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
# Pillar walaghar (URM infilled RC frame buildings)

| | |
|---|---|
| Report # | 145 |
| Report Date | 09-12-2007 |
| Country | NEPAL |
| 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 building type is widely constructed in the urban and semi-urban area of Nepal. It has all the characteristics of a vernacular building only with the exception that few of the construction materials are not local. It is one of the most emerging building typologies in

Nepal. This is mostly non-engineered building typology. However, in urban areas sometimes competent structural engineers are also involved in the design. This technology was picked up after its relatively better performance during 1988 Udaypur earthquake which recorded M6.4 on Richter scale, that severely hit eastern Nepal. In this type of building a lightly reinforced frame is constructed first and then infill walls are erected later between columns. Though not usual, sometimes walls are constructed first and columns and beams later. These buildings serve multifunctional purposes such as residential, commercial, official, religious, educational, etc. These buildings are highly vulnerable to earthquake because of deficient detailing, inferior construction materials and the inadequate technology employed. Despite the use of modern materials of construction there is an ever growing risk to life and property due to potential earthquake attack. This building type, if designed and constructed properly, is suitable for low rise buildings up to 3 to 4 stories high. It is necessary to disseminate simple techniques of earthquake resistant measures for these buildings to the grass-root level.

# 1. General Information

Buildings of this construction type can be found in many areas of Nepal. This type of housing construction is commonly found in both sub-urban and urban areas.

This building type is perceived to be the safest and strongest in every respect compared to all the other building types in Nepal.

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

Currently, this type of construction is being built. Pillarwala ghar (literally meaning a house with columns) is a modern building type constructed of a reinforced concrete frame with masonry infill walls. Nepal has not suffered a major earthquake after the introduction of this building type, so there is a general notion among public at large that this building type is safe. Further, there is a general acceptance that with this building type owners can go as high as they like. So in urban areas where land is scarce and expensive, this is the invariably accepted building type. In addition, this building typology has become a status symbol in Nepal, and any one who can afford it prefers to construct this building type. Hence, slowly it is gaining widespread social acceptance in urban semi-urban and rural areas. Though, this building type is used for all occupancies, this report is mostly focused towards residential buildings.

A typical RC frame building with masonry infill


A typical mix use 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. Usually there is no separation gap with adjoining buildings if a building is constructed along an urban strip, especially where the land is expensive and scarce. Hence, openings are provided only in the front and rear part of the building. However, in residential areas, they are usually free-standing buildings; hence the openings could be on all sides When separated from adjacent buildings, the typical distance from a neighboring building is 0 meters.

## 2.2 Building Configuration

Building configuration in general depends on where the building is located and its function. Usually these buildings are rectangular and regular in plan shape depending on the shape of land. Sometimes, these buildings have wings. In residential buildings, the storey height, number of columns and quantity of walls per story is usually similar. Walls are usually well distributed. However, in commercial buildings, the ground floor is usually open with a lot of walls in upper storey for partitions which are never tied to the frames. There are 3 to 5 rooms in each story in a typical residential building of this type. However, there could be many rooms per floor in a large apartment building. A room has two windows and a door provided that there are no legal and other practical restrictions such as building on or near the property line. The openings are usually around 30-40% of the plinth area. These buildings range between 2 to 6-7 stories high.

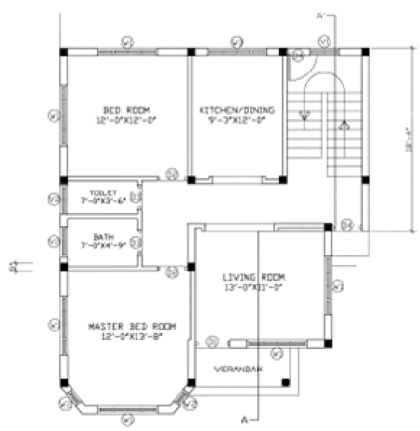
## 2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). It is used for apartments. These buildings are used for all sorts of functions such as commercial; residential, educational, religious and official purposes.They are also used as hostels, hospitals, etc. In a typical building of this type, there are no elevators and no fire-protected exit staircases. Usually there are two doors in the bottom story in this type of building, one in the front and the other in the rear. However, upper stories usually have only one egress route.

