): Crushing of brick material

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is

FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	TRUE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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.	TRUE
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.	TRUE
Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the	TRUE

	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.	TRUE
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	FALSE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	N/A
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building	FALSE

	elements (concrete, steel, timber).

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	SetbackChange in vertical structureOther
Seismic deficiency in walls	Brittle material, mostly no confinements
Earthquake-resilient features in walls	Vaulted roof and massive masonry piers.
Seismic deficiency in frames	Constructed of low strength brittle materials, the structuralelements are unreinforced.
Earthquake-resilient features in frame	Well defined load path, highrigidity
Seismic deficiency in roof and floors	Constructed of low strength brittle materials, heavy inweight, the roof is unreinforced, opening in the roof, largespan
Earthquake resilient features in roof and floors	Well defined load path, perfectdistribution of forces andstresses
Seismic deficiency in foundation	Lack of Lateral resistance
Earthquake-resilient features in foundation	N/A

Seismic Vulnerability Rating

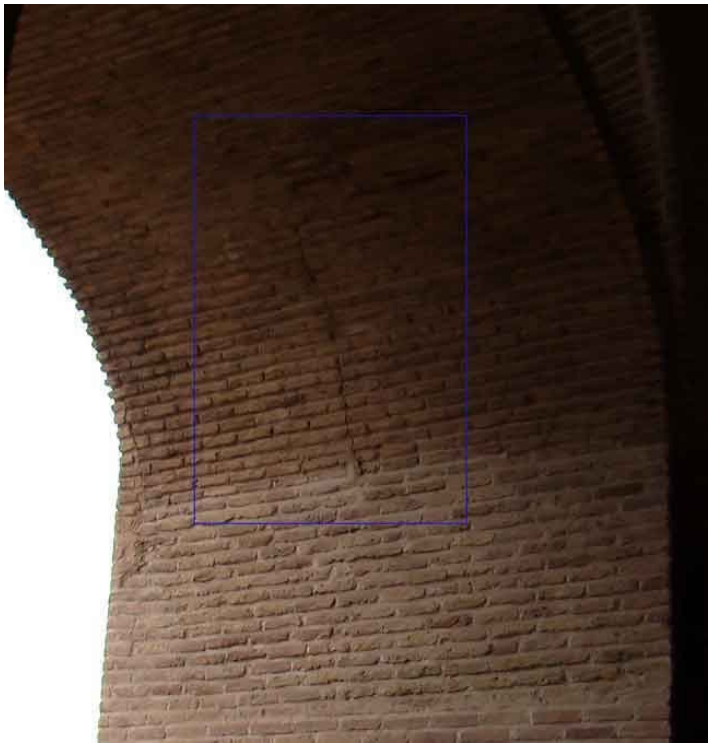
For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F

Seismic vulnerability class		-	o	-	

1- Cracks in the dome-roof (it may not have been caused by an earthquake). Photo fromKerman bazaar, in the city of Kerman

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



3- Collapse of the structure due to nonductile materials (Bam earthquake, 2003, IRAN)This is the Kerman bazaar in the city of Kerman.

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
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; Unreinforced arch	Strengthening all around the opening; Reinforcing of the arch by prestressed with cable or steel bar at spring level
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).

Additional comments on seismic strengthening provisions	Unreinforced arch - Reinforcing of the arch by prestressed with cable or steel bar at spring level
Has seismic strengthening described in the above table been performed?	No
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	They are used for both issues.
Was the construction inspected in the same manner as new construction?	No.

Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Government.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	N/A
Additional comments section 6	The construction materials used in these buildings do not comply with the Iranian codes.

Modification and strengtheningtechnique of arches. This is the Toqrol Tower,built around 400 A.D., in the city of Ray, provinceof Tehran.

The holes that carry the timber tiebeams to prevent slipping the roof. This building islocated in the city of Aqda, province of Yazd.

Modern structure based on principles ofolder Persian

architecture. This is Azadi Square,built in the 1970's, in the city of Tehran

References

History of engineering in IranFarshad,M.Balkh Publications 1997

Iranian retrofitting provision for existing buildings : Section 7 - Masonry structures and infillsIIEES

Iran insurance co., http://www.iraninsurance.ir

Earthquake Engineering Theory and ApplicationsMoghaddam,H.Farahang Publication 2002

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