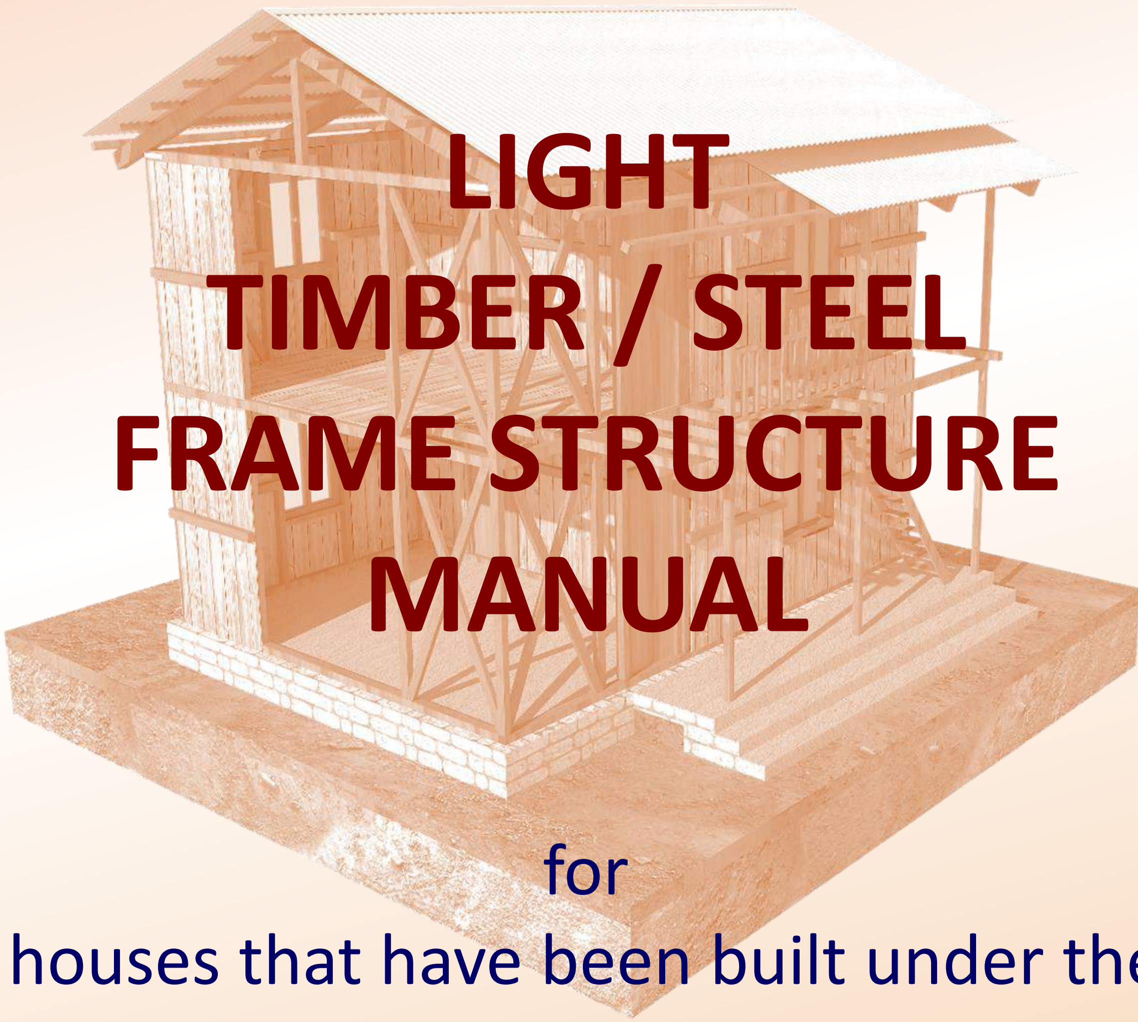
Government of Nepal
National Reconstruction Authority
Singhadurbar, Kathmandu



LIGHT TIMBER / STEEL FRAME STRUCTURE MANUAL

for

houses that have been built under the HOUSING RECONSTRUCTION PROGRAMME

2018

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FOREWORD

I would sincerely like to congratulate all involved in the development of the Light Timber/Steel Frame Structure Manual for Reconstruction of Earthquake Resistant Houses, which has been published by the National Reconstruction Authority (NRA). This manual will support timber/steel frame structure, especially found in Sindhuli, Makawanpur and Okhaldhunga districts.

Thirty-one districts have been identified by the GoN Post Disaster Needs Assessment (PDNA) as being earthquake affected. To date, around 750,000 households across the 31 districts have been identified as being eligible to receive 300,000 NPRs housing reconstruction grant.

I look forward to seeking the implementation of manual and its impact across the earthquake affected districts. This represents another positive step forward in the reconstruction process, and will support households to overcome non-compliance issues and secure approval to receive tranches of the reconstruction grant and to have safe, compliant houses.

....

Yubaraj Bhusal
Chief Executive Officer, NRA

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PREFACE

Under the housing reconstruction programme, houses that have been constructed or are in the process of construction need to comply with the Minimum Requirements (MRs) for compliant construction. In order to receive the housing reconstruction grant, the buildings need to comply with all the descriptions mentioned in the inspection check sheet which were formulated on the basis of MRs. For light timber/steel frame structure no any guideline and MRs has been published till date, as a result it became difficult to inspect these typology of buildings. In order to inspect, evaluate and correct these buildings, light timber/steel frame structure manual has been prepared.

Traditional construction shall have an appropriate technical guideline (Including MR, Inspection sheet) to ensure seismic requirements to support the housing reconstruction programme. In some parts of Siwalik range, use of wood in building construction is found quite high. Also wooden frame building are found to be constructed using traditional method in Sindhuli, Makawanpur and Okhaldhunga district.

This manual is helpful to all the engineers who are working for the reconstruction and are deployed by GoN for inspection, it will help them to fill up the inspection check sheet.
The manual has been divided into three sections so that they could be conveniently used for inspection and provide correction order, if need.

PART-1: Theory of Seismic Evaluation
PART-2: Technical Specification
PART-3: Correction for existing buildings

Dr. Hari Ram Parajuli
Executive member, NRA

Earthquake resistant private housing standardization committee, NRA

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Our sincere thanks to the respected senior experts Prof. Dr. Prem Nath Maskey, Prof. Dr. Hikmat Raj Joshi, Prof. Dr. Gokarna Bahadur Motra, Er. Manohar Raj Bhandari, Dr. Jagat Kumar Shrestha, Dr. Hiroshi Imai, Dr. Ramesh Guragain and Dr. Narayan Marasini for their support and suggestions during the discussions on critical issues which were required to finalize this manual.

We are thankful of NRA technical Working Group: JICA TPIS-ERP, NSET and HRRP-Nepal. We also thank Senior St. Er. Hima Gurubacharya, Senior St. Er. Kuber Bogati, St. Er. Nabin Paudel, St. Er. Aasish Tiwari, Ar. Sabika Mastran and Ar. Ambu Chaudhary for their continuous work during the preparation of this manual.

We appreciate Partner Organisations who worked to review and contribute to the draft manual.

We would like to congratulate all personnel involved, both directly and indirectly, for their valuable contribution to the preparation of this manual.

Standardization Committee, NRA
for Reconstruction of Earthquake Resistant Houses

ACRONYMS

GoN	Government of Nepal
PDNA	Post Disaster Needs Assessment
NRA	National Reconstruction Authority
MoUD	Ministry of Urban Development
DUDBC	Department of Urban Development and Building Construction
MoFALD	Ministry of Federal Affairs and Local Development
IOE, TU	Institute of Engineering, Tribhuvan University
JICA	Japan International Cooperation Agency
TPIS-ERP	Transitional Project Implementation support for Emergency Reconstruction Projects
NSET	National Society for Earthquake Technology-Nepal
USAID	United States Agency for International Development
EERT	Earthquake Engineering Research and Training Division
HRRP	Housing Recovery and Reconstruction Platform-Nepal
NBC	National Building Code, NEPAL
IS	Indian Standard
MRs	Minimum Requirements
SMM	Stone Masonry in Mud mortar
BMM	Brick Masonry in Mud mortar
SMC	Stone Masonry in Cement mortar
BMC	Brick Masonry in Cement mortar
RCC	Reinforced Cement Concrete
CGI	Corrugated Galvanized Iron
GI	Galvanized Iron
CL-PIU	Central Level Project Implementation Unit
DL-PIU	District Level Project Implementation Unit
DSE	District Support Engineer

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Contents

PART-1: Theory of Seismic Evaluation

PART-2: Technical Specification

PART-3: Correction measures for existing buildings

APPENDIX

PART-1: Theory of Seismic Evaluation

1. Background
2. Introduction
3. Typology of frame structure
4. Limitation of this manual

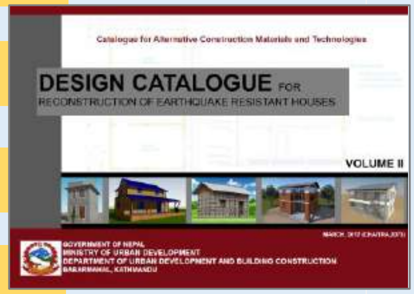
1. Background

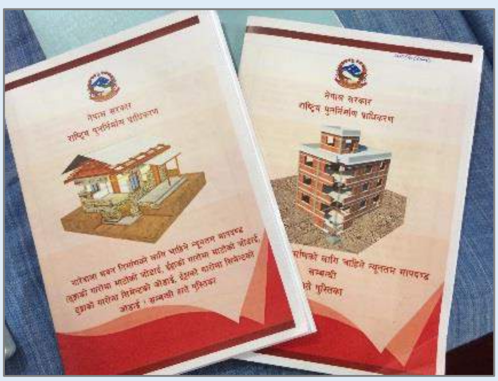
On 25th April, an earthquake of magnitude 7.8 struck with epicenter in Barpak, Gorkha. Where several aftershocks were still being felt, meanwhile another major aftershock hit Sindupalchowk district on 12th May, 2015.
A total of 755,549 houses have been damaged by the earthquakes in 31 districts in Nepal. Of which, 498,852 houses (66.0%) were completely destroyed and 256,697 houses (34%) were partially damaged.

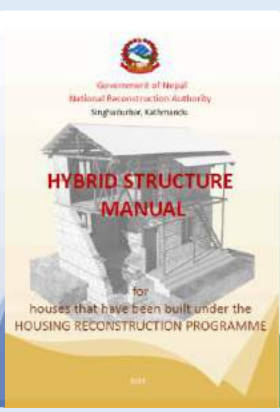
Under Housing reconstruction programme, in order to achieve "Build Back Better" (BBB), satisfying NBC 105 as seismic code.
To reach this target, many technical guidelines and manuals are developed.

Existing guideline and Manuals

Oct, 2015	Design Catalogue Vol. 1
Oct, 2016	Minimum Requirements
Dec, 2016	Inspection SOP and Manual
Mar, 2017	Correction/Exception Manual
Apr, 2017	Design Catalogue Vol. 2
Sep, 2017	Hybrid Structure Manual
Sep, 2017	Retrofitting Manual







2. Introduction

Construction of various building typologies are in practices in many parts of the country such as masonry buildings, RCC buildings, traditional (local area specific) building using wooden or steel etc. Likewise, masonry and RCC construction, traditional construction shall have an appropriate technical guideline (Including MR, Inspection sheet) to ensure seismic requirements to support the housing reconstruction programme.

In some parts of Siwalik range, high use of wood in building construction is found. Similarly, wooden frame building are found to be constructed using traditional method in Sindhuli, Makawanpur and Okhaldhunga district.

In order to inspect traditionally built houses, development of light timber/steel frame structure manual (seismic evaluation manual) is necessary, this manual consists of inspection sheet and detailed evaluation methods.

The objectives of content mentioned in these manual is to educate engineers/technical staff who are involve in inspection process. This manual is based on recognized engineering principles and practices. It consists of simplified calculation and hands on correction methods.

Wood is light construction material with high strength, therefore, is highly preferred material in construction. However, heavy cladding walls increases loading demand laterally on a frame beyond its structural capacity.

The wood has the following peculiarities that are not seen in other materials.

1) It is a non-homogeneous and anisotropic material showing different characteristics not only in different directions but also in tension and compression.
2) Shrinkage of wood on drying is relatively large. Joints loosen easily due to construction in the direction perpendicular to fibers. Therefore dry wood shall be used with the moisture content less than 20%.
3) Preservative treatment is necessary to avoid premature rotting and insect attack.
4) The defect and notches of wood influence greatly its strength and stiffness. Consequently it is necessary to select and to arrange structural members considering their structural properties.

The typical features of earthquake damage to timber structure are as follows:

1) The failure of the joints connecting columns and beams frequently occurs. As the inclination of the building increases, its restoring force against distortion decreases to the structural deterioration and the vertical load, and finally leads to the complete collapse of the building.
2) Incase of two storey buildings, the first storey usually suffers severe damage than the second storey. Often the first storey collapses while the second storey has less damage.

3. Typology of frame structure

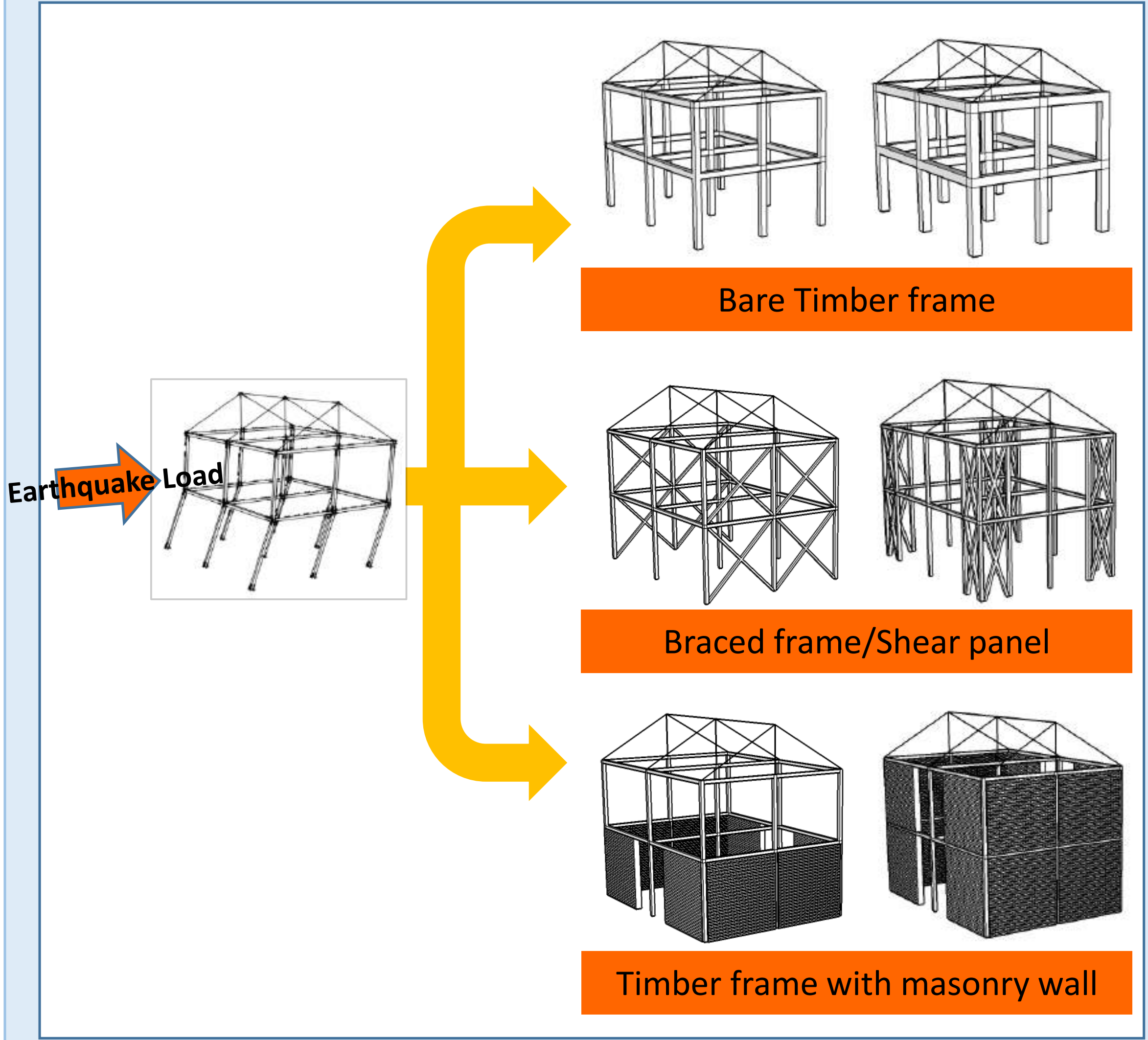
NRA Technical Team (TWG) has surveyed wooden framed structure in Sindhuli district (kamalamai municipality, Bharakali VDC, Bhiman municipality and Ranibash). The team has noted architectural and structural detailing of existing building components along with material specifications.

Photos of existing timber structures

At the result of survey, timber framed structure can be categorized into three structural systems from seismic point of view as mentioned below:

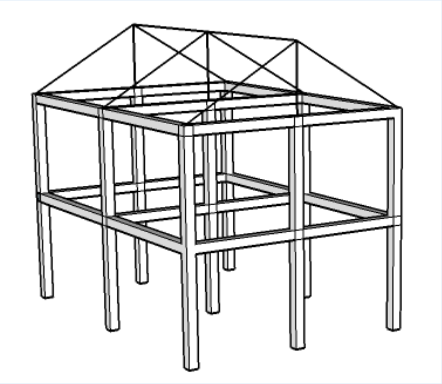
Those typology can be adaptable to steel structure.

1. <u>Bare timber frame</u>
2. <u>Braced timber frame</u>
3. <u>Timber frame with masonry wall</u>



Category on structural system of Timber structure as called.

Bare timber frame

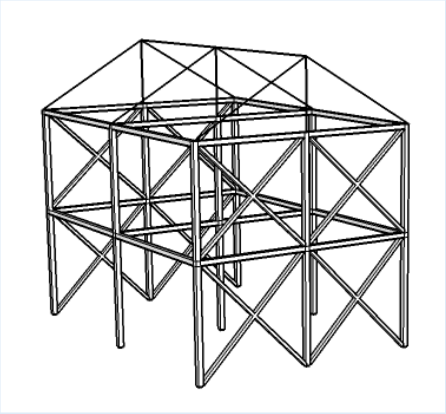


Rigid frame system also known as "**Bare timber Frame**" is an unbraced frame, that is capable of resisting both vertical and lateral load by the bendings of beams and columns. It is a rectilinear assemblage of beams and columns, with rigid connection between column and beam.
Resistance to lateral forces is provided primarily by rigid frame action.

Bare frame is designed and constructed with enough rigid connections to resist lateral seismic forces. Structures that use bare frames tend to have greater flexibility than structures that use shear panels.

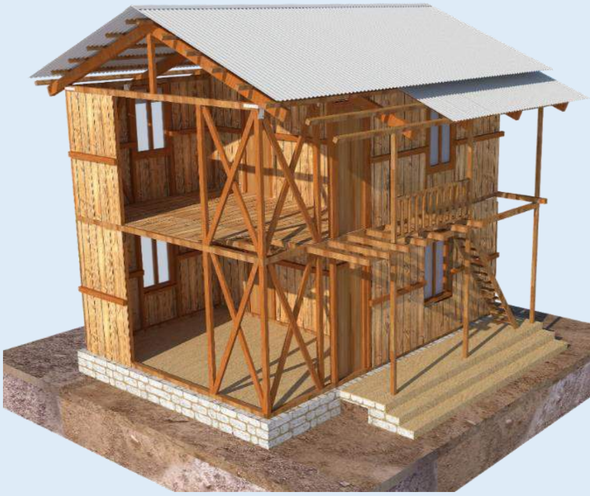
- Rigidity of connection should be increased, i.e. knee brace etc.

Braced timber frame / Shear panel



A braced frame is a structural system commonly used in structures subjected to lateral loads. The addition of a bracing frame increases a structure's stability against lateral loads such as earthquake and wind load. The members in braced frame are generally made of timber or steel member, which can work effectively both in tension and compression.

The beams and columns that form the frame carry vertical loads, and the bracing system carries the lateral loads. Braced frames reduce lateral displacement, as well as the bending moment in columns.
Braced frames have beams and columns that are "pin" connected with bracing to resist lateral loads.



- Required brace / shear panel member should be calculated. Simplified calculation method is introduced in this manual.

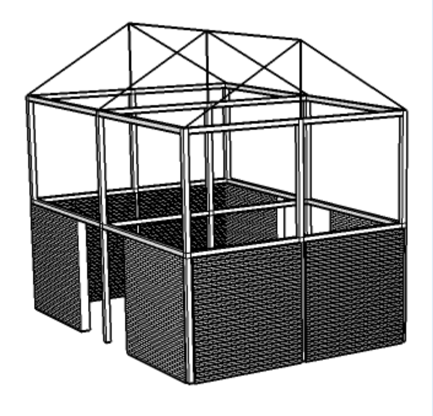
Timber frame with masonry wall [Load bearing wall]

Timber/steel framed (confined) masonry represents a special structural system because of its higher strength than of a timber structure, and higher ductility than of an unreinforced masonry structure.
Same as bracing, The addition of masonry wall increases structure's stability against lateral loads such as earthquake and wind load.
There are wall types which are dependent upon the construction of masonry. These walls have the ability to potentially transfer axial loads from the beam of the frame as well as transfer shear from the beam or the columns.

Load bearing walls
Masonry wall constructed outside of the plane of the timber framing, will become the main structural part of the building. The timber framing were designed only for gravity loads whereas the masonry provided redundancy for lateral load support. These masonry walls shall be reinforced to provide structural redundancy.

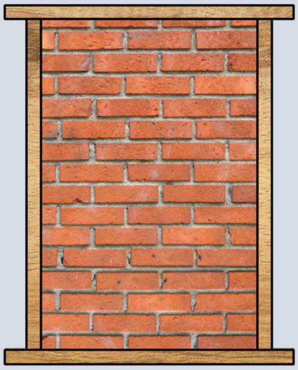
- This type should be followed masonry structure minimum requirements.

Timber frame with masonry wall [Confined/Infill wall type]



Confined walls

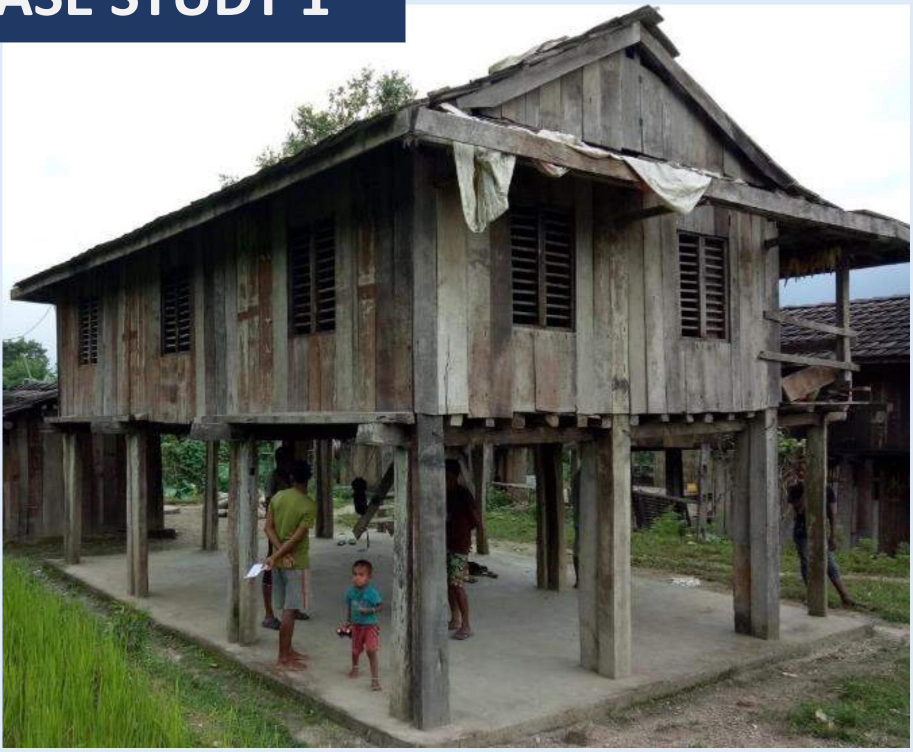
The masonry walls are constructed within the plane of the framing as confined. Here, the masonry infill wall is used as the shear wall panel.



The walls are built tight to the columns, top and bottom of the wall.

- This type should be followed masonry structure MRs or calculate as shear panel.

CASE STUDY 1



CONDITION OF BUILDING

- Timber frame is unbraced bare frame structure.
- Traditional method of timber framed structure.
- Exterior column continued up to the roof, whereas the internal Column continued up to upper level of ground floor.

- This building has bare Frame from structural view point.
- According structural analysis, the rigidity of connection is not strong, therefore, Seismic requirement is not satisfied.

Correction method is also introduced in this manual. Addition of knee brace on each beam-column joint is necessary.

CASE STUDY 2

CONDITION OF BUILDING

- The masonry wall is outside of the plane of the timber framing
- The timber framing were provided to support gravity loads.
- The masonry provides redundancy for lateral load support. This masonry wall is the main structural part of the building.
- Brick masonry wall with horizontal band

- This building can be inspected as masonry building and upper part can be inspect as frame structure, same as hybrid structure.

CASE STUDY 3


CONDITION OF BUILDING

- The masonry walls are constructed within the plane of the framing as confined.
- This timber framed masonry walls are the main structural part of the building.
- The timber framed masonry walls are supported for gravity load and lateral load as well.

- This timber framed masonry walls is shear wall panel, therefore, it can be calculated as frame structure with brace member.
- Use simplified calculation of brace member.

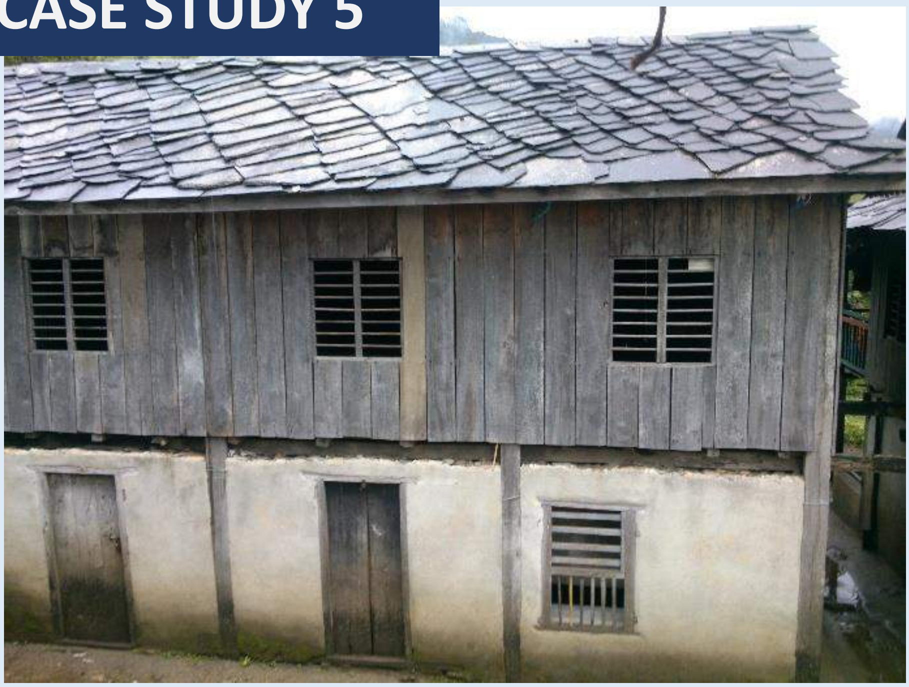
CASE STUDY 4

CONDITION OF BUILDING

- The masonry walls are constructed within the plane.
- The masonry walls supported both gravity and lateral load.
- The timber framing were designed for only gravity loads.
- The masonry walls has horizontal band

- Ground floor can be evaluated as masonry structure. Same as hybrid structure.

