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

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Earthquake Engineering Research Institute (EERI) and
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# HOUSING REPORT
# Gravity-Designed Reinforced Concrete Frame Buildings with Unreinforced Masonry Infill Walls

| | |
|---|---|
| Report # | 13 |
| Report Date | 05-06-2002 |
| Country | CYPRUS |
| Housing Type | RC Moment Frame Building |
| Housing Sub-Type | RC Moment Frame Building : Designed for gravity loads only, with URM infills |
| Author(s) | V. Levtchitch |
| Reviewer(s) | Craig D. Comartin |



## Summary

This type of concrete apartment building was widely constructed after the 1974 Turkish invasion in order to accommodate approximately 200,000 refugees. Typically, these buildings are low-rise (up to 5 stories) apartment blocks. As a rule, architectural considerations prevail

over structural requirements. Very often columns are located irregularly and do not form a definite grid. Soft ground stories are used for car-parks (garages) and shops. Staircases and lift (elevator) shafts are not located symmetrically. The vulnerability of these buildings should be very high when the inherent seismic deficiencies of this structural type (design mistakes, construction faults, unavoidable aging, lack of maintenance, accumulation of minor damage from previous earthquakes, deterioration of the concrete and corrosion of the reinforcing bars) are taken into account. But against all odds the majority of these buildings have stood well in numerous small earthquakes and exhibited rather good performance under the peak ground accelerations of up to 0.15g (the maximum expected in Cyprus). Damage and destruction have been very selective depending on the local soil conditions and periods of natural vibration.

# 1. General Information

Buildings of this construction type can be found in the entire country. This type of housing construction is commonly found in both rural and urban areas.

This type of housing accounts for more than 30% of the total dwelling stock. In urban areas these buildings constitute approximately 45% of houses.

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

Currently, this type of construction is not being built. Since 1994 the seismic code for design and construction was introduced.

Figure 1: Typical Building

# 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. The typical separation distance between buildings is 6 meters 3 meters from the property border, i.e. 6 m between buildings. At present there are clearly defined width of seismic separation joints for buildings located within one building site but in the past majority of joints were of evidently inadequate width When separated from adjacent buildings, the typical distance from a neighboring building is 6 meters.

## 2.2 Building Configuration

Basically rectangular, but rather often an irregular location of columns and asymmetric position of stairs-and-lift-shafts, re-entrant corners and set-backs transform them into structurally irregular systems. Sometimes a building plot shape influences the configuration of buildings. In external infill-walls openings may cover up to 40% of the wall surface and in internal walls - up to 20%. Openings in infill-walls (if they are not located immediately near the columns) do not constitute a major vulnerability factor. Framing of continuous lintels into columns is to be considered.

## 2.3 Functional Planning

The main function of this building typology is multi-family housing. Mixed use (both commercial and residential use). In the vast majority of cases there is a mixed functional use. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. In buildings of more than one floor, commonly there is an additional exit stair for the emergency escape.

## 2.4 Modification to Building

Internal infill walls and partitions can be removed or added to meet new functional requirements. As a rule , columns remain unaffected. Balconies can be supplemented by enclosing walls made of various materials. In one-two storey private buildings there can be the plan extensions of different types without paying any attention to a seismic structural integrity of a modified structure. Practically all private one-three storey buildings are provided with the starter reinforcement bars projecting from the columns for the future construction of additional stories. This strong desire for the additions is not always backed by the initially provided foundations and the structural capacities of a first-phase constructed frame. The unprotected starter bars are usually extensively corroded and practically cannot serve the purpose. Moreover, their corrosion inevitably propagates inside and there are cracks due to corrosion products expansion. Occasionally, the additional stairs have been constructed.

