World Housing Encyclopedia
an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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HOUSING REPORT
Single-family reinforced concrete frame houses

Report #	103
Report Date	24-11-2003
Country	ALGERIA
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for gravity loads only, with URM infills
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Summary

This privately owned housing constitutes about 60 to 70% of the housing stock and is widespread throughout northern Algeria, the region of the country's highest seismic risk. Generally, these buildings are from 1 to 3 stories high. The ground floor is used for parking or for commercial purposes. The structural system consists of reinforced concrete frames with masonry infill walls made out of hollow brick tiles. The infill walls are usually provided in the

residential part of the building (upper floors). Due to the limited amount of infill walls at the ground floor level, these buildings are characterized by soft-story behavior during earthquakes. These buildings have most often been built after the development of the 1981 Algerian seismic code. However, the seismic code is not enforced in private construction and most of the buildings have been built without seismic strengthening provisions and historically have been severely affected in Algerian earthquakes, including the May 21, 2003 Boumerdes earthquake. This report does not describe reinforced concrete frame buildings financed by public or private property developers and built according to the seismic code.

1. General Information

Buildings of this construction type can be found in northern Algeria, which is an area of high seismic activity. This construction constitutes about 60-70% of the total residential building stock. This type of housing construction is commonly found in sub-urban areas.

This construction type is rarely found in densely populated urban areas; it is rather practiced in suburban areas where building lots are still available. In rural areas, the most common housing construction is tied stone masonry.

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

Currently, this type of construction is being built. The construction of individual reinforced concrete frame houses has been practiced since 1980s. To solve the housing crisis in the 1980s, the Algerian government encouraged its citizens to build their own homes. The Housing Authority requires that only architectural plans need to be submitted to obtain a building permit. This construction is not designed according to the requirements of the seismic code.


FIgure 1: Typical building


Figure 2: Typical building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They share common walls with adjacent buildings. Buildings located on the same street are usually attached to one another (without a separation joint). Less often, a small, non-regular joint is used When separated from adjacent buildings, the typical distance from a neighboring building is 0 meters.

2.2 Building Configuration

The typical shape of a building plan for this housing type is rectangular or L-shaped. The area of window openings at the peripheral walls is 1.44 m² and the area of balcony doors is 2.20 m². The area of the openings constitutes approximately 10% of the overall wall surface area. The size of the openings at the ground floor level is: 2.5 to 3.0 m width, and 3.5 m height (case of commercial ground floors), and 2.5 width x 2.5 height in case of residential ground floor, when there is a garage at that level. This variation in the size of openings between the ground floor and upper stories is one of the causes for the soft storey behaviour in these buildings.

2.3 Functional Planning

Single family house and Mixed use (commercial ground floor, residential above). Seismic vulnerability in this building type is due to the fact that the ground floor is used for commercial purposes and the upper levels for residences. Sometimes heavy items are stored on the upper floors when the entire building is used for commercial activity. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. The only means of escape is the main entrance door; there is only one staircase in each building.

2.4 Modification to Building

Typical modifications include closing off the balconies and demolishing the interior walls to rearrange the apartments or to change the use. Often, additional stories are added without a building permit and without taking into account the load-bearing capacity of the structure.

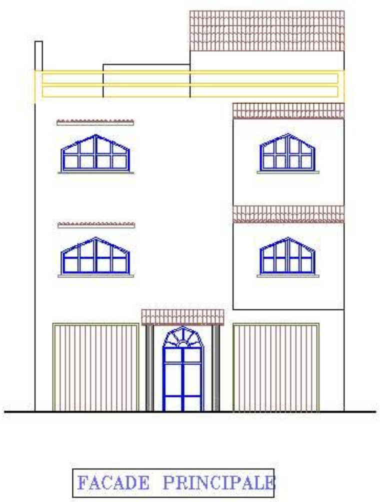

Figure 3: Facade view of a typical building

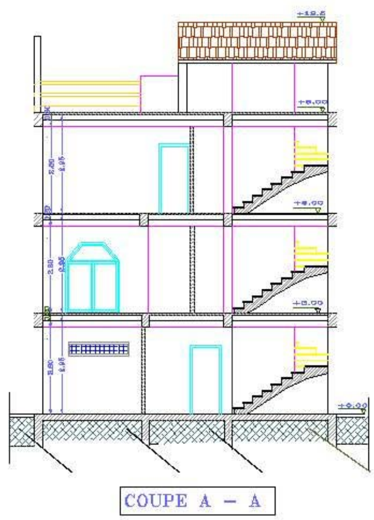

Figure 4: A typical vertical section through a building showing key load-bearing elements