CASE STUDY 5



CONDITION OF BUILDING

- The masonry walls are constructed within the plane of the framing as confined.
- The timber framed masonry walls were provided to support for both gravity load and lateral load.
- Confined masonry walls has huge openings.

- Confined area should be solid of masonry. Therefore, Bracing calculation method cannot be used.

As masonry wall, it should be follow minimum requirement of masonry structure.
Or Side of opening should provide vertical element for confining masonry wall.

CASE STUDY 6

CONDITION OF BUILDING

- Timber frame is only vertical and horizontal, unbraced frame.
- The traditional method of timber framed structure.
- The exterior column continue up to the first floor, whereas the internal Column will run only up to the height of ground floor.

- This structural system of this building is bare timber frame.
- According structural analysis, the connection is not strong enough, therefore, Seismic requirement is not satisfied.

Correction method is introduced in this manual.
Addition of knee brace on each connection is necessary.

4. Limitation of this manual

Limitations

Under the GoN housing reconstruction programme, this manual covers bare frame, braced/shear wall panel and timber frame with masonry wall structures that are either newly constructed or under construction.
Light steel frame structure basically refers to use of steel sections similar as use of rebar in load bearing structure. It does not mean to moment resisting steel frame structures.

This manual has certain limitations and is only relevant for buildings which are:

I. Residential and fall under category 'C' and 'D' of NBC.

- ✓ Category "A": Modern building to be built, based on the international state-of-the-art, also in pursuance of the building codes to be followed in developed countries.
- ✓ Category "B": Buildings with plinth area of more than One Thousand square feet, with more than three floors including the ground floor or with structural span of more than 4.5 meters.
- ✓ Category "C": Buildings with plinth area of up to One Thousand square feet, with up to three floors including the ground floor or with structural span of up to 4.5 meters.
- ✓ Category "D": Small houses, sheds made of baked or unbaked brick, stone, clay, bamboo, grass etc., except those set forth in clauses (a), (b) and (c)

Applicability

This manual is prepared on the basis of NBC105, NBC104 and IS 875. The designs mentioned in the manual are ready-to-use designs for all structural components.

Masonry structure

Hybrid structure

Frame structure

This manual is intended to cover those buildings that are constructed using light timber or steel frame structure

Frame structure + infill wall

Mix structure

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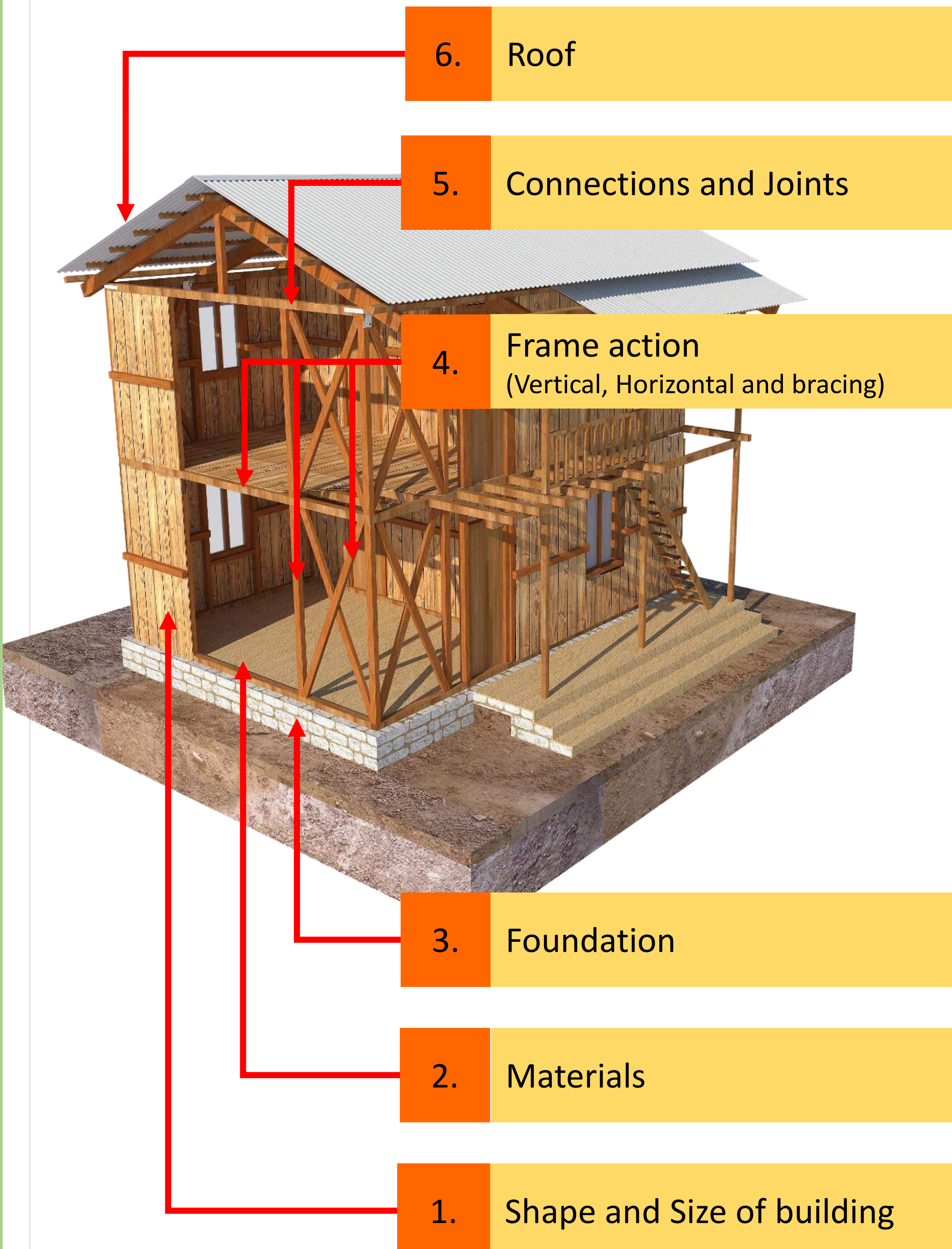
PART-2: Technical specification

a. Key evaluation/inspection items
b. Minimum requirements
1. Shape and size of building
2. Materials
3. Foundation
4. Frame action
5. Connection and joint
6. Roof

a. Key evaluation/inspection items



1. Shape and Size of building

Simple rectangular shapes behave better in an earthquake than shapes with projections. The inertia forces are proportional to the mass (or weight) of the building and only building elements or contents that possess mass will give rise to seismic forces on the building.

2. Materials

Inadequate materials does not have sufficient stability and strength to withstand the lateral forces. Hence, use of these substandard materials might leads to the failure or ultimately collapse of the overall structure.

3. Foundation

Buildings which are structurally robust against earthquakes sometimes fails due to inadequate foundation. Tilting, cracking and failure of superstructures may result from soil liquefaction and differential settlements of footing.

4. Frame (vertical, horizontal and bracing)

Earthquake-induced inertia forces are distributed to wall which consists of vertical, horizontal frame and bracing. Therefore, frame should support each other horizontally and vertically.

Wall framing should have diagonal braces, or sheathing boards so that the frame acts as a shear or bracing wall.

Diagonal braces are used to resist the frame against lateral load due to earthquake and wind.

5. Connections and Joints

If there is poor connection between the ground floor and first floor with rigid structure, the building might tends to uplifting/rocking or sliding behavior, when the lateral load is imposed on to the structure.

6. Roof

In order to resist against lateral forces, proper connection of roof to the vertical post and top plate is essential. Depending upon the structures cross bracing is also required.

Minimum requirements

<table>
<tr><th>No.</th><th>Category</th><th colspan="2">Sub Category</th><th colspan="4">Description</th></tr>
<tr><td rowspan="5">1.</td><td rowspan="5">Shape of house</td><td colspan="2">No. of storey</td><td colspan="4">Not more than two storey</td></tr>
<tr><td colspan="2">No. of bays</td><td colspan="4">At least two bay</td></tr>
<tr><td colspan="2" rowspan="2">Proportion</td><td colspan="4">Simple and regular shape as square or rectangular</td></tr>
<tr><td colspan="4">Length is not more three times of its width</td></tr>
<tr><td colspan="2">Height of floor</td><td colspan="4">Not more than 2500 mm</td></tr>
<tr><td rowspan="9">2.</td><td rowspan="9">Materials</td><td colspan="2">Nail</td><td colspan="4">Common wire nails shall be made of mild steel having a minimum tensile strength of 250N/mm2. Nails with appropriate diameter and length shall be provided.</td></tr>
<tr><td colspan="2">Bolt, metal plate</td><td colspan="4">It shall be used in such the number, diameter, length, spacing as shall be as per the specification.</td></tr>
<tr><td colspan="2">Rebar</td><td colspan="4">High strength deformed bars with fy = 415 Mpa or 500 Mpa.</td></tr>
<tr><td colspan="2">Timber</td><td colspan="4">Treated and well seasoned hard wood or locally available wood without knots shall be used.</td></tr>
<tr><td colspan="2">Brick</td><td colspan="4">It shall not be over-burnt, under-burnt and deformed.</td></tr>
<tr><td colspan="2">Mortar</td><td colspan="4">Strength not less than 1 cement: 6 sand mixture.</td></tr>
<tr><td colspan="2">Concrete</td><td colspan="4">M20 grade (1 cement: 1.5 sand: 3 aggregate)</td></tr>
<tr><td colspan="2">stone</td><td colspan="4">It shall not be round, easily breakable soft stone.</td></tr>
<tr><td colspan="2">Concrete block</td><td colspan="4">Compressive strength must be 5Mpa
Size: 400mm*150mm*200mm</td></tr>
<tr><td rowspan="3">3.</td><td rowspan="3">Foundation</td><td colspan="2">Wooden post</td><td colspan="4">It shall rest on a firm base pad.
Deterioration of wood shall be prevented as per specification.</td></tr>
<tr><td colspan="2">Masonry</td><td colspan="4">Masonry unit shall be large flat-bedded stone, regular-sized well-burnt bricks. The gaps in the core shall be well-packed with the masonry unites</td></tr>
<tr><td colspan="2">Size and shape</td><td colspan="4">It shall be as per specification.</td></tr>
<tr><td rowspan="7">4.</td><td rowspan="7">Frame</td><td rowspan="7">Vertical member</td><td>General</td><td colspan="4">It shall be placed in the same position of ground and first floor. The continuous post is recommended at each corner of building.</td></tr>
<tr><td rowspan="6">Post</td><td colspan="2">Span</td><td>Hard wood (mm)</td><td>Soft wood (mm)</td></tr>
<tr><td rowspan="4">Brace/ Shear Panel</td><td>2m</td><td>110 x 110</td><td>120 x 120</td></tr>
<tr><td>2.5m</td><td>110 x 110</td><td>120 x 120</td></tr>
<tr><td>3m</td><td>120 x 120</td><td>130 x 130</td></tr>
<tr><td>3.5m</td><td>130 x 130</td><td>140 x 140</td></tr>
<tr><td>Bare Frame</td><td>Up to 2.5m</td><td>130 x 180</td><td>150 x 200</td></tr>
</table>

No.	Category	Description				
4.	Frame	Horizontal member	General	Base plate, Floor beam, Top plate shall be provided.		
				It shall be continuous and both direction.		
			Beam	Span	Hard wood (mm)	Soft wood(mm)
				2m	190 x 100	230 x 120
				2m - 2.5m	220 x 100	270 x 140
				2.5m - 3m	240 x 120	310 x 150
				3m - 3.5m	270 x 140	340 x 160
				3.5m – 4m	300 x 150	370 x 170
			Joist	1m	100 x 65	140 x 75
				1.5m	100 x 65	140 x 75
				2m	100 x 65	140 x 75
				2.5m	120 x 65	170 x 90
				3m	130 x 75	180 x 90
				3.5m	140 x 80	200 x 100
				Spacing	Less or equal to 0.5m	
		Bracing	location	It shall be located symmetrically.		
			Direction	It shall not be in same direction.		
			Size/number	It shall be as per the specification or calculation.		
			Knee brace	For bare frame structure, It shall be provided at all junction of beam – column.		
5.	Connections and joints	All the structural members shall be properly connected by nails, bolts and metal plate as per the specification.				
6.	Roof	Wood	Material	Use of light roof		
			Connection	All member shall be properly connected.		
			Bracing	For flexible diaphragm, diagonal bracing shall be considered.		

- Note : if structural steel is used in place of wooden element, it shall have a equivalent capacity of wooden element. Also, gross cross section area of steel element shall not be less than 7% that of gross cross sectional area of wooden element in any case ***except Steel moment resisting frame***.

Table: Equivalent size of steel member

S.N.	Size of wood	Equivalent size of steel member (grade250)
1	110mm*110mm	70mm*70mm (3mm thick)
2	190mm*100mm	110mm*110mm (3mm thick)
3	240mm*120mm	170mm*170mm (3mm thick)

1. Shape and Size of building

Requirements

No.	Category	Sub Category	Description
1.	Shape of house	No.of storey	Not more than two storey
		No. of bays	At least two bay
		Proportion	Simple and regular shape as square or rectangular
			Length is not more three times of its width
		Height of floor	Not more than 2500 mm

Why important?

No. of storey: The seismic load is distinctly different from dead and live load. If attic is used as storage, heavy weight will be on the top of building, hence, larger seismic force will be subjected.

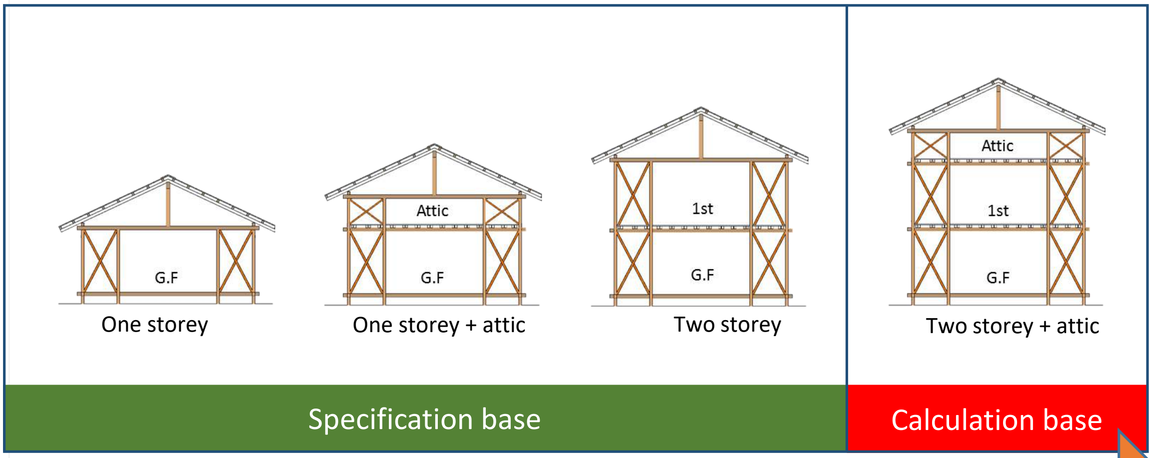
Shape and Size of building: Simple rectangular shapes behave better in an earthquake than shapes with projections. Torsional effects of ground motion are pronounced in long narrow rectangular blocks.

Exception

- If structure is found to be safe after structural calculation, L-shape, T-shape or two plus attic of house can be constructed.

Inspection methodology

- Regular shape and size and upto two storey, inspection is specification base, however, if two storey plus attic, structural calculation is mandatory.



Simplified structural calculation is shown in P55

2. Materials

Requirements

2.	Materials	Nail	Common wire nails shall be made of mild steel having a minimum tensile strength of 250N/mm2. Nails with appropriate diameter and length shall be provided.
		Bolt, metal plate	It shall be used in such the number, diameter, length, spacing as shall be as per the specification.
		Rebar	High strength deformed bars with fy = 415 Mpa or 500 Mpa.
		Timber	Treated and well seasoned hard wood or locally available wood without knots shall be used.
		Brick	It shall not be over-burnt, under-burnt and deformed.
		Mortar	Strength not less than 1 cement: 6 sand mixture.
		Concrete	M20 grade (1 cement: 1.5 sand: 3 aggregate)
		stone	It shall not be round, easily breakable soft stone.
		Concrete block	Compressive strength must be 5Mpa Size: 400mm*150mm*200mm

Why important?

- Inadequate materials does not have sufficient stability and strength to withstand the lateral forces. Hence, use of these substandard materials might lead to the failure or ultimately collapse of the overall structure.
- Moisture causes wooden surfaces to swell and deform. Excessive moisture leads the wood to decay, caused by decay fungi that ruin the material completely.
- Shrinkage of wood on drying is relatively large. Joint loosen easily due to contraction in the direction perpendicular to fibers. Therefore dry wood shall be used with moisture content less than 20 %.
- Wood can decay from repeated change of moistures. Therefore seasoned wood should be used in construction.

Inspection methodology

It can be checked by the observation and measurement.

2.1 Wood

Exception

Tolerances:

- Permissible tolerances in measurements of cut sizes of structural timber shall be as follows:

a) For width and thickness:

1)	Up to and including 100mm	+3mm -0mm
2)	Above 100mm	+6mm -3mm

b) For length: +10mm
-0mm

Inspection methodology

- Timber treatment can be identified by the observation or questionnaires survey with the house owner and mason.
- Typology of the wood can be identified by observation and field test.
- Defects in timber can be identified by observation.
- Moisture content in the timber can be identified by oven-dry method.

Wood can readily be identified as a hardwood or softwood by the following procedure:

- The color of hardwood is dark brown and light brown in softwood.
- When the thumb nail is pressed against hardwood it will not leave a mark but when it is pressed in softwood and pull it along a surface it leaves a scratch mark. Deeper the mark, the softer the wood.

When pressed by tip of nail leave a mark (Soft wood)

When pressed by tip of nail doesn't leave a mark (Hard wood)

Source: http://www.instructables.com/id/Hard-Wood-or-Soft-Wood%3F/

Table: List of Hardwood and softwood

HARD WOOD		SOFT WOOD	
Babul	Mesua	Chir	Simal
Blacksiris	Oak	Deodar	Uttis (Red)
Dhaman	Sain	Jack	Uttis (White)
Indian Rose Wood (Shisam)	Sal	Mango	Salla
Jaman	Sandan		
Sissao	Teak		
Khair			Source: NBC 203:2015

- Timber treatment
  It can be treated by using coal tar or any other preservative that prevent timber from being decayed and attacked by insects.

- Moisture content in Timber:
  Moisture content means the weight of water contained in wood, expressed as a percentage of its oven dry weight. It can be determined by the oven-dry method.

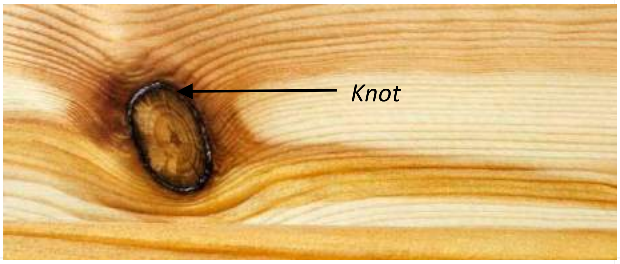
Table: Unit of weight of wood

S.N	Kinds of wood	Weight (12% moisture content) lb/cft
1	SAL (AGRAKH)	56
2	SISAU	50
3	KHOTE SALLA	33
4	GOBRE SALLA	32
5	UTTIS (RED)	36
6	UTTIS (WHITE)	34
7	CHAMP	33
8	SATISAL	38
9	ASNA	46
10	PHALAT	60
11	TOONI	37
12	SEMAL	25
13	OKHAR	45
14	OAK	64
15	KHAIR	60
16	BIJYASAL	49

Source: NBC 112:1994

Defects in Timber:

- Dead Knot: It is the knot in which the layers of annual growth are not completely intergrown with those of the adjacent wood. It is surrounded by pitch or bark. The encasement may be partial or complete.



Source: https://www.wagnermeters.com/wp-content/uploads/2012/12/knot.jpg

3. Foundation

Requirements

No.	Category	Sub Category	Description
3.	Foundation	Wooden post	It shall rest on a firm base pad. Deterioration of wood shall be prevented as per specification.
		Masonry	Masonry unit shall be large flat-bedded stone, regular-sized well-burnt bricks. The gaps in the core shall be well-packed with the masonry unites
		Size and shape	It shall be as per specification.

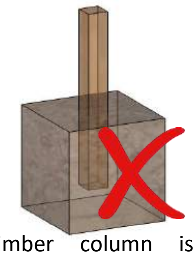
Why important?

- Certain types of foundation are more susceptible to damage than others. For example, isolated footing of columns are likely to be subjected to differential settlement particularly where the supporting ground consists of different or soft type of soil.

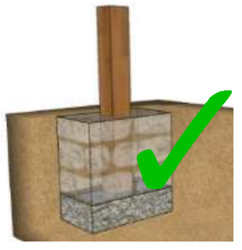
Common defects of wooden post

1. Wooden post is embedded in soil only.
2. Wooden post is fixed in stone/brick masonry in mud.
3. Wooden post is fixed in stone/brick masonry in cement but foundation size is not sufficient.
4. Wooden post simply rests on large stone.

Correction for Improvement



Timber column is embedded in soil only



Excavate the soil around the column and construct stone/brick masonry.

See Detail of correction P82

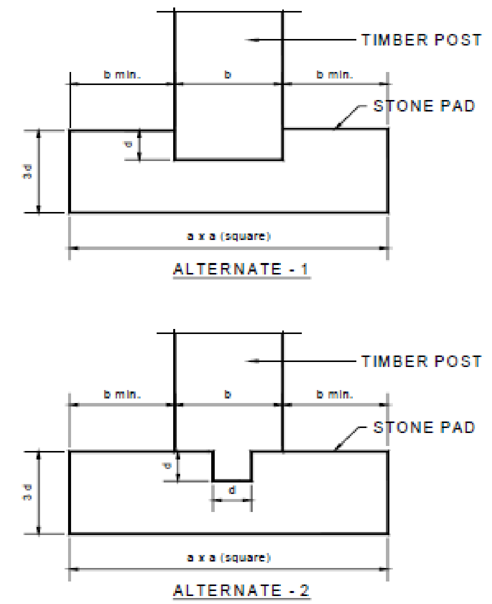
Using masonry foundation

- It shall be follow the minimum requirements of masonry structure.

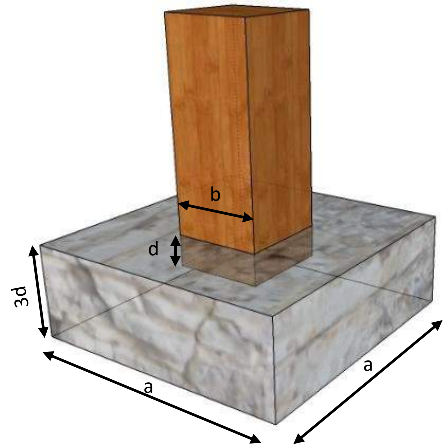
Base pad of wooden post

- ✓ Each wooden post shall rested on a firm base pad of stone, treated timber or concrete slab.

- ✓ The base pad should have a groove in to which the post shall be housed



Souse: NBC 203

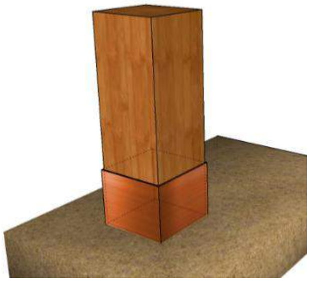


a= 3b or greater
d=b/3 or 50mm, whichever is maximum
b= size of column

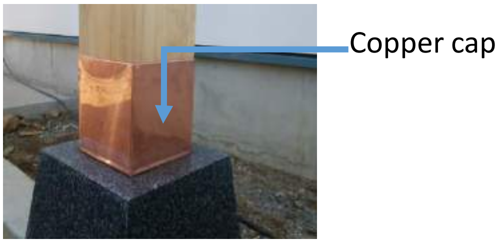
Connection details of fixing wooden column on stone base pad

Capping for wooden post

- ✓ Deterioration of wood can be prevented by copper preservative effect.

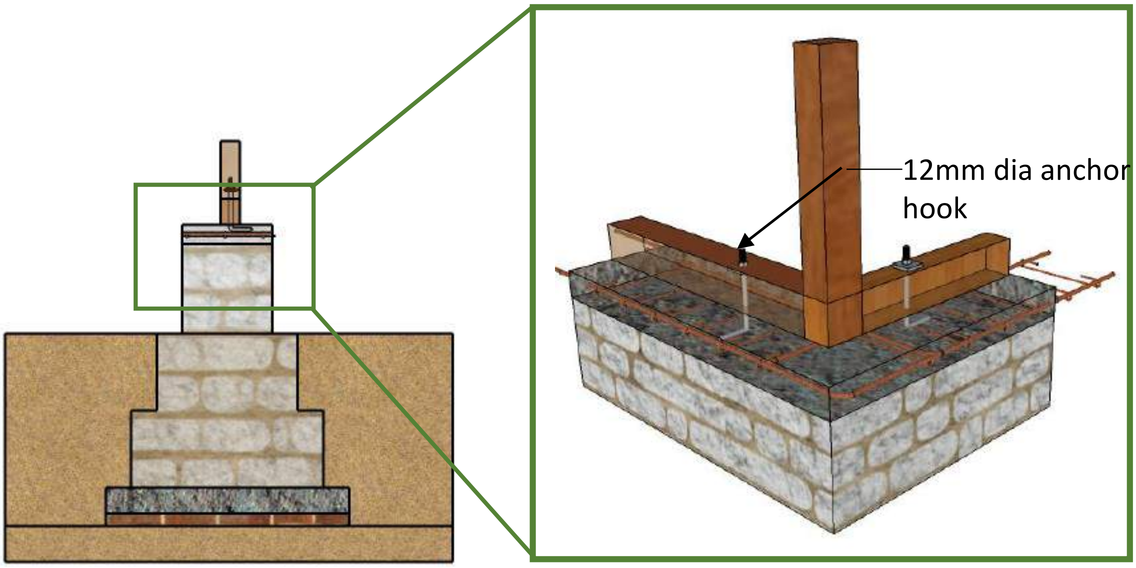


Provision of copper cap on wooden column.

