World Housing Encyclopedia

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

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Uncoursed rubble stone masonry walls with timber floor and roof

Report #	74
Report Date	05-06-2002
Country	NEPAL
Housing Type	Stone Masonry House
Housing Sub-Type	Stone Masonry House : Rubble stone without/with mud/lime/cement mortar
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Summary

This is a typical rural housing construction in the hills and mountains throughout Nepal. It is a traditional construction practice followed for over 200 years. These buildings are basically loose-fitting, load-bearing structures constructed of uncoursed rubble stone walls in mud

mortar, with timber floors and roofs. They are expected to be extremely vulnerable to the effects of earthquakes due to their lack of structural integrity.

1. General Information

Buildings of this construction type can be found in Nepal, most extensively constructed throughout the foothills, hills and mountains. The proportionate amount of this building type in the total housing stock and the percentage of the total population inhabiting these buildings of this type are unknown. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. This is traditional construction having being followed for over 200 years.

Figure 1: Typical Building

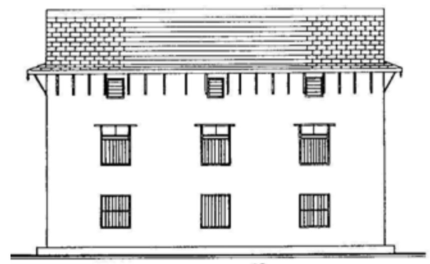

Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is several meters.

2.2 Building Configuration

The building plan is rectangular in shape. Typically, three to four openings are provided in each story, one for a door and the rest for windows in main building. The front façade has more openings than the back. Openings are limited in size. Openings constitute some 15-20% or even less of the total wall length. Spacing between openings is generally more than twice the length of the opening.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. There is usually only one door in a building of this type.

2.4 Modification to Building

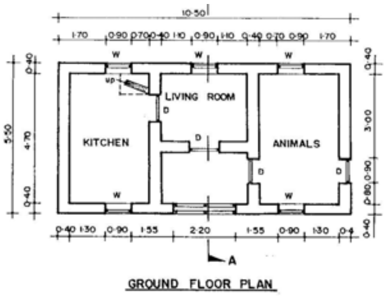

Figure 3: Ground Floor Plan

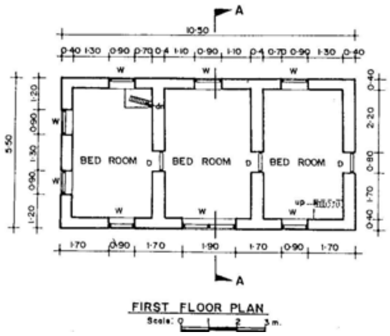

Figure 3A: First Floor Plan

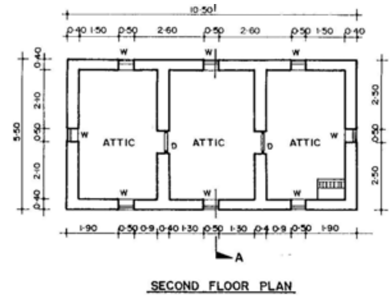

Figure 3B: Second Floor Plan

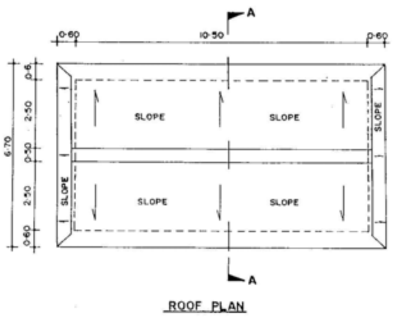

Figure 3C: Roof Plan

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☑
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
			Concrete block masonry in	

		16	cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is stone masonry walls. The gravity loads of the main building are carried by load-bearing stone masonry walls (typical thickness - 450 to 600 mm). The floor and roof are timber structures that transfer the load to the walls down to the foundation (uncoursed rubble stone masonry strip footings). The veranda, a lean-to structure annexed to the main building, is supported by timber posts. The posts generally rest above ground on stone pedestals without any anchorage. Beam-column connections at the veranda are not rigid.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is stone masonry walls. The load-bearing masonry walls carry the lateral load, i.e., the masonry walls act as shear walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 6 and 10 meters, and widths between 4 and 7 meters. The building is 2 storey high. The typical span of the roofing/flooring system is 5 meters. Typical Plan Dimensions: Length varies from 6 to 10.0 m, and the width varies from 4-7 m. Typical Span: Typical distance between cross wall s varies from 4-6m. The typical storey height in such buildings is 2.2 meters. The typical structural wall density is more than 20 %. Total wall density (total plan area of wall/ total plinth area) is around 25%.

