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
Steel frame with semi-rigid "Khorjini" connections and jack arch roof "Taagh-e-Zarbi".

Report #	25
Report Date	06-05-2002
Country	IRAN
Housing Type	Steel Moment Frame Building
Housing Sub-Type	Steel Moment Frame Building : Brick masonry infills
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Summary

This is a common type of urban/rural construction in many parts of Iran. It is widely used in the cities as a popular structural system for low-rise residential buildings because of the ease of construction and of erecting the frame. Buildings of this type are up to 5 stories high, with a

height/width aspect ratio on the order of 1.5. This system consists of a special kind of steel framing with heavy brick infills as partitions. Roof girders are connected to the supporting columns by means of semi-rigid connections. Diaphragms may range from flexible to rigid depending on the detailing and the construction quality. The structure is extremely heavy because of the brick infills between the roof beams. The roof is constructed in the form of a shallow arch called a 'jack arch'. Roofs, ceilings, and floors constructed in this way contributed to building failures and to an unusually high death toll in many recent earthquakes in Iran. As many as half the buildings completed in the early 1970s in Iran had jack arches. In a jack arch system, steel beams or a reinforced concrete joist system span the distance between the main girders across the length of the building. An arch made of small bricks connect the beams. Each arch rises only about ten centimeters. The 'valleys' of this wave-like surface are filled with mortar. The completed ceiling, roof, or floor is thick and heavy. Frequently the steel support beams are not tied together properly or are left untied (From: http://www.johnmartin.com/eqshow/647014_00.htm). Seismic vulnerability of this system is observed as medium to high. The dynamic behavior of the system in the two main perpendicular directions of the building plan differs significantly because of the differences in the stiffness and configuration of the connections in these two directions. Furthermore, 'X' bracings are usually used in the weak direction which further magnifies the non-uniform behavior of the structural system.

1. General Information

Buildings of this construction type can be found in all parts of Iran. In general, this housing type constitutes 30 to 40% of urban construction types in most of the Iranian cities. However, in northern provinces (Golestan, Mazandaran, Gilan) and in the areas close to the central desert of Iran, (Khorasan, Yazd, and Sistan-va-Baloochestan) this ratio is lower (around 20 to 35%). This type of housing construction is commonly found in both rural and urban areas.

This system of construction is not obviously the first choice for low-income families living in the villages but it's more widely spread in the cities where material and workmanship can be found cheaper.

This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. The question of how to estimate the rigidity of this type of connections has been the subject of many analytical and experimental research studies since the behavior of the structural system is a strong function of performance of the connections (References No.2). Buildings are constructed side-by-side forming a long block. They connect to each other without any seismic gap.


Figure 1A: Typical Building


Figure 1B: Typical Building

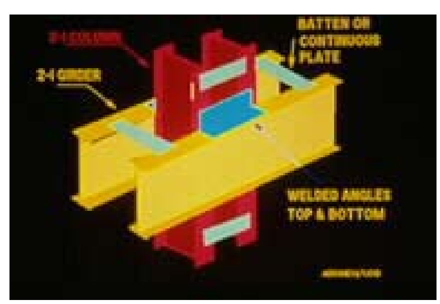

Figure 2A: Key Load-Bearing Elements

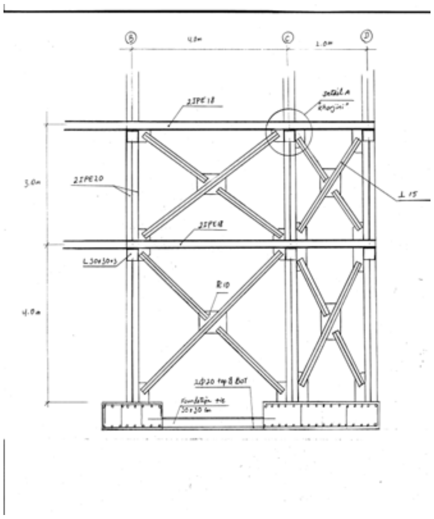

Figure 2B: Vertical elevation of a typical showing lateral bracing

Figure 2C: Typical "Khorjini" connection

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They share common walls with adjacent buildings.