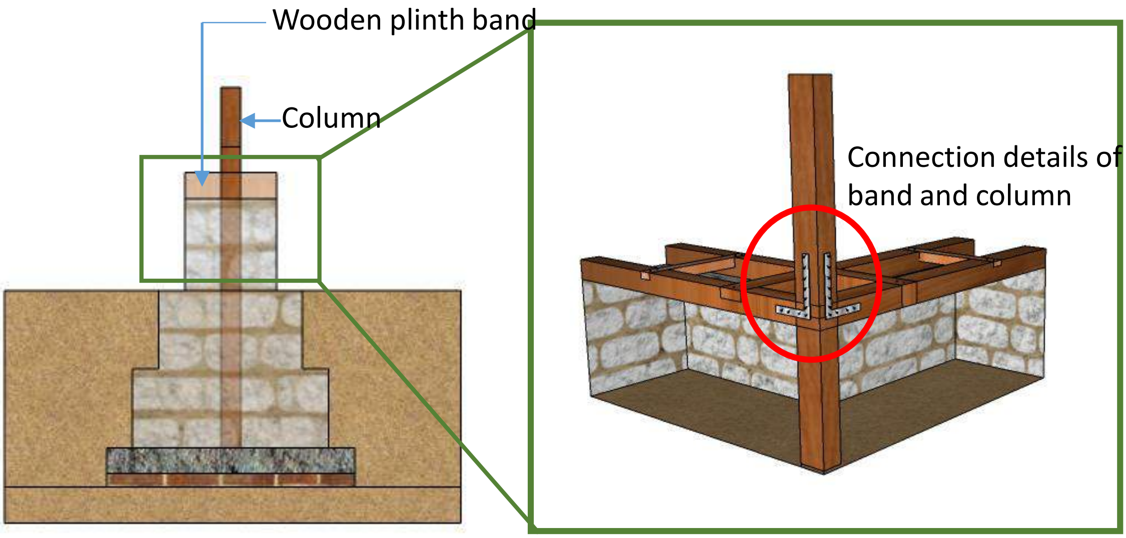


PART-2: Technical Specification

Plinth band



Connection details of wooden Plinth band and column



Connection details of wooden Plinth band and column

RCC Plinth band

Wooden Plinth band

4. Frame action (Vertical, Horizontal and Brace)

Requirements

No.	Category	Description					
4.	Frame	Vertical member	General	It shall be placed in same position of ground and first floor. The continues post is recommended at each corner of building.			
			Post	Span		Hard wood	Soft wood
				Brace/ Shear Panel	2m	110 x 110	120 x 120
					2.5m	110 x 110	120 x 120
					3m	120 x 120	130 x 130
					3.5m	130 x 130	140 x 140
				Bare Frame	2.5m	130 x 180	150 x 200
		Horizontal member	General	Base plate, Floor beam, Top plate shall be provided.			
				It shall be continuous and both direction.			
			Beam	Span		Hard wood(mm)	Soft wood(mm)
				2m		190 x 100	230 x 120
				2m - 2.5m		220 x 100	270 x 140
				2.5m - 3m		240 x 120	310 x 150
				3m - 3.5m		270 x 140	340 x 160
				3.5m – 4m		300 x 150	370 x 170
			Beam (bare frame)	2.5m		100 x 130	130 x 140
			Joist (or Equivalent cross sectional area shall be acceptable)	1m		100 x 65	140 x 75
				1.5m		100 x 65	140 x 75
				2m		100 x 65	140 x 75
				2.5m		120 x 65	170 x 90
				3m		130 x 75	180 x 90
				3.5m		140 x 80	200 x 100
				Spacing		Less or equal to 0.5m	
		Bracing	location	It shall be located symmetrical as balanced			
			Direction	It shall not be in same direction.			
			Size/number	It shall be as per the specification or calculation.			
			Knee brace	For bare frame structure, It shall be provided each connection between post and beam..			

*1. For circular section, radius(*r*)is taken equal to the side of square of equal area

Why important?

Earthquake-induced inertia forces will be distributed to wall consist of vertical, horizontal member and bracing. Therefore, frame should be supported horizontally and vertically.

Diagonal bracing is main element to resist the frame against lateral loads due to earthquake and wind.

Exception

- Steel can be used instead of wood, but its strength shall be equivalent to the required strength of wood.
- If structure is found to be safe after structural calculation.

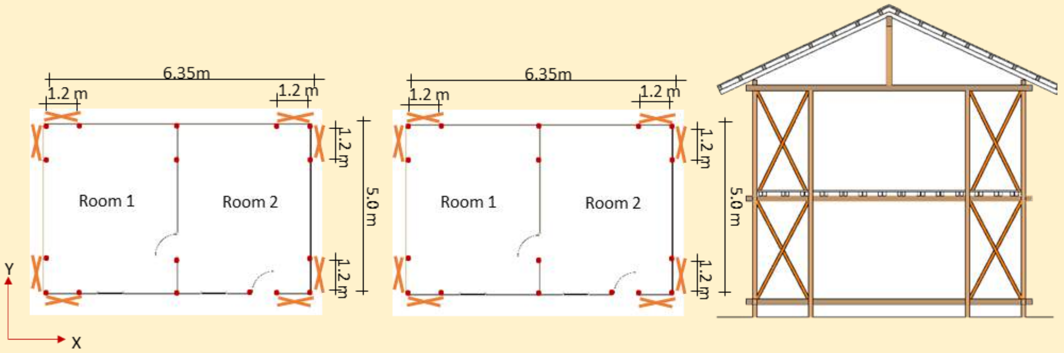
Bracing member

Size and Number of bracing member

Specification base. Inspection shall be as per the specification

Under the following condition, inspection on the basis of specification is enabled.

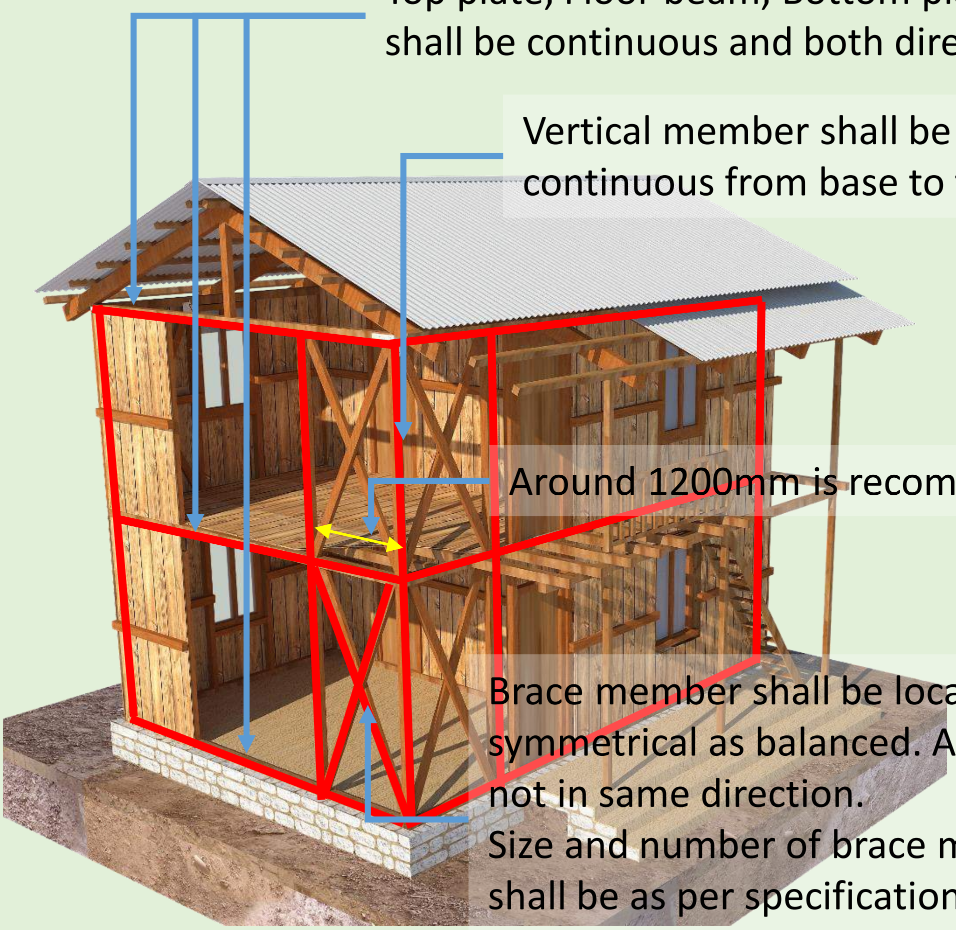
- ✓ Area of building is less than 35 sq m.
- ✓ Upto 2 storey without attic.
- ✓ Wall height of first floor is less than 2.5m
- ✓ Size and number of brace is following as below table.
- ✓ Using light weight material for floor, wall and roof.
- ✓ And all other requirements of each item are fulfilled.



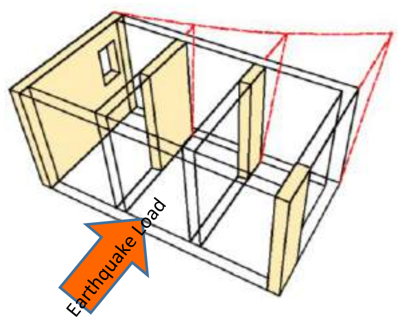
Specification of size and number of brace

Wooden Brace fixed by steel plate	Size	90 x 45 mm	double
	length	1.2meter	
	Number of each direction (X and Y)	4 (Located at each corner)	
Calculation	90x45: unit strength 3.2kN/m 2.6 x 2 (double) x 1.2 (meter) x 4 = 30.72kN		

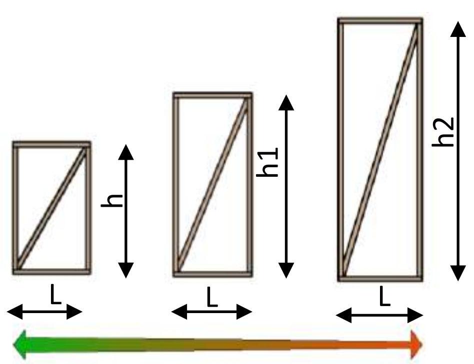
If the materials and size of the bracing members vary then the simplified calculation shall be done using the shear strength provided in this session.



Bracing/Shear wall

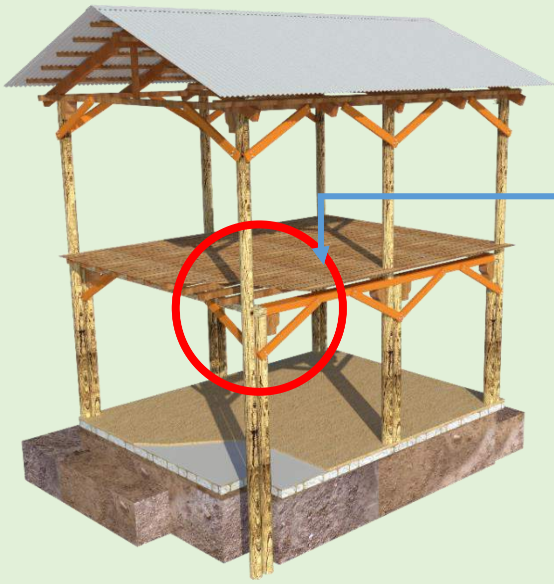


Effect of unbalanced bracing



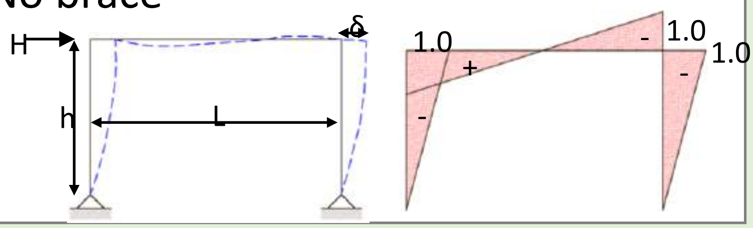
Decrease in the efficiency of bracing

Bracing/Shear wall

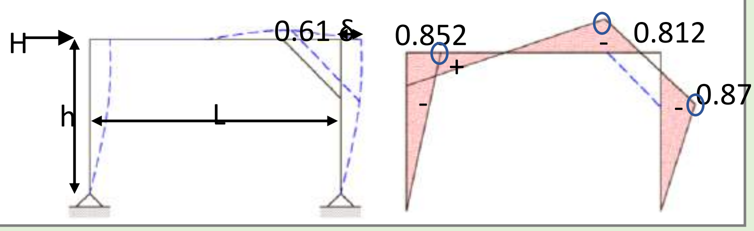


Knee bracing shall be provided each connection between posts and beams.

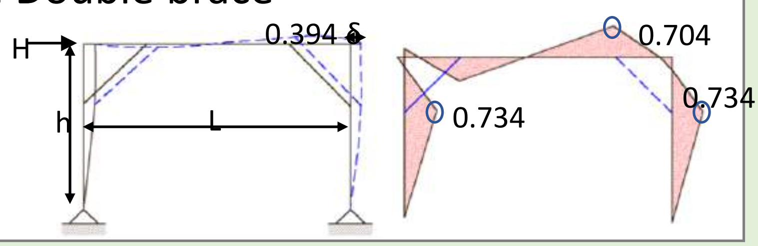
Case I: No brace



Case II: Single brace



Case III: Double brace

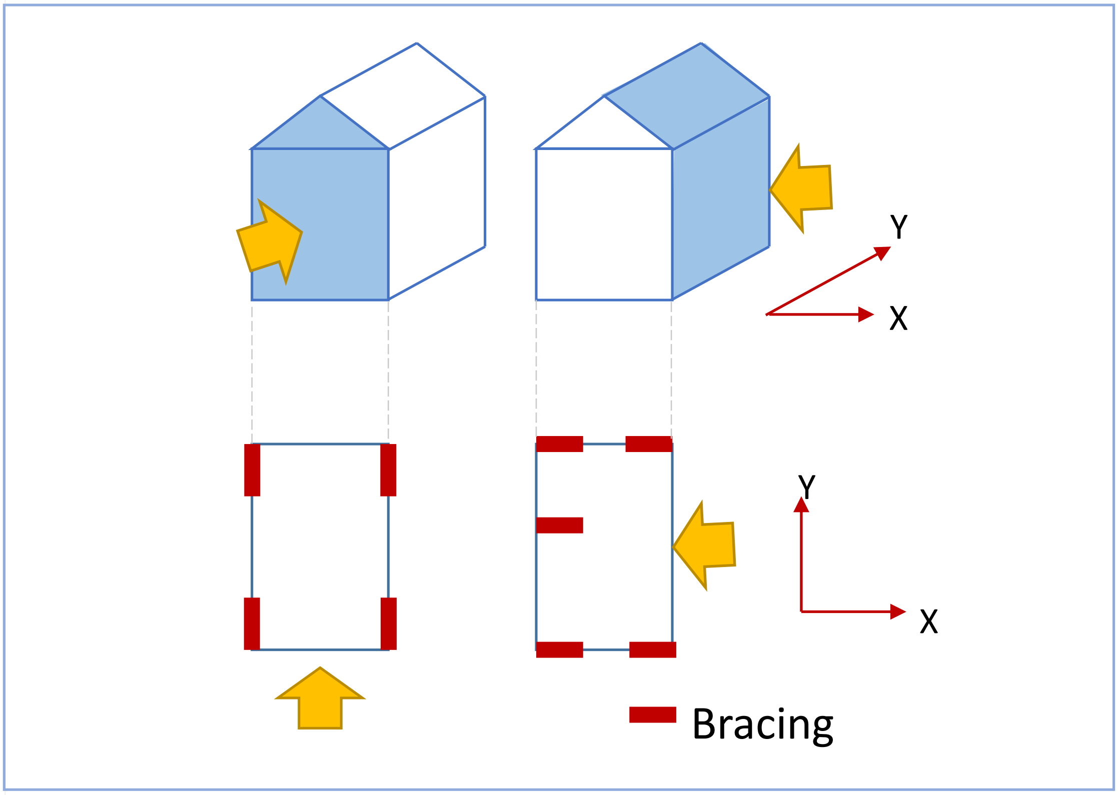


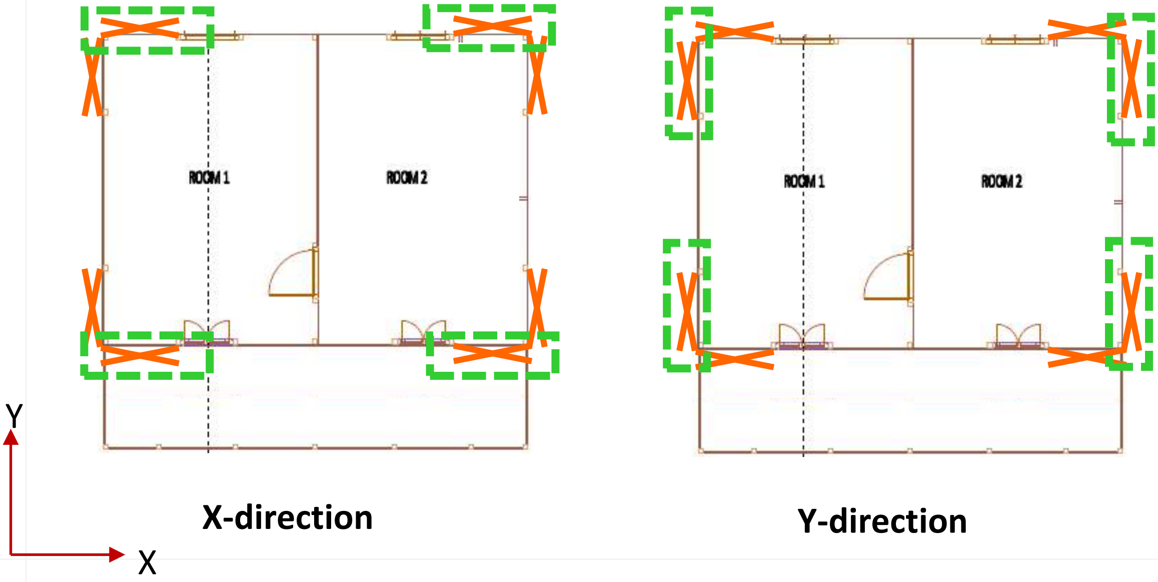
Bare Frame

Bracing member

Size and Number of bracing member

Diagonal bracing is main element to resist the frame against lateral loads due to earthquake and wind.
Size and number of bracing should be consider at each X and Y direction.

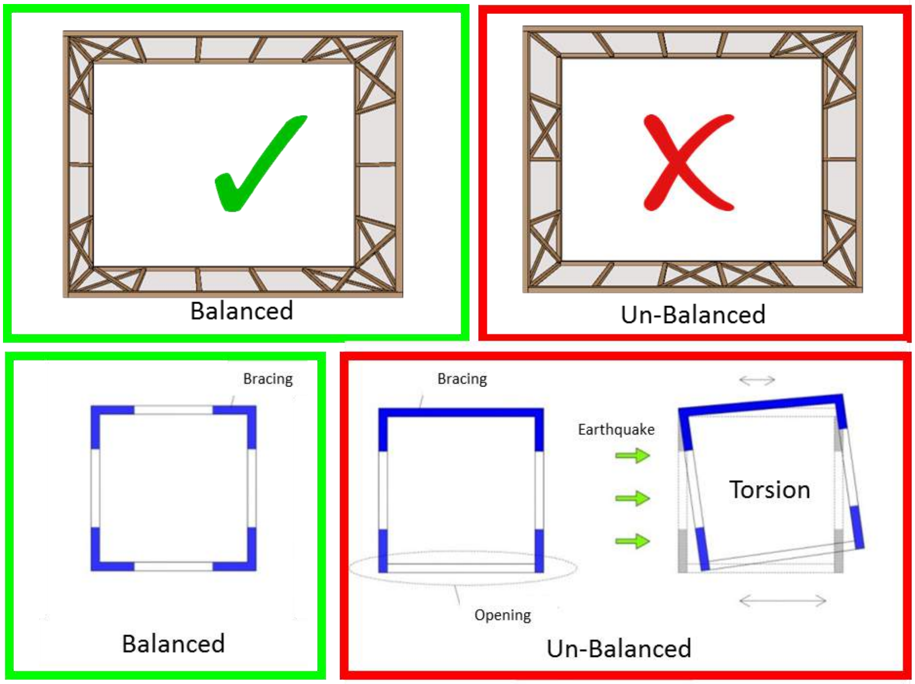




Bracing member

Location

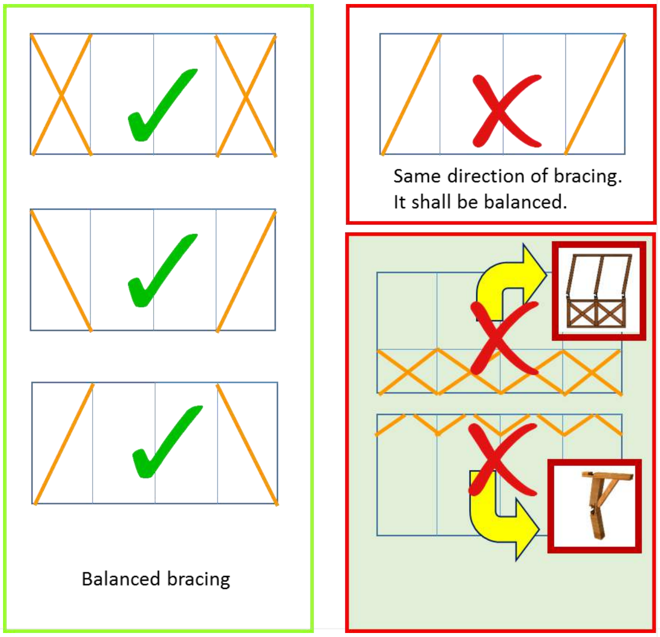
Diagonal bracing shall be located at each corner. Incase of unbalanced bracing the center of gravity will be shifted and the structure will be subjected to torsion.



Direction

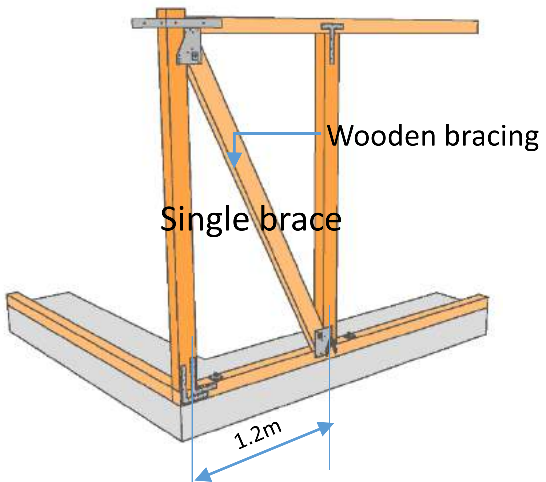
It shall not be in same direction.

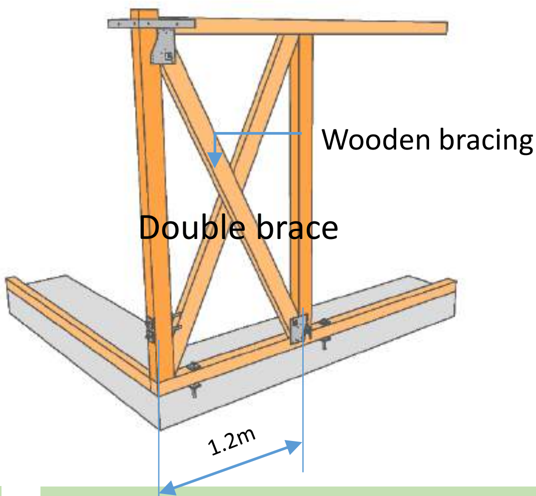
To achieve the adequate seismic resistance, provide diagonal bracing members in the planes of walls starting from base to top plate as shown in fig.



Size and Number of bracing member

Wooden bracing member

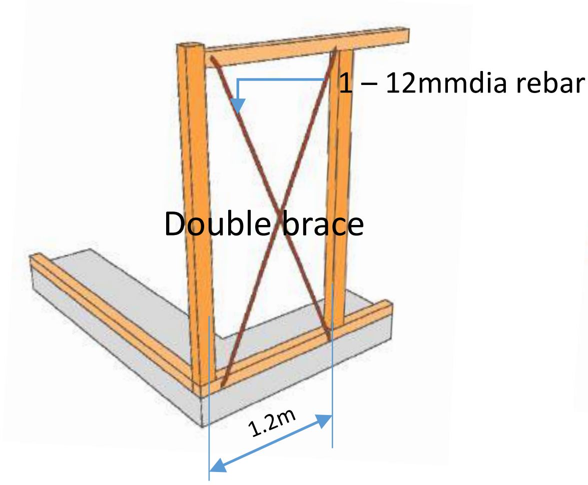


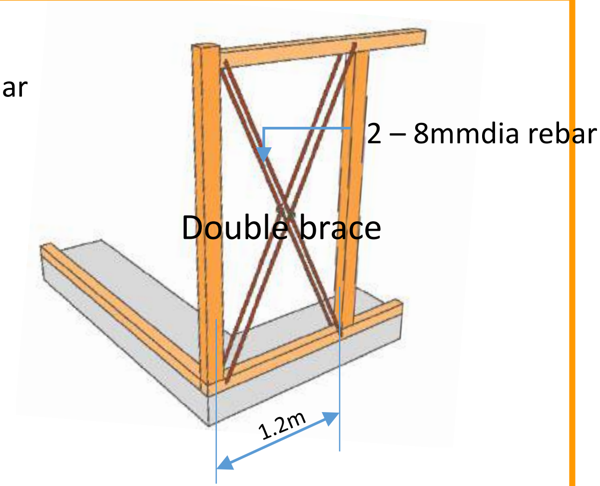


If wooden brace 100 x 100(single) fixed by metal plate:
Shear strength:
4.8kN/m(unit strength)x1(single) x1.2(meter) = 5.76kN

If wooden brace 100 x 50(double) fixed by metal plate:
Shear strength:
3.2kN/m(unit strength)x2(double) x1.2(meter) = 7.68kN

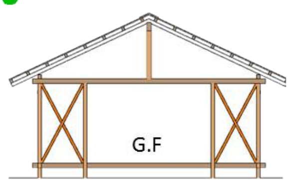
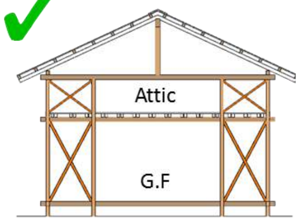
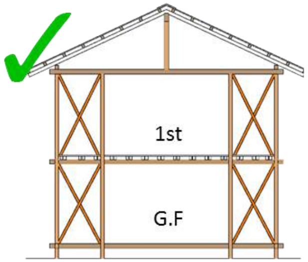
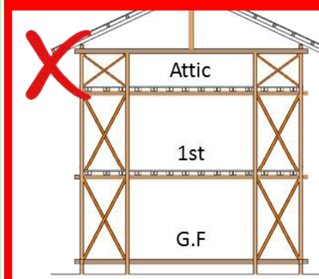
Rebar bracing member





If 1-12mm dia. Rebar:
Shear strength:
1.6kN/m(unit strength)x2(double)
x1.2(meter) = 3.84kN

Instead of 12mm dia. 2number of 8mm dia. also can be used.