## 2.4 Modification to Building

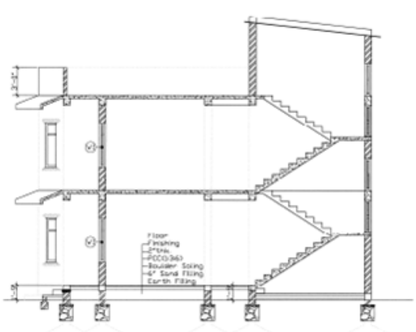
Both vertical and horizontal extensions of a building are common depending on the requirement of space and availability of funds. Vertical extension is more common in this type of building as this building type is perceived as strong enough to go as high as required. Change in room size by removing walls is quite common in the upper storeys depending on functional needs. This requires placing of partition walls away from the frame or walls in the storey below. Sometimes columns are also removed to make larger rooms.


Different height buildings along a street.



Plan of a typical RC frame residential house


Typical elevations of a RC frame residential house


Typical section of a residential building

A long narrow building


A stepped building


A building with increasing floor areas with height


A free standing building with large top story

# 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 | ☐ |
| | | 17 | Flat slab structure | ☐ |
| | | 18 | Designed for gravity loads only, with URM infill walls | ☑ |

| | | | | |
|---|---|---|---|---|
| Structural concrete | Moment resisting frame | 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 most common practice is to construct the frame first and infill later. The most common infill is fired brick in cement mortar, though block or stone infills are also common. Infills constructed of stone in mud mortar have also been seen in remote areas. This building type does not work as moment resisting system.

## 3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete moment resisting frame. Vertical load resistance is primarily provided by a RC frame, though part of the load is carried by infill walls.

## 3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. Lateral loads on the buildings are resisted by the combined effect of RC Frames and the brick or block masonry infill walls.

## 3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 20 meters, and widths between 8 and 10 meters. The building has 2 to 4 storey(s). The typical span of the roofing/flooring system is 3-5 meters. The building size depends on the available plot size. In urban areas, due to intensive land fragmentation buildings with width less than five meters can also be found. The typical storey height in such buildings is 2.75-3.3 meters. The typical structural wall density is up to 10 %. Wall density depends upon the function of the building. In mixed used buildings the bottom story could be open if used for commercial purpose. In commercial, institutional buildings, wall density is much lower than that of a residential building.

## 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 | ☑ | ☑ |

## 3.6 Foundation

| Type | Description | Most appropriate type |
|---|---|---|
| | Wall or column embedded in soil, without footing | ☐ |
| | Rubble stone, fieldstone isolated footing | ☐ |
| | Rubble stone, fieldstone strip | ☐ |

| | | |
|---|---|---|
| Shallow foundation | 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 | ☐ |

These isolated footings are not tied together at the foundation level though a plinth beam is provided at plinth level. Sometimes combined footings are also used. For large commercial buildings, raft foundations are also used. Pile foundations for buildings are not common in Nepal. In hilly terrain, foundation pads are placed at different levels.

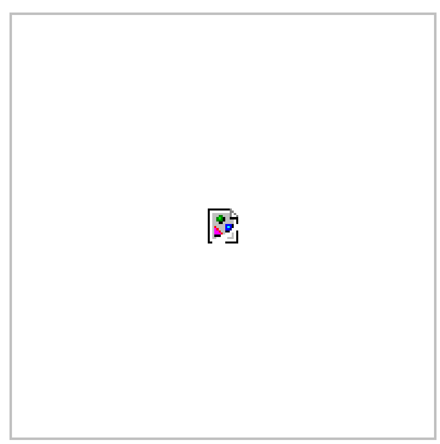

Column starting from 5th storey

Missing columns in top storey

Missing beams

No anchorage of beam bars in column


Beam reinforcement hooking into column reinforcement. Also note inadequately large spacing of stirrups in the beam and column, and no stirrups in beam-column joint.



