

World Housing Encyclopedia

A Resource on Construction in Earthquake Regions



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International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

Gravity designed reinforced concrete frame buildings with unreinforced masonry infill walls.

Report#	13
Last Updated	
Country	Cyprus
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Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International

General Information

Building Type:	Gravity designed reinforced concrete frame buildings with unreinforced masonry infill walls.
Country:	Cyprus
Author(s):	V. Levtchitch
Last Updated:	
Regions Where Found:	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.
Summary:	<p>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.</p>
Length of time practiced:	25-60 years
Still Practiced:	No

In practice as of:	1994
Building Occupancy:	Residential, 5-9 units Residential, 10-19 units Mixed residential/commercial
Typical number of stories:	4-5
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	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.
Typical plan length (meters)	12
Typical plan width (meters)	18
Typical story height (meters)	3
Type of Structural System	Structural Concrete: Moment Resisting Frame: Designed for gravity loads only, with URM infill walls
	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. 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

Additional comments on structural system

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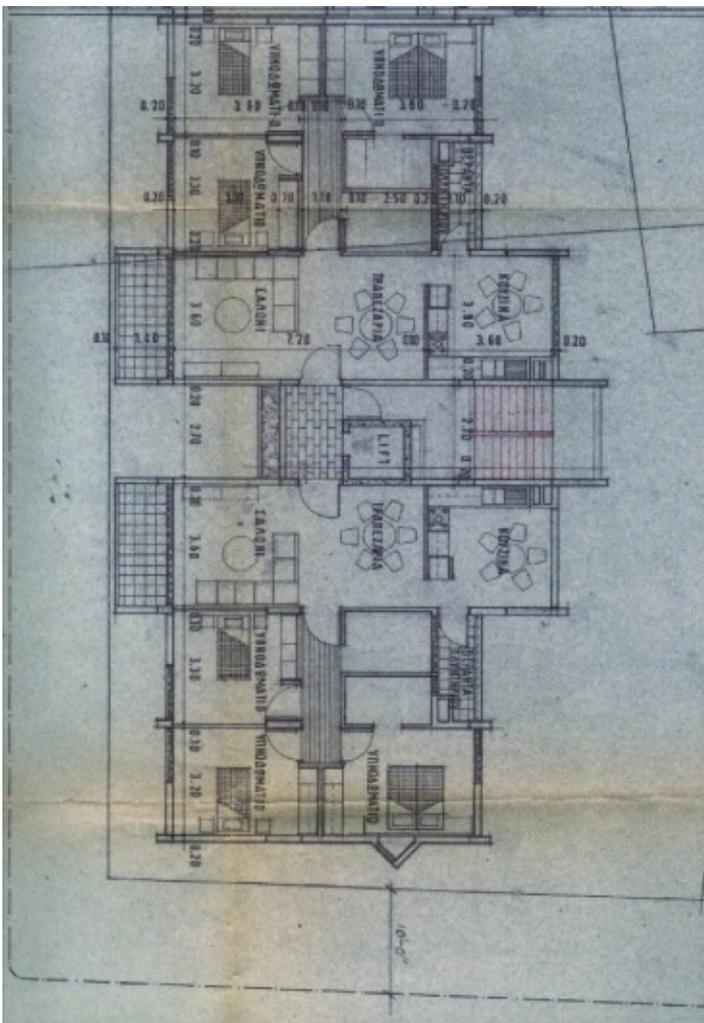
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Gravity load-bearing & lateral load-resisting

systems

Typical wall densities in direction 1	5-10%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	The typical structural wall density is approximately 10% (infill-walls).
Wall Openings	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.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	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 storeys. 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.
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footing
Additional comments on foundation	In the coastal areas the mat foundations were sometimes used.
Type of Floor System	Other floor system
Additional comments on floor system	Structural concrete: cast-in-place and precast solid slabs In most cases floors and roofs can be treated as the rigid diaphragms.

Type of Roof System	Roof system, other
Additional comments on roof system	Structural concrete: cast-in-place and precast solid slabs In most cases floors and roofs can be treated as the rigid diaphragms.
Additional comments section 2	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.



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
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Wall/Frame	Frame: Concrete, Steel	15-25 N/mm ² , S220-S500
Foundations	Concrete	15-20 N/mm ²
Floors	Concrete , Steel	15-20 N/mm ² , S220-S400
Roof	Concrete , Steel	15-20 N/mm ² , S220-S400
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	At present a design is to be prepared by the registered engineer and architect. Architects are responsible for the architectural planing and drawings . Civil Engineers are responsible for the structural design.
Expertise of those involved in the design process	The compulsory site-control by engineers was introduced only in 1999.

Construction Process

Who typically builds this construction type?	BuilderContractor
Roles of those involved in the building process	Typically these buildings are constructed by developers, but the builders can live in them.
Expertise of those involved in building process	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.
Construction process 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.
Construction issues	

Building Codes and Standards

Is this construction type address by	Yes
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codes/standards?	
Applicable codes or standards	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 , SNIIP and some others.
Process for building code enforcement	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 , SNIIP 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.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	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.