2.2 Building Configuration

Buildings of this type are generally of rectangular shape, however there are also cases of irregularities in plan and height (Figure 7). In most of the cases openings are only in two parallel sides of the building plan as in the other two sides the building is standing side by side by the neighboring structure. X bracings are provided in the closed sides.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). There are many variations in building functions. Even hospitals, fire departments and government buildings may be found constructed earlier using this structural system. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. For most of the cases there is no emergency exit stairway. Units generally have only one main door which opens to the lobby or the main stairway. For taller buildings emergency exit and stairways are provided.

2.4 Modification to Building

Adding stories on the top of the building, removing the partition walls.

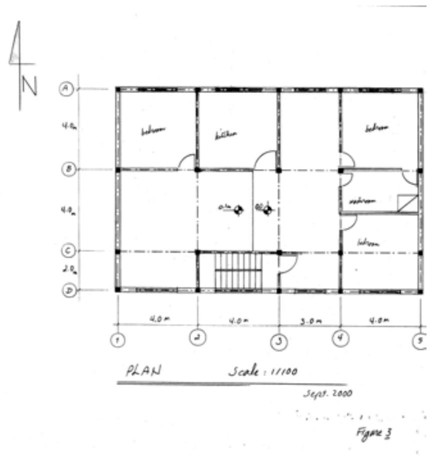

Figure 3: Plan of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
	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	☐

Structural concrete		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)	☐

As mentioned before, buildings of this type have X bracings in one direction (perpendicular to the street) and semi-rigid connections in the other direction. Please refer to Figure 5F.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is steel moment resisting frame. Consists of Steel frames (girders and columns with semi-rigid connections).

3.3 Lateral Load-Resisting System

The lateral load-resisting system is steel moment resisting frame. 1- Light bracing, L or T sections, most of the times in one direction of the building only (perpendicular to street) where the building does not have any openings and hence connected to the adjacent building 2- On the other sides, lateral forces are resisted by means of semi-rigid connections "Khorjini" 3- Also un-reinforced brick infills between frame panels (without any gap) may contribute to the lateral force resistance but usually during seismic analysis and design process their effects are ignored and the R factor (inelastic reduction factor of seismic coefficient) is rather chosen based on the bare steel frame (as a common mistake). According to the Iranian National Building Code, steel bracing should be provided in both directions of the building.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 15 and 15 meters, and widths between 15 and 15 meters. The building has 2 to 5 storey(s). The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimensions: It is on average. Variation of length is 12-20 meters and width 9-15 meters. Typical Story Height: First floor usually has higher height, in the rage of about 4.0 m, for commercial use. Typical Span: Variation of span is 3-5 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 5 %. 4%.

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	☑	☑

Masonry and steel jack arch structure. Masonry and steel jack arch structure Roofs/floors are very heavy and behave as flexible diaphragm unless special detailing is considered. The system consists of parallel roof steel beams at about one meter distance; beams support the shallow brick arches which are covered and leveled by gypsum finishing.

3.6 Foundation

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

Shallow foundation	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	☐

Seismic problems related to the foundation system are rare. Single footings are connected to each other by strong ties.

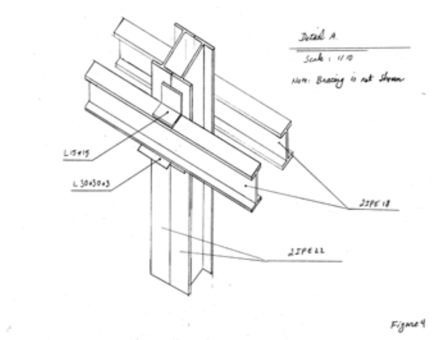

Figure 4: Critical Structural Detail - "Khorjini" connection

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 2 housing unit(s). 2-6 units in each building. The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is 11-20. Roughly an Iranian family has 4~6 members.

4.2 Patterns of Occupancy

Typically one family occupies one housing unit.

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: For Poor Class the Housing Unit Price is 10,000 and the Annual Income is 3,000. For Middle Class the Housing Unit Price is 60,000 and the Annual Income is 6,000. For Rich Class the Housing Unit Price is 250,000 and the Annual Income is 50,000.

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)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Bathrooms or latrines are rarely shared between units. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership , ownership with debt (mortgage or other) , individual ownership and long-term lease.