STEP : CHECKING Brace member			ONE STOREY	ONE STOREY+ATTIC	TWO STOREY	TWO STOREY + ATTIC
			Specification base.			Calculation base.
TIMBER STRUCURE Floor Area: 6.35m*5.0=31.75m^2			 Brace (X:90*45) fixed by nail, L=1.2m at each corner	 Brace (X:90*45) fixed by nail l, L=1.2m at each corner	 Brace (X:90*45) fixed by metal plate l, L=1.2m at each corner	 Brace (X:90*45) fixed by metal plate l, L=1.2m at each corner
Area of wall		Attic		(6.35m x 3+5m x 3) x 1.0 m =27.7m^2		(6.35m x 3+5m x 3) x 1.0 m =27.7m^2
		1st			(6.35m x 3+5m x 3) x 2.4m =66.48m^2	(6.35m x 3+5m x 3) x 2.4m =66.48m^2
		G.F	(6.35m x 3+5m x 3) x 2.4m =66.48m^2	(6.35m x 3+5m x 3) x 2.4m =66.48m^2	(6.35m x 3+5m x 3) x 2.4m =66.48m^2	(6.35m x 3+5m x 3) x 2.4m =66.48m^2
Combination Load	Roof		0.79 KN/m^2 X 6.8m X 8.15m= **43.80 kN**	0.79 KN/m^2 X 6.8m X 8.15m= **43.80 kN**	0.79 KN/m^2 X 6.8m X 8.15m= **43.80 kN**	0.79 KN/m^2 X 6.8m X 8.15m= **43.80 kN**
	Floor	Attic		0.50 KN/m^2 X 31.75m^2 = **15.87 kN**		0.50 KN/m^2 X 31.75m^2 = **15.87 kN**
		1st			0.50 KN/m^2 X 31.75m^2 = **15.87 kN**	0.50 KN/m^2 X 31.75m^2 = **15.87 kN**
	Wall	Attic		0.50 KN/m^2 X 27.7m^2 = **13.85 kN**		0.50 KN/m^2 X 27.7m^2 = **13.85 kN**
		1st			0.50 KN/m^2 X 66.48m^2 = **33.24 kN**	0.50 KN/m^2 X 66.48m^2 = **33.24 kN**
		G.F	0.50 KN/m^2 X 66.48m^2 = **33.24 kN**	0.50 KN/m^2 X 66.48m^2 = **33.24 kN**	0.50 KN/m^2 X 66.48m^2 = **33.24 kN**	0.50 KN/m^2 X 66.48m^2 = **33.24 kN**
	TOTAL WT. (WT of 1st)		**77.04 kN**	**106.76 kN (57.65kN)**	**126.15 kN (77.04kN)**	**155.87 kN (106.76kN)**
SEISMIC LOAD Cd= 0.08*1*1*2.5=0.2		G.F	**V=77.04 kN*0.2=15.04 kN**	**V=106.76 kN*0.2=21.35 kN**	**V=126.15*0.2=25.23 kN**	**V=155.87kN*0.2=31.17 kN**
		1st		**V=57.65*0.2=11.53 kN**	**V=78.34*0.2=15.41 kN**	**V=106.76*0.2=21.95 kN**
Allowable strength	G.F	X-direction	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 15.04 kN ⇒OK	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 21.35 kN ⇒OK	Brace (X:90*45 by metel) =3.2*2*4*1.2m =30.72 kN > 25.23 kN ⇒OK	(Brace (X:90*45 by metel) =3.2*2*4*1.2m =30.72 kN > 25.23 kN ⇒ Fail
		Y-direction	Brace (X:90*45) =2.6*2*4 =24.96 kN > 15.04 kN ⇒OK	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 21.35 kN ⇒OK	Brace (X:90*45by metel) =3.2*2*4*1.2m =30.72 kN > 25.23 kN ⇒OK	(Brace (X:90*45 by metel) =3.2*2*4*1.2m =30.72 kN > 25.23 kN ⇒ Fail
	1st/ Attic	X-direction		Brace (X:90*45) =2.6*2*4 =20.8 kN > 11.53 kN ⇒OK	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 15.41 kN ⇒OK	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 21.95 kN ⇒OK
		Y-direction		Brace (X:90*45) =2.6*2*4 =20.8 kN > 11.53 kN ⇒OK	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 15.41 kN ⇒OK	Brace (X:90*45) =2.6*2*4*1.2m =24.96 kN > 21.95 kN ⇒OK

PART-2: Technical Specification

Bracing member

Size and Number of bracing member

Simplified calculation of bracing member

CONCEPT

$$\frac{Qu}{Vu} \geq 1.0$$

Allowable strength shall be larger than required seismic load from code

Vu: SEISMIC LOAD

Required Seismic force following NBC105

V=Cd * Wt
seismic coefficient
Cd=C*Z*I*K

- Dead load
- Live load
- Wind load
- Snow load

<

Qu: Allowable strength

Wall ratio of each direction
(Ground floor and First floor)

Required seismic load from NBC105

10.1 Horizontal Seismic Base Shear

10.1.1 The horizontal seismic shear force acting at the base of the structure, in the direction being considered, shall be :

$$V = C_d W_t \qquad 10.1$$

where C_d is as defined in **8.1.1**.

8.1 Design Spectra and Lateral Force Coefficients

8.1.1 Design Horizontal Seismic Coefficient for the Seismic Coefficient Method

The design horizontal seismic force coefficient, C_d shall be taken as :

$$C_d = CZIK \qquad 8.1$$

Where C is the basic seismic coefficient for the fundamental translational period in the direction under consideration.

STEP1. Calculation of SEISMIC LOAD

The horizontal seismic base shear force

V=Cd * Wt

Design horizontal seismic coefficient

Cd=C*Z*I*K

Where, C=basic seismic coefficient
Z= Zone factor
I=Importance factor
K= Structural performance factor

Calculate weight of individual structural/non-structural component.
To calculate the total weight of individual structural components the total area shall be multiplied with unit weight. These unit weight depends upon the types of materials used for construction. Hence, depending upon these materials appropriate value of unit weight must be adopted.

Table. Unit weight

Roof	Heavy	Slate roof, Mud roof	2.52	kN/sq.m.
	Light	CGI roof,	0.79	kN/sq.m.
Floor	Heavy	Wooden floor with mud	2.52	kN/sq.m.
	Light	Wooden floor	0.5	kN/sq.m.
Wall	Heavy	Masonry wall	2.52	kN/sq.m.
	Light	CGI sheet, wooden plank	0.5	kN/sq.m.

STEP2. Calculation of ALLOWABLE STRENGTH

Adopt proper typology of the bracing as per the availability of the materials and site condition. The shear strength of unit wall depends upon the method of bracing, hence select the appropriate methods and its value.

Allowable strength

Shear strength of unit wall* 1(Single diagonal bracing)*2(cross bracing)* length (distance between two vertical post where bracing is rested)* number of bracing provided in each direction.
When infill wall is used instead of bracing, during calculation only take the total confined thickness of the wall.

Table . Shear strength of unit wall (kN/m)

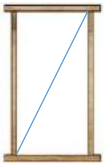
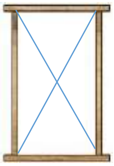
Method of bracing	
No brace	0
Mud wall < 50mm	1.5
Mud wall 50mm-100mm	2
Mud wal > 100mm	2.5
Rebar 9mm	1.6
Wooden brace 90*15 nail	1.6
Wooden brace 90*30 nail	1.9
Wooden brace 90*30 plate	2.4
Wooden brace 90*45 nail	2.6
Wooden brace 90*45 plate	3.2
Wooden brace 90*90 olate	4.8
Structural plywood 12mm	5.2
Gypsum board 9mm	1.1
Plywood 3mm	0.9
Brick with cement	33.4
Brick with mud	10
Stone with cement	67.5
Stone with mud	11.2
Concrete block	34.46
wooden plank wall	0.8

STEP3.RESULT: SEISMIC LOAD ≤ ALLOWABLE STRENGH

Bracing member

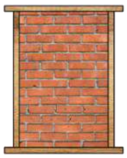
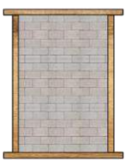
Size and Number of bracing member

Calculation base Inspection shall be used calculation

Method of Bracing/ wall construction				Shear Strength of Unit wall (kN/m)
	No brace			**0.0**
	Mud wall	Thickness less than 50mm		**1.5**
		Thickness 50mm~100mm		**2.0**
		Thickness more than 100mm		**2.5**
  Single brace Double brace	Brace rebar Φ9			**1.6 (3.2)** *** ( ) is double brace**
  Single brace Double brace	Wooden Brace	90mm*15mm	Nail	**1.6 (3.2)**
		90mm*30mm	Nail	**1.9 (3.8)**
			Steel Plate	**2.4 (4.8)**
		90mm*45mm	Nail	**2.6 (5.2)**
			Steel Plate	**3.2 (6.4)**
		90mm*90mm	Steel Plate	**4.8 (9.6)**
	Structural Plywood	12mm		**5.2**
	Gypsum Board	9mm		**1.1**
	Plywood	3mm		**0.9**

Note: Incase of double bracing, wooden brace of dimension 90mmX90mm needs to be cutout for fixing two braces which reduces its ultimate strength. Hence, this size of bracing is not recommended.

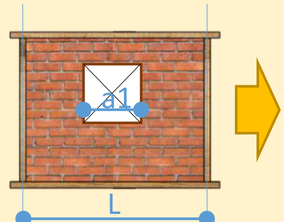
Size and Number of bracing member

Method of Bracing/ wall construction			Shear Strength of Unit wall (KN/m)
	Masonry infill brick wall	Cement mortar	**33.4**
		Mud mortar	**10**
	Masonry infill stone wall	Cement mortar	**67.5**
		Mud mortar	**11.2**
` 	Block masonry wall (100mm thick)		**34.46**
	Vertical/Horizontal Wooden plank (1”) wall		**0.8**

*Shear strength of masonry unit wall is calculated by using the following value SMC=0.3375 MP, BMC=0.167 MPa, SMM=0.056 MPa, BMM=0.05 MPa

Reduction value of openings

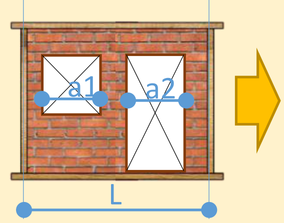
- When total length of openings is not more than 1/3 of infill wall span, it is able to calculate as 30% of full strength of unit wall.



a1 < 1/3L

30% of full strength

- When total length of openings is more than 1/3 of infill wall span, it is not calculate as infill wall.



a1 + a2 > 1/3L

Should not include as infill wall.

EXCEPTION

If the openings are provisioned with wooden double framed box, its total length can be ignored.

Vu: SEISMIC LOAD

Seismic coefficient	C	Basic seismic coefficient		1		0.08	
	Z	Zone factor		2		1	
	I	Importance factor		3		1	
	K	Structural performance factor		4	Masonry structure	4	
					Frame structure	2.5	
	Cd=CZIK		1*2*3*4	5	Masonry structure	0.32	
					Frame structure	0.2	
Weight of building	Roof	Unit weight		6	Heavy (Stone, tile roof)	2.52	kN/sq.m
					light (CGI roof)	0.79	kN/sq.m
		Area		7			sq.m
		Sub total	6*7	8			kN
	Wall (GFL)	Unit weight		9	Heavy (Masonry, Mud wall)	2.52	kN/sq.m
					light (CGI, wood plank)	0.79	kN/sq.m
		Area	total length	10			
			height	11			m
		Sub tatal	9*10*11	12			kN
	Wall (1FL)	Unit weight		13	Heavy (Masonry, Mud wall)	2.52	kN/sq.m
					light (CGI, wood plank)	0.79	kN/sq.m
		Area	total length	14			m
			height	15			m
		Sub tatal	13*14*15	16			kN
	Floor (1FL)	Unit weight		17	Heavy (with mud floor)	2.52	kN/sq.m
					light (without mud floor)	0.79	kN/sq.m
		Area		18			sq.m
		Sub total	17*18	19			kN
	Floor (If attic is there)	Unit weight		20	Heavy (with mud floor)	2.52	kN/sq.m
					light (without mud floor)	0.79	kN/sq.m
		Area		21			sq.m
		Sub total	20*21	22			kN
	Total weigth of GFL		8+12+16+19+22	23			kN
	Total weight of 1FL		8+16+22	24			kN
Seismic load for GFL			5*23	25			kN
Seismic load for 1FL			5*24	26			kN

Note: The wall of first floor shall not be cantilevered.

Qu: ALLOWABLE STRENGTH

Floor	Direction	Method	Item	No.			Unit
Ground Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table.1	1			kN/m
			Applicable only for wooden brace	2	Single	1	
					Double	2	
			length of one brace	3			m
			Number	4			
		Total strength	1*2*3*4	5			kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	6			kN/m
			Applicable only for wooden brace	7	Single	1	
					Double	2	
			length of one brace	8			m
			Number	9			
		Total strength	6*7*8*9	10			kN
1st Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	11			kN/m
			Applicable only for wooden brace	12	Single	1	
					Double	2	
			length of one brace	13			m
			Number	14			
		Total strength	11*12*13*14	15			kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	16			kN/m
			Applicable only for wooden brace	17	Single	1	
					Double	2	
			length of one brace	18			m
			Number	19			
		Total strength	16*17*18*19	20			kN

Table 1. Shear strength of unit wall (kN/m)

Method of bracing	
No brace	0
Mud wall < 50mm	1.5
Mud wall 50mm-100mm	2
Mud wal > 100mm	2.5
Rebar 9mm	1.6
Wooden brace 90*15 nail	1.6
Wooden brace 90*30 nail	1.9
Wooden brace 90*30 plate	2.4
Wooden brace 90*45 nail	2.6
Wooden brace 90*45 plate	3.2
Wooden brace 90*90 olate	4.8
Structural plywood 12mm	5.2
Gypsum board 9mm	1.1
Plywood 3mm	0.9
Brick with cement	33.4
Brick with mud	10
Stone with cement	67.5
Stone with mud	11.2
Concrete block	34.46
wooden plank wall	0.8

RESULT

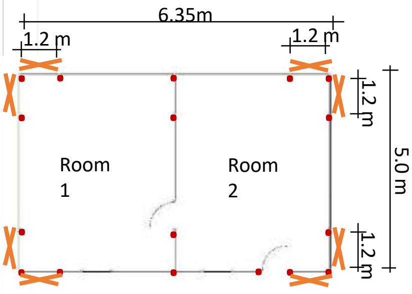
$$\frac{Qu}{Vu} \geq 1.0$$

Vu: SEISMIC LOAD ≤ Qu: Allowable strength

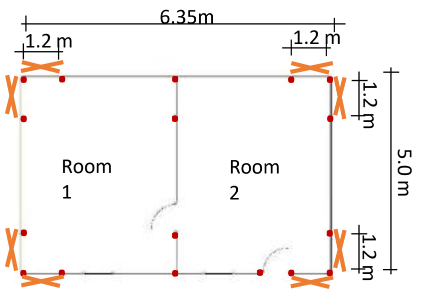
OK or FAIL

Calculation base | Inspection shall be used calculation

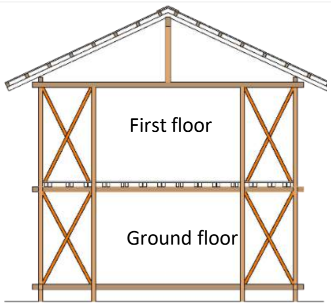
Workout example 1: Timber frame structure, two storey



Ground floor plan



First floor plan



Section

Building description:				
	Floor area	5.0m x 6.35m	=	31.75 m^2
	Roof area	6.0m x 8.0m	=	48.0 m^2
	Wall area	Length:(5.0mx3+6.35mx2) x height 2.4	=	66.48 m^2

SEISMIC LOAD CALCULATION

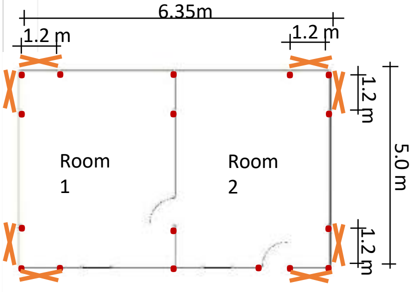
Seismic coefficient	C	Basic seismic coefficient		1		0.08	
	Z	Zone factor		2		1	
	I	Importance factor		3		1	
	K	Structural performance factor		4	frame	2.5	
	Cd=CZIK		1*2*3*4	5		0.2	
Weight of building	Roof	Unit weight		6	light (CGI)	0.79	kN/sq.m
		Area		7		48	sq.m
		Sub total	6*7	8		37.92	kN
	Wall (GFL)	Unit weight		9	light (CGI, wooden plank)	0.5	kN/sq.m
		Area	total length	10		27.7	m
			height	11		2.4	m
		Sub tatal	9*10*11	12		33.24	kN
	Wall (1FL)	Unit weight		13	light (CGI, wooden plank)	0.5	kN/sq.m
		Area	total length	14		27.7	m
			height	15		2.4	m
		Sub tatal	13*14*15	16		33.24	kN
	Floor (1FL)	Unit weight		17	light (without mud)	0.5	kN/sq.m
		Area		18		31.75	sq.m
		Sub total	17*18	19		15.875	kN
	Floor (If attic is there)	Unit weight		20	light (without mud)	0.5	kN/sq.m
		Area		21		0	sq.m
		Sub total	20*21	22		0	kN
	Total weigth of GFL		8+12+16+19+22	23		120.28	kN
	Total weight of 1FL		8+16+22	24		71.16	kN
Seismic load for GFL			5*23	25		**24.06**	kN
Seismic load for 1FL			5*24	26		**14.23**	kN

ALLOWABLE STRENGTH							
Ground Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	1	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	2	double	2	
			length of one brace	3		1.2	m
			Number	4		4	
		Total strength	1*2*3*4	5		24.96	kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	6	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	7	double	2	
			length of one brace	8		1.2	m
			Number	9		4	
		Total strength	6*7*8*9	10		24.96	kN
1st Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	11	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	12	double	2	
			length of one brace	13		1.2	m
			Number	14		4	
		Total strength	11*12*13*14	15		24.96	kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	16	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	17	double	2	
			length of one brace	18		1.2	m
			Number	19		4	
		Total strength	16*17*18*19	20		24.96	kN

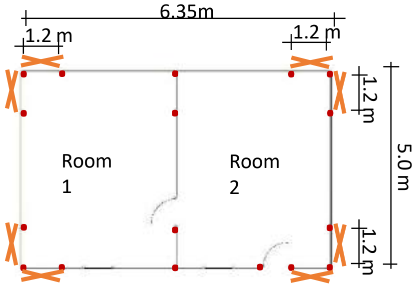
RESULT					
Floor	Direction	Vu: Seismic Load		Qu: Allowable strength	Result
Ground	X	24.06	≤	24.96	OK
	Y	24.06	≤	24.96	OK
1^{st}	X	14.23	≤	24.96	OK
	Y	14.23	≤	24.96	OK

Calculation base	Inspection shall be used calculation

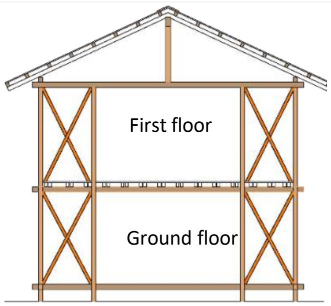
Workout example 2: Same as example 1, but floor is with mud



Ground floor plan



First floor plan



Section

Building description:				
	Floor area	5.0m x 6.35m	=	31.75 m^2
	Roof area	6.0m x 8.0m	=	48.0 m^2
	Wall area	Length:(5.0mx3+6.35mx2) x height 2.4	=	66.48 m^2

SEISMIC LOAD CALCULATION

Seismic coefficient	C	Basic seismic coefficient		1		0.08	
	Z	Zone factor		2		1	
	I	Importance factor		3		1	
	K	Structural performance factor		4	frame	2.5	
	Cd=CZIK		1*2*3*4	5		0.2	
Weight of building	Roof	Unit weight		6	light (CGI)	0.79	kN/sq.m
		Area		7		48	sq.m
		Sub total	6*7	8		37.92	kN
	Wall (GFL)	Unit weight		9	light (CGI, wooden plank)	0.5	kN/sq.m
		Area	total length	10		27.7	m
			height	11		2.4	m
		Sub tatal	9*10*11	12		33.24	kN
	Wall (1FL)	Unit weight		13	light (CGI, wooden plank)	0.5	kN/sq.m
		Area	total length	14		27.7	m
			height	15		2.4	m
		Sub tatal	13*14*15	16		33.24	kN
	Floor (1FL)	Unit weight		17	heavy (with mud)	2.52	kN/sq.m
		Area		18		31.75	sq.m
		Sub total	17*18	19		80.01	kN
	Floor (If attic is there)	Unit weight		20	light (without mud)	0.5	kN/sq.m
		Area		21		0	sq.m
		Sub total	20*21	22		0	kN
	Total weigth of GFL		8+12+16+19+22	23		184.41	kN
	Total weight of 1FL		8+16+22	24		71.16	kN
Seismic load for GFL			5*23	25		**36.88**	kN
Seismic load for 1FL			5*24	26		**14.23**	kN

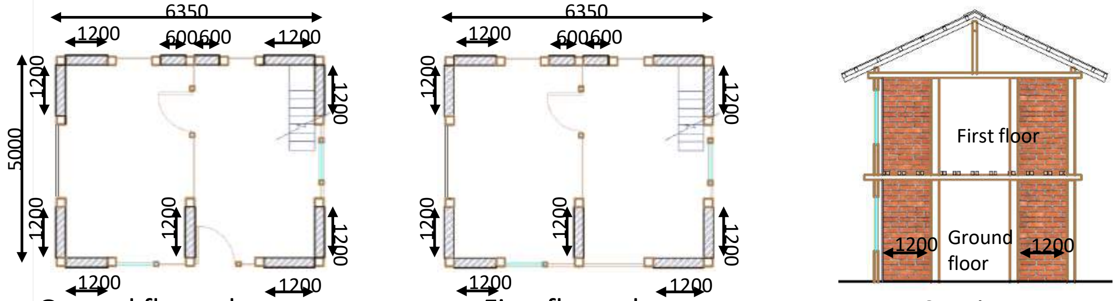
ALLOWABLE STRENGTH							
Ground Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	1	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	2	double	2	
			length of one brace	3		1.2	m
			Number	4		4	
		Total strength	1*2*3*4	5		**24.96**	kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	6	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	7	double	2	
			length of one brace	8		1.2	m
			Number	9		4	
		Total strength	6*7*8*9	10		**24.96**	kN
1st Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	11	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	12	double	2	
			length of one brace	13		1.2	m
			Number	14		4	
		Total strength	11*12*13*14	15		**24.96**	kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1	16	Wooden brace 90*45 nail	2.6	kN/m
			Applicable only for wooden brace	17	double	2	
			length of one brace	18		1.2	m
			Number	19		4	
		Total strength	16*17*18*19	20		**24.96**	kN

RESULT					
Floor	Direction	Vu: Seismic Load		Qu: Allowable strength	Result
Ground	X	**36.88**	≤	**24.96**	FAIL
	Y	**36.88**	≤	**24.96**	FAIL
1^{st}	X	**14.23**	≤	**24.96**	OK
	Y	**14.23**	≤	**24.96**	OK

Calculation base

Inspection shall be used calculation

Workout example 2:



Ground floor plan　　First floor plan　　Section

Building description:				
	Floor area	5.0m x 6.35m	=	31.75 m^2
	Roof area	6.0m x 8.0m	=	48.0 m^2
	Wall area	Length:(5.0mx3+6.35mx2) x height 2.4	=	66.48 m^2

SEISMIC LOAD CALCULATION

				No.		Value	Unit
Seismic coefficient	C	Basic seismic coefficient		1		0.08	
	Z	Zone factor		2		1	
	I	Importance factor		3		1	
	K	Structural performance factor		4	masonry	4	
	Cd=CZIK		1*2*3*4	5		0.32	
Weight of building	Roof	Unit weight		6	light (CGI)	0.79	kN/sq.m
		Area		7		48	sq.m
		Sub total	6*7	8		37.92	kN
	Wall (GFL)	Unit weight		9	heavy (masonry, mud wall)	2.52	kN/sq.m
		Area	total length	10		27.7	m
			height	11		2.4	m
		Sub tatal	9*10*11	12		167.53	kN
	Wall (1FL)	Unit weight		13	heavy (masonry, mud wall)	2.52	kN/sq.m
		Area	total length	14		27.7	m
			height	15		2.4	m
		Sub total	13*14*15	16		167.53	kN
	Floor (1FL)	Unit weight		17	light (without mud)	0.5	kN/sq.m
		Area		18		31.75	sq.m
		Sub total	17*18	19		15.88	kN
	Floor (If attic is there)	Unit weight		20	light (without mud)	0.5	kN/sq.m
		Area		21		0	sq.m
		Sub total	20*21	22		0	kN
	Total weight of GFL		8+12+16+19+22	23		388.85	kN
	Total weight of 1FL		8+16+22	24		205.45	kN
Seismic load for GFL			5*23	25		**124.43**	kN
Seismic load for 1FL			5*24	26		**65.74**	kN

ALLOWABLE STRENGTH								
Ground Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1		1	Brick with cement	33.4	kN/m
			Applicable only for wooden brace		2	single	1	
			length of one brace		3		1.2	m
			Number		4		5	
			Total strength	1*2*3*4	5		200.4	kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1		6	Brick with cement	33.4	kN/m
			Applicable only for wooden brace		7	single	1	
			length of one brace		8		1.2	m
			Number		9		5	
			Total strength	6*7*8*9	10		200.4	kN
1st Floor	X-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1		11	Brick with cement	33.4	kN/m
			Applicable only for wooden brace		12	single	1	
			length of one brace		13		1.2	m
			Number		14		5	
			Total strength	11*12*13*14	15		200.4	kN
	Y-directoin	Method of bracing/wall construction Shear panel	Refer from table no.1		16	Brick with cement	33.4	kN/m
			Applicable only for wooden brace		17	single	1	
			length of one brace		18		1.2	m
			Number		19		5	
			Total strength	16*17*18*19	20		200.4	kN

RESULT						
Floor	Direction	Vu: Seismic Load		Qu: Allowable strength		Result
Ground	X	**124.43**	≤	**200.4**		OK
	Y	**124.43**	≤	**200.4**		OK
1st	X	**65.74**	≤	**200.4**		OK
	Y	**65.74**	≤	**200.4**		OK

Calculation of BALANCE of bracing member

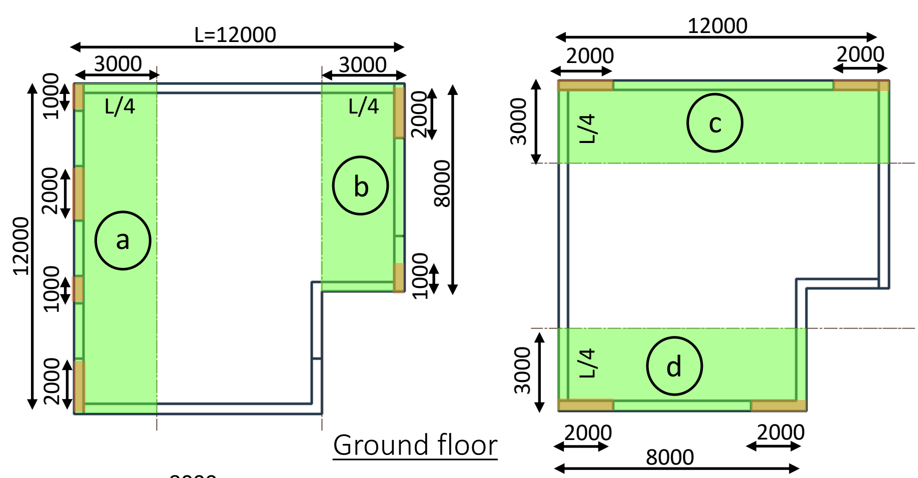
Simplified Calculation method: Quadrant method

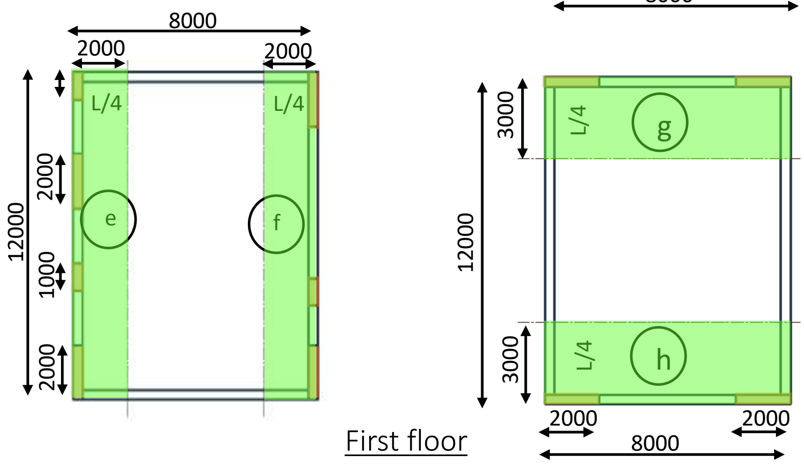
In case of an irregular shaped building, if the walls and the elements resisting seismic forces are not well balanced, torsion are likely to occurr during an earthquake. The concentration of the stress is maximized to the weak point. Hence, the simplified method known as quadrant methods is used to check the torsion.