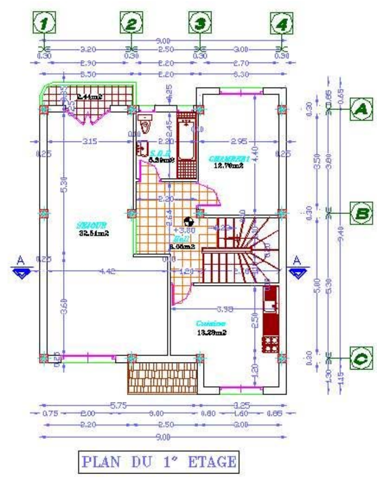

Figure 5: Plan of a typical building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
	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	☐

Masonry	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	☐
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)	☐

The moment-resisting frame in this building type has a very limited earthquake resistance.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete moment resisting frame. RC frames (columns-beams) designed for gravity load only, with infilled masonry walls.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. These non-engineered reinforced concrete frames have been designed for gravity loads only. Typical column dimensions are 250 mm x 250 mm; in some cases, 300 mm x 300 mm columns have been used. Typical column reinforcement consists of 6 - 12 mm diameter bars or 4 - 14 mm bars. The ties typically consist of 8 mm bars at 200 mm spacing; the tie spacing remains unchanged even in the beam-column joint area. Typical beam dimensions are 250 mm width x 300 mm depth; in some cases, 300 mm beam width is used to match column dimensions. Beams are usually reinforced with 6 bars of 12 mm or 14 mm diameter. The stirrups consist of 8 mm bars at 200 mm spacing; the spacing is constant over the beam span. Seismic detailing is not provided in the beam-column joint region; column and beam longitudinal reinforcement is generally continuous through the joints, however ties are not provided in the joint area. The frames are infilled with unreinforced hollow clay tile wall panels. These panels are not attached to the frames; the gap between the infills and the frame is filled with mortar. Floor slabs are of composite construction, consisting of precast reinforced concrete beams supporting hollow concrete blocks (160 mm thickness) topped with a 40 mm thick reinforced concrete slab, see Fig.7. The slab is reinforced with 8 mm reinforcement bars at 150 mm spacing. The overall thickness of the floor slab is 200 mm.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 15 and 15 meters, and widths between 10 and 10 meters. The building has 1 to 3 storey(s). The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimensions: These are typical dimensions, with variations of not more than +/- 2 meters. Typical Story Height: The ground floor height is about 4-5 meters, whereas the floor height of the upper floors is around 3 meters. Typical Span: The average distance between the columns is about 4 meters, but it can vary from 3 to 5 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 2 %. 1.1% - 1.3% These wall density figures apply to the walls in the principal direction.

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 floor/roof system is made with a precast joist system, hollow concrete blocks and a 40-50 mm thick cast-in-place slab.

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	☐

Common foundations are reinforced concrete isolated footings. This foundation type has been adopted without geotechnical study of the site and without the recommendation of civil engineers.