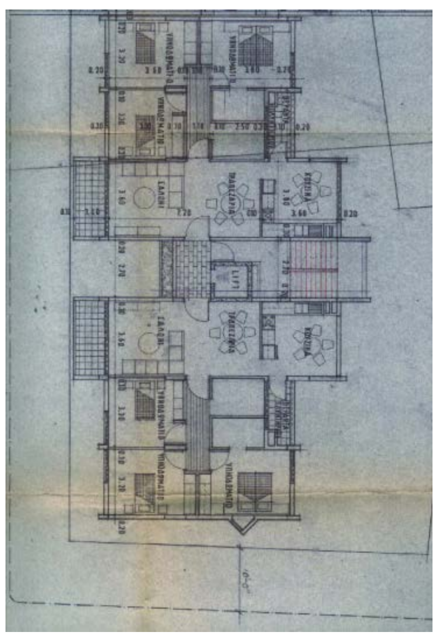

Figure 2: Plan of a Typical Building

# 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 | ☐ |
| 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 | ☐ |
| | | 36 | Thatch | ☐ |

| | | | | |
|---|---|---|---|---|
| Timber | Load-bearing timber frame | 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 reinforced concrete moment resisting frame. Common cast-in-situ R.C. frame, basically of usual dimensions and typical proportions. In spite of frequent irregularities of the beam-arrangement, the commonly used 150 mm deep slab over usual spans contributes to the lateral diaphragm action of the floor-and-roof system. Re-entrant corners and set-backs were provided without taking into account torsional effects, distribution of lateral seismic forces and overloading of outward external columns. "Strong column-weak beam" principle was not followed. Just the opposite is the case. Rigid and slender columns are used within the same storey and "short column effect" was not considered. Interaction between flexible R.C. frames and rigid-low-strain-capacity-brittle infill walls was not addressed. Joints between them are not specified. Generally, deformation compatibility was not analyzed. Usually, floor systems are rigid enough in their own plane to act as the horizontal stiff diaphragm and to distribute seismic forces between columns in accordance with their rigidities. But rather often some beams are omitted or arranged in one direction only. The continuity is disrupted, slab supports are altered, membrane action is affected, load path is complicated and frame lateral performance is influenced adversely. Besides, sometimes slabs have the hollow core clay bricks as the filler in tensile (bottom) zone. Since seismic forces alternate in both vertical and horizontal directions and generate torsional movements this is not a good choice to resist them. Spans of a single continuous beam usually differ considerably, but their cross-sections remain the same and, hence, their relative rigidities and forces transferred to them are quite different. End anchorage of beams and slabs in the outer bays is not adequate. Top reinforcement in both beams and slabs is not sufficient in terms of quantity and length of extension into spans. Usually there is overcapacity of bottom reinforcement and undercapacity of the top reinforcement. In spite of the fact that these buildings were neither designed nor detailed for earthquakes, they have certain reserves of lateral resistance. Tied-up columns can take lateral drifts. Floor-and-roof diaphragms this. Provided that anchorage and continuity are maintained, concrete structures reinforced with ductile steel have an inherent ability to adapt to cyclic loadings due to spatial redistribution of stresses, change of rigidities and natural periods of vibration, strain hardening of steel. In many cases their available capacities are somewhat higher than those determined by simplified methods of analysis.

## 3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. Reinforced concrete frame acts as the stabilizing-lateral load resisting system. The rigid, brittle infill walls have approximately two times smaller interstory-drift capacities than those of the columns. Their joint response can be utilized only within low levels of lateral displacements. After shearing of infill walls, the whole of the lateral load is suddenly transferred to columns and this makes them very vulnerable.

## 3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 12 and 12 meters, and widths between 18 and 18 meters. The building has 3 to 5 storey(s). The typical span of the roofing/flooring system is 3.5 - 4.5 meters. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 10 %. Approximately

10% (infill-walls).

## 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 | ☑ | ☑ |

In most cases floors and roofs can be treated as the 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 | ☐ |
| | Reinforced-concrete bearing piles | ☐ |
| | Reinforced-concrete skin friction piles | ☐ |
| | Steel bearing piles | ☐ |

| | | |
|---|---|---|
| Deep foundation | Steel skin friction piles | ☐ |
| | Wood piles | ☐ |
| | Cast-in-place concrete piers | ☐ |
| | Caissons | ☐ |
| Other | Described below | ☐ |

In the coastal areas the mat foundations were sometimes used.