As shown in fig. mentioned below, the area of the building is divided into ¼ in each direction i.e. a,b,c and d. The seismic load and allowable strength of these individual area is calculated. The ratio of the allowable strength to seismic load of individual quadrant in each direction shall be equal or more than 0.5.

i.e. in X and Y- direction,

$$\frac{\text{Minimum area} \quad \mathit{Allowable\ strength}\ (d) \,/\, \mathit{Seismic\ load}\ (d)}{\text{Maximum area} \quad \mathit{Allowable\ strength}\ (c) \,/\, \mathit{Seismic\ load}\ (c)} \geq 0.5$$





Unit weight(KN/m)	
Roof	0.79
Wall	0.5
Floor	0.5

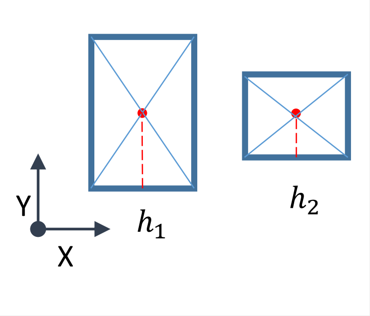
Workout example of quadrant method

Ground floor	Y-direction	ⓐ	Area		1	36.00	sq.m	
			Seismic load	weight	2	52.44	kN	36*0.79+12*0.5+36*0.5
				seismic coefficient	3	0.20		Frame structure, K=2.5
				2*3	4	10.49	kN	
			Allowable strength	length	5	6.00	m	2+1+2+1
				unit strength	6	5.20	kN/m	2.6*2, Wooden brace 90*45nail, Double
				5*6	7	31.20	kN	
			Ratio of 7/4		8	2.97		
		ⓑ	Area		9	24.00	sq.m	
			Seismic load	weight	10	34.96	kN	24*0.79+8*0.5+24*0.5
				seismic coefficient	11	0.20		Frame structure, K=2.5
				10*11	12	6.99	kN	
			Allowable strength	length	13	3.00	m	2+1+2+1
				unit strength	14	5.20	kN/m	2.6, Wooden brace 90*45nail, Single
				13*14	15	15.60	kN	
			Ratio of 15/12		16	2.23		
	Ratio minimum area / maximum area				ⓑ/ⓐ	0.75		OK
	X-direction	ⓒ	Area		1	36.00	sq.m	
			Seismic load	weight	2	52.44	kN	36*0.79+12*0.5+36*0.5
				seismic coefficient	3	0.20		Frame structure, K=2.5
				2*3	4	10.49	kN	
			Allowable strength	length	5	5.00	m	2+1+2+1
				unit strength	6	5.20	kN/m	2.6*2, Wooden brace 90*45nail, Double
				5*6	7	26.00	kN	
			Ratio of 7/4		8	2.48		
		ⓓ	Area		9	24.00	sq.m	
			Seismic load	weight	10	34.96	kN	24*0.79+8*0.5+24*0.5
				seismic coefficient	11	0.20		Frame structure, K=2.5
				10*11	12	6.99	kN	
			Allowable strength	length	13	4.00	m	2+1+2+1
				unit strength	14	5.20	kN/m	2.6, Wooden brace 90*45nail, Single
				13*14	15	20.80	kN	
			Ratio of 15/12		16	2.97		
	Ratio minimum area / maximum area				ⓓ/ⓒ	0.83		OK

Detailed Calculation method: Eccentricity method

1. Center of gravity

Center of gravity is the point which locates the resultant weight of a body.
The center of gravity of an object is calculated by taking the sum of its moments divided by the overall weight of the object. The moment is the product of the weight and its location as measured from a set point called the **origin**.

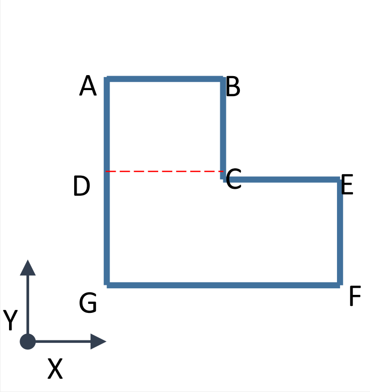


Center of gravity(Cg)

along x axis = $\frac{W1*d1+W2*d2}{W}$ where, $d_1 = \frac{h_1}{2}$, $d_2 = \frac{h_2}{2}$

Center of gravity of an irregular object:

The given L section is not symmetrical. Therefore for this section there will be two axis of reference. Line GF will be taken an axis of reference for calculating $\bar{y}$ and the left line of the section AG will be reference axis for calculating $\bar{x}$, where $(\bar{x}, \bar{y})$ is center of gravity. Split the given section into two rectangle ABCD and DEFG.



To find $\bar{y}$

a_1= area of rectangle ABCD

y_1= distance of CG of rectangle ABCD from bottom line GF = GD+$\frac{AD}{2}$

a_2= area of rectangle DEFG

y_2= distance of CG of rectangle DEFG from bottom line GF = $\frac{GD}{2}$

$$\bar{y} = \frac{a_1*y_1*a_2*y_2}{A}$$ where, $A=a_1+a_2$

To find $\bar{x}$

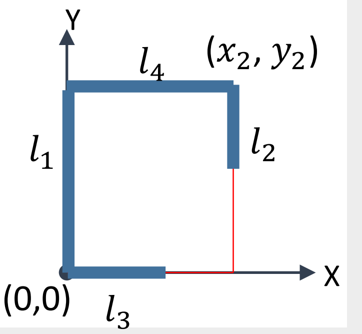
x_1= distance of CG of rectangle ABCD from reference line AG = $\frac{GF}{2}$

x_2= distance of CG of rectangle DEFG from reference line AG = $\frac{AB}{2}$

$$\bar{x} = \frac{a_1*x_1*a_2*x_2}{A}$$ where, $A=a_1+a_2$

2. Center of stiffness

Center of stiffness also known as center of rigidity is the point where the object at which, if force is applied, it won't be able to rotate. It is the stiffness centroid within a floor-diaphragm plan. When the center of rigidity is subjected to lateral loading, the floor diaphragm will experience only translational displacement.



Center of stiffness (x_s, y_s)

To find x_s,

Taking moment about y-axis,

$\sum My = 0$, $\quad l_1 * x_1 + l_2 * x_2 - \sum Lix_s = 0$

$$x_s = \frac{l_1 * x_1 + l_2 * x_2}{\sum Li}$$

Where,
$x_1, y_1 = 0,0$
$Li = l_1 + l_2$

To find y_s,

Taking moment about x-axis,

$\sum Mx = 0$, $\quad l_3 * y_1 + l_4 * y_2 - \sum Liy_s = 0$

$$y_s = \frac{l_3 * y_1 + l_4 * y_2}{\sum Li}$$

Where,
$x_1, y_1 = 0,0$
$Li = l_1 + l_2$

3. Distance of eccentricity

The distance between the center of gravity and rigidity is called the eccentric distance. Buildings with unbalanced wall have long eccentric distances and are easily subjected to torsion.

4. Torsional rigidity

Torsional rigidity is the amount of resistance a cross section has against torsional deformation. The higher the rigidity, the more resistance the cross section has.

5. Radius of elasticity

In buildings, there is torsional rigidity as a resistance to twisting, and those expressing them by distance are called resilience radius. The greater the elastic radius, the greater resistance to twisting.

6. Ratio of eccentricity:

The ratio of eccentricity as an index is representing the balance of the wall arrangement. Arrangement of seismic element walls balanced buildings have low ratio of eccentricity, and buildings with poor arrangement balance have large ratio of eccentricity.

7. Reduction factor

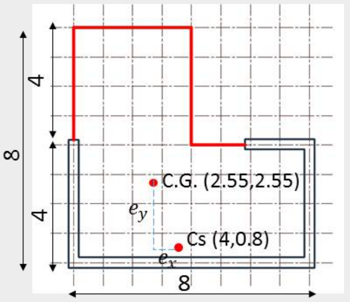
For buildings with an eccentricity of 0.15 or more, it is necessary to reduce holding capacity. Since wooden originally had low floor rigidity, the building is easy to twist and the reduction rate is large.

Reduction factor

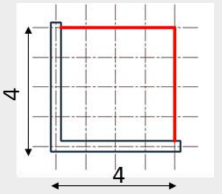
Re < 0.15	0.15 ≤ Re < 0.6	0.6 ≤ Re
1.0	1.2-4/3Re	0.4

Calculation of BALANCE of bracing member

Workout example 1 of **Eccentricity method**



Ground floor



First floor

Unit weight:
Ground floor = $0.5+0.788=1.038\ \mathrm{KN/m^2}$
First floor = $0.5+0.5+0.788+2.53=4.318\ \mathrm{KN/m^2}$

Center of gravity each floor:

$$\bar{x} = \frac{a_1{*}x_1{+}a_2{*}x_2}{A} \quad where,\ A{=}a_1{+}a_2,$$

$$\bar{y} = \frac{a_1{*}y_1{*}a_2{*}y_2}{A} \quad where,\ A{=}a_1{+}a_2$$

Ground floor:

$$\bar{x}=\frac{8{*}4{*}4{+}4{*}4{*}2}{8{*}4{+}4{*}4}=3.33$$

$$\bar{y}=\frac{8{*}4{*}2{+}4{*}4{*}6}{8{*}4{+}4{*}4}=3.33$$

First floor:

$$\bar{x}=\frac{4{*}4{*}2}{4{*}4}=2$$

$$\bar{y}=\frac{4{*}4{*}2}{4{*}4}=2$$

1. Center of gravity :

$$Xg=\frac{1.038{*}48{*}3.33{+}4.318{*}16{*}2}{1.038{*}48{+}4.318{*}16}=2.55$$

$$Yg=\frac{1.038{*}48{*}3.33{+}4.068{*}16{*}2}{\ldots}=2.55$$

2. Center of stiffness :

$$x_s=\frac{4{*}0{+}4{*}8}{4{+}4}=4$$

$$y_s=\frac{8{*}0{+}2{*}4}{8{+}2}=0.8$$

3. Distance of Eccentricity: $e = C_s\text{-}C_g$

$e_x = 4.0\text{-}2.55 = 1.45,$ $\quad e_y = 0.8\text{-}2.55 = 1.75$

4. Torsion rigidity :

$$KR = \sum lx\,(y\text{-}y_s) + \sum ly\,(x\text{-}x_s)$$
$$= 4{*}2.6(0\text{-}0.8)^2{+}4{*}2.6(8\text{-}0.8)^2 + 8{*}2.6(0\text{-}4)^2{+}2{*}2.6(4\text{-}0.8)^2$$
$$= 6.656 + 539.136 + 332.8 + 53.24$$
$$= 931.832$$

5. Ratio of elasticity:

$$r_{ax}=\sqrt{\frac{KR}{\sum ly}}=\sqrt{\frac{931.832}{8{*}2.6}}=\sqrt{44.79}=6.69,\qquad r_{ay}=\sqrt{\frac{KR}{\sum lx}}=\sqrt{\frac{931.832}{10{*}2.6}}=\sqrt{35.84}=5.98$$

6. Ratio of eccentricity: Re= distance of eccentricity/Radius of elasticity

$$Re_x=\frac{1.45}{6.69}=0.21,\qquad Re_y=\frac{1.75}{5.98}=0.29$$

7. Reduction factor:

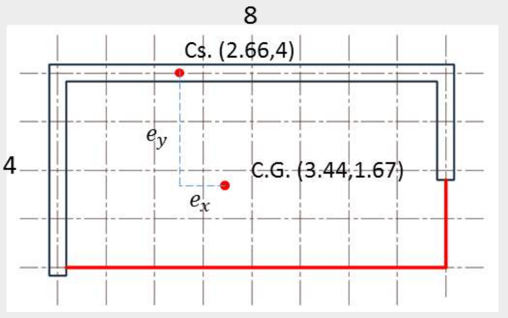
Reduction factor

Re < 0.15	0.15 ≤ Re < 0.6	0.6 ≤ Re
1.0	1.2-4/3Re	0.4

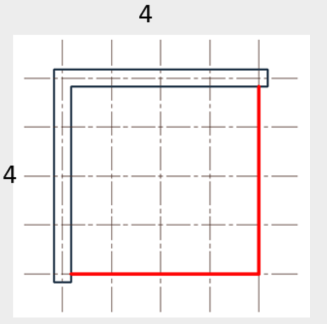
Higher Ratio is Re_x = 0.29,

R factor = 1.2-4/3Re=1.2-4/3*0.29= **0.81**

Workout example 1 of **Eccentricity method**



Ground floor



First floor

1. Center of gravity :

$$Cg= \frac{Unit\ weight * Area(GFl) * {}^{Total\ length}/_{2} + Unit\ weight * Area(FFL) * {}^{Total\ length}/_{2}}{Unit\ weight * area(GFL) + Unit\ weight * area(FFL)}$$

$$Xg= \frac{1.038*32*4+4.318*16*2}{1.038*32+4.318*16} = \frac{271.04}{102.304} = 2.65 \qquad Yg= \frac{1.038*32*2+4.318*16*2}{1.038*32+4.318*16} = \frac{204.606}{102.304} = 2$$

2. Center of stiffness :

$$Xs= \frac{4*0+2*8}{6} = 2.66 \qquad Ys= \frac{0*0+8*4}{8} = 4$$

3. Distance of Eccentricity: $e = C_s - C_g$

e_x = 2.66 – 2.65 = 0.01, e_y = 4 - 2 = 2

4. Torsion rigidity :

KR = $\sum lx\,(y-y_s) + \sum ly\,(x-x_s)$
= 4*2.6(0-4) ^{2}+4*2.6(8-4)^2 + 8*2.6(0-2.66) ^{2}+4*2.6(4-2.66)^2
= 498.472

5. Ratio of elasticity:

$$r_{ax}= \sqrt{\frac{KR}{\sum ly}} = \sqrt{\frac{498.472}{6*2.6}} = \sqrt{31.95} = 5.65 \qquad r_{ay}= \sqrt{\frac{KR}{\sum lx}} = \sqrt{\frac{498.472}{8*2.6}} = \sqrt{23.96} = 4.89$$

6. Ratio of eccentricity: Re= distance of eccentricity/Radius of elasticity

$$Re_x = \frac{0.01}{5.65} = 0.0017, \qquad Re_y = \frac{2}{4.89} = 0.408$$

7. Reduction factor:

Reduction factor		
Re < 0.15	0.15 ≤ Re < 0.6	0.6 ≤ Re
1.0	1.2-4/3Re	0.4

Higher Ratio is Re_x = 0.408,

R factor = 1.2-4/3Re=1.2-4/3*0.408= **0.65**

5. Connections and Joints

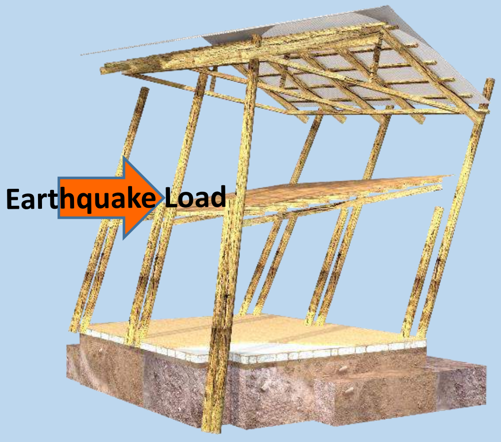
Requirements

No.	Category	Description
5.	Connections and joints	All the structural members shall be properly connected by nails, bolts and metal plate as per the specification

Why important ?

Connections and joint of structural member

- The failure in the joints connecting structural member such as vertical, horizontal and bracing frequently occurs. Structural member should be uniform, so that the frame will acts as earthquake resistance elements.
- The joints of structural members should be firmly connected by nail or bolts. The use of metal straps is recommended at structurally important joints such as post/ studs with sill or wall plates and horizontal noggin members at the end of every bearing wall.

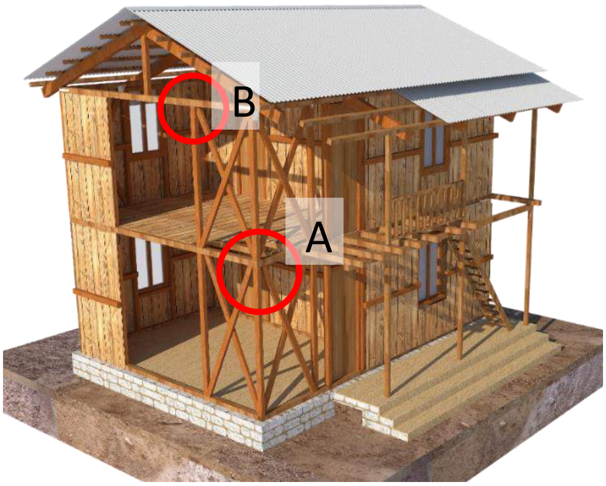


Inspection procedure

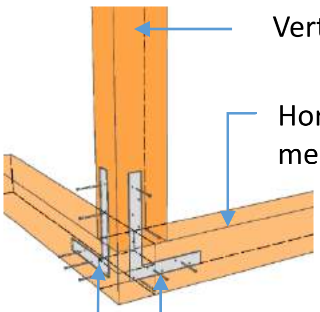
The detail of connection that needs to be checked are:

- Connection between post and beam.
- Connection of braces with the vertical and horizontal member (base and Top plate).

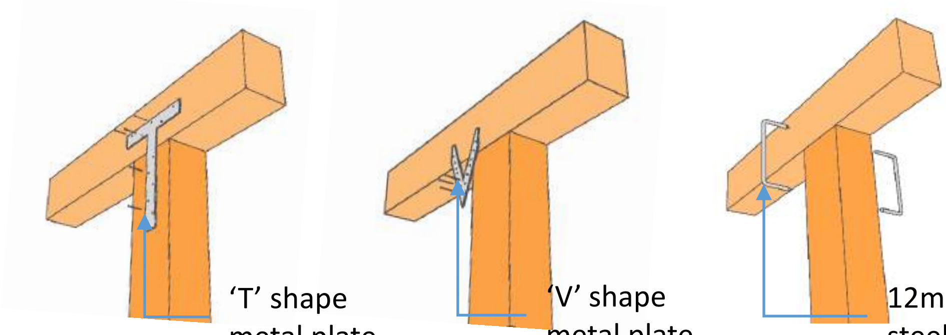
Connections between vertical and horizontal member



Detail A: Connection of corner

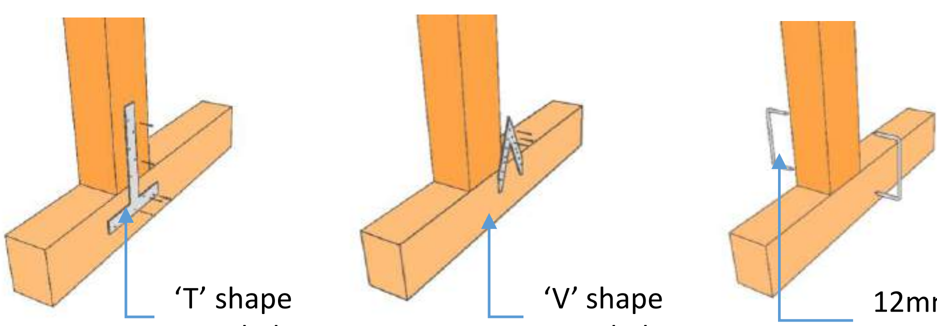


Detail B: Connection horizontal and vertical at middle



Detail of metal plate P46

Detail B: Connection horizontal and vertical at middle



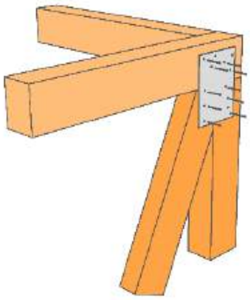
PART-2: Technical Specification

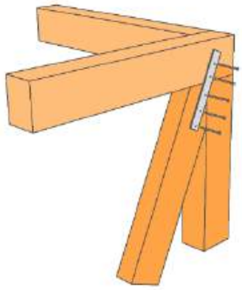
Connections between top plate, vertical and bracing member

Wooden vertical member should be properly connected to horizontal member as shown in figure.

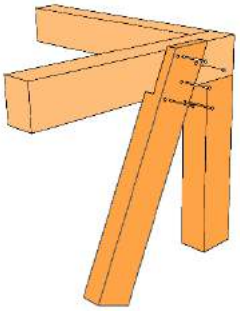
Detail of metal plate P46

Detail: Connection of bracing member



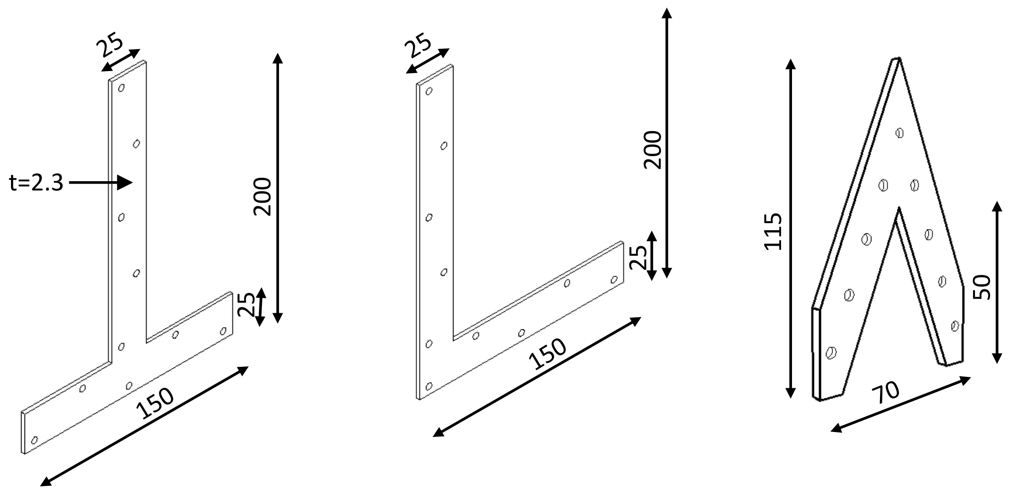


Connected by metal plate



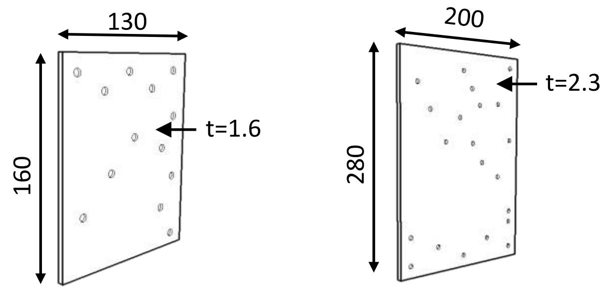
Connected by nail
Nail: length 75mm x 5

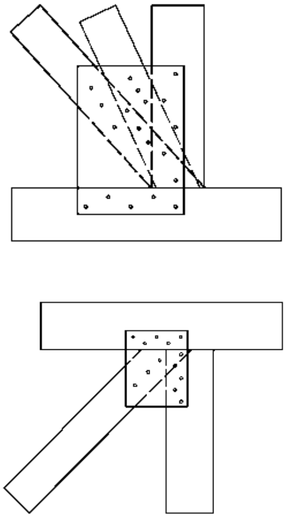
Detail of metal plates



'T' shape metal plate

'V' shape metal plate





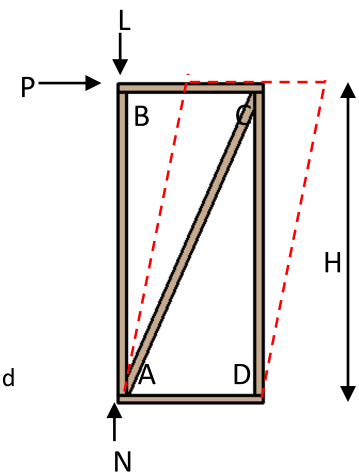
Note: Instead of metal plate, three layers of 0.55mm GI sheet can be used.

The length of a nail shall be at least 2.5 times the thickness of the thinnest member and it shall penetrate the thicker member by 1.5 times the thickness of the thinner member, whichever is further.

Analysis of connection details:

Connections between vertical and horizontal member

Let us consider the section ABCD where, AB and CD are the wooden column and AC is the wooden bracing.
In order to design the connection details of these section, foremost we need to calculate the tensile strength of uplifting and depending upon this strength, the design of the connection details of each individual member can be done.

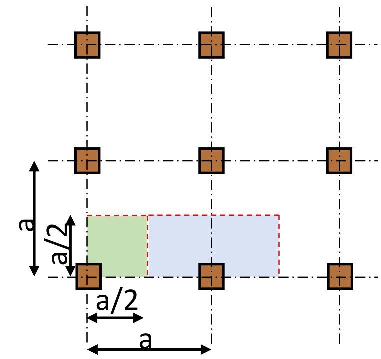


$$N = \frac{P*H*B}{W} - L = \frac{A*W*H*B}{W} - L = A*H*B - L$$

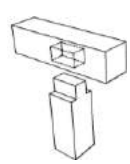
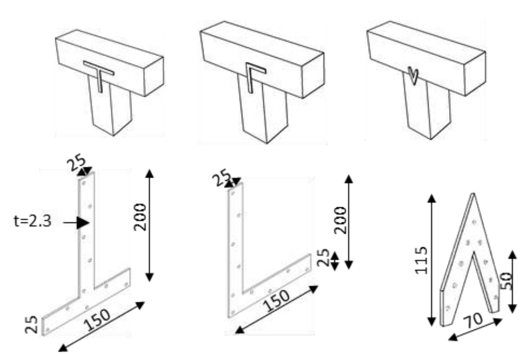
N = A*H*B- L (For single storey column and first floor column of two storey)

N = (A1*B1+ A2 * B2)*h -L (Ground floor column of two storey)

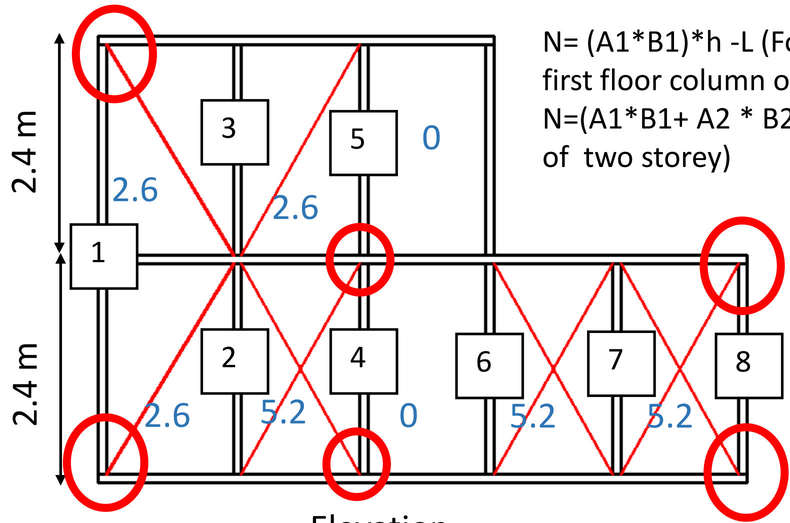
Where,
N= tensile strength for uplifting
P= Lateral load
H= height of the column
W= tributary load
B= reduction factor; Corner column= 0.8,Face and mid column=0.5
L= axial load on column; Corner column = 5.3 KN, Mid column= 8.48 KN



Distribution of load of corner and face column

Tensile strength	Connection details
0.0 KN	
~3.4 KN	
~15.0 KN	

Worked out example of joint between column and beam



Elevation

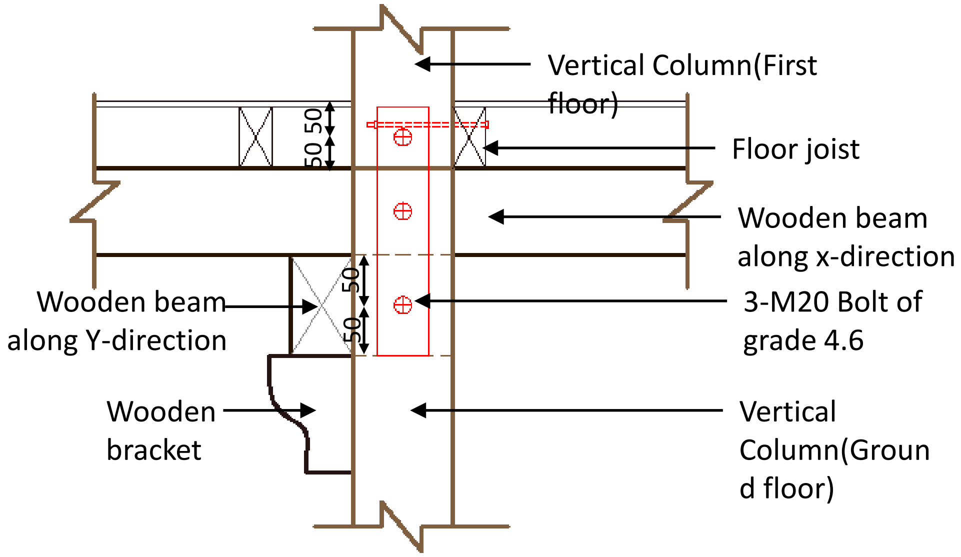
N= (A1*B1)*h -L (For single storey column and first floor column of two storey)
N=(A1*B1+ A2 * B2)*h -L (Ground floor column of two storey)