Column reinforcement left for splicing of upper story column reinforcement

Column reinforcement is far too short for the continuity of the column

Defective stirrups due to 90 degree bends

No stirrups in beam-column joint

# 4. Socio-Economic Aspects

## 4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). However, a building could have multiple households as well, depending on the building size. The number of inhabitants in a building during the day or business hours is less than 5. On an average there are 2 to 5 occupants during day/business hours if the building is being used for a single household unit. During the day/business hours typically babies, very small children, mothers, sick people and grandparents would be at home. Children of school age and working men will typically be at school or work. School children will return earlier in the day than working adults. In the evenings and night time these buildings will have the largest number of inhabitants. As these buildings are mainly family homes, they will likely to have their highest occupancy level during school holidays. The number of inhabitants during the evening and night is 5-10. However, in institutional buildings (educational, day care centers, office, etc), the occupancy is much higher in day time. In schools, there could be 100s of children in one building during day time, but after school time none. Although this type of structure has many uses, the information supplied here addresses a typical residential building.

## 4.2 Patterns of Occupancy

Houses of this type are occupied by a single family as well as multiple families depending on size of the building and number of stories. The number of households depends on size of building. Typically, one small building is occupied by one household 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) | ☑ |

| 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) | ☐ |

These days, people can obtain a mortgage from a bank to buy an apartment or house, although it is not common. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and no bathroom(s) including toilet(s).

The number of bathrooms and toilets depends on household size, economic status of the building owner, number of stories in the buildings. Usually toilets and bathrooms are provided on each floor. .

### 4.4 Ownership

The type of ownership or occupancy is outright ownership, ownership with debt (mortgage or other) 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) | ☐ |

Most of the houses in Nepal are outright ownership. Ownership with mortgage is a relatively new concept in Nepal.

## 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 | The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its | | | |

| | | | | |
|---|---|---|---|---|
| construction | 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 | Many times severe structural deficiencies such as dislocation or abrupt interruption of columns can be seen. The other problem with these building types is reinforcement detailing such as deficient lapping of bars, deficient anchorage of beam bars in the column, open stirrups, etc. Further, due to lack of proper cover to reinforcement and porous concrete, severe corrosion of the reinforcement can be seen. It is also common to have areas where the load paths are indirect, and such configuration problems lead to soft-storeys in the case of commercial and residential occupancies. | | | |

## 5.2 Seismic Features

| Structural Element | Seismic Deficiency | Earthquake Resilient Features | Earthquake Damage Patterns |
|---|---|---|---|
| Wall | 1. Walls and frame are not integrated. The infills are not tied to the frames 2. Walls are placed without any judicious | The following features listed are recommended rather than existing features 1. Provide horizontal dowel bars in columns to tie infill walls to the frame. Provide lintel and sill level bands passing through columns. 2. Equal walls provided at extreme ends of the building in both the directions. 3. Continue | 1 Out-of-plane toppling of infill walls. 2. Serious soft-storey and torsional problems. 3. Short column |

| | | | |
|---|---|---|---|
| | thought from a seismic point of view and so severe configuration problems such as soft-storeys can occur. 3. Provision of open ground floor for shops, parking, lobby etc that leads to a soft-story. 4. Trapped columns by partial-height confining walls. | some walls down to the foundation level to mitigate the soft storey effect. 4. Provide RC walls that continue from the foundation to the roof. The stiffness of the ground floor walls should be at least 70% of the upper storey. 5. Provide bracing to improve stiffness and strength of open story. 6. Isolate partial height walls from the frame to avoid the short- column effect. Provide closely spaced stirrups throughout the height of column where there is a possibility of a short column. Provide at least few full height shear walls in both the directions to reduce deflections that lead to short column effect damage. | effect. |
| Frame (columns, beams) | 1. Columns are deficient in terms of size, reinforcement and detailing. 2. Columns and beams suffer severely deficient detailing 2.1 Deficient reinforcement splicing, eg. length and location 2.2 Deficient anchorage for beam reinforcement in columns 2.3 Open stirrups at too widely spaced. 2.4. No foundation beam to tie column bases together. | 2.1 Splice away from high action areas, longer splicing length to develop full strength of reinforcement 2.2 Enough length of anchorages with L-bends or hooks at the end of beam bars inside the column. 2.3 Closed stirrups with 135 degree hooks at close spacing. 2.4 Foundation beams at base of columns to tie column bases together. | 2.1. Crushing of concrete, high brittleness of structural elements. 2.2 Splicing failure leading to severe damage and destruction of the building structure. 2.3 Anchorage failure of beam bars 2.4 Bursting of column due to lack of adequate confinement. 2.5 Relative movement between columns leading to column failure. |
| Roof and floors | | Roof and floor slabs are strong and stiff enough to act as rigid diaphragms. | |
| Other | Quality of materials is usually inferior such as - Low strength of concrete, - Highly brittle reinforcement. | | - Crushing of concrete, - Snapping of reinforcement. |

1.Open bottom story is common in mixed use buildings such as shops, where there is parking in the bottom storey, /or and residential/ office use in upper stories. This creates a soft-storey that can often lead to building collapse. 2. Non-alignment of walls: In many cases walls are not constructed in the same vertical line but are constructed according to the functional requirements.