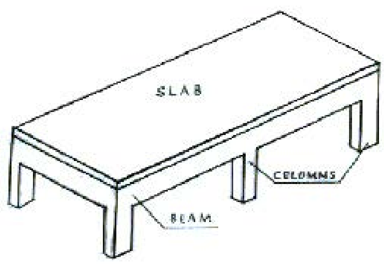


Figure 3: Key Load-bearing Elements

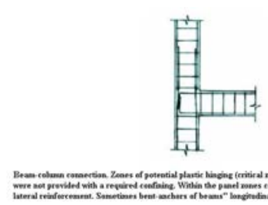


Figure 4: Critical Structural Detail

Figure 5A: Soft ground story

Figure 5B: Plan and elevation irregularities

Figure 5C: Non symmetrical location of stairwell

Figure 5D: Inadequate seismic joint

Figure 5F: Short columns: sharp difference in capacities of adjacent columns

Figure 5G: Excessive length of a cantilever canopy

Figure 5H: Large balconies

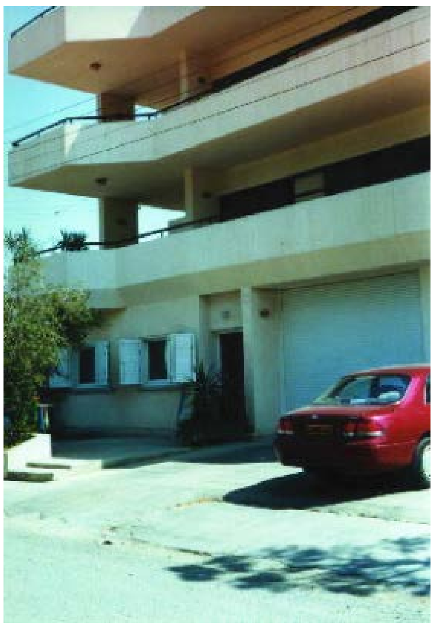

Figure 5I: Heavy concentrated loads are transferred to a thin balcony slab

Figure 5J: Weak columns, incomplete beam-grid and a heavy-rigid parapet wall of the additional constructed top story

# 4. Socio-Economic Aspects

## 4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 8-14 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 more than 20.

## 4.2 Patterns of Occupancy

One family per 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) | ☐ |

Rich-15%, middle class-75%, poor-10%.

| 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), no toilet(s) only and 1 bathroom(s) including toilet(s).

Usually 1 bathroom per unit, but in more recent buildings can be 2. .

### 4.4 Ownership

The type of ownership or occupancy is renting and individual 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 | | |
|---|---|---|---|---|
| | | True | False | 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 | ☐ | ☑ | ☐ |
| Wall openings | 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;<br><br>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 | | | | |