Where,
N= tensile strength for uplifting
A1= differences between unit strength of adjacent bracing of column.
B1/B2= 0.8 (corner column), 0.5(face/middle column)
L= 5.3KN (corners), 8.48KN (middle section)

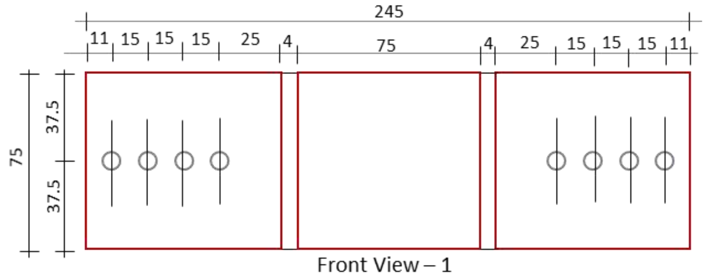
Column	Strength(KN)	Remarks
1	**14.66**	N = A1*B1*h-L = (2.6+2.6 -0)*0.8*4.8 -5.3 = 14.66
2	**-5.36**	N =(A1*B1 + A2 * B2)*h -L =[(5.2-2.6)*0.5 + (2.6 – 2.6)* 0.5]*2.4 – 8.48 = -5.36
3	**-8.48**	N = A1*B1*h-L = (2.6-2.6)*0.5*2.4 -8.48 = -8.48
4	**0.88**	N =(A1*B1 + A2 * B2)*h -L =[(5.2-0)*0.5 + (2.6 – 0)* 0.5]*2.4 – 8.48 = 0.88
5	**-5.36**	N = A1*B1*h-L = (2.6-0)*0.5*2.4 -8.48 = -5.36
6	**-2.24**	N =(A1*B1 + A2 * B2)*h -L =[(5.2-0)*0.5 + (0 – 0)* 0.8]*2.4 – 8.48 = -2.24
7	**-8.48**	N = A1*B1*h-L = (5.2-5.2)*0.5*2.4 -8.48 = -8.48
8	**4.68**	N = A1*B1*h-L = (5.2-0)*0.8*2.4 -5.3 = 4.68

Connection details between the column and beam shall be as per the details mentioned in Table 1

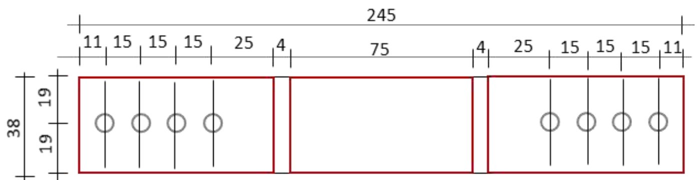
Detail B: Connection horizontal and vertical at middle



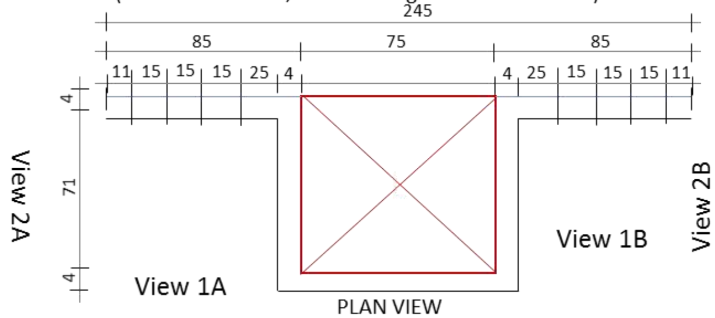
Metal plate for connection between horizontal and vertical member



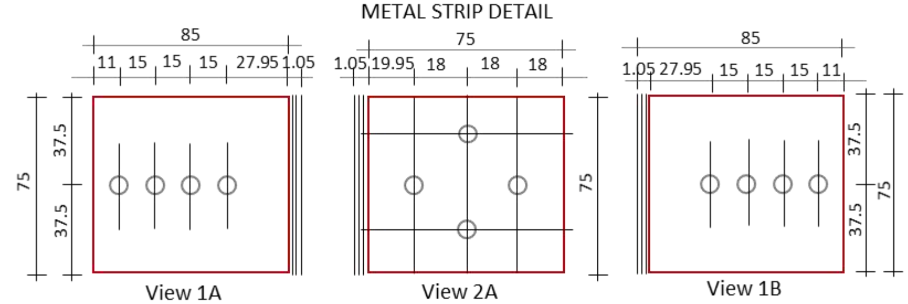
Front View – 1
(To be used for floor and roof bandage)

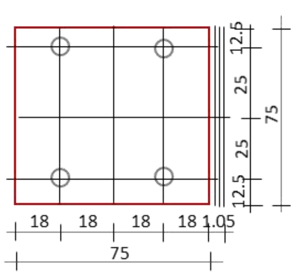


Front View – 2
(To be used for sill, lintel bandage and corner stitch)

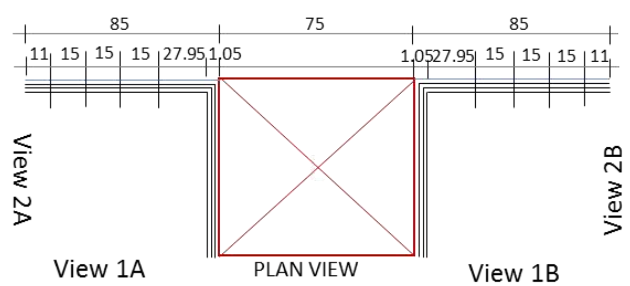


PLAN VIEW
METAL STRIP DETAIL





View 2B



PLAN VIEW
CGI SHEET DETAIL
(Alternate option for metal strip)

5. Roof

Requirements

No	Category	Description		
7	Roof	Wood	Material	Use of light roof
			Connection	All member shall be properly connected.
			Bracing	For flexible diaphragm, diagonal bracing shall be considered.

Why important?

- If heavy weight is on the top of building it will be subjected to larger seismic force. Therefore, Light weight roof is required.
- The joints of wooden roof trusses need to be bolted together and tied with metal straps as it will provides flexibility and prevent from collapse.
- In order to resist lateral forces, depending upon the structures of roof, it might be need cross bracing at all levels. It provides strength against lateral forces so that the building does not collapse sideways but is held together.

Exception

- If structure is found to be safe after structural calculation.

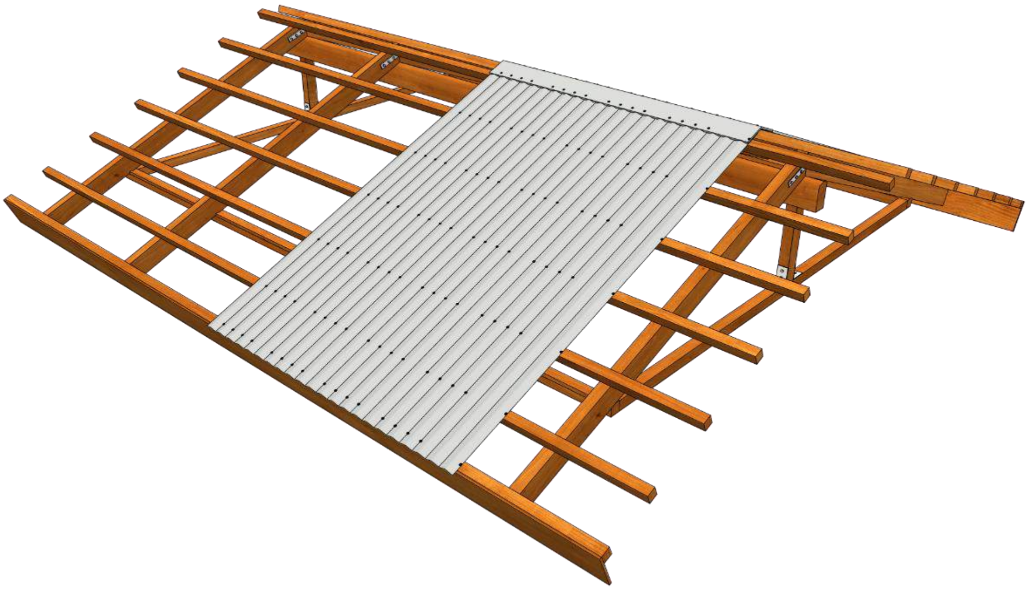
Inspection methodology

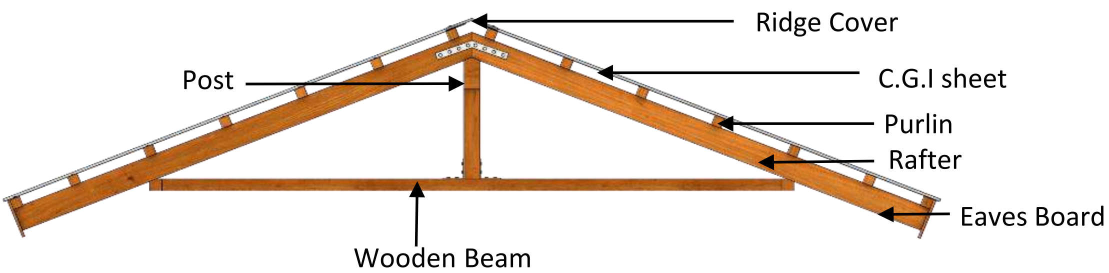
- The size of the rafter and purlin can be identified by measurement.
- The spacing of the purlin can also checked by the measurement whereas the connection can be checked by the observation.

Fundamental items

1. Use a continuous wall plate, ridge and purlins to tie the rafters or trusses together.
2. Stiffening of roof
    - Diagonal straps with steel nut bolts or metal nails
    - Diagonal steel truss with steel nut bolts or metal nails
    - Timber bracing with metal nails or timber nails

Wooden Roof truss

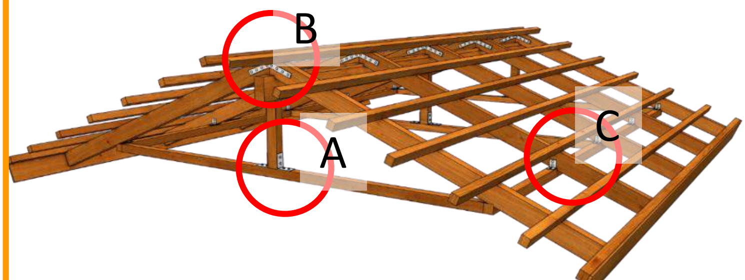




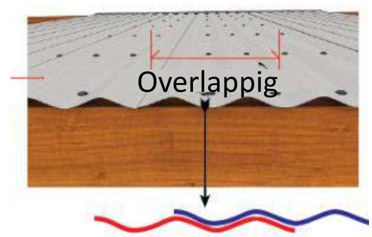
A **timber roof truss** is a structural framework of timbers designed to bridge the space above a room and to provide support for a roof. Trusses usually occur at regular intervals, linked by longitudinal timbers such as purlins.

Rafters are inclined timbers fixed between wall plate and ridge which transmit live and dead loads to wall plate.

Connection details

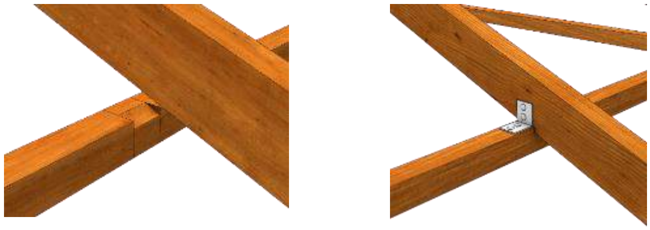


Details of Wooden Truss



Detail A: Joints of Wooden Truss

Detail C: Joints of Rafter



Detail B: Joints of Wooden Truss

Strengthening roof

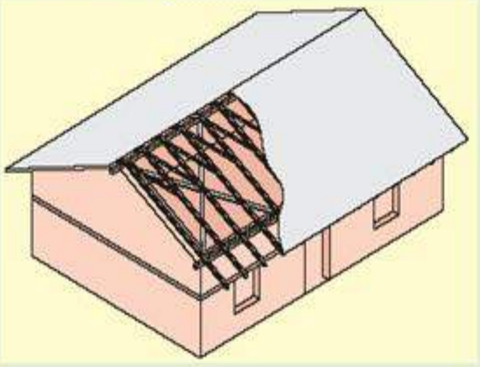
In case of Roof/floor bracing missing

Correction measures

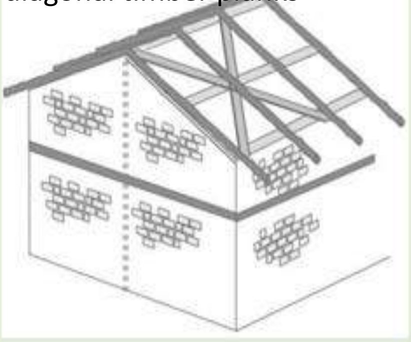
Option : from Retrofitting manual.

- Provide X-bracing at end bays on each sloppy side
- Provide additional roof/floor member as needed

Diagonal bracing to roof



Stiffening of the floor with diagonal timber planks



Diagonal steel bracing to roof

Steel bracing to roof

Flexible diaphragm improvements

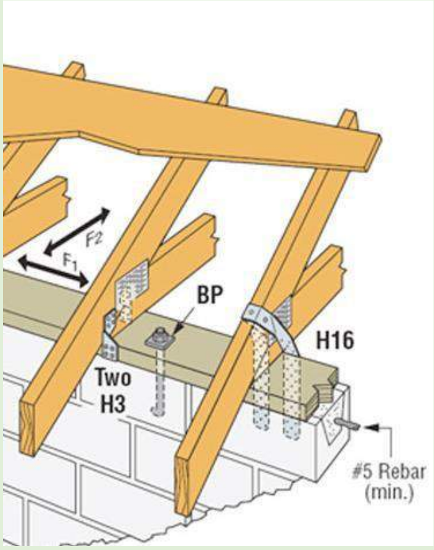
Strengthening roof

Connection improvement between wall to roof

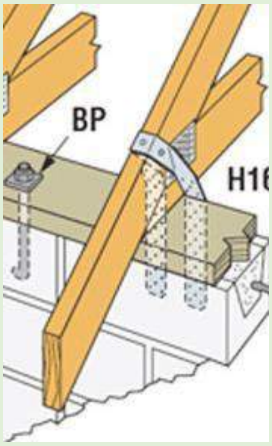
Correction measures

Option : from Retrofitting manual.

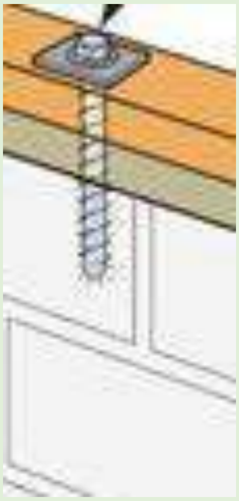
- Metal Strap with Screws



Note : 3 mmm thick metal strap, Minimum four numbers of 50 mm long nails (Fe250) with Floor member and Minimum four numbers of M16 grade expansion bolts with walling material



Details of Anchor plate



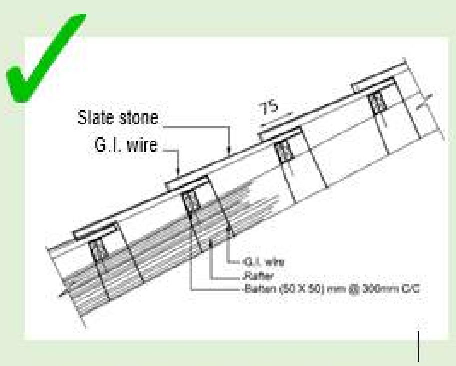
Strengthening roof

Sliding of Roofing materials

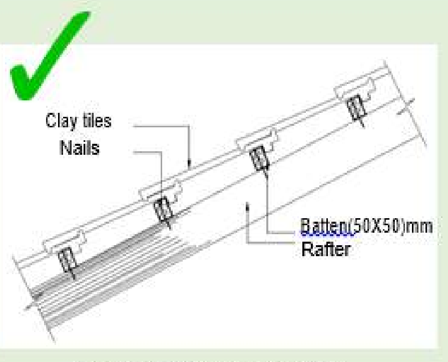
Correction measures

Option : from Retrofitting manual. Fixing roofing tile.

1.Replace damaged tiles.
2.Using appropriate correct fixing method for roofing materials.
3.Connect the roof with the roof band by inserting reinforcement or GI sheet.
4.Slatestone and clay tiles should be properly anchored to purlin as NBC.

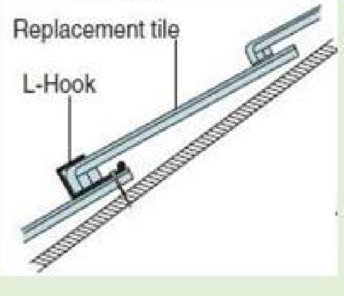


Detail of anchoring slate stone
Source: NBC203 2015, P44

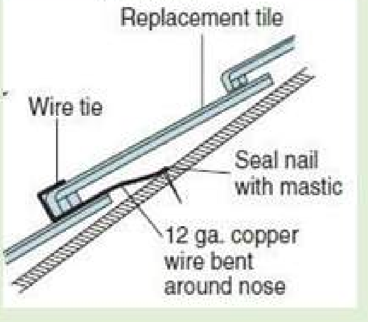


Detail of fixing clay tile
Source: NBC203 2015, P45

L-hooks



Wire ties



Gently lift the overlapping tile and twist loose the damaged tile.
After filling any nail holes, slip in a new tile and secure with an L-hooks (left) or bent copper wire (right)

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PART 3: Correction measures for existing buildings

1. Foundation
2. Double post
3. Beam
4. Vertical post and Horizontal beam connection

Traditional timber framed structures

Figure is shown in traditional of timber framed structures in Siwalik range.

Existing condition

1. The system works for only gravity load. No resisting elements for lateral load.
2. One post of double post is continued upto roof, whereas the other post run only upto the height of ground floor for supporting first floor.
3. Vertical post are connected with only one direction of beam.
4. Beam is only one direction. From other direction, joist are rested on the this beam.
5. Connection is fix by bolts, nail, and rope lacing.
6. Vertical posts are directly embedded into the ground soil.
7. Large size of timber and hard wood are used.

Typical size of timber member	
Vertical post	Rectangular : 5”x6” ~ 6”x8”
	Circular : 6”~10” dia
Horizontal beam	Main: 4”x 5”
	Joist: 3”x4”
	Rafter: 3”x4”, Purlin: 2”x3”or3”x4”
Connection bolt	Nut-Bolt (16~20)mm dia.
Plank	1”

Common defect of existing house

1. Most critical inadequate part is rigidity of connection of post and beams.
2. Horizontal beam is only one direction.
3. There is no resisting element for lateral load (Earthquake load)
4. Poor connection between post and beam.

PART-3: Correction measures of existing buildings

Correction measures:

Foundation:

Problem

- If wooden post is embedded in soil only, it will be deteriorate by moisture, termites.

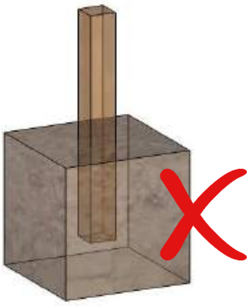
Solution

- Deterioration of wood shall be prevented by using preservative materials such as plastic sheet, concrete, stone or brick masonry.

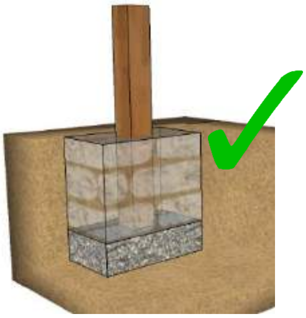
Correction

Steps:

1. Excavate the soil around the column and construct stone/brick masonry in cement or concreting (M15)
2. Remove top part minimum 300 mm deep and construct stone/brick masonry in cement or concreting (M15) also continue 300mm above plinth level.
3. To ensure sufficiency of foundation, add stone/brick masonry in cement or concreting equivalent to per minimum requirement considering existing size above plinth level.



Timber column is embedded in soil only



Excavate the soil around the column and construct stone/brick masonry.

Correction measures:

Double posts:

Problem

- This double column is supporting only vertical load indivisibly.
- Poor connection between two posts.

Solution

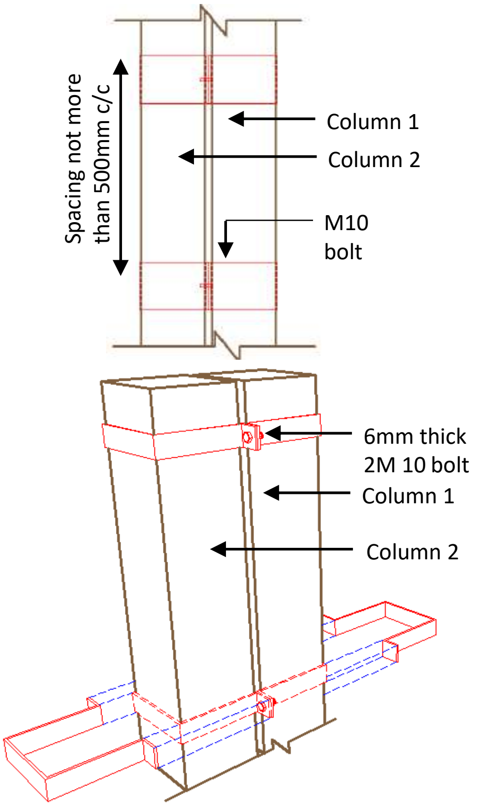
- It shall be tight together for uniformity.

Correction

1. Connect two posts properly.

Two post are not connected.

Option1: Wooden connector



Option2: Metal connector

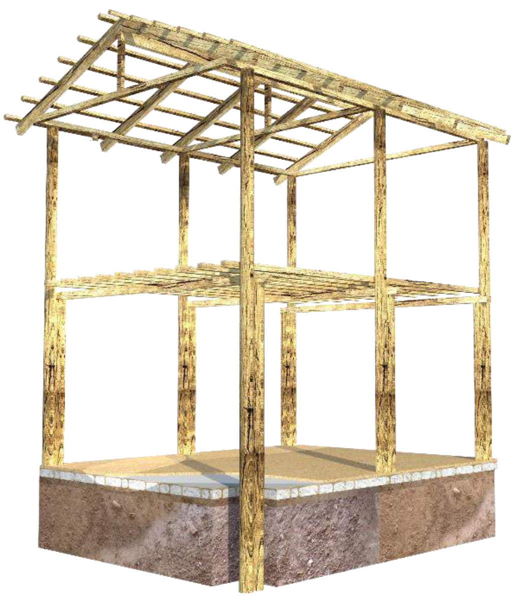
Traditional timber framed structures

Correction measures:

Beam:

Problem

- Wooden beam is provided in only one direction.
- The size of wooden beam is insufficient.



Solution

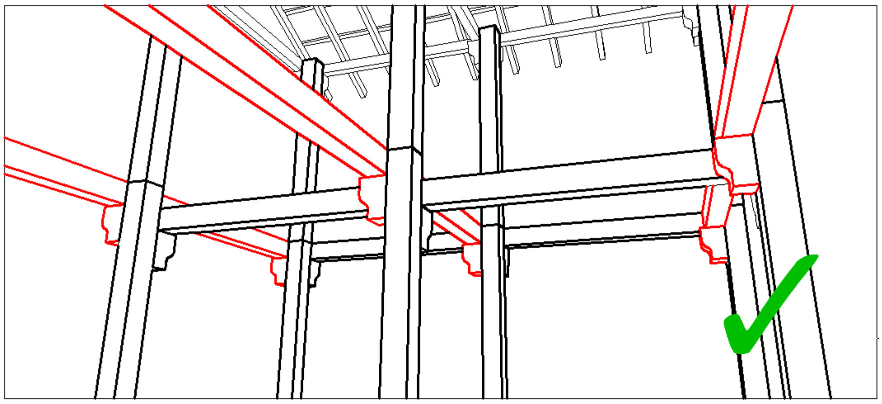
- Provide additional beam in the direction where the beam is missing.
- Add new beam beneath or above, wherever possible, in existing beam such that two (new and old beam) acts in composite manner or add supporting vertical column (size as per MRs) at mid location of the beam with proper connection.

Correction

Construction of beam in missing direction

Steps:

1. Construct bracket and connect it properly with the column.
2. Place the beam above the bracket with proper connection.

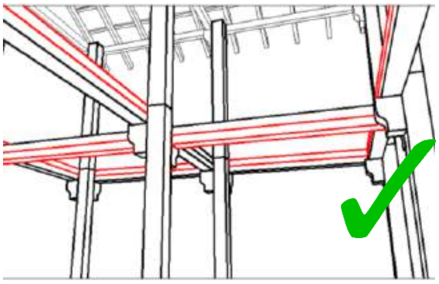


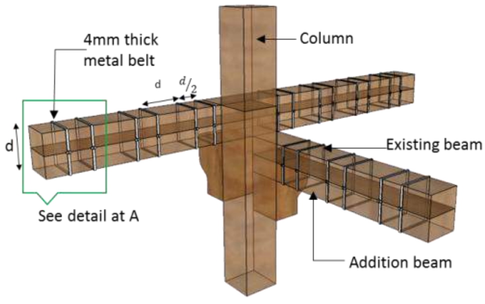
Note: Add new beams in missing direction with constructability approach (i.e. beam in all direction may be in different level).

Addition of beam

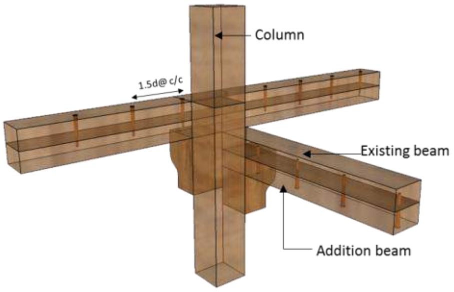
Steps:

1. Surface preparation
2. Apply adhesive materials between the two beams (new and old beams)
3. Apply metal belt or wooden peg or GI wire mesh as per the specification to connect the two beams.





OPTION 1. Connection details of addition of horizontal member



OPTION 2. Connection details of addition of horizontal member through wooden nails

Note: Wooden nail shall penetrate ¾ d of the lower beam, where d is the total depth of the beam

Traditional timber framed structures

Correction measures:

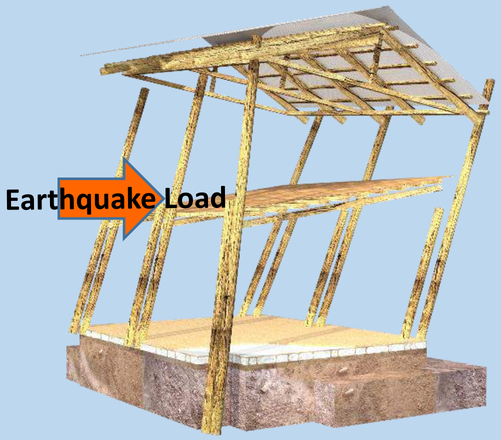
Vertical post and horizontal beam connection

Problem

- Poor connection between the post and beam.