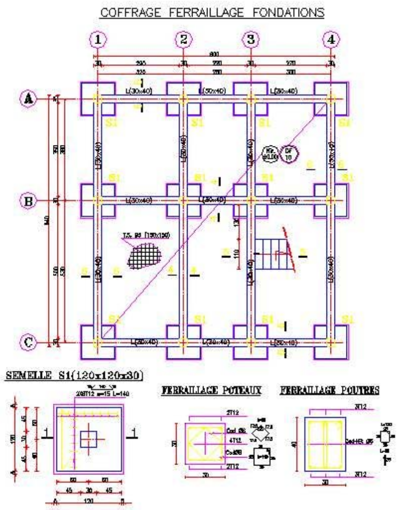

Figure 6: Foundation plan

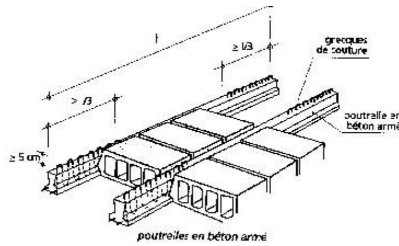

Figure 7: Typical floor slab construction

Figure 12: Typical building under construction

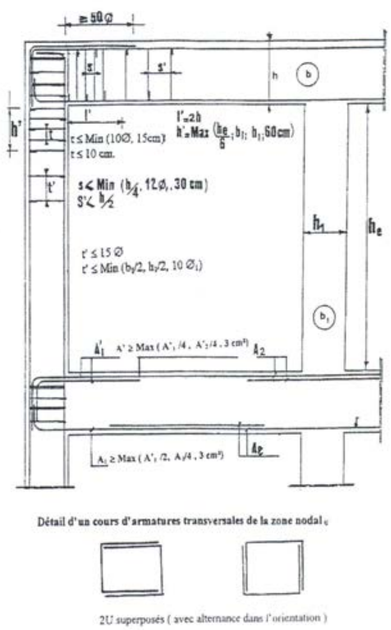

Figure 14: Earthquake-resistant provisions of the RPA99 related to RC frame construction

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. There is generally one housing unit (in each house or building). Sometimes this building contains one apartment on each floor when married sons live with their parents. 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 5-10. The number of persons living in one building depends on the social and economic status of the occupants. The number of occupants is smaller for families from higher economic levels. Usually, there are 6 to 8 family members living in the same building.

4.2 Patterns of Occupancy

Usually 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)	☑

For most owners (who are generally of the intellectual class), the construction takes many years. Economic Level: For Middle Class the ratio of the Housing Unit Price to their Annual Income is 20:1. For Rich Class the ratio of the Housing Unit Price to their Annual Income is 6:1.

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)	☐

This is a privately owned construction, that is, the construction is self-financed. The owner can obtain a small loan from the bank. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

In general, there are 1-2 bathrooms and 1-2 latrines per housing unit. In some cases, there is 1 bathroom and 1 latrine on each floor level. .

4.4 Ownership

The type of ownership or occupancy is 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)	☐

Generally, this housing type is occupied by middle class individuals who obtain a mortgage for a period of several years.

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	Reinforced concrete frame construction, built after the first seismic code was issued in 1981, was (in spite of the existence of the code) designed for gravity loads only and without seismic features. Currently, a major problem related to this type of construction results from the lack of quality construction materials and insufficient controls during construction.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall			
Frame (Columns, beams)	Lack of seismic resistance, as the structural elements are designed for gravity load only. The main deficiencies include: - column cross-section not sufficient to provide earthquake resistance. - absence of stirrups in beam-column joints. - lack of infilled masonry walls at the ground floor, thus creating a soft storey effect (see Fig. 10 and 11) - excessively large stirrup spacing in columns. - poor quality of materials and workmanship.		Partial or total collapse of the building due essentially to excessive displacement (P-delta effect) at the ground floor level. The characteristic damage patterns include: failure of the top portion of columns at the ground floor level, development of plastic hinges in the columns (ground floor), crushing of columns due to axial compression, shear failure in column-beam joints
Roof and floors		- act as rigid diaphragms	No damage in general
Other			

This type of construction was severely damaged in the May 21, 2003 Boumerdes earthquake.

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 B: MEDIUM-HIGH VULNERABILITY (i.e., 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
1980	El Asnam	7.3	X
1989	Tipaza	6.1	VIII-IX
		5.8	

1999	Ain Temouchent		VIII
2003	Zemmouri (Boumerdes)	6.8	VIII-IX

The Tipaza (1989) and Ain Temouchent (1999) earthquakes severely affected concrete frame housing construction designed without seismic features. The typical patterns of damage included collapse of some houses, failure of short columns at the ground floor level and below (vide sanitaire), development of plastic hinges in the ground floor, axial crushing of concrete in the columns and shear damage to the column-beam joints. During the 1980 El Asnam earthquake, two- and three-level stone masonry that had been strengthened after the El Asnam (Orleanville) earthquake of September 1954 performed well. The 2003 Boumerdes earthquake severely affected concrete frame housing designed without seismic features. Generally, a significant number of RC buildings built after the 1980 were damaged and this specific building type was the most affected by the earthquake.