## 5.2 Seismic Features

| Structural Element | Seismic Deficiency | Earthquake Resilient Features | Earthquake Damage Patterns |
|---|---|---|---|
| Wall | Rigid, brittle infill-walls are in contact with the much more flexible columns. Infill-walls suffer heavy damage themselves and trigger the damage and destruction of columns. A low quality site-prepared cement mortar has been used. The characteristic bond can be as low as 0.015 MPa, i.e. approximately 10 times lower than that required for a good quality masonry. Vertical joints have not been filled with mortar. Neither an effect of infill panels on a frame nor that of a swaying R.C. frame on a brittle infill walls have been considered. | In spite of their brittleness masonry infill panels can absorb and dissipate a considerable part of earthquake energy. Their strength must be lower than that of a basic R.C. frame. After breaking down of infill panels the consecutive earthquake motions must be within the capacities of a R.C. frame alone. The undesirable interaction between columns and walls may be prevented by providing of separation joints. An infill panel can be upgraded to a structural type, which will respond jointly with R.C. frames, i.e. as boundary columns with a wall or a column with the side-walls. | Extensive diagonal cracking due to the principal tensile stresses is estimated to take place at interstory drifts between 1/400 and 1/200, while the common R.C. columns can accommodate interstory drifts of up to 1/100 or even more. Separation gaps at the corners and along beams are the common feature. Occasionally, the out-of- the -plane loss of stability has been observed. Sometimes, the lateral shear cracks have been developed. |
| Frame (columns, beams) | Columns are not specifically designed and detailed for seismic forces. "Strong column-weak beam" principle was not followed. Shear and confining reinforcement is not adequate. Panel zones of beam-column joints are not provided with lateral reinforcement and frequently are not compacted properly. Stiff and flexible columns are used within one floor. Soft ground floor. Columns with the large aspect ratio are used. Torsion of peripheral columns is not addressed. Anchorage of lateral reinforcement inside the core is not provided. Shear reinforcement of beams is not sufficient. Confining within the potential plastic-hinge zones is not adequate. Excessive bottom reinforcement and not adequate top reinforcement. Not sufficient length of top reinforcement. End anchorage in the outer bays is not sufficient. | Although columns were not designed for seismic forces, they were reinforced by the high-ductility steels and performed as a part of a spatial frame. Columns of some older buildings have longitudinal reinforcement of plane mild steel which has an inherently high survival power. A certain continuity and redundancy have been intuitively provided. When anchorage of beams reinforcement was adequate and shear reinforcement required for the gravitational loads was provided their performance under a low intensity earthquake loadings (up to 0.10 g) was satisfactory. Usually, a beam's capacities were predetermined by its connections | Both columns of buildings with "soft stories" and "short-rigid columns" incorporated into more flexible R.C. frames have suffered heavy damages. The shearing failure is the most common mode of destruction. Combined effects of shear, eccentrical compression and torsion resulted in shear cracking, spalling of concrete and buckling of longitudinal reinforcement at the top and bottom parts. In some cases the corrosion of reinforcement aggravated the damage. Beams usually suffered some visible, but not life- threatening damages. Flexural and shearing cracks could have a maximum opening of up to 0.6 mm. In some spandrel beams the torsional effects triggered a shear type cracking. |
| Roof and floors | In most cases the roof and floor systems can be classified as rigid in their own plane. But there are cases of beams spanning in one direction, chaotic arrangement of beams and lack of their continuity, beams within a slab depth. | Slabs of 15cm depth, when rigidly fixed into four supporting beams of adequate dimensions and spans, can effectively provide for the uniform distribution of lateral seismic forces. | Some minor cracking was observed in one-way spanning floor slabs, when supporting beams were provided in one direction only. |
| Other | In many cases the basements are not under the whole area of buildings. More-than-one-level foundations do not have an appropriate transition zones from one depth to another. Tie-beams are not always of an adequate capacity to hold pad footings together and to prevent their mutual displacements and rotations. These beams support infill-walls and are not located at the bottom of footings. | | Generally, foundations performed satisfactorily, except some isolated cases where uneven settlements and certain base distortions were |

## 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 |
|---|---|---|---|
| 1995 | Paphos | 5.7 | MMI-VII |
| 1996 | Paphos - Limassol | 6.5 | MMI-VII-VIII |
| 1999 | Limassol | 5.8 | MMI-VII |

Main bulk of destruction was in masonry buildings. Note: the vulnerability rating of medium assigned in the previous section reflects the level of seismic hazard officially adopted in Cyprus (i.e. peak ground acceleration of 0.15g). For the higher intensities, this assessment would not be true, and buildings would be expected to be rated in the B category of vulnerability.

