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
Semi-rigid steel frame with "Khorjinee" connections

Report #	26
Report Date	06-05-2002
Country	IRAN
Housing Type	Steel Braced Frame Building
Housing Sub-Type	Steel Braced Frame Building : Concentric connections in all panels
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Reviewer(s)	Farzad Naeim

Summary

This housing type is commonly used for low-rise building construction in Iran, mainly for family apartment buildings. This structure is characterized with a special type of semi-rigid beam-to-column connection called "Khorjinee connection." This connection consists of a pair

of continuous beams spanning over several columns and connected to the column sides by means of angle sections. Beam and column are welded to the angle section. A major problem with the Khorjinee connection is that it is very difficult to improve the rigidity of the connection in the weak direction (the direction perpendicular to the connection) since the crossed beams are connected to the web of Khorjinee beams. Thus, in the weak direction of the frames, the connections are considered as pinned (hinges) and the bracing is used to resist seismic loads. However, in the Khorjinee direction, since the possibility of using the bracing is very limited, the frame is considered a rigid structure. Also, out-of-plane partial beam-to-column transfer of bending moment and early onset of failure in the angles are the most likely causes of failure for a building subjected to lateral earthquake loads. These buildings are vulnerable in earthquakes (e.g., 1990 Manjil earthquake).

1. General Information

Buildings of this construction type can be found in urban and in some rural areas of Iran, especially in less humid regions. The percentage of this housing type in those regions is almost 70% of steel buildings. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. This type of construction is followed in the last 30 years.

Figure 1: Typical Building

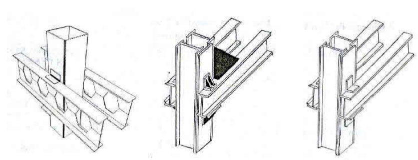

Figure 2A: A typical layout of a Khorjinee connection

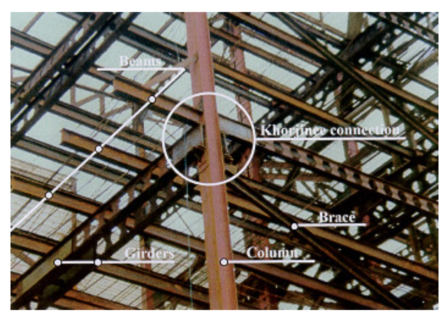

Figure 2B: An Illustration of a building with a Khorjinee connection

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is several meters.

2.2 Building Configuration

The typical shape of a building plan for this housing type is rectangular. To view outside the building, typically a large window opening is in the transverse direction of the building. This window almost takes 70% of the external wall area. The other wall has one or two doors or windows opening. The door sizes are typically 90 X 210 (cm) and the other window sizes are 160 X 90 (cm). The overall window and door areas are about 35% of the overall wall surface area.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases.

2.4 Modification to Building

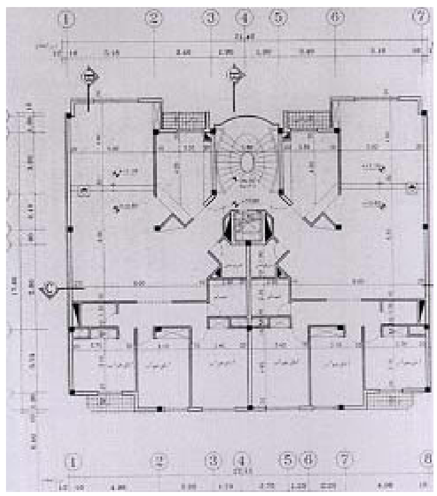

Figure 3: Plan of a Typical Building

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	☐
		11	Clay brick/tile masonry, with wooden posts and beams	☐

	Confined masonry	12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☑
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is steel braced frame. Gravity loads are sustained by steel frames.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is steel braced frame. In both directions of the building the lateral load-resisting system should be provided by steel bracing (according to seismic code of Iran). However in most of these buildings, the steel bracing system is only used in one direction (the direction which is perpendicular to the street). The other direction (which is usually parallel to street), due to the existence of large opening in the wall of this direction, does not have any lateral resisting system.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 15 and 15 meters. The building has 4 to 6 storey(s). The typical span of the roofing/flooring system is 4.5 meters. Typical Plan Dimensions: Length variation is 12 - 20 meters, width variation is 9 - 15 meters. Typical Span: Usually span is 3 - 4.5 meters. The typical storey height in such buildings is 2.7 meters. The typical structural wall density is none. 0.1.