## 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 |
| | ☐ | ☑ | ☐ | ☑ | ☐ | ☐ |

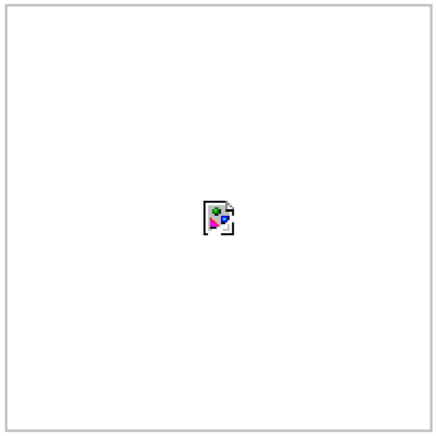
## 5.4 History of Past Earthquakes

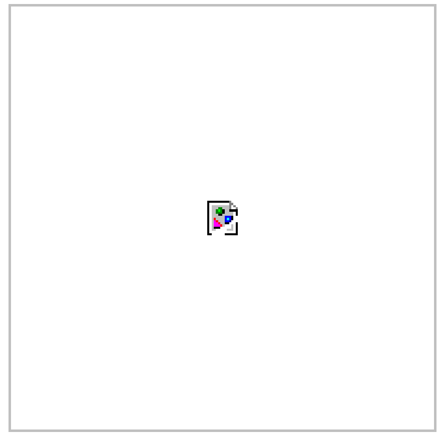
| Date | Epicenter, region | Magnitude | Max. Intensity |
|---|---|---|---|
| 1255 | Data Not Available | 7.7 | X(MMI) |
| 1681 | Data Not Available | | IX (MMI) |
| 1803 | Data Not Available | | IX (MMI) |
| 1833, | Data Not Available | 7.0 | X(MMI) |
| 1934, | Sankhuwasabha, Nepal | 8.3 | IX-X(MMI) |
| | | | |

| | | | |
|---|---|---|---|
| 1980 | Bajang, Nepal | 6.1 | VII(MMI) |
| 1988 | Udayapur, Nepal | 6.4 | VIII(MMI) |
| 1993 | Data Not Available | | |
| 2003 | Pokhara, Nepal | 5.0 | VIII(MMI) |

Nepal has not suffered any major seismic event since the introduction of this building type.


Deficient lap length, and very poor lap location leading to partial collapse of the building