Figure 6A: A Photograph Illustrating Typical Earthquake Damage. Shearing failure of a partition

Figure 6B: Diagonal shearing of an infill wall

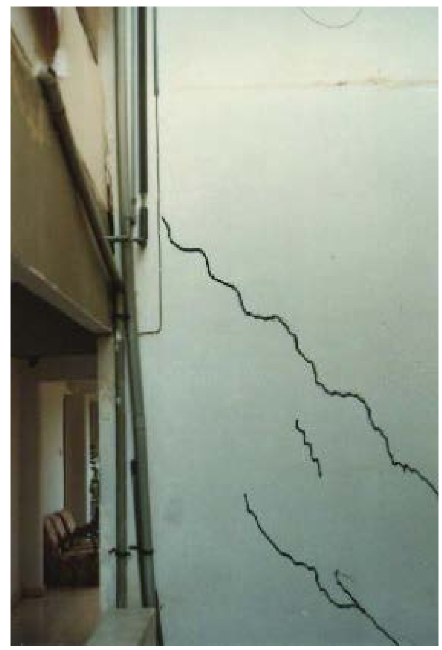

Figure 6C: Horizontal shearing displacement

Figure 6D: Shearing failure of a short column

Figure 6E: Shearing of concrete and buckling of

Figure 6F: Torsional shearing and buckling of longitudinal reinforcement due to inadequate lateral reinforcement

longitudinal reinforcement at the bottom of a corner column

Figure 6G: Shearing and buckling at the bottom of a column

Figure 6H: Buckling of reinforcement at the bottom of a cylindrical column

Figure 6I: Eccentric beam-short column connection

Figure 6J: Support failure

# 6. Construction

| Structural element | Building material | Characteristic strength | Mix proportions/dimensions | Comments |
|---|---|---|---|---|
| Walls | | | | |
| Foundation | Concrete | 15-20 N/mm² | | |
| Frames (beams & columns) | Concrete, Steel | 15-25 N/mm², S220-S500 | | |
| Roof and floor(s) | Concrete , Steel | 15-20 N/mm², S220-S400 | | |

### 6.2 Builder

Typically these buildings are constructed by developers, but the builders can live in them.

### 6.3 Construction Process, Problems and Phasing

Usually developers and contractors have built up these type of buildings. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. Modifications, alterations and additions are possible. Permissions are to be obtained.

### 6.4 Design and Construction Expertise

At present a design is to be prepared by the registered engineer and architect. Contracts are awarded on the tendering basis. Contractors are to be registered with the specified qualification and experience. In the past, however, this practice was not followed. Architects are responsible for the architectural planning and drawings. Civil Engineers are responsible for the structural design The compulsory site-control by engineers have been introduced only in 1999.

### 6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Before adoption of the National Code of Practice in 1994 the codes of any developed country could be used , provided that a design will be checked and approved by the authority. As a result the following codes have been used: CP114, CP110, BS8110, ACI318, BAEL, DIN , SNiP and some others. The year the first code/standard addressing this type of construction issued was Beginning of the last century. Seismic design and construction of reinforces concrete structures. 1994. Practically it is a version proposed by the CEB-FIP. But the described here type of buildings does not conform with it. Title of the code or standard: Before adoption of the National Code of Practice in 1994 the codes of any developed country could be used , provided that a design will be checked and approved by the authority. As a result the following codes have been used: CP114, CP110, BS8110, ACI318, BAEL, DIN , SNiP and some others. Year the first code/standard addressing this type of construction issued: Beginning of the last century. National building code, material codes and seismic codes/standards: Seismic design and construction of reinforces concrete structures. 1994. Practically it is a version proposed by the CEB-FIP. But the described here type of buildings does not conform with it.

These buildings were constructed before the adoption and enforcement of current Codes. In the past a lax inspection and quality control resulted in a shoddy construction which can be rated as one of the main contributing factors to destructions. At present a site inspection by a structural engineer is compulsory.

### 6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and 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 Owner(s). Poor maintenance presents a huge problem.

### 6.8 Construction Economics

Approximately 450 US$/m². 5-6 months for a 4-storey building by the 8-10 person-strong team.