Figure 8: Seismic deficiencies: weak beam-column joint (2003 Boumerdes earthquake)

Figure 9: Seismic deficiencies - very poor quality of concrete (2003 Boumerdes earthquake)

Figure 10: Typical earthquake damage: building collapse due to the soft storey effect (2003 Boumerdes earthquake)

Figure 11: Typical earthquake damage: soft story collapse (2003 Boumerdes earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Bricks		200 mm x 300 mm (block height x length)	Thickness is variable: typical values are 50, 100, 150 and 200 mm
Foundation	Reinforced concrete	fe28=20 MPa (concrete) fe=400 MPa (steel yield strength)	1:2:4 (cement:sand: aggregate)	The concrete compressive strength is often less than 20 MPa.
Frames (beams & columns)	Reinforced concrete	fe28=20 MPa fe=400 MPa	1:2:4	The concrete compressive strength is often less than 20 MPa.
Roof and floor(s)	Reinforced concrete	fe28=20 MPa fe=400 MPa	1:2:4	The concrete compressive strength is often less than 20 MPa but is sufficient in comparison with the slab rigidity.

6.2 Builder

This housing type is built by the owners themselves. They live in the house and very rarely rent it out.

6.3 Construction Process, Problems and Phasing

Often, after the owner obtains a building permit, (s)he hires a mason to build the house. The owner supplies the construction materials himself. Seldom are developers or contractors involved. The construction of this type of housing takes place incrementally over time. Typically, the building is originally designed for its final constructed size. It often takes 6-7 years to complete individual buildings; frequently this is because of financing problems. Sometimes the completed building has undergone modification during the construction as compared to the original design.

6.4 Design and Construction Expertise

Generally, the architect who planned the house has a sufficient level of expertise, however, the houses are not designed for seismic events. The mason doing the construction does not have this expertise. The role of the architect is to design the building and to develop design drawings and architectural plans. Engineers do not play a role in the construction of these buildings because they are not involved by the owners and architects.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. RPA99 (Seismic Algerian Code 1999) and CBA93 (Reinforced Concrete Code). The year the first code/standard addressing this type of construction issued was 1981 (the first Algerian Seismic Code). RPA99 (Algerian Seismic Code), CBA1993 (National Building Code). The most recent code/standard addressing this construction type issued was CBA93 (Reinforced Concrete Code) was issued in 1993 and RPA99 (Algerian Seismic Code) was issued in 1999. Title of the code or standard: RPA99 (Seismic Algerian Code 1999) and CBA93 (Reinforced Concrete Code) Year the first code/standard addressing this type of construction issued: 1981 (the first Algerian Seismic Code) National building code, material codes and seismic codes/standards: RPA99 (Algerian Seismic Code), CBA1993 (National Building Code) When was the most recent code/standard addressing this construction type issued? CBA93 (Reinforced Concrete Code) was issued in 1993 and RPA99 (Algerian Seismic Code) was issued in 1999.

The enforcement of the building code for public buildings in Algeria is done by the Controle Technique de la Construction (CTC). After the architectural plans have been prepared, their conformity to the building codes (CBA93, RPA99, etc.) must be approved by the CTC. The approval is related to the phases of the construction and the quality of the building materials. However, code enforcement is not required by Planning Services for private housing. As a result, the construction can proceed with only architectural plans. There is no inspection or quality control enforced during the construction.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules.

This type of construction continues to be practiced in the present and is authorized by the regulations controlling development. There is no requirement that the work be performed in compliance with the rules of construction practice or seismic design. Some of the construction is carried out informally. 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). Generally, this type of building is well maintained by the owners.