Failure of column bar splicing


Failure of column bar splicing


Shear failure of first storey columns


Cold-joint problem


Onset of plastic hinging at top of columns


Onset of development of soft storey mechanism at 1st floor level


Failure of column due to shear imposed by infill wall


Short column due to partial height infill wall

Onset of out-of-plane collapse of infill wall

Building being supported by infill walls after failure of column

# 6. Construction

## 6.1 Building Materials

| Structural element | Building material | Characteristic strength | Mix proportions/dimensions | Comments |
|---|---|---|---|---|
| Walls | Bricks or blocks are commonly used construction materials for walls, however, sometimes stones are also used. | Strength of bricks varies between 40-120 kg/cm2. | Cement sand mortar is mixed in the proportion of 1:6-8 Brick size ranges from 20x10x10 to 50x50x20 cm. Wall thickness ranges from 12.5 to 23 cm. | Strength, size and quality of materials of wall construction varies from place to place. Many times, bricks or blocks are of inferior quality such as low crushing strength, broken corners, etc. |
| Foundation | Reinforced concrete is used in the foundation. | Strength of concrete varies from 100 to 150 kg/cm2. Standard yield strength of steel, commonly used for longitudinal steel is 415 and 500 MPa. | Cement:sand:aggregate is mixed in the proportion of 1:3:5 to 1:3:4 | Mostly hand mixing and hand compaction is applied to the concrete. Recently however, there is a growing tendency to use machines for mixing and compacting. |
| Frames (beams & columns) | Reinforced concrete is used in beams and column. | Strength of concrete varies from 100 to 150 kg/cm2. Standard yield strength of steel, commonly used for longitudinal steel is 415 and 500 MPa. For stirrups 250 MPa plain bars are used. | Cement:sand:aggregate is mixed in the proportion of 1:3:5 to 1:3:4 | Mostly hand mixing and hand compaction is applied in concrete. However, in recent days there is a growing trend to use machines for mixing and compacting |
| Roof and floor(s) | Reinforced concrete is used in roof and floors. | Strength of concrete varies from 100 to 150 kg/cm2. Standard yield strength of steel, commonly used for longitudinal steel is 415 and 500 MPa. | Cement:sand:aggregate is mixed in the proportion of 1:3:5 to 1:3:4 | Mostly hand mixing and hand compaction is applied in concrete. Recently however, there is a growing tendency to use machines for mixing and compacting |

## 6.2 Builder

House owners themselves are involved in the construction right from the beginning to the end. This construction is mostly informal construction. Basically, the building owner himself manages the project and procures the materials. The leader craftsman (Naike) plays a pivotal role in the building development process by helping the building owner in various ways such as quantity estimates, time estimates, providing advice etc.

## 6.3 Construction Process, Problems and Phasing

It is basically owner-built construction. Locally known contractors cum masons (leader craftsmen) are invited and entrusted with the labor contract. Construction is carried out under the advice and consultation of the mason though sometimes engineers/ architects are also involved. Construction material is procured by the building owner. Column and wall foundations are packed with rubble stone and soil alternately in layers up to ground level. After constructing the plinth beam, about 2.5 m high columns are cast. Then formwork for beam and slab are laid. Beams and slab are cast together though it is not a norm in many parts of the country. Then masonry walls are erected in cement sand mortar. The tools used are hammer, trowel, concrete mixtures, concrete vibrator etc. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. As a vernacular building, it is also constructed over the years depending upon availability of funds and requirement of space. Vertical extension is the most common form of extension. Usually these buildings are constructed by convention rather than design.

## 6.4 Design and Construction Expertise

Design/ construction expertise exists in the country, particularly in urban areas. The irony is that these buildings behave very differently than that of the moment resisting frame. However, most engineers design them as moment resisting frame without considering the infill walls in the design. Most of this type of building is non-engineered although technicians are involved in the preparation of drawings for building permit in municipal areas. However, mostly it is mere official formality. Owners rely on masons who play a crucial role in building construction of this type. However, they are unaware of the National Building Code. Moreover, all masons are not equally competent in their profession. In most of the cases, the role of engineers is limited only in making drawings and building permit processes. In some cases, they are involved in structural design, construction monitoring, and quality control as well.

## 6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. These are the Nepal National Building Code, NBC 201, Mandatory Rules of Thumb, Reinforced Concrete Buildings with Masonry Infill.

A building permit is required in municipal/ urban areas only; no building permit is required in rural areas. This type of construction is most common in the urban area but it has been spreading to the rural area as well.

## 6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules.

Even in municipal areas most of the time engineers are involved in obtaining the building permit only. In theory, only buildings larger than a certain size require structural design, but most of the time this is a ritual rather than reality. 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).

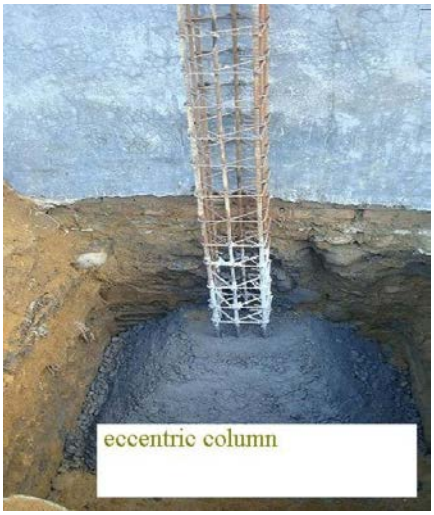
## 6.8 Construction Economics

Approximately US$ 250/ m2. For construction of a one story average sized house (say 100 sqm), 4-6 persons work for about 9 months to a year. For upper stories it could be a little less, say 6 to 9 months. However, on the day of floor/ roof slab concreting 40-50 people work together as everything such as concrete mixing, placing, and compacting is done manually. Now manual mixing and compacting are being gradually replaced by machine mixing and compacting, which reduces the labor requirements from 40-50 to 30-40.