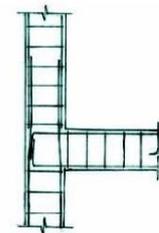
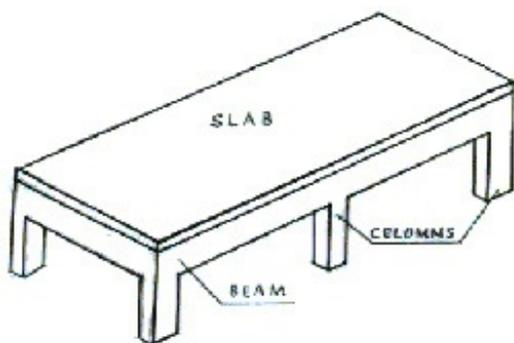
Building Maintenance and Condition

Typical problems associated with this type	Torsional vulnerability. Short-column effects. Inadequacy of shear and confining reinforcement. Combination of stiff and flexible structural and non-structural elements. Poor detailing in terms of seismic performance. In many instances, the depth of carbonation is larger than the cover to reinforcement which itself is rather frequently not
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of construction	adequate and sometimes-it does not exist at all. Corrosion of reinforcement and subsequent cracking of concrete are widespread. In coastal areas the sea-ward sides of buildings are heavily affected by concrete deterioration and the corrosion of reinforcement.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	Poor maintenance presents a huge problem.

Construction Economics

Unit construction cost	Approximately 450 US\$/m ²
Labor requirements	5-6 months for a 4-storey building by the 8-10 person-strong team.
Additional comments section 3	



Beam-column connection. Zones of potential plastic hinging (critical zones) in both columns and beams were not provided with a required confining. Within the panel zones columns were not provided with a lateral reinforcement. Sometimes bent-anchors of beams' longitudinal reinforcement were not provided

Critical Structural Detail

Key Load-bearing Elements



Soft ground story



Plan and elevation irregularities



Non symmetrical location of stairwell



Inadequate seismic joint



Short columns: sharp difference in capacities of adjacent columns



Excessive length of a cantilever canopy



Large balconies



Heavy concentrated loads are transferred to a thin balcony slab



Weak columns, incomplete beam-grid and a heavy-rigid parapet wall

of the additional constructed top story

Socio-Economic Issues

Patterns of occupancy	One family per housing unit. Each building typically has 8-14 units.
Number of inhabitants in a typical building of this construction type during the day	5-10
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	
Economic level of inhabitants	Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	Rich-15%, middle class-75%, poor-10%. Ratio of housing unit price to annual income: 4:1
Typical Source of Financing	Personal savingsCommercial banks/mortgagesGovernment-owned housing
Additional comments on financing	
Type of Ownership	RentUnits owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to	No

incorporate seismically resistant features?

Additional comments on premium discounts

Additional comments section 4

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1995	Paphos
1996	Paphos-Limassol
1999	Limassol

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type

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.

Walls: Extensive diagonal cracking due to the principal tensile stresses is estimated to take place at inter-storey drifts between 1/400 and 1/200., while the common r.c. columns can accommodate inter-storey 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: .Both columns of buildings with "soft storeys" and "short-rigid columns" incorporated into more flexible r. c. frames have suffered heavy damages. The shearing failure is the

Additional comments on earthquake damage patterns

most common mode of destruction. Combined effects of shear, eccentric 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 0.6mm. In some spandrel beams the torsional effects triggered a shear type cracking. Roof/floor: Some minor cracking was observed in one-way spanning floor slabs, when supporting beams were provided in one direction only. Generally, foundations performed satisfactorily, except some isolated cases of uneven settlements and certain base distortions.

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 "Handbook for the Seismic Evaluation of Buildings-A Pre-standard", Federal Emergency Management Agency, Washington, D.C., 1998.

The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than $\frac{1}{2}$ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than $\frac{1}{3}$ of the distance between the adjacent cross walls; For precast concrete wall structures: less than $\frac{3}{4}$ of the length of a perimeter wall.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	FALSE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	FALSE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will	TRUE

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.	TRUE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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);	N/A
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doveled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		N/A

Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Short column
Seismic deficiency in walls	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 strength can be as low as 0.015MPa, 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-resilient features in walls

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.

Seismic deficiency in frames

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.

Earthquake-resilient features in frame

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 0.10g) was satisfactory. Usually, a beam's capacities were predetermined by its connections.

Seismic deficiency in 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.

Earthquake resilient features in roof and floors

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.