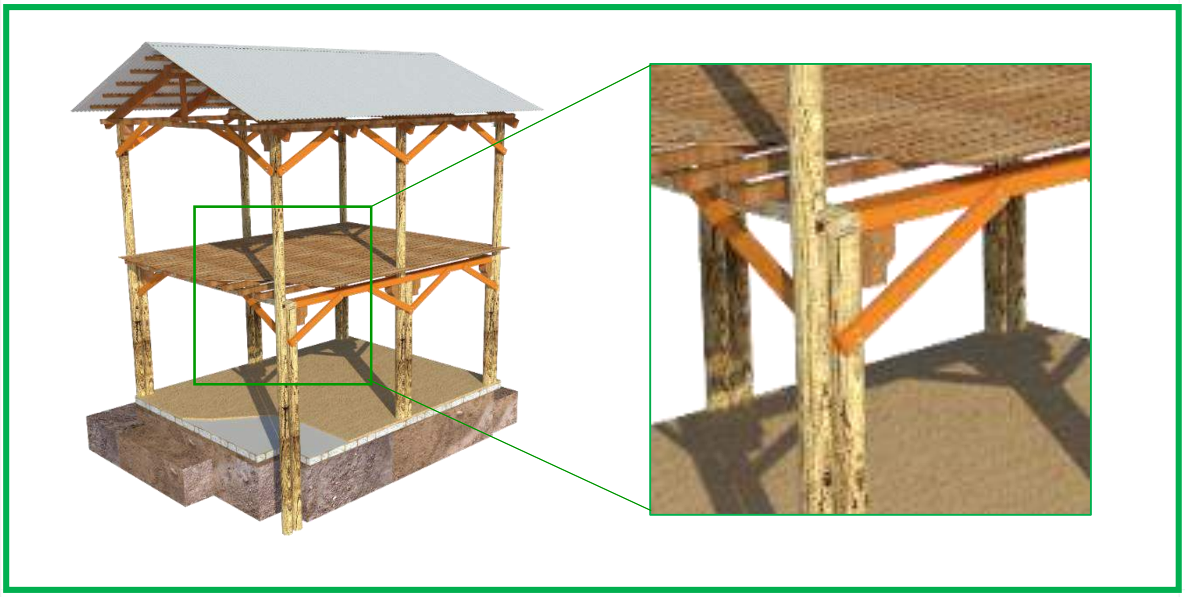
Why important ?

The failure of the joints connecting structural member such as vertical, horizontal and bracing frequently occurs. Structural member should be uniform, so that the frame will acts as earthquake resistance elements.



Solution

- Provide knee bracing using wooden member or metal strips to increase the rigidity between the beam and column.



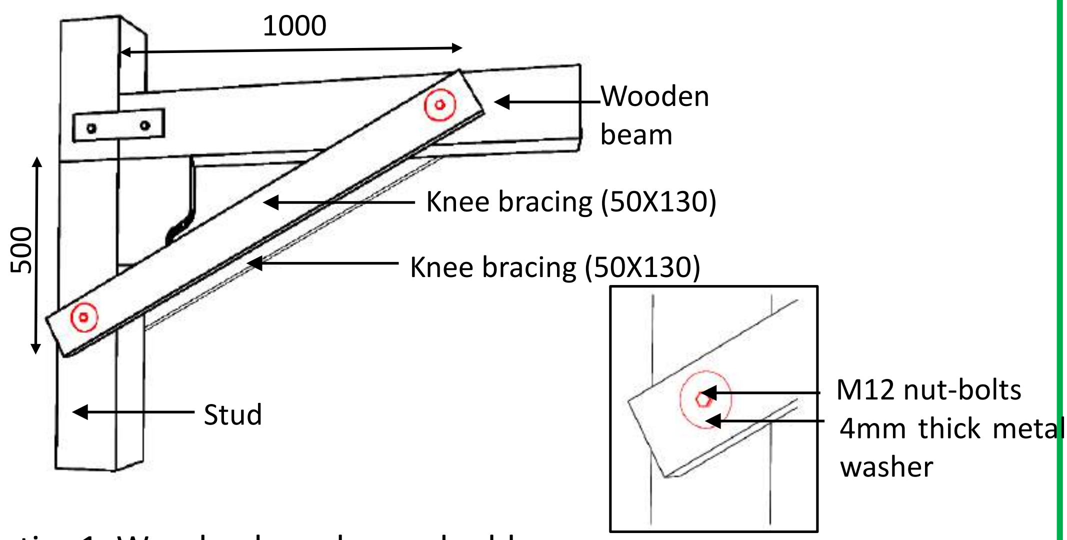
Correction

Additional wooden Knee bracing

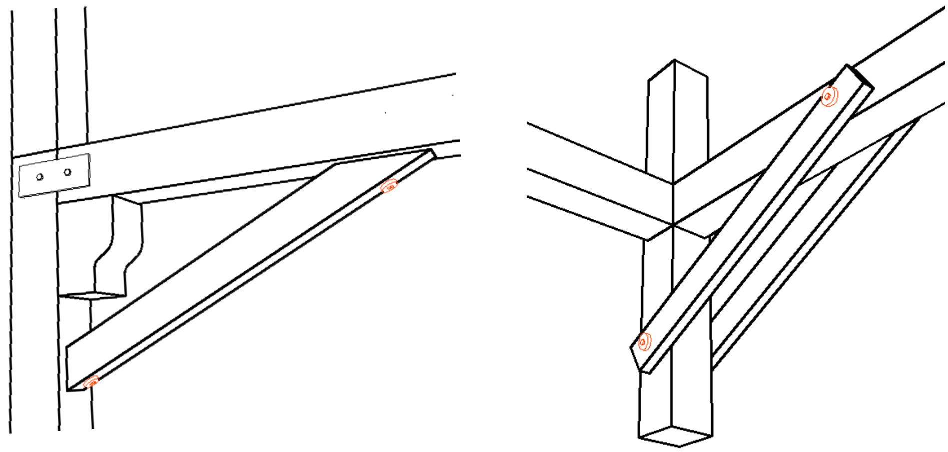
Steps:

1. Place wooden knee bracing (100mm X 130mm) as per the specification. If 50X 130mm bracing size is being used, place it in two sides of beam and column.
2. Connect these knee bracing to the beam and column using 1-M12 bolt. To make the three hinge connection, connect the column and beam using bolt or screw.

Note: If screw is being used in place of bolt two number of screw is required.



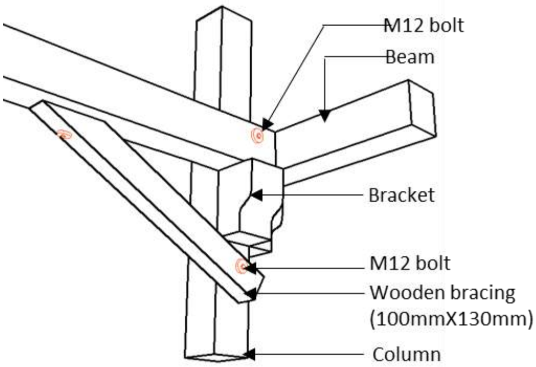
Option1. Wooden knee brace double



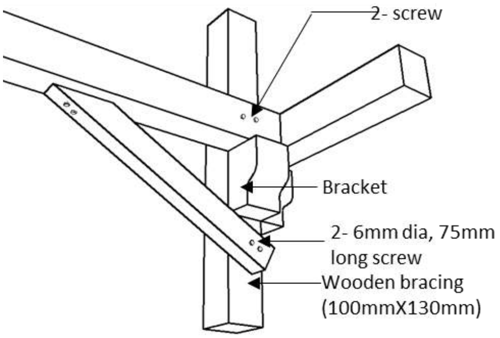
Option2. Wooden knee brace single

Correction measures:

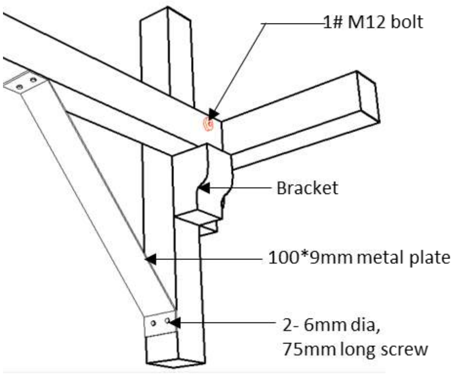
OPTIONS: Additional wooden Knee bracing



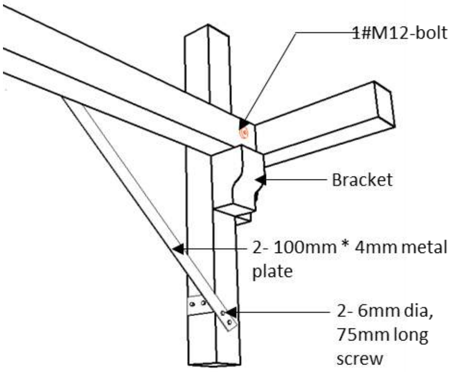
Option1. Wooden knee brace fixed by bolt



Option2. Wooden knee brace fixed by screw



Option3. Metal knee brace fixed by bolt



Option4. Metal knee brace fixed by screw

Correction measures:

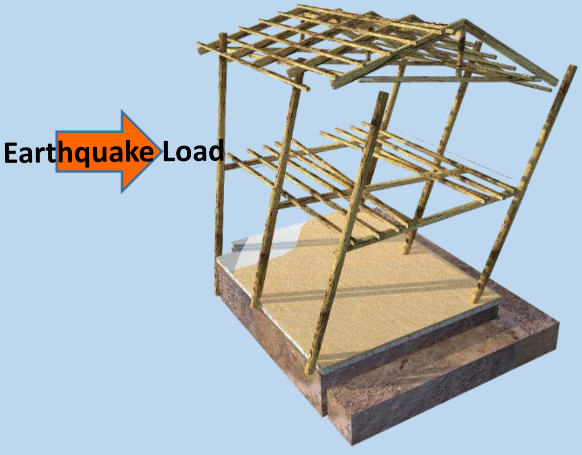
Diaphragm of floor

Problem

- Poor diaphragm of floor, building can not act uniform.

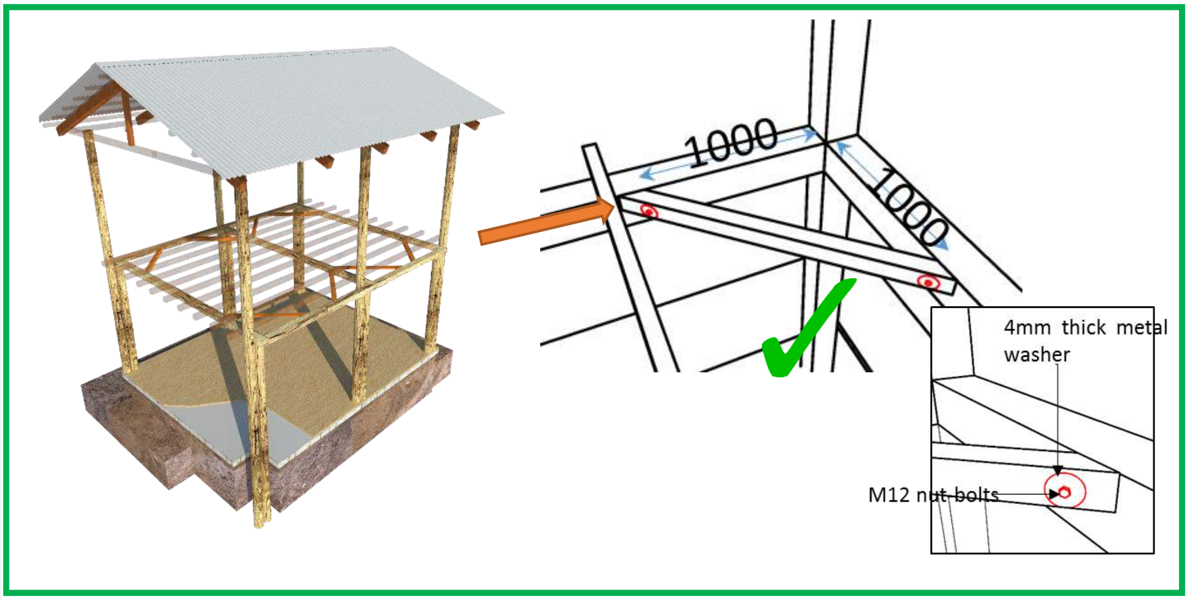
Why important ?

If the floor or roof is rigid, it will act as a uniform member and its inertia force will be distributed to all the walls in proportion to their stiffness.
The enclosure will act as a box for resisting the lateral (earthquake) loads.



Solution

- Provide diaphragm bracing using wooden member or metal strips to increase the rigidity of floor and roof.



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APPENDIX

1. Inspection sheet
2. Prototype drawings
3. Structural Calculation
4. Structural Analysis

Annex-19: Forms for technical inspection of light timber frame structure Category "c" buildings

Light Timber Frame structure CATEGORY"C" BUILDINGS -FIRST INSPECTION

Government of Nepal
Ministry of Urban Development
Central Level Project Implementation Unit

Inspection Sheet

Light Timber Frame structure CATEGORY "C" BUILDINGS FOR FIRST INSPECTION

Information of House Owner/Beneficiary		Date of Inspection	M M D D Y Y Y Y
Name		Grant Agreement No.	
Address	District	VDC/Municipality	ward · tole · Land plot No

SECTION-I: DESCRIPTION PROVIDED IN THE APPLICATION TO SURVEY THE HOUSE

If use fix design from design catalogue,	Design No.	
If free design by house owner	Technique and Construction material	
Fill construction typology from P.A form	Construction of roof and materials	
Technical Assistance ☐Yes ☐No	Organization	☐ GoN, ☐ NGO ( )
Trained Masons Used ☐Yes ☐No	Soil Type	☐Hard, ☐Medium, ☐Soft

SECTION- II: DETAILED TECHNICAL INSPECTION

No.	Category	Description		Comply to MRs Yes	Comply to MRs No	Remarks
1	Site selection located away from	Geological fault or Ruptured Area		☐	☐	
		Steep Slope > 20°		☐	☐	
		Landslide susceptible Area		☐	☐	
		River bank and Water logged Area		☐	☐	
		Rock-fall Area		☐	☐	
		Liquefaction susceptible Area		☐	☐	
		Filled Area		☐	☐	
2	Shape of House	No. of storey	Not more than two storey	☐	☐	
		No of bays	At least two bay	☐	☐	
		Proportion	Simple and regular shape as square or rectangular	☐	☐	
			Length is not more than three times of its width	☐	☐	
		Height of floor	Not more than 2500 mm	☐	☐	
3	Materials	Nail	Common wire nails shall be made of mild steel having a minimum tensile strength of 250N/mm2. Nails with appropriate diameter and length shall be provided.	☐	☐	
		Bolt, Metal plate	It shall be used in such a way that its number, diameter, length, spacing shall be as per the specification.	☐	☐	
		Rebar	High strength deformed bars with fy = 415 Mpa or 500 Mpa	☐	☐	
		Timber	Treated and well-seasoned hard wood or locally available wood without knots shall be used.	☐	☐	
		Brick	It shall not be over-burnt, under-burnt and deformed.	☐	☐	
		Mortar	Strength is not less than 1 cement : 6 sand mixture	☐	☐	
		Concrete	M20grade (1cement: 1.5sand: 3aggregate)	☐	☐	
		Stone	It shall not be round, easily breakable soft stone.	☐	☐	
		Concrete block	Compressive strength must be 5 Mpa	☐	☐	
			Size:400 mm x 150mm x 200 mm	☐	☐	
4	Foundation	Wooden Post	It shall rest on a firm base pad. Deterioration of wood shall be prevented as per specification.	☐	☐	

		Masonry	Masonry unit shall be large flat-bedded stone, regular-sized well-burnt bricks. The gaps in the core shall be well-packed with the masonry units.					☐	☐	
		Size and shape	It shall be as per specification.					☐	☐	
5	**Frame**	Vertical member	Post	It shall be placed in same position of ground and first floor. The continuous post is recommended at each corner of building.						
			Post	Span		Hard wood	Soft wood	☐	☐	
				Brace/ Shear Panel	2m	110 x 110	120 x 120	☐	☐	
					2.5m	110 x 110	120 x 120	☐	☐	
					3m	120 x 120	130 x 130	☐	☐	
					3.5m	130 x 130	140 x 140	☐	☐	
				Bare Frame	Up to 2.5m	130 x 180	150 x 200	☐	☐	

Others:

a. At least six number of photographs with their number (eg: dsc0152.jpg)

b. G.P.S Co-ordinate

Number ☐ Direction ☐ height from sea level ☐

c. Tentative drawings of building:

d) After the detail description of the under constructed house, is it satisfactory to give permit for the further construction.

Yes ☐ , No ☐

☐ Passed from technical Inspection so,it is certify that further construction work can be proceed and Rs 150,000 can be received as 2nd tranche.

e) After the detail description of the under constructed house, is it necessary to give additional correction order?

☐ Yes ☐ No

☐ Correction/ Retrofitting Order is needed so,use Annex-11 Correction/ Retrofitting Order and Inspection form

f) Acceptation of Description provided after technical supervision:

House owner/Beneficiaries or representative name:....................................... Signature:..........................

Relationship with house owner (In case of representative):..............................Date:................................

g) Approval for description of Technical Inspection

Technical Inspector of MoUD-DLPIU:..

Name:.. Post:...

Signature: .... Date: ....

h) Description of Technical Inspection approval by

Technical Engineer of MoUD-DLPIU:..

Name:.. Post:...

Signature: .... Date: ....

Annex-19: Forms for technical inspection of light timber frame structure Category "c" buildings

Government of Nepal
Ministry of Urban Development
Central Level Project Implementation Unit

Light Timber Frame structure CATEGORY"C" BUILDINGS
-SECOND INSPECTION

Inspection Sheet

Light Timber Frame structure CATEGORY "C" BUILDINGS FOR SECOND INSPECTION

Information of House Owner/Beneficiary			Date of Inspection	M	M	D	D	Y	Y	Y	Y	
Name			Grant Agreement No.									
Address		District	VDC/Municipality	ward		tole			Land plot No			

SECTION-I: DESCRIPTION PROVIDED IN THE APPLICATION TO SURVEY THE HOUSE		
If use fix design from design catalogue,	Design No.	
If free design by house owner	Technique and Construction material	
Fill construction typology from P.A form	Construction of roof and materials	
Technical Assistance ☐Yes ☐No	Organization	☐ GoN, ☐ NGO ( )
Trained Masons Used ☐Yes ☐No	Soil Type	☐Hard, ☐Medium, ☐Soft

SECTION- II: DETAILED TECHNICAL INSPECTION

No.	Category	Description					Comply to MRs: Yes	Comply to MRs: No	Remarks
2	Shape of House	No. of storey	Not more than two storey				☐	☐	
		No of bays	At least two bay				☐	☐	
		Proportion	Simple and regular shape as square and rectangular				☐	☐	
			Length is not more three times of its width				☐	☐	
		Height of floor	Not more than 2500 mm				☐	☐	
3	Materials	Nail	Common wire nails shall be made of mild steel having a minimum tensile strength of 250N/mm2. Nails with appropriate diameter and length shall be provided.				☐	☐	
		Bolt, Metal plate	It shall be used in such a way that its number, diameter, length, spacing shall be as per the specification.				☐	☐	
		Rebar	High strength deformed bars with fy = 415 Mpa or 500 Mpa				☐	☐	
		Timber	Treated and well-seasoned hard wood or locally available wood without knots shall be used.				☐	☐	
		Brick	It shall not be over-burnt, under-burnt and deformed.				☐	☐	
		Mortar	Strength is not less than 1 cement : 6 sand mixture				☐	☐	
		Concrete	M20grade (1cement: 1.5sand: 3aggregate)				☐	☐	
		Stone	It shall not be round, easily breakable soft stone.				☐	☐	
		Concrete block	Compressive strength must be 5 Mpa				☐	☐	
5	Frame	Vertical member	General	It shall be placed in same position of ground and first floor. The continuous post is recommended at each corner of building.			☐	☐	
			Post	Span		Hard wood / Soft wood	☐	☐	
				Brace/ Shear Panel	2m	110 x 110 / 120 x 120	☐	☐	
					2.5m	110 x 110 / 120 x 120	☐	☐	
					3m	120 x 120 / 130 x 130	☐	☐	
					3.5m	130 x 130 / 140 x 140	☐	☐	

				Bare Frame	Up to 2.5m	130 x 180	150 x 200	☐	☐	
		Horizontal member	General	Base plate, Floor beam, Top plate shall be provided.				☐	☐	
				It shall be continuous and both direction.				☐	☐	
			Beam	Span		Hard wood	Soft wood	☐	☐	
				2m		190 x 100	230 x 120	☐	☐	
				2.5m		220 x 100	270 x 140	☐	☐	
				2.5m - 3m		240 x 120	310 x 150	☐	☐	
				3m - 3.5m		270 x 140	340 x 160	☐	☐	
				3.5m – 4m		300 x 150	370 x 170	☐	☐	
			Beam(bare frame)	2.5m		100 x 130	130 x 140	☐	☐	
			Joist	1m		100 x 65	140 x 75	☐	☐	
				1.5m		100 x 65	140 x 75	☐	☐	
				2m		100 x 65	140 x 75	☐	☐	
				2.5m		120 x 65	170 x 90	☐	☐	
				3m		130 x 75	180 x 90	☐	☐	
				3.5m		140 x 80	200 x 100	☐	☐	
				Spacing		Less or equal to 0.5m		☐	☐	
		Bracing	location	It shall be located symmetrical and balanced.				☐	☐	
			Direction	It shall not be in same direction.				☐	☐	
			Size/number	It shall be as per the specification or calculation.				☐	☐	
			Knee brace	For bare frame structure, It shall be provided at all junction of beam and column.				☐	☐	
6	**Connection and joints**	All the structural members shall be properly connected using either nails, bolts or metal plate as per the specification.						☐	☐	

Others:

a. At least six number of photographs with their number (eg: dsc0152.jpg)

b. G.P.S Co-ordinate

Number ☐ Direction ☐ height from sea level ☐

c. Tentative drawings of building:

d) After the detail description of the under constructed house, is it necessary to give additional correction order?

☐ Yes ☐ No

☐ After the technical inspection it has been passed hence it is certified for further construction and the receiving third tranche ie. Rs 75000 and if toilet/alternative solar technology is installed additional 25000 can be provided.

☐Correction/ Retrofitting Order is needed so,use Annex-11 Correction/ Retrofitting Order and Inspection form

e) Acceptation of Description provided after technical supervision:

House owner/Beneficiaries or representative name:.. Signature:..........................

Relationship with house owner (In case of representative):..............................Date:...................................

f) Approval for description of Technical Inspection

Technical Inspector of MoUD DLPIU:..

Name:... Post:...

Signature: .... Date: ....

g) Description of Technical Inspection approval by

Technical Engineer of MoUD DLPIU:..

Name:... Post:...

Signature: .... Date: ....

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Annex-19: Forms for technical inspection of light timber frame structure Category "c" buildings

Light Timber Frame structure CATEGORY"C" BUILDINGS -FINAL INSPECTION

Government of Nepal
Ministry of Urban Development
Central Level Project Implementation Unit

Inspection Sheet

Light Timber Frame structure CATEGORY "C" BUILDINGS FOR FINAL INSPECTION

Information of House Owner/Beneficiary		Date of Inspection	M M	D D	Y Y Y Y		
Name		Grant Agreement No.					
Address		District	VDC/Municipality	ward	tole	Land plot No	

SECTION-I: DESCRIPTION PROVIDED IN THE APPLICATION TO SURVEY THE HOUSE

If use fix design from design catalogue,		Design No.	
If free design by house owner Fill construction typology from P.A form		Technique and Construction material	
		Construction of roof and materials	
Technical Assistance	☐Yes ☐No	Organization	☐ GoN, ☐ NGO ( )
Trained Masons Used	☐Yes ☐No	Soil Type	☐Hard, ☐Medium, ☐Soft

SECTION- II: DETAILED TECHNICAL INSPECTION

No.	Category	Description			Comply to MRs Yes	Comply to MRs No	Remarks
6	Connection and joints	All the structural members shall be properly connected using either nails, bolts or metal plate as per the specification.			☐	☐	
7	Roof	Wood	Material	Use of light roof	☐	☐	
			Connection	All member shall be properly connected.	☐	☐	
			Bracing	For flexible diaphragm, diagonal bracing shall be provided at extreme end bay.	☐	☐	

a. Others:
b. At least six number of photographs with their number (eg: dsc0152.jpg)
c. G.P.S Co-ordinate

Number ☐ Directi ☐ height from sea level ☐

d. Tentative drawings of building:
e. After the detail description of the constructed house, is it satisfactory to give certification of construction completion.

Yes ☐ , No ☐

f. If it is satisfactory, then please provide Inspection certificate based on annex-X, if not please order for correction based on Annex-X
g. Acceptation of Description provided after technical supervision:

House owner/Beneficiaries or representative name:…………………………………. Signature:…………………….