Pits for isolated footings

Pits for combined foundation

Isolated footings under construction



Eccentric footing along property line


A corner eccentric footing


Constructing toe wall for tie (at plinth level) beam in stone masonry


Toe wall below tie beam in mud mortar


Plinth/ tie beam construction

RC frame under construction (note anchor bars at lintel and sill level for respective bands to tie the infill walls)

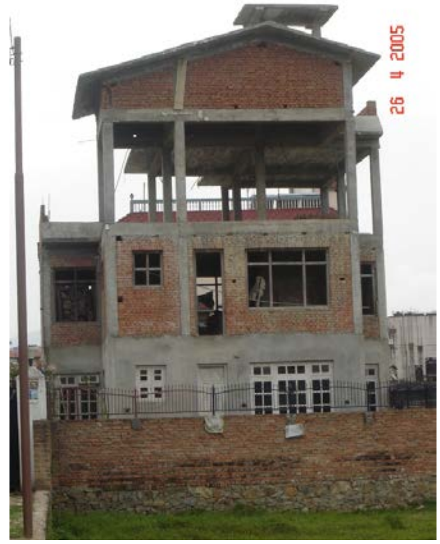
RC frame ready to receive infill walls. Note that there are no horizontal ties protruding from the columns to prevent the infills from falling out of the frame.


Infill wall under construction


Infill wall in stone masonry

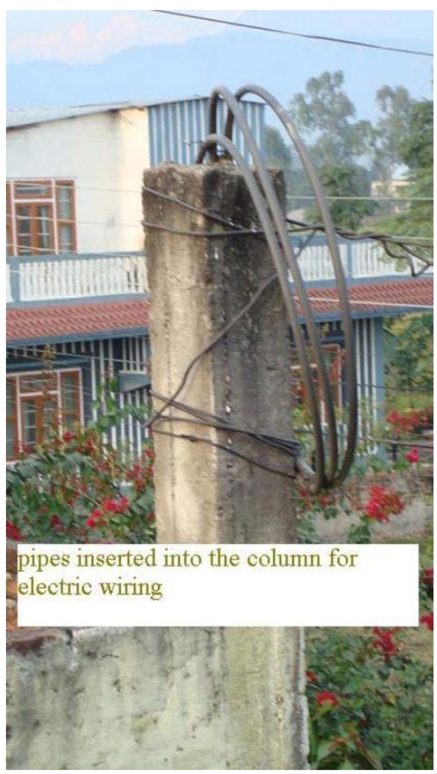
Infill wall erected before concreting column

Toothing in brick work for extension of walls



Building with bottom storey ineffectively infilled because there are no solid bracing panels. The top storey is infilled and all the storeys below are very weak and vulnerable.

Construction of floor slab



Reinforcement left for future extension

# 7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is available. Earthquake Insurance is not common in Nepal. However, insurance companies have started to offer insurance schemes and a few people procure it.

# 8. Strengthening

## 8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

| Seismic Deficiency | Description of Seismic Strengthening provisions used |
|---|---|
| Plan irregularity | Provide additional walls, or bracing along open sides such as for a corner building |
| Soft storey effect | Continue most of the infill down to ground level in both orthogonal directions, increase the size of columns in bottom storey, or best of all, provide RC shear walls to resist lateral forces in both directions. |
| Short column effect | Provide full height walls to stiffen the frame thereby reducing the deflection, provide closely spaced stirrups in columns, isolate infill walls structurally from the columns. |
| Weak structure | Provide new RC shear walls in both directions, provide jacketing to the existing walls, increase the strength of the structure. |
| Out-of-plane toppling of walls | Provide a bandage at lintel level to integrate the walls with the frame. |
| Anchorage failure of beam bars | Could consider providing a haunch to improve tying of the beam with column but the best solution is to provide new lateral load resisting structure that relieves the poorly detailed frames from having to provide resistance. |