Seismic deficiency in foundation

Earthquake-resilient features in foundation

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines](#)

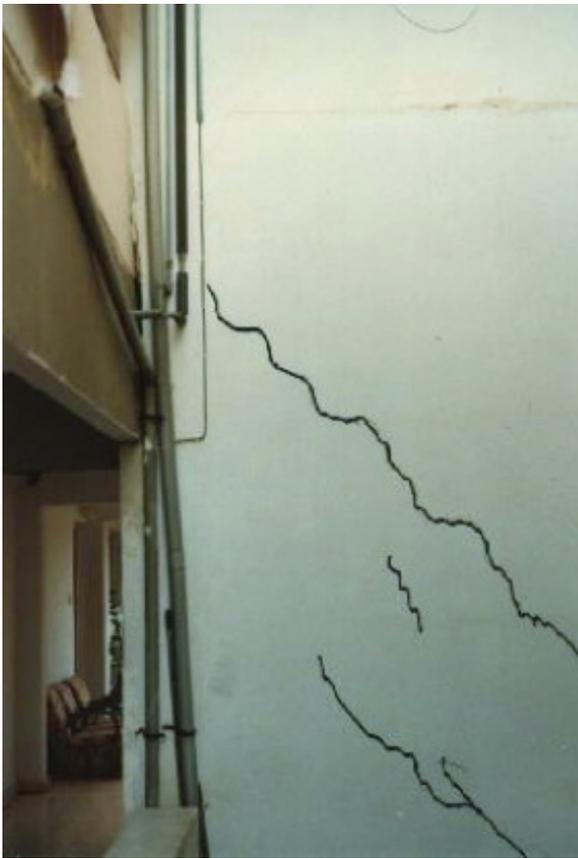
	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class		-	o	-		



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



Diagonal shearing of an infill wall



Horizontal shearing displacement



Shearing failure of a short column



Shearing of concrete and buckling of longitudinal reinforcement due to inadequate lateral reinforcement



Torsional shearing and buckling of longitudinal reinforcement at the bottom of a corner column



Shearing and buckling at the bottom of a column



Buckling of reinforcement at the bottom of a cylindrical column



Eccentric beam-short column connection



Support failure

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Low shearing capacity and ductility of columns	<ol style="list-style-type: none">1. Steel angles-strips jacketing over the whole height of a column. See Fig.26 Strength, stiffness and ductility are all affected. Concrete cover or granite concrete is added on the top.
	<ol style="list-style-type: none">2. Traditional r.c. jacketing. 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.
	<ol style="list-style-type: none">3. Confining of concrete by the spiral wire tightly wrapped around a column and welded to vertical steel strips. See Fig.27
Excessive interstorey drift	<ol style="list-style-type: none">1. Diagonal bracing. See Fig.28
	<ol style="list-style-type: none">2. Infilling into opening , infilling into frame, infilling of a panel with an opening. See Fig.29

Additional comments on seismic strengthening provisions

A considerable improvement of confining by steel angles jacketing 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 substantially improved by prestressing of longitudinal angles by means of lateral bolts tightening. 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.

Has seismic strengthening described

These methods have been used in several cases

in the above table been performed?

THESE METHODS HAVE BEEN USED IN SEVERAL CASES.

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

Steel angles-strips jacketing, R.C. jacketing , bracing and in-fills 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.

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

Yes

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

Contractor. Structural engineer was involved.

What has been 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.

Additional comments section 6

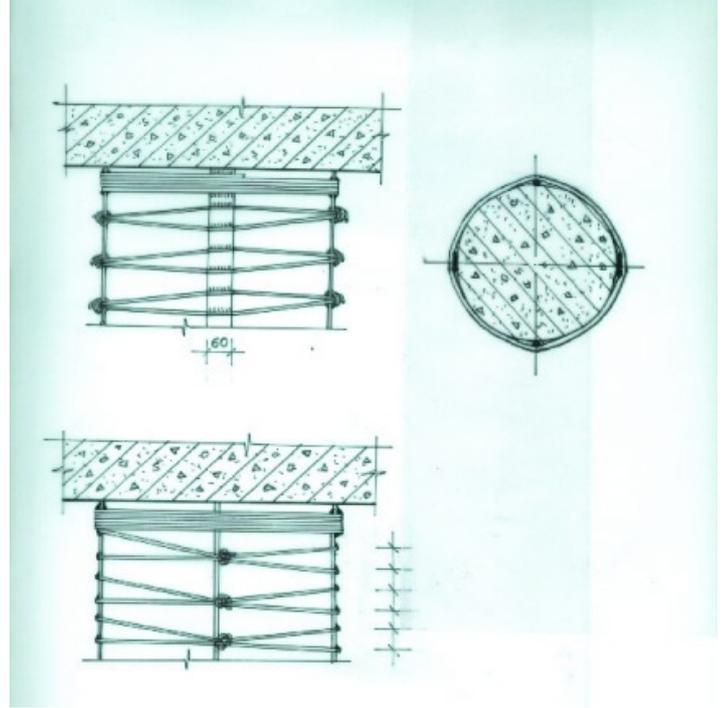


Traditional R/C jacketing

Illustration of Seismic Strengthening Techniques



Confining of concrete by spiral wire



Diagonal bracing



Infillings. a) Into opening, b) Into frame, c) Steel bracing, d) Panel

with opening

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