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	☑	☑

Concrete joists with infilled hollow blocks topped with concrete slab. Concrete joists with infilled hollow blocks topped with concrete slab The floor and roof are considered to be rigid diaphragm.

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	☐

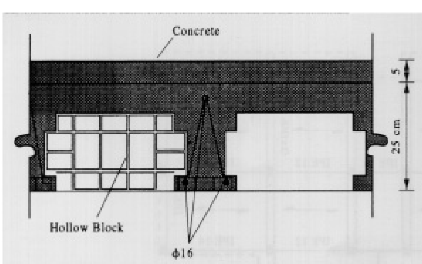

Figure 4A: A typical floor slab construction

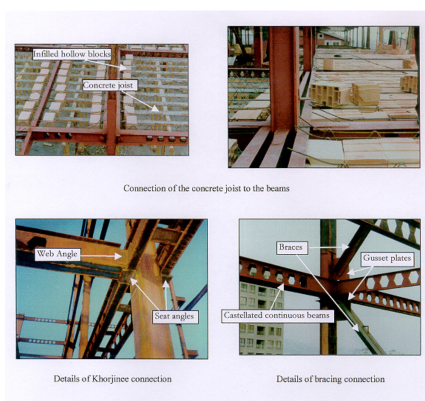

Figure 4B: Critical Structural Details


Figure 5A: A seismic deficiency: wrong connection detail


Figure 5B: Seismic deficiency-use of undefined bracing system

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). 8 units in each building. Typically there are from 4 to 8 units in 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.

4.2 Patterns of Occupancy

One family usually occupies each 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 12,500 and the Annual Income is 1,000. For Middle Class the Housing Unit Price is 25,000 and the Annual Income is 3,000.

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).

Depending on the size of house, typically one or two bathrooms and one or two latrines for each housing unit are built. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and ownership with debt (mortgage or other).

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	☐	☑	☐
	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less			

Wall openings	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**
Wall	Due to lack of proper connections between walls and column, beam floor, walls are very vulnerable to seismic forces.		
Frame (columns, beams)	Tear of the beam-to-column connections.		
Roof and floors	None.		

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance)*, the lower bound (i.e., the worst possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is *E: LOW VULNERABILITY (i.e., very 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	Manjil	7.6	IX

Figure 6A: Building damage in the 1990 Manjil earthquake-collapse caused by the connection failure

Figure 6B: Building damage in the 1990 Manjil earthquake-collapse caused by the connection failure

Figure 6C: Minor damage due to pounding between two adjacent buildings in the 1990 Manjil earthquake

Figure 6D: Failure due to soft story behavior in the 1990 Manjil earthquake

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Clay brick masonry Concrete Steel bars.	100 kg/cm² 8 kg/cm² 210 kg/cm² 4200 kg/cm².	1:6 / 55 X 110 X 220 (mm) 1:2:4 n/a.	
Foundation				
Frames (beams & columns)	Steel.	2400 kg/cm²		
Roof and floor(s)	Concrete.	210 kg/cm².		

6.2 Builder

It is typically built by developers or for speculation.