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	☑	☑

Wood planks (or fire wood) and joists covered with thick mud overlay. Floor and roof structures are loose fit structure, with one component stacked atop the other without any nailing, and should be considered as a flexible diaphragm. In past earthquakes such floors were scattered due to ground shaking.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

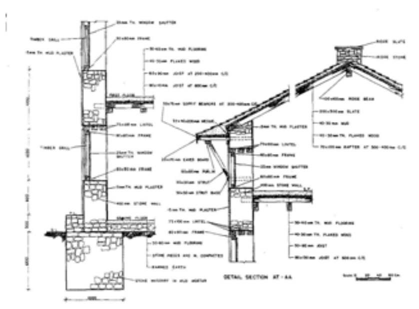

Figure 4: Critical Structural Details: Wall Section, Foundations, Roof-Wall Connections

Figure 5: Key Seismic Deficiencies: Lack of Connection Between the Wall Wythes (note loose stone rubble)

Figure 5A: Seismic Deficiencies: Inadequate Wall-Roof Connections

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 unit 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 5-10.

4.2 Patterns of Occupancy

Single or multi-family housing.

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)	☑

It is difficult to establish the ratio between house price and annual income because of the informal nature of the housing construction.

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 no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

This building typology does not comprise an attached toilet or bathroom. In the past, there were no latrines or bathrooms available in this type of house. At the present time, toilets are constructed but away from the houses and in isolation. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☐

Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
	Quality of workmanship (based on visual inspection of			

Quality of workmanship	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	Binding material (mortar) for walls is too weak (mud mortar) or there is no binding material at all (dry stone masonry); Stone units (boulders) are irregular; Absence of header stones at wall junctions and corners. Absence of through stones.	In some cases, bond stones or timber bands are provided.	Separation of the walls at the junctions; In-plane and out-of-plane wall failure.
Timber frame (veranda)	Inadequate beam-column and beam-wall connections; Lack of anchorage between timber posts and foundation.		
Roof and floors	Flexible: Lack of integrity (connections) between different structural elements: Absence of wall-floor and wall-roof connection (in general); Heavy floors.		Total disintegration of roof/floor structure, separation of floor/roof structure from walls due to the absence of wall-floor anchorage (ties).
Foundation	Inadequate foundation provided.		Because the superstructure is very weak, it fails before the foundation.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is A: HIGH VULNERABILITY (i.e., very poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☑	☐	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1988	Udaypur earthquake	6.4	VIII
1999	Chamoli, India	6.5	VIII

This building type is among the most vulnerable to the effects of earthquake because it suffers fatal damage in even minor shaking. Many buildings in Nepal suffered severe damage in the 1999 Chamoli Earthquake, although the epicentre was approximately 140 km away. The main source of damage is loss of integrity of building components, dislodging of rubble stones, delamination of walls etc.


Figure 6: Typical Earthquake Damage: Roof Collapse Due to the Absence of Wall-Roof Connection


Figure 6A: Typical Earthquake Damage - Delamination of Stone Walls Due to Absence of Bond Stones (through-stones)


Figure 6B: Typical Earthquake Damage to Stone Masonry Buildings


Figure 6C: Complete Collapse of a Stone Building in an Earthquake


Figure 6D: Typical Earthquake Damage: Out-of-plane Wall Collapse Due to Lack of Anchorage


Figure 6E: Typical Earthquake Damage: Wall Bulging Due to Delamination


Figure 6F: Typical Earthquake Damage: In-plane Failure of a Stone Masonry Wall

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Rubble stone	Not known	Irregular boulders (size 200-300 mm or less)	Slates, lime stone, quartzite
Foundation	Mud	Very low compressive strength and no tensile strength		Used for mortar.
Frames (beams & columns)	Timber frame: Soft wood and hard wood		Timber frame: Depends on the structural value of the member.	Timber frame: Hard wood used for the main structural elements (e.g., columns, main beams), whereas soft wood used for structural members of secondary importance (e.g., joists, purlins).
Roof and floor(s)	Timber and bamboo Roofing material: Thatch, shingle, slate, corrugated iron sheets.	Not known		Difficult to define because of the use of various wood species. Roofing material: The choice of roofing material depends on availability of materials and cost. Hard wood used for the main structural elements (e.g. columns main beams) whereas soft wood used for structural members of secondary importance (e.g. joists purlins).

6.2 Builder

Yes, builders and owners live in this construction type. (The homeowner himself is a part of the construction team).