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	

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Walls	Cracking at the corners of un-reinforced masonry walls. Out-of-plane collapse of unanchored walls.	Relatively enough in-plane stiffness, which contributes to the lateral resistance.	Out of plane collapse, Classical X shear cracking.
Frames (columns, beams)	Buckling/collapse of the first-storey columns due to soft story behavior. Buckling of the braces.	Generally enough storey shear resistance. Shear failure is rare.	Buckling of the storey.
Roof and floors	Insufficient roof support, vulnerability height due to the weak behavior of the heavy flexible roofs.	N/A	Total/partial collapse.
Connections	Slippage between the girders and the columns. Insufficient sitting width for the girders on the columns angel connections.	N/A	Excessive rotations, shear failure of the welds, unsitting.

Please refer to Figures.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good 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
1990	36.96 N, 49.41 E, Rudbar-Manjil	7.3	N/A
1997	Bojnoord	6.1	N/A
1997	33.654 N latitude and 59.739 E longitude according to USGS, Ardekul	7.3	N/A
1997	Ardebil	5.5	N/A

1997 Ardebil magnitude: mb=5.5 1997 Bojnoord magnitude: mb=6.1 1990 Rudbar-Manjil magnitude: Mw=7.3 The same pattern of damage as mentioned in part 5. Please refer to the tectonic and seismicity maps of Iran, Figures: 6A, 6B, 6C and 6D.

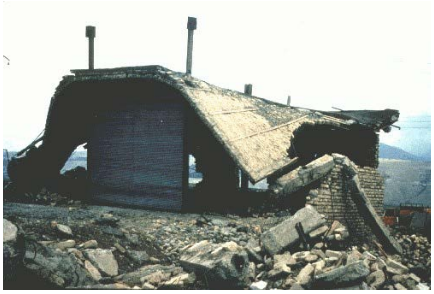

Figure 5A: The 1990 Rudbar Manjil Earthquake, Partial Collapse of the Storey, Buckling of the Bracings, and permanent Sidesway (EERI Slide Collection)

Figure 5B: Earthquake Damage. 1990 Rudbar Manjil Earthquake (EERI Slide Collection)

Figure 5C: Earthquake Damage, 1990 Rudbar Manjil Earthquake (EERI Slide Collection)

Figure 5D: Earthquake Damage, 1990 Rudbar Manjil Earthquake (EERI Slide Collection)

Figure 5E: Earthquake Damage, 1990 Rudbar Manjil Earthquake (EERI Slide Collection)

Figure 5F: Earthquake Damage, 1990 Rudbar Manjil Earthquake (EERI Slide Collection)

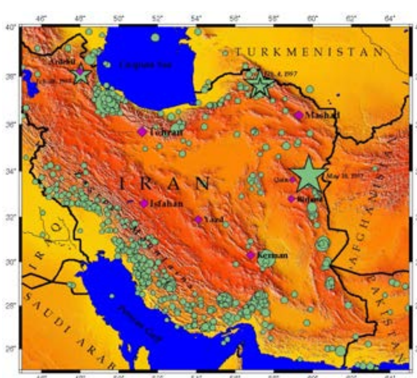

Figure 6A: Earthquake Map

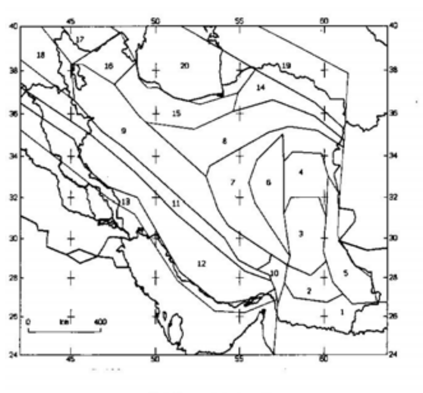

Figure 6B: Earthquake Map

Figure 6C: Earthquake Map

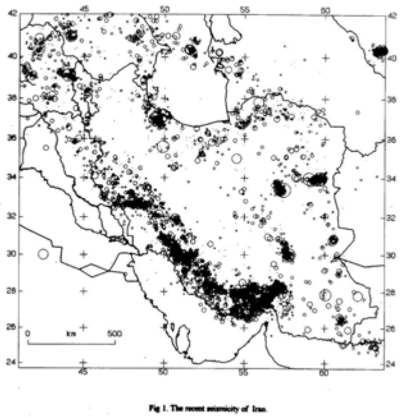

Figure 6D: Earthquake Map

Figure 6E: Earthquake Map


Figure 7: A typical building

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Masonry (clay brick and cement/lime mortar)	fc=200 kg/cm^2	1:6, 55 X 110 X 220 mm	N/A
Foundation	Reinforced Concrete	f'c= 250 kg/cm^2	1:2:4	N/A
Frames (beams & columns)	Steel	fy= 2400kg/cm^2	N/A	N/A
Roof and floor(s)	Steel Beams and Masonry Infill, (Brick and Gypsum)	N/A	N/A	N/A

6.2 Builder

Sometimes, but these days it is typically designed and built by the developers.