Strengthening of New Construction :

| Seismic Deficiency | Description of Seismic Strengthening provisions used |
|---|---|
| Plan irregularity | Provide walls judiciously to avoid torsion and tie them into the frame. |
| Vertical irregularity | Provide walls continuous from foundation to roof level uninterrupted. |
| Weak structure | Provide solid masonry walls, or much better, RC walls in both the directions from foundation to roof. |
| Short column effect | In the vicinity of the column provide a length of solid masonry so as a diagonal strut can form in the infiill walls and not cause shear failure in the column. Provide solid walls in all the directions so the deflection can be reduced, provide closely spaced stirrups in the column (realising that this will be insufficient on its own). |
| Soft storey effect | Provide solid (RC) shear walls from foundation to roof level. |
| Wall on two adjoining sides only (corner building) | Provide bracing infill walls along the open fronts. |
| Deficient splicing length , open stirrups | Meet provisions for ductile detailing. |
| Beam-column joint failure | Provide stirrups in the beam column joint region. |
| Anchorage failure of beam bars | Provide enough anchorage length of beam reinforcement in column with bend at the end of the reinforcement as well as other recommended measures. |

The national code provides rules of thumb for buildings up to three storey high. However, it does not discuss the retrofitting of such buildings.

## 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?
Retrofitting is a completely new terminology even among practicing civil engineers. Retrofitting is practically non-existent but it is slowly emerging.

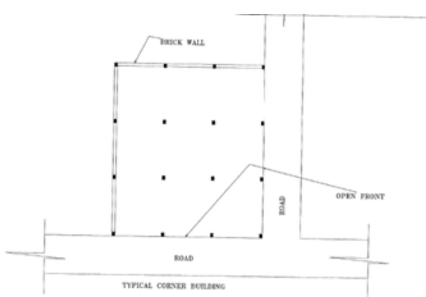
Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Such work is rare but a few retrofit projects have been accomplished. These are as part of a mitigation program.

## 8.3 Construction and Performance of Seismic Strengthening

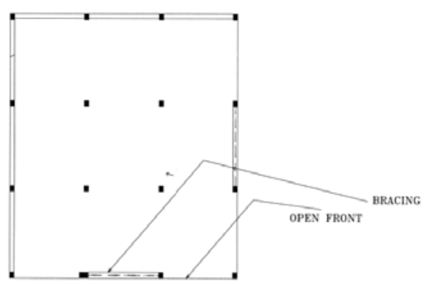
Was the construction inspected in the same manner as the new construction?
Yes.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Engineers are involved in the design of strengthening. The strengthening is implemented by contractors.

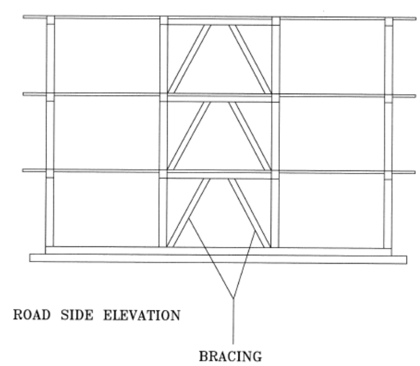
What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Not applicable. Nepal has not suffered any significant earthquake in recent history to test this work.



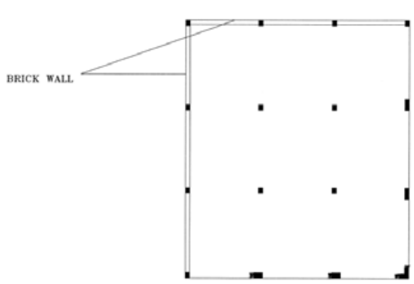
Plan of a corner building with walls on adjoing sides



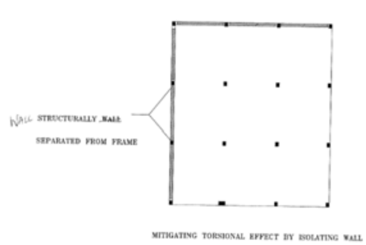
Adding bracing along open front to mitigate torsional effect



Elevation of bracing along street front



Widening the column width along the open front of a corner building to mitigate torsional effect



Mitigating torsional effect in a corner building by structurally isolating infill walls

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