6.3 Construction Process, Problems and Phasing

The walls are constructed in a random uncoursed manner by using irregular stones bound with mud mortar. The stones are collected from quarries, riverbeds or fields, and are sometimes partially dressed. Space between the interior and exterior wythes is filled with stone rubble and mud. The joists and rafters are placed on walls without any anchorage or connection. This type of building is owner-built and village artisans play a pivotal role. Simple tools, such as chisels, hammers, saws, etc., are used for construction. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

The artisans do not have any formal training. The construction know-how is transferred from generation to generation, or people learn the process on-site in a very informal way. The head mason is skilled but the level of expertise varies from person to person. There are no standard or minimum qualification requirements for the head mason or for the other masons. Besides the head mason, the working team is composed of semi-skilled or unskilled personnel. Engineers, architects and technicians are not involved in this construction type unless the building is constructed by a government agency.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. NBC203: Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry (Draft). Title of the code or standard: NBC203: Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry (Draft).

A process for building code enforcement in rural areas (in Village Development Committee areas) does not exist.

6.6 Building Permits and Development Control Rules

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

The building bylaws, building permit process and building construction controlling monitoring mechanisms only exist in municipal areas and not in Village Development Committee (the local authority at village units-rural areas). This type is basically a rural house type where the building permit process does not exist. If this building type is constructed in a municipal area, it has to follow the formal process, however the approval of structural drawings for a building of this size is not required. Present building bylaws or regulations do not prohibit the construction of this type of building in municipal areas. Building permits are not required to build this housing type.

6.7 Building Maintenance

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

6.8 Construction Economics

Cash flow in such construction is very minimal so it is difficult to estimate the building cost. 120-150 man-days (excluding effort required for collection of construction materials).

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. Not applicable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Delamination of walls	Introduction of bond (through) stones
Separation of walls at junctions	Introduction of stitches
Out-of-plane collapse of walls	Introduction of bandage (reinforced concrete, timber, steel) at different levels, or bolting the opposite walls
Vertical tension (unstability)	Introduction of splints (reinforced concrete, steel, timber)
Lack of integrity at floor/roof level	Nailing and straping of different floor and roof elements together and anchoring floor and roof joists and rafters to the walls
Floor/ roof flexibility	Introduction of floor and roof bracing

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?

The seismic strengthening described above will significantly increase the seismic safety of the building so it can sustain an earthquake of moderate intensity. However, as the wall construction is rather weak, it is expected that even the strengthened buildings would not be able to withstand a major earthquake.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
Not very often.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
These are mostly owner-built buildings. Sometimes engineers and architects are involved, if the construction is formal (government-funded or if funding is provided by international organizations) and if constructed in remote areas.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
There have been no reported major earthquakes since the retrofitting was performed.


Figure 7: Illustration of Seismic Strengthening Techniques

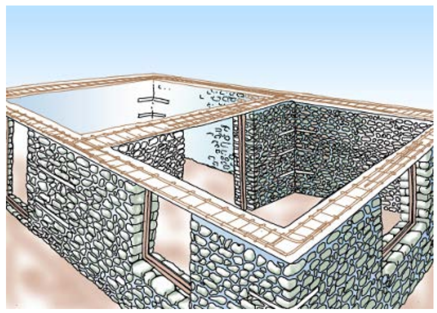
Figure 7A: Seismic Strengthening Techniques: Stone Masonry Walls Strengthened with Wall Corner Stitches and Bands (bond beams)

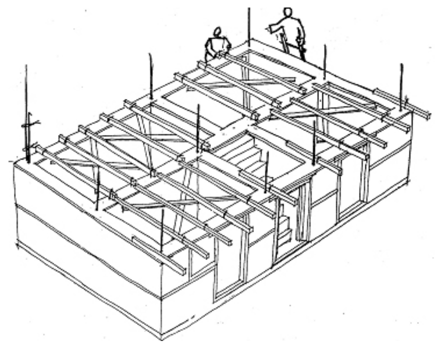
Figure 7B: Seismic Strengthening: Floor Horizontal Bracing and Vertical Reinforcement Bars

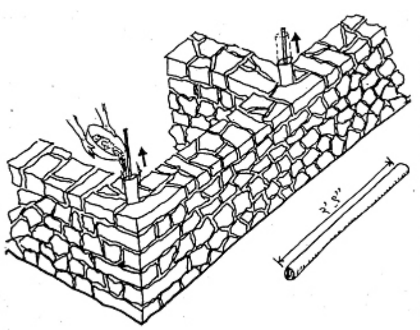
Figure 7C: Seismic Strengthening: Installation of Vertical Bars at Wall Corners

Reference(s)

1. Appendix-A: Prototype Building inventory; the Development of Alternative Building Materials and Technologies for Nepal
   UNDP/UNCHS (Habitat) Sub-project Nep 88/054/21.03, His Majesty's Government of Nepal, Ministry of House and Physical Planning 1994

2. NBC 203 Guidelines for Earthquake Resistant Building Construction: Low Strength Masonry
   UNDP/UNCHS (Habitat) Sub-project Nep 88/054/21.03, His Majesty's Government of Nepal, Ministry of House and Physical Planning 1994

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