## 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 |
|---|---|
| Low shearing capacity and ductility of columns | 1. Steel angles-strips jacketing over the whole height of a column. See Fig. 7A Strength, stiffness and ductility are all affected. Concrete cover or ganite concrete is added on the top. |
| Null | 2. Traditional R.C. jacketing. See Fig. 7B Existing concrete cover is to be removed, existing reinforcement is to be cleaned (if needed), new longitudinal reinforcement should be anchored into foundations and floors. Closely spaced lateral ties at the top and bottom are to be provided. Concrete cover should be reinstalled. |
| Null | 3. Confining of concrete by the spiral wire tightly wrapped around a column and welded to vertical steel strips. See Fig. 7C |
| Excessive interstory drift | 1. Diagonal bracing. See Fig. 7D. |
| Null | 2. Infilling into opening , infilling into frame, infilling of a panel with an opening. See Fig. 7E. |

A considerable improvement of confining by steel angles jacket can be achieved by preliminary prestressing of a jacket. Before welding the steel strips are to be heated up to 300 deg C, ensuring that at a time of welding their temperature is not lower than 150 deg C. While cooling down the contraction forces create lateral tightening. The weak point of the steel-angle jacketing is the electric welds, which are brittle in themselves and commonly are not of an adequate length and capacity. Moreover, an anchorage of angles into floors and foundations is difficult. The joint response of newly added angle jackets and existing columns can be significantly improved by prestressing of longitudinal angles by means of lateral bolts tightening ,as it is shown in Fig.7. Before installing angles the lateral notches are made in them to allow their slight bending. While tightening lateral bolts the angles are straightened and the vertical thrust forces are transferred to frame beams. Usually one of these techniques is used.

## 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 methods have been used in several cases.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Steel angles-strips jacketing,, R.C. jacketing , bracing and infillings were used as the repair-upgrading measures following slight damages after earthquakes. A confining of corner columns of circular cross-section by a spiral wire was done as a mitigation effort.

## 8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

Yes.

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

Contractor. Structural engineer was involved.

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

Satisfactory. There was no strong quake since then, but they stood well to several light tremors.

Figure 7A: Illustration of Seismic Strengthening Techniques

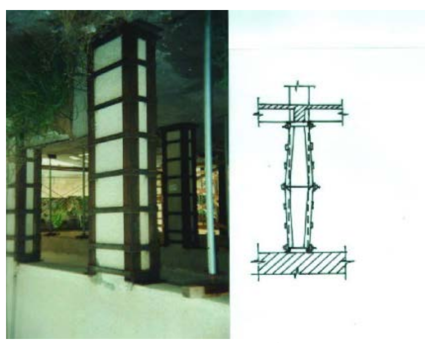

Figure 7B: Traditional R/C jacketing

Figure 7C: Confining of concrete by spiral wire

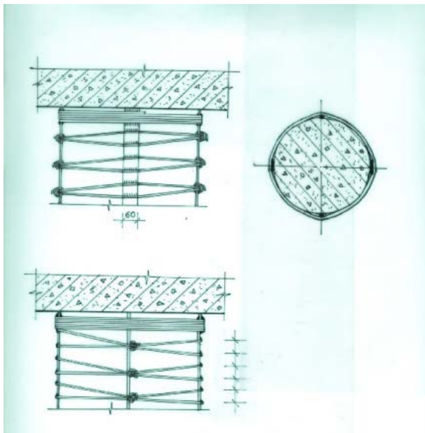

Figure 7D: Diagonal bracing

Figure 7E: Infillings. a) Into opening, b) Into frame, c) Steel bracing, d) Panel with opening

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# Author(s)


1. V. Levtchitch
   Professor, Frederick Institute of Technology

P.O. Box 24729 p.c. 1303, Nicosia , CYPRUS
Email:savvas@research. fit.ac.cy FAX: -437879

# Reviewer(s)

1. Craig D. Comartin
President
, C.D. Comartin Associates
Stockton CA 95207-1705, USA
Email:ccomartin@comartin.net FAX: (209) 472-7294