6.3 Construction Process, Problems and Phasing

In most of the cases, owner or a contractor on behalf is in charge of the construction. The construction process has 3 main parts, excavation and foundation construction, steel frames erection, masonry works and the installation of electrical and mechanical systems. Simple machinery is used throughout the construction like a small crane. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. NA.

6.4 Design and Construction Expertise

Usually the whole process of construction is being done by a team of workers (not always certified workers). A registered engineer checks the final design. In spite of many lessons learnt in the previous earthquakes proving poor performance of this structural system, many engineers still design the buildings using this system. Lack of quality control by the engineers during design and construction is obvious.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. "Iranian Code of Practice For Seismic Resistance Design of Buildings, 2nd Edition 1999, Iranian National Building Code"; special detailing required to improved the seismic performance are addressed in the appendix. The year the first code/standard addressing this type of construction issued was 1999. N.A. The most recent code/standard addressing this construction type issued was 1999. Title of the code or standard: "Iranian Code of Practice For Seismic Resistance Design of Buildings, 2nd Edition 1999, Iranian National Building Code"; special detailing required to improved the seismic performance are addressed in the appendix. Year the first code/standard addressing this type of construction issued: 1999 National building code, material codes and seismic codes/standards: N.A.

The new edition of the "Iranian Code of Practice for Seismic Resistant Design of Buildings-Standard No. 2800", which is a very well prepared code, was subjected to the Iranian government approval in December 1999. However there are not much strong interest among building officials towards the enforcement of the code and quality control of the constructed infrastructures in many parts of the country is low. "In general the building departments of municipalities have the responsibility to check and approve the design process, however the design engineer holds the responsibility for the projects. When the construction is completed then the municipal authorities check the finished project to issue the occupancy permit." (Ref: www.johnmartin.com/EERI).

6.6 Building Permits and Development Control Rules

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

N.A. 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). N.A.

6.8 Construction Economics

2,000,000.00 Rials/m² (US$ 250.00 /m²) (Note: Exchange rate of US$ 1.00 = 8,000 Rials is used). Foundation: 20 Days - 1 Technical Staff - 5 Workers Steel Structure Erections and Masonry Work: 3 Months - 2 Technical Staff - 10 Workers Final Finishing: 4 Months - 2 Technical Staff - 6 Workers.

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 unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Out of plane wall collapse/ creaking	Addition of concentric bracing to the spans
Partial/ total collapse of the stories, soft storey	Adding concentric bracings
Roof collapse	Horizontal bracings welded on the roof/floor beams
Connection unsitting/slippage	Strengthening the connection, connection confinement using steel plates

No practical example is unfortunately available to the author at this time however there are plenty research projects going on or already completed on this issues. Please refer to reference no. 5: http://www.dena.iiees.ac.ir.

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?

Yes, depending on the importance of the project different retrofitting strategies could be implemented.

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

Mitigation on an existing undamaged building.

8.3 Construction and Performance of Seismic Strengthening

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

Retrofit designed by an engineer, constructed by a contractor under supervision of the engineer.

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

Relatively good when the code considerations are taken into account.

Reference(s)

1. Iranian Code of Practice for Seismic Resistant Design of Buildings-Standard No. 2800
2. The Seismic Design Handbook
   Naeim,F.
   Second Edition, ICBO, SEA and Kluwer Publishers 2001
3. www.johnmartin.com/eqshow/647014_00.htm
4. sharif.ac.ir/~civilinfo/Thesis/Structural99.htm
5. www.eeri.org
6. www.johnmartin.com/EERI
7. www.dena.iiees.ac.ir

8. seismo.ethz.ch/gshap/iran/report.html

9. geohaz.org/radius/Tehran/

10. www.worldclimate.com/

11. www.itto.org/weather/climate.htm

12. www.ldeo.columbia.edu/~mwest/museum/

13. seismo.univ.trieste.it/CdRom/reports/QR230.htm

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