6.8 Construction Economics

The unit construction cost is estimated to be 25,000-35,000 DA/m² (250-350 $US) (market rate is 1$=100 DA). The number of work days required to complete the construction depends on the financing and the number of stories. If there is not a problem with the financing, one story can be completed within 8-12 months. For the typical three-story building, 2-3 years are required for completion.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. In general, strengthening of buildings by incorporating seismic features is not common. Some government-financed retrofit projects were recently completed for some strategic buildings in the capital city Algiers. The government also finances strengthening of damaged public buildings following an earthquake. As there is no insurance, the owners of individual housing may be given symbolic aid from the government if damage is slight. If the damage is heavy, repairing and strengthening is financed by the government as was the case after the 2003 Boumerdes earthquake. Earthquake insurance is not available for this building type.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Slight crack	Local repair with injection
Columns and beams: heavy cracks, development of plastic hinges, axial compression crushing	Local repair by providing reinforced concrete jacketing; new structural elements added to increase the seismic resistance (shear walls or bracing)

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Column design requirements (RPA99), see Fig.14	Dimensions (b1= width, h1= depth): Min (b1 , h1) > 25 cm (seismic zones I and IIa); Min (b1 , h1) > 30 cm (seismic zones IIb and III); Min (b1 , h1) > he/20 (he = story height); ¼ < b1/h1 < 4. Minimum reinforcement ratio (longitudinal bars): 0.8% (zone IIa); 0.9% (zone IIb and III); Transverse reinforcement (ties) should also be provided.
Beam design requirements (RPA 99), see Fig.14	Dimensions (b= width, h= depth): b > 20 cm , h > 30 cm, h/b < 4.0, bmax < 1.5 h + b1. Reinforcement: the minimum longitudinal reinforcement ratio is 0.5%.
Joint requirements, see Fig.14	Transverse reinforcement (ties) should be continuous through the joints

The most commonly used method for strengthening reinforced concrete frame buildings is reinforced concrete jacketing. The addition of new structural elements (such as shear walls or bracings) is rarely used. Construction of new shear walls is a common retrofit method for larger reinforced concrete frame buildings despite its high cost. (For example, this was done after the 1999 Ain Temouchent earthquake.) The addition of shear walls results in the increased lateral strength and stiffness of a building. As a result, seismic performance increases significantly as well. The walls are laid in a symmetrical manner to reduce torsional response. The bracing systems are not used very often.

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?
The first experience related to repairing and strengthening damaged buildings in Algeria was following the 1980 El Asnam earthquake (M 7.3). Also, some buildings strengthened after the previous (1954) El Asnam earthquake performed very well (without damage) in the 1980 Asnam earthquake. The methods described in Section 10.1 were applied. Other projects to strengthen damaged public buildings were undertaken after recent earthquakes such as the 1999 Ain Temouchent earthquake. The strengthening of buildings after the 2003 Boumerdes eq. has started but is not yet finished as of this writing (January 2004). The related seismic strengthening studies were entrusted to local engineering and design offices. The damaged elements were repaired with injection or with reinforced concrete jacketing. New structural elements (shear walls) were added only to the damaged structures of existing public buildings to increase their lateral load resistance.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
This work was done as the repair following the earthquake. In a few cases it was done specifically as part of a mitigation effort for a few undamaged strategic buildings in Algiers.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
The damaged construction is inspected in the same manner as the new construction.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Owners build their own homes, and architects and engineers are never, or rarely ever, involved. In the aftermath of the 2003 Boumerdes earthquake, the repairing and strengthening operation was financed by the government and performed by contractors and developers. In this case both the architects and engineers were involved.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Construction which was strengthened following the earthquakes which struck northern Algeria (Tipaza, 1989 and Ain Temouchent, 1999) was not affected by other earthquakes. The 2003 Boumerdes earthquake did not affect those areas so it is not yet known how retrofitted buildings will perform in future earthquakes. However, some vulnerability studies of the strengthened housing were completed, which concluded that strengthened buildings should perform well in future moderate earthquakes.

Figure 13: Seismic strengthening techniques: jacketing of columns and construction of new shear walls in the two directions (after the 2003 Boumerdes earthquake)

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