6.3 Construction Process, Problems and Phasing

Typically developers build these types of constructions. Process starts with the foundations and fixing base plates on them. Then erection of steel frame and placing of joists and blocks, purring the concrete topping and then working out the infill walls and finally putting the finishing on the hole building. The construction of this type of housing takes place incrementally over time. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

As far as the member sizes and foundations design concern, engineers are expert enough to design this type of building. In most projects engineers do not address any detail of the connection and they leave this part of job to experienced builders. For design of building, engineers and architectures are both involved. However, in most projects, during the construction process they do not spend any remarkable time to visit the site.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. The first official issue about this type of building was in 1999. The Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800) in its 2nd revised edition (1999) addressed this type of construction to be considered as a Type 2 construction (i.e. simple framing in both directions). Iranian Code of Practice for Seismic Resistant Design of Building, 2nd Edition-1999 Iranian National Building Code, Part: 10, Steel Structures, 1994. The first official issue about this type of building was in 1999. The Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800) in its 2nd revised edition (1999) addressed this type of construction to be considered as a Type 2 construction (i.e. simple framing in both directions). Iranian Code of Practice for Seismic Resistant Design of Building, 2nd Edition-1999 Iranian National Building Code, Part: 10, Steel Structures, 1994.

The building department of municipalities approves the design and holds the designer responsible for the projects. After finishing the construction the municipal authorities check the finished project and issue occupancy permit stage. However, most of these controls are the subjects of the architectural views.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and not authorized as per development control rules. Building permits are required to build this housing type.

6.7 Building Maintenance

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

6.8 Construction Economics

For only load bearing system, the cost of this type of building is about 300,000-400,000 Rials/m² (150-200 $US/m²). For a typical 4 to 6 stories building needs about 30 to 45 days to complete the load bearing structure.

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
Steel frame	Add diagonal steel bracings as required (high cost/high effectiveness/simple construction)
Connections	Strengthening connections by adequate and proper welding (medium cost/medium effectiveness/simple construction)
Foundations	At the location of the new bracing, strengthening of foundation is essential (high cost/medium effectiveness/complex construction)

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Steel frame	Design steel frame for gravity load and steel bracing for lateral resistant system (medium cost/medium effectiveness)
Connections	Provide proper details for connections (low cost/high effectiveness)
Foundations	Proper design (low cost/high effectiveness)

8.2 Seismic Strengthening Adopted

8.3 Construction and Performance of Seismic Strengthening

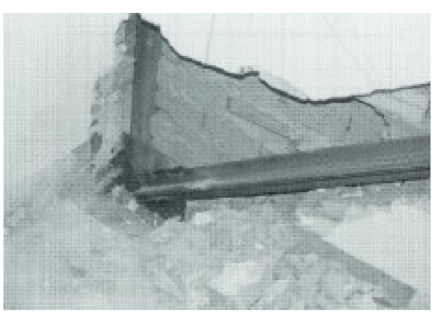

Figure 7A: Illustration of Seismic Strengthening Techniques-New Braces Added to the Main Frame

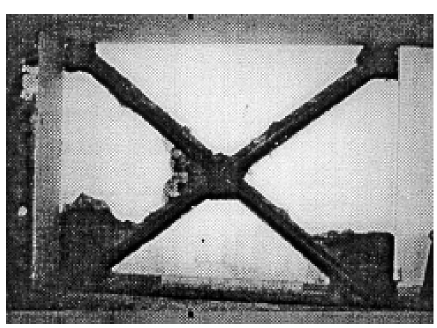

Figure 7B: Strengthening of the existing braces

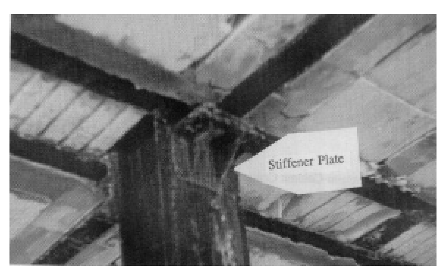

Figure 7C: Stiffener plates used for strengthening the connections

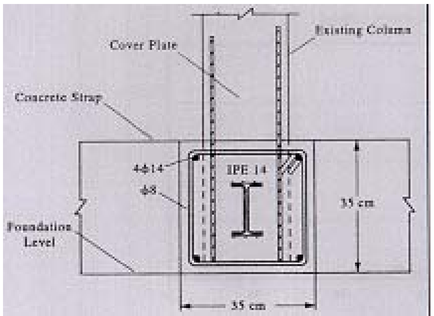

Figure 7D: Detail used to join footing together through steel tie beam

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