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
# Stone masonry apartment building

| | |
|---|---|
| Report # | 75 |
| Report Date | 05-06-2002 |
| Country | ALGERIA |
| Housing Type | Stone Masonry House |
| Housing Sub-Type | Stone Masonry House : Rubble stone without/with mud/lime/cement mortar |
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| Reviewer(s) | Marjana Lutman |



## Summary

This is a typical residential construction type found in most Algerian urban centers, constituting 40 to 50% of the total urban housing stock. This construction, built mostly before the 1950s by French contractors, is no longer practiced. Buildings of this type are typically 4 to 6 stories high. The slabs are wooden structures or shallow arches supported by steel beams (jack arch system). Stone masonry walls, usually 400 to 600 mm thick, have adequate gravity

load-bearing capacity; however, their lateral load resistance is very low. As a result, these buildings are considered to be highly vulnerable to seismic effects.

# 1. General Information

Buildings of this construction type can be found in northern Algeria. In particular, the multi-story buildings exist mainly in the major cities, e.g. Algiers, Oran, Constantine, Annaba, etc. This construction type may constitute 40 to 50% of the urban housing stock. This type of housing construction is commonly found in urban areas.

This type of construction is found in the older urban districts.

This construction type has been in practice for less than 200 years.

Currently, this type of construction is not being built. This construction was practiced prior to 1950 by French contractors.

Figure 1: Typical Building

Figure 1B: A typical old stone masonry building in Algiers city

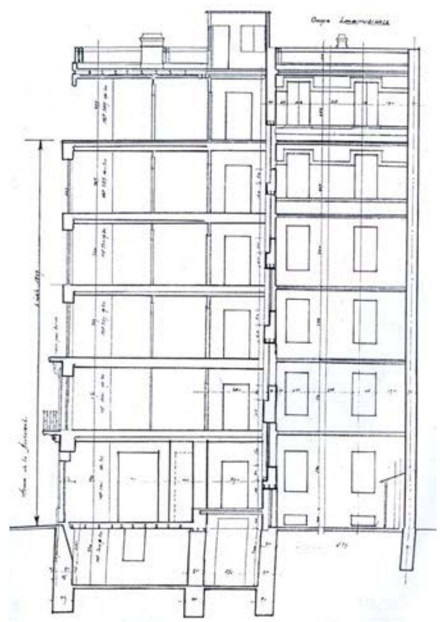

Figure 2: Perspective Drawing Showing Key Load-Bearing Elements

# 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 5 meters.

## 2.2 Building Configuration

The building plan for this housing type can be of different forms: rectangular, L-shaped, U-shaped, etc. The number, size and position of openings for a typical floor in a building are shown on the typical plan (Figure 3A). The total window and door area is about 25% of the overall wall surface area.

## 2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). Buildings of this type are also used as offices and hospitals. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. The majority of these multi-storied buildings have only one exit and one main interior staircase.

## 2.4 Modification to Building

Modifications are often undertaken by the residents without any professional assistance provided by engineers. The modifications include the demolition of interior walls, opening commercial areas, and vertical extensions.

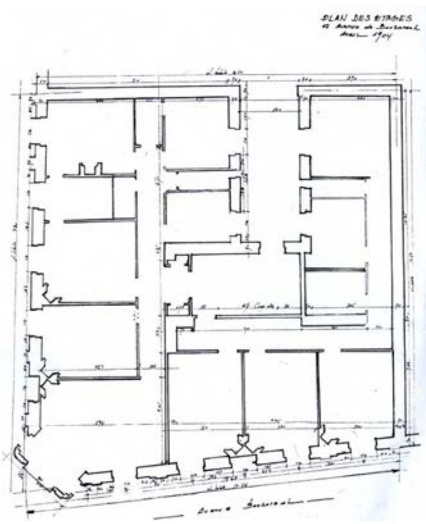

Figure 3A: Typical Building Plan

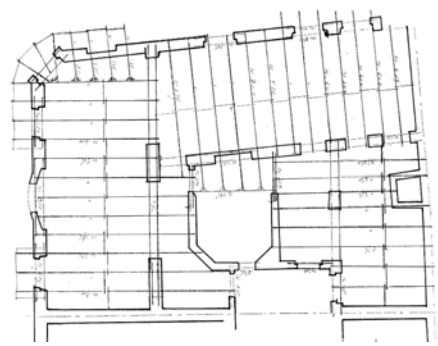

Figure 3B: Typical Roof Plan

# 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 | ☐ |
| 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 stone masonry walls. Stone masonry walls are the principal elements of the gravity load-bearing structure.

## 3.3 Lateral Load-Resisting System

The lateral load-resisting system is stone masonry walls. The lateral load-resisting system consists of the stone masonry walls built in longitudinal and cross directions. Wall thickness varies from 400 to 600 mm. Field masonry has been mainly used, and massive stones exist only at the corners and around the openings. Low-strength mortar (either cement and/or mud mortar) has been used. According to the Algerian Seismic Code (RPA99) and the Strengthening Guide, many buildings of this structural type have been strengthened after suffering damages during the last earthquakes (El Asnam 1980, Tipaza 1989, Mascar 1994 and Ain Temouchent 1999). They were strengthened with reinforced concrete ties in both vertical and horizontal directions and with RC slabs used as floor and roof structures. The maximum building height allowed by the Code depends on the seismic zone (17 m, 14 m and 11 m, for seismic zones I, II and III, respectively).

## 3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 25 and 25 meters, and widths between 15 and 15 meters. The building is 5 storey high. The typical span of the roofing/flooring system is 4 meters. The typical storey height in such buildings is 3.5 meters. The typical structural wall density is up to 5 %. 5% - 6% The ratio of the total wall area/plan area (for each floor) in each principal direction is between 5% and 6%.

## 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. Floor and roof structures are not considered as rigid diaphragms.

# 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 | ☐ |

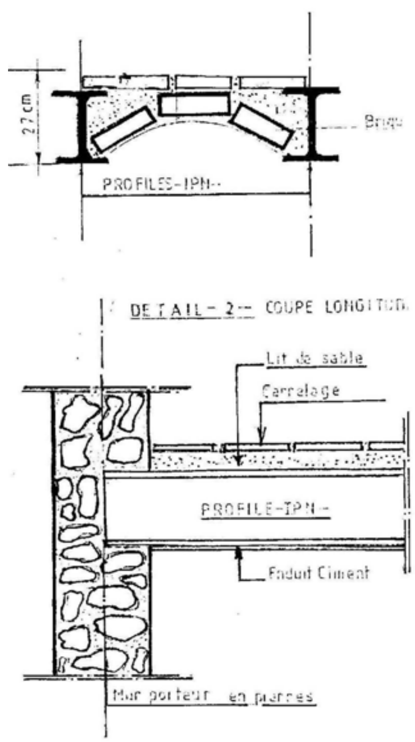


Figure 4: Critical Structural Details: Wall-Roof Connection and Vaulted Brick Floor Structure

# 4. Socio-Economic Aspects

## 4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 10-15 units in each building. The number of inhabitants in a building during the day or business hours is 11-20. The number of inhabitants during the evening and night is more than 20. In most cases the women in the families are not working outside the home and are at home during the day.

## 4.2 Patterns of Occupancy

There is a serious housing crisis in Algeria. On average, two generations occupy the same housing unit: parents and the family unit of an adult child.

## 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 the Poor Class the ratio of Housing Price Unit to their Annual Income is 10:1.

| 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) | ☐ |

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

## 4.4 Ownership

The type of ownership or occupancy is renting and outright ownership.

| 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:<br><br>Less than 25 (concrete walls);<br><br>Less than 30 (reinforced masonry walls);<br><br>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:<br><br>For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; | | | |

| | | | | |
|---|---|---|---|---|
| Wall openings | For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls;<br><br>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 | Others: It is good In some cases, that the use of these buildings has changed. | | | |

## 5.2 Seismic Features

| Structural Element | Seismic Deficiency | Earthquake Resilient Features | Earthquake Damage Patterns |
|---|---|---|---|
| Wall | Poor mortar strength; walls not tied together | | X-cracks and total collapse in some cases; very low seismic resistance |
| Frame (columns, beams) | | | |
| Roof and floors | Not monolithic; not rigid in-plane | | |
| Other | | | |

## 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 A: HIGH VULNERABILITY (i.e., very 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 (MMI) |
| 1989 | Tipaza | 6.2 | VIII-IX (MSK) |
| 1994 | Mascara | 5.6 | VIII (MSK) |

| | | | |
|---|---|---|---|
| 1999 | Ain-Témouchent | 5.8 | VIII (MSK) |

Buildings of this type were affected by the May 21, 2003 earthquake with the epicenter dose to Zemmouri. The earthquake was of magnitude Mw= 6.8 and the intensity was IX-X (MMI scale). In general damage patterns vary from diagonal "X"-cracks to total wall collapse, and partial to total collapse of the roofs/slabs. Earthquake, Total Number of Apartment Buildings (all types), Damage level (MSK scale) 1 2 3 4 5 1980 El-Asnam, 4844 439 1304 1351 863 887 1989 Tipaza, 4511 1480 1102 223 426 1280 1994 Mascara, 1874 470 302 351 212 539 1999 Ain-Témouchent, 3398 1062 606 684 528 518.

Figure 5A: Typical Earthquake Damage: Partial Roof Collapse (1999 Ain-Temouchent Earthquake)

Figure 5B: Typical Earthquake Damage: Collapsed Roof of a Masonry Building (1989 Tipaza Earthquake)

Figure 5C: Typical Earthquake Damage: Cracking in the Wall Corners


Figure 5D: Damage to a stone masonry building in Algiers in the May 21, 2003 earthquake


Figure 5E: Collapse of a roof and a side wall na multi-storey stone masonry building in Algiers city in the May 21, 2003 earthquake

Figure 5F: Totally collapsed stone masonry building in Dellys (Boumerdes) in the May 21, 2003 earthquake

Figure 5G: Collapse of the vaulted brick and steel floor system in the May 21, 2003 earthquake (EI Harrach district, Algiers)

Figure 5I: Collapse of a rubble stone masonry wall made of river stones and mud mortar in the May 21, 2003 earthquake (Sidi Daoud, Boumerdes)

# 6. Construction

## 6.1 Building Materials

| Structural element | Building material | Characteristic strength | Mix proportions/dimensions | Comments |
|---|---|---|---|---|
| Walls | Field stone in cement or mud mortar | Massive stones used at the corners and around the openings | | Data not available |
| Foundation | Field stone in cement or mud mortar | | | |
| Frames (beams & columns) | | | | |
| Roof and floor(s) | Vaulted bricks | | | |

## 6.2 Builder

This construction was practiced prior to 1950 by French contractors.

## 6.3 Construction Process, Problems and Phasing

Owners and contractors were involved in the construction of this type. The stone blocks were laid by hand and basic construction equipment was used. (See Figures 7a--7h.). The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

## 6.4 Design and Construction Expertise

The level of expertise of all parties involved in the design and construction process was at the 20th century level worldwide. Only architects had a role in the design/construction of this housing type.

## 6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

Not applicable - building codes are not applicable to this construction practice.

## 6.6 Building Permits and Development Control Rules

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

Permits are now required for public buildings for the vertical extensions, structural interventions and for repair and strengthening. Building permits are not required to build this housing type.

### 6.7 Building Maintenance

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

### 6.8 Construction Economics

10,000-15,000 Algerian Dinars /m² (150-200 $US/m²). Information not available.

## 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.

## 8. Strengthening

### 8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

| Seismic Deficiency | Description of Seismic Strengthening provisions used |
|---|---|
| Cracks in the stone masonry walls | RC jacketing |
| Lack of integrity | Installation of horizontal and vertical RC ties at exterior and steel ties in the interior (see Figure 6A). |

### 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?
These strengthening techniques were used to repair and strengthen the damaged buildings after the Algerian earthquakes reported in this contribution. A guide for using these seismic strengthening techniques is available in Algeria ("Méthodes de Réparation et de Renforcement des Ouvrages", was edited by CGS in 1992).

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Vulnerability studies for strategic buildings were done in 1996 at Algiers City, and some buildings of this type were strengthened as a result of the study.

### 8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
No.

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

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

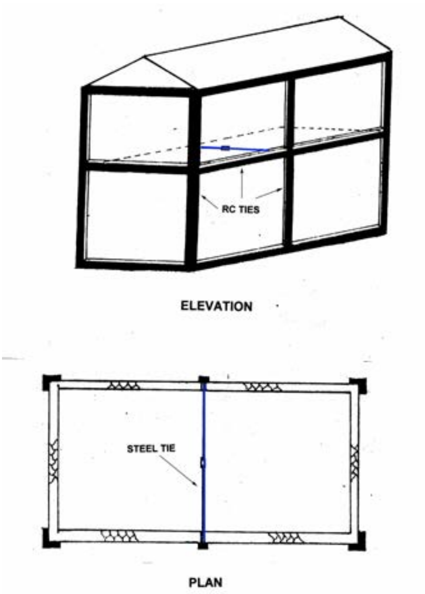


Figure 6A: Seismic Strengthening Techniques: Provision of Horizontal and Vertical RC Ties at the Exterior and Horizontal Steel Ties at the Interior


Figure 6B: Seismic Strengthening Techniques: An Example of a Strengthened Building with Vertical and Horizontal RC Ties at the First Floor Level

Figure 6C: Seismic Strengthening Techniques: Construction of RC Ties

Figure 8: Young victims of 21 May 2003 earthquake in Al Bordj Menail city- there is a hope in spite of the tragedy that affected population and caused severe human and economic losses; the earthquake killed more than 2,200 people, injured more

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