Relationship with house owner (In case of representative):……………………….Date:…………………………

h. Approval for description of Technical Inspection

Technical Inspector of MoUD-DLPIU:……………………………………………………

Name:…………………………………………… Post:…………………………………………

Signature: ……………………………………… Date: ………………………………

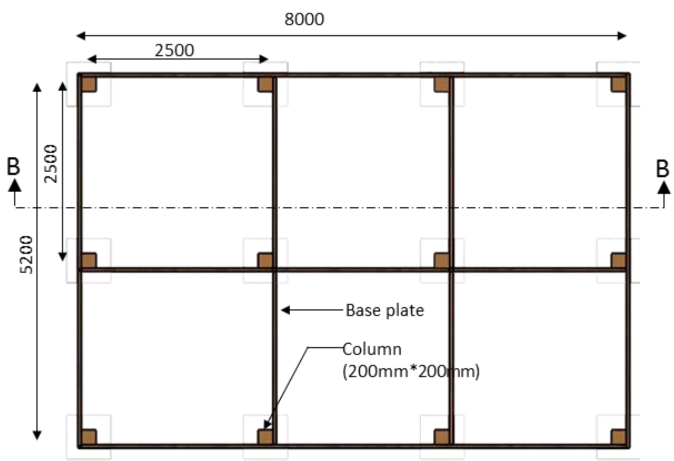
i. Description of Technical Inspection approval by

Technical Engineer of MoUD-DLPIU:……………………………………………………

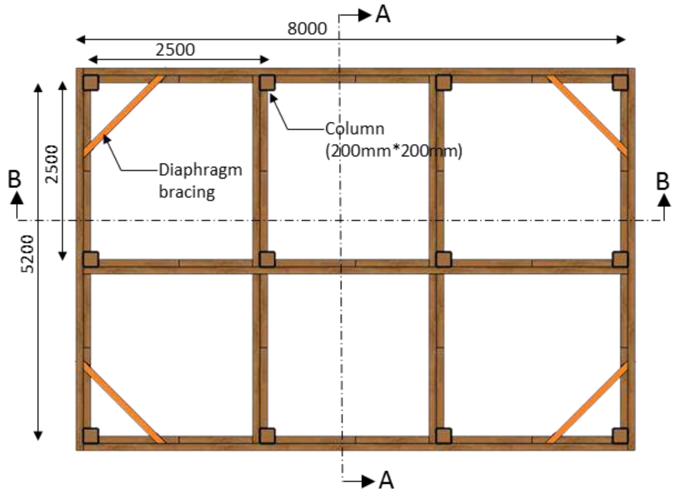
Name:…………………………………………… Post:…………………………………………

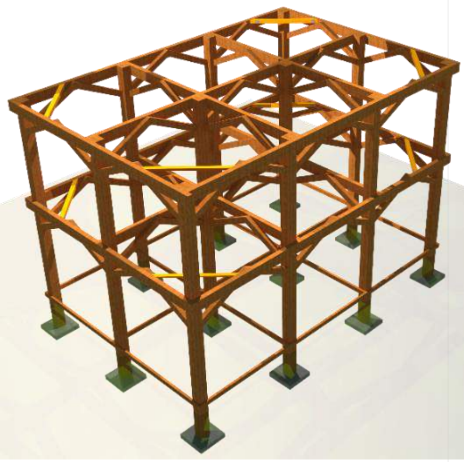
Signature: ……………………………………… Date: ………………………………

Prototype traditional model

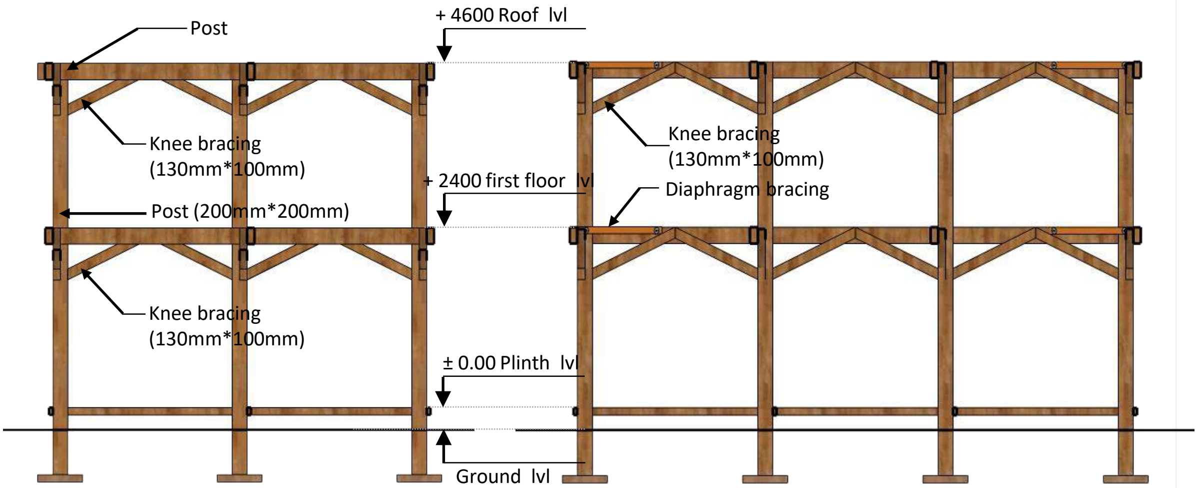


Ground floor plan





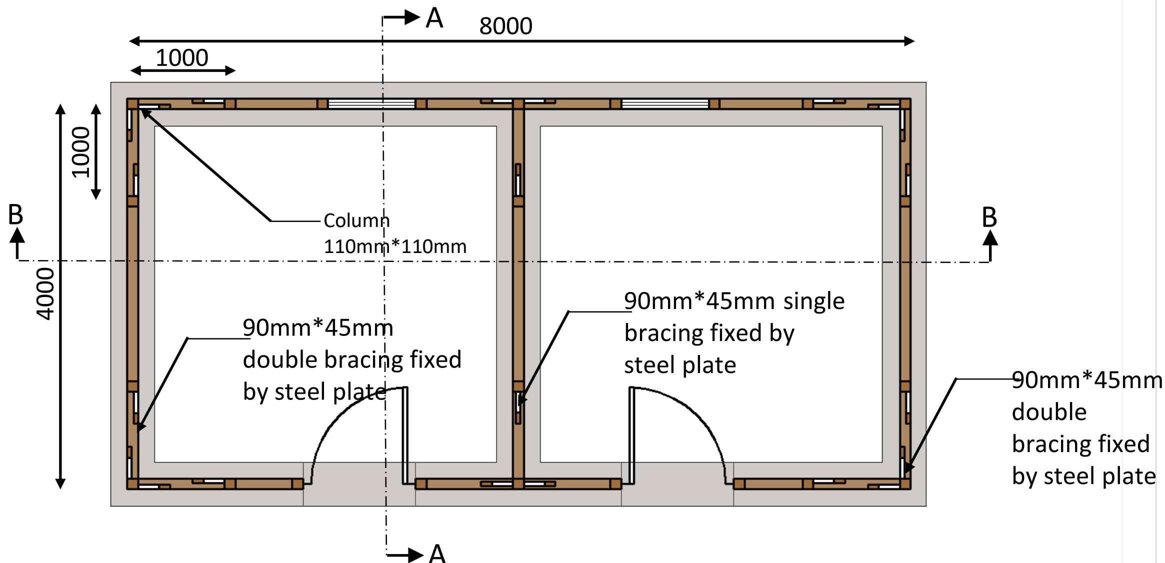
Isometric view



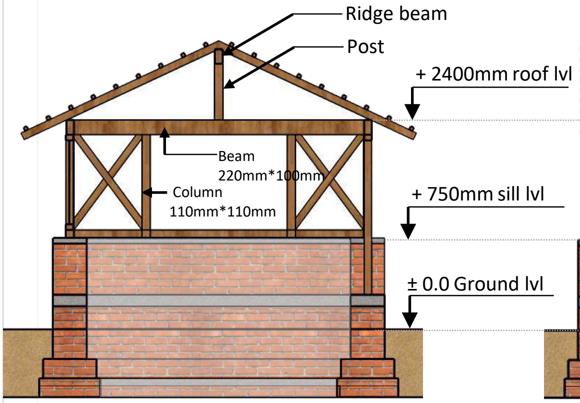
Section at A-A

Section at B-B

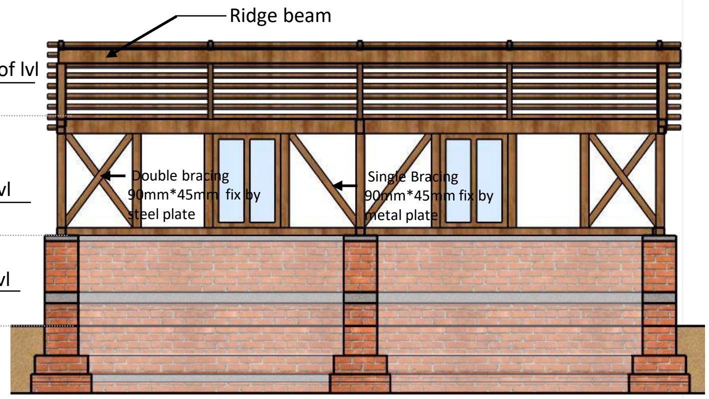
Prototype half frame model



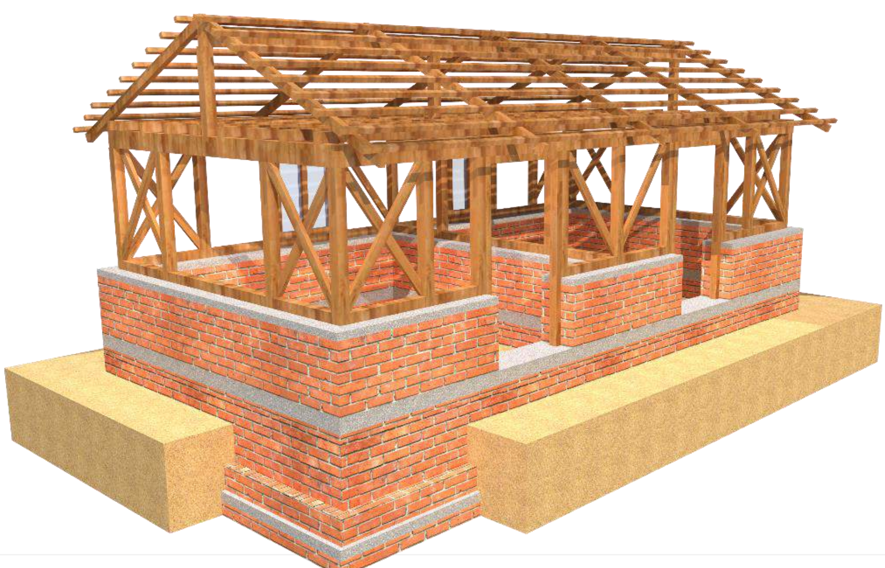
Ground floor plan



Section at A-A

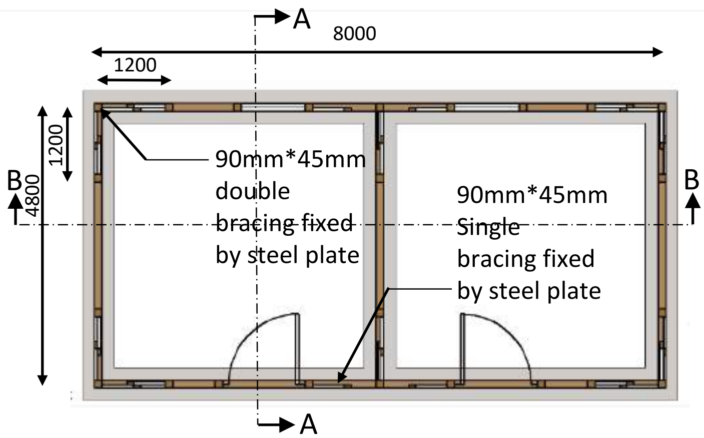


Section at B-B

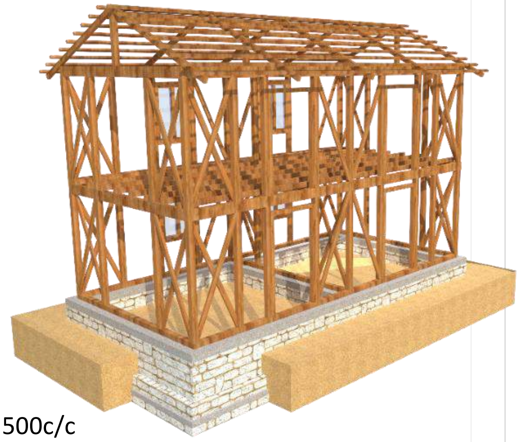


Isometric view

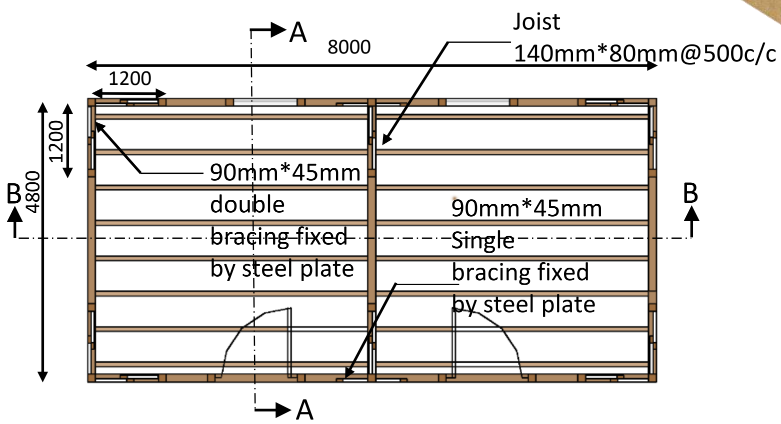
Prototype two storey frame model



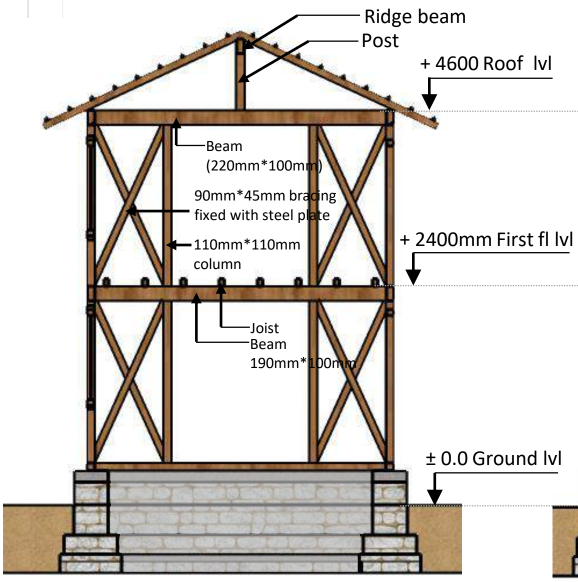
Ground floor plan



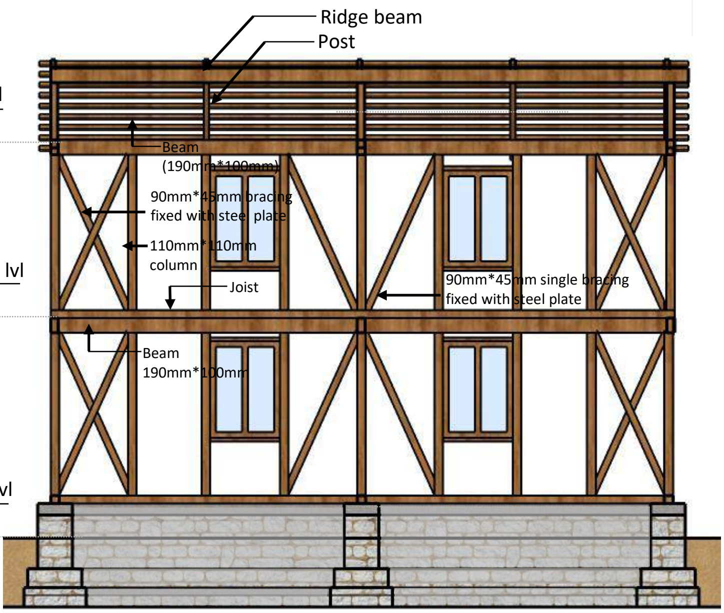
Isometric view



First floor plan



Section at A-A



Section at B-B

SEISMIC LOAD CALCULATION

Weight of building	Roof	Unit weight		6	light (CGI)	0.79	kN/sq.m
		Area		7		61.20	sq.m
		Sub total	6*7	8		48.35	kN
	Wall (GFL)	Unit weight		9	light (CGI, wooden plank)	0.50	kN/sq.m
		Area total length		10		30.40	m
		Area height		11		2.40	m
		Sub tatal	9*10*11	12		36.48	kN
	Wall (1FL)	Unit weight		13	light (CGI, wooden plank)	0.50	kN/sq.m
		Area total length		14		30.40	m
		Area height		15		2.40	m
		Sub tatal	13*14*15	16		36.48	kN
	Floor (1FL)	Unit weight		17	heavy (with mud)	2.52	kN/sq.m
		Area		18		38.40	sq.m
		Sub total	17*18	19		96.77	kN
	Floor (If attic is there)	Unit weight		20	light (without mud)	0.50	kN/sq.m
		Area		21		0.00	sq.m
		Sub total	20*21	22		0.00	kN
	Total weigth of GFL		8+12+16+19+22	23		218.08	kN
	Total weight of 1FL		8+16+22	24		84.83	kN
Seismic load for GFL			5*23	25		**43.62**	kN
Seismic load for 1FL			5*24	26		**16.97**	kN

ALLOWABLE STRENGTH

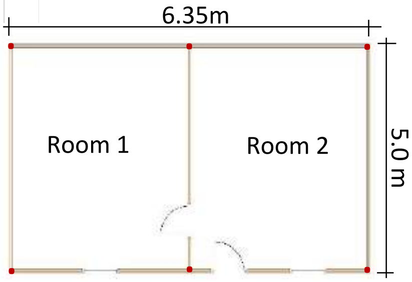
Ground Floor	X-directoin	Method of bracing/wall construction	Refer from table no.1	1	Wooden brace 90*45 plate	3.20	kN/m	
		Applicable only for wooden brace		2	double	2.00		
		Shear panel	Length of one brace	3		1.20	m	
			Number	4		6.00		
		Total strength	1*2*3*4	5		**46.08**	kN	OK
	Y-directoin	Method of bracing/wall construction	Refer from table no.1	6	Wooden brace 90*45 plate	3.20	kN/m	
		Applicable only for wooden brace		7	double	2.00		
		Shear panel	Length of one brace	8		1.20	m	
			Number	9		6.00		
		Total strength	6*7*8*9	10		**46.08**	kN	OK
1st Floor	X-directoin	Method of bracing/wall construction	Refer from table no.1	11	Wooden brace 90*30 nail	1.90	kN/m	
		Applicable only for wooden brace		12	double	2.00		
		Shear panel	Length of one brace	13		1.20	m	
			Number	14		6.00		
		Total strength	11*12*13*14	15		**27.36**	kN	OK
	Y-directoin	Method of bracing/wall construction	Refer from table no.1	16	Wooden brace 90*30 nail	1.90	kN/m	
		Applicable only for wooden brace		17	double	2.00		
		Shear panel	Length of one brace	18		1.20	m	
			Number	19		6.00		
		Total strength	16*17*18*19	20		**27.36**	kN	OK

Calculation base

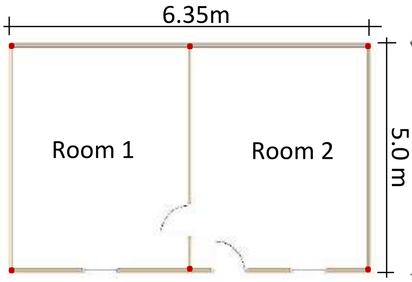
Inspection shall be used calculation

Workout example 4: Timber frame structure, two storey

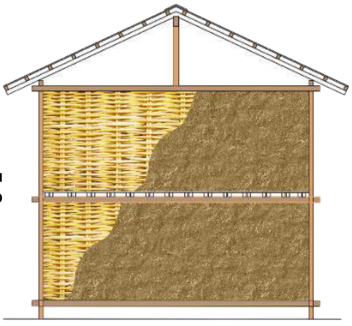
Seismic load calculation:



Ground floor plan



First floor plan



Section

Building description:				
	Floor area	5.0m x 6.35m	=	31.75 m^2
	Roof area	6.0m x 8.0m	=	48.0 m^2
	Wall area	Length:(5.0mx3+6.35mx2) x height 2.4	=	66.48 m^2

STEP1. Horizontal Seismic base shear force

The horizontal seismic base shear force

V=Cd * Wt

Design horizontal seismic coefficient

Cd=C*Z*I*K

=0.08*1*1*2.5=0.2

= Where, C=basic seismic coefficient

Z= Zone factor

I=Importance factor

K= Structural performance factor

Note: The value of K depends upon the typology of the structure. Take the value of K for framed structure.

STEP 2. Seismic load

Calculate weight of individual structural/non-structural component.

To calculate the total weight of individual structural components the total area shall be multiplied with unit weight. These unit weight depends upon the types of materials used for construction. Hence, depending upon these materials appropriate value of unit weight must be adopted.

Explanation of Unit weight :

Roof	Heavy	Slate roof, Mud roof	2.52	KN/sq.m.
	Light	CGI roof,	0.79	KN/sq.m.
Floor	Heavy	Wooden floor with mud plastered	2.52	KN/sq.m.
	Light	Wooden floor	0.5	KN/sq.m.
Wall	Heavy	Masonry wall	2.52	KN/sq.m.
	Light	CGI sheet, wooden plank	0.5	KN/sq.m.

Wt. of roof	=	Roof area*Unit weight (Light)
	=	48m2*0.79KN/m
	=	37.92KN
Wt of wall (first floor)	=	Wall area*Unit weight (Heavy)
	=	66.48 m2*2.52KN/m
	=	167.53 KN
Wt. of floor	=	Floor area*Unit weight(Light)
	=	31.75m2*0.5KN
	=	15.875KN
Wt. of wall (Ground floor)	=	Wall area*Unit weight (Heavy)
	=	66.48 m2*2.52 KN/m
	=	167.53 KN

Seismic capacity of wall:

Total weight in ground floor
= wt of roof+ wt of attic floor(if present) + wt. of first floor (wall+floor)+ wt of ground floor wall
= 37.92 KN+167.53 KN+15.87 KN+167.53 KN
=388.85 KN

Seismic load in ground floor =total weight(GFL)* Cd
= 388.85 KN*0.2
= 77.77 KN

Total weight in first floor
= wt of roof+ wt of attic floor(if present) + wt. of first floor (wall+floor)
= 37.92 KN+167.53 KN+15.87 KN
=221.32 KN

Seismic load in first floor =total weight(FFL)* Cd
= 221.32 KN*0.2
= 44.26 KN

Workout example:

If bamboo mesh with 50-70mm thick mud plastered being used instead of brace.

STEP3. Allowable strength:

Allowable strength=

Shear strength of unit wall* length* number of bracing/wall construction provided in each direction.

Brace:

Lets take bamboo mesh with 50-70mm thick mud plastered, where shear strength of unit wall is 1.8 KN/m.

Note: The shear strength of unit wall depends upon the method of bracing/wall construction, hence select the appropriate methods and its value.

Assumption:

Shear strength of unit wall=1.8 KN/m
Wall construction: Bamboo mesh with 50-70mm thick mud plaster.
Length=1.2m
Number of bracing provided=2(X-direction/Y-direction)

Ground floor:

X-direction:
Allowable strength=1.8*6.35 *2=22.86 KN
Y-direction:
Allowable strength=1.8*5*2=18 KN

Seismic load in ground floor=77.77 KN
Results:

∴ Allowable strength < Seismic load. *FAIL

Since, the allowable strength in ground floor is less than the seismic load in ground floor the bracing member/wall construction needs to be replaced.

First floor:

X-direction:
Allowable strength=1.8*6.35 *2=22.86 KN
Y-direction:
Allowable strength=1.8*5*2=18 KN

Seismic load in first floor=44.26 KN
Results:

∴ Allowable strength < Seismic load. *FAIL

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Description of existing building:

Majority of the buildings existing in the site are somehow approximate to the descriptions presented below:

Dimensions:

Generally most of the buildings, which are two storied and without attic floor, are square symmetrical in shape. This considered building has a planar dimensions of 9.6 m X 9.47 m; in addition, the storey height of the building is 2.13 m and height difference of ridge beam from eaves level is one meter.

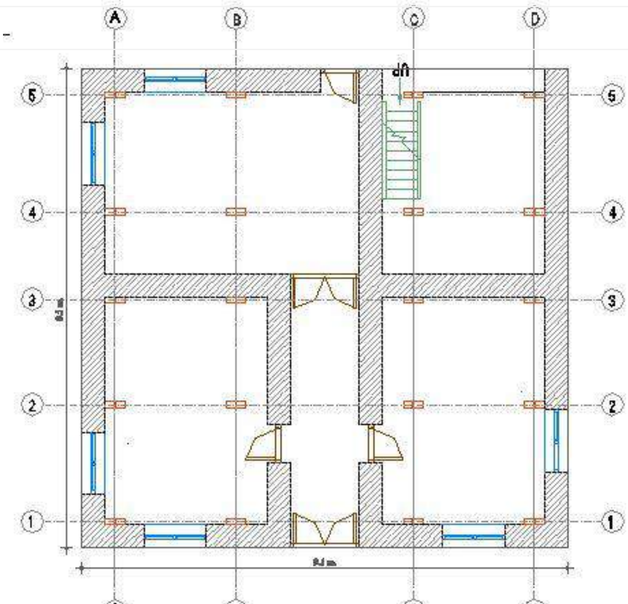
Frame structures:

Most of the timber columns in ground story consist of two wooden posts, out of which one ends at floor level supporting the beams running in perpendicular direction to joists whereas next post continues up to eaves level to support the beams running in both directions. Moreover, there are no beams on the first floor level in the direction parallel to joists.

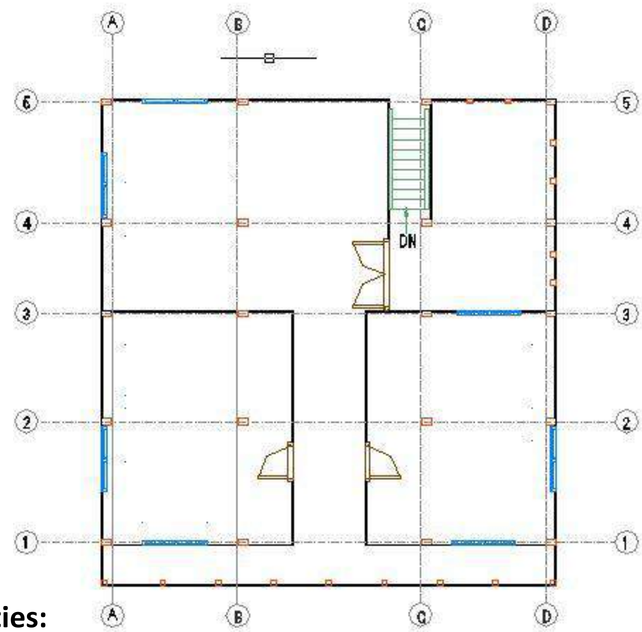
Description	Size	Remarks
Beam	130 mm X 110 mm	Depth X Breadth
Column	180 mm X 130 mm	
Joist	80 mm X 50 mm	
Wooden Plank	25 mm thick	
Ridge Beam	Diameter 150 mm	
Rafter	75 mm X 50 mm	
Purlin	75 mm X 50 mm	

Walls:

Usually, the external and the internal walls in the ground story are of stone masonry of 450 mm thickness whereas the walls in the upper story are of light materials: wooden plank (25 mm), CGI sheets, etc. Furthermore, the walls in the ground story are either outside or inside of the plane of timber frames. In addition, these walls do not transmit any load of the building except their self-weight and are functioning only as a partition walls.



Ground Floor plan



First Floor plan

Material Properties:

<u>Wood</u>

Type = Hardwood (Sal)

Unit weight = 8.65 KN/m^3

Modulus of elasticity =12500000 KN/m^2

Bending strength (inside location) =16.5 Mpa

Compressive strength (inside location) = 10.4 Mpa

Shear strength, horizontal in beams = 0.9 Mpa

Shear strength, along grain = 1.3 Mpa

References: NBC 112 (1994)

<u>Roofing material</u>

Type = stone tiles (slate)

Unit weight = 27.45 KN/m^3 (*References: IS 875 Part 1)*

Thickness = 25 mm

Modelling:

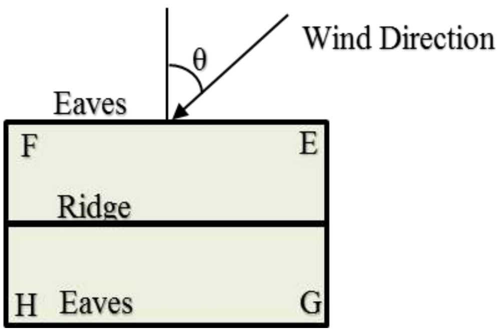
Loads
Live load (floor) = 2 KN/m2
Live load in roof = 0.75 KN/m2

Design Horizontal Seismic Coefficient (NBC 105:1994)

Zone factor	Z	1		Figure 8.2
Importance factor	I	1		cl 8.1.7, table 8.1, other structures
Structural performance factor	K	2		
Height of the building	h	5.26	m	Refer dwg.
Dimension of the building along X	D_x	9.47	m	Refer dwg.
Dimension of the building along Y	D_y	9.60	m	Refer dwg.
Time period of the building along X	T_x	0.154	sec	Tx = 0.09h/√Dx, Cl 7.3
Time period of the building along Y	T_y	0.153	sec	Ty = 0.09h/√Dy, Cl 7.3
Soil type		Medium (Type II)		Cl 8.1.5
Basic seismic coefficient along X	C_x	0.08		Cl 8.1.4, fig 8.1
Basic seismic coefficient along Y	C_y	0.08		Cl 8.1.4, fig 8.2
Design horizontal seismic coefficient	C_d	0.16		Cd = CZIK, Cl 8.1.1

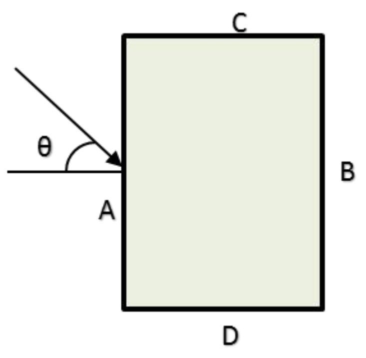
Wind Load:

Wind load is calculated as per IS 875 (Part 3)-1987 as referred by NBC 104:1994.
Design wind speed (Vz) = 47 m/s (lower zone of Sindhuli district, which is connected to terai belt and has fairly even area)
Probability factor (K_1) = 1
(Ref: T-1 of IS 875 (Part 3)-1987)
Terrain, height and structure size factor (K_2) = 1.05
(Ref: T-2 of IS 875 (Part 3)-1987
Terrain Category = 1
Building class = A)
Topography factor (K_3) = 1+C*S=1+0.36*1= 1.36
C = 0.36 *(Annex: C-2, IS 875 (Part 3)-1987)*
S = 1 *(Annex: C-2.1, IS 875 (Part 3)-1987)*
<u>Wind load coefficients</u>
<u>Coefficient for pitched roofs</u>:



	Cp (Windward)	Cp (Leeward)
Normal to Ridge, θ =0	-1.17	-0.60
Parallel to Ridge, θ =90	-0.97	-0.80

(Cpe, external pressure coefficient (T-5, IS 875 (Part 3)-1987)
Cpi, internal pressure coefficient (cl.6.2.3.1, IS 875 (Part 3)-1987))
<u>Coefficient for walls</u>:



	Cp (Windward)	Cp (Leeward)	Cp (Adjacent)
Normal to Longer wall, θ =0	0.90	-0.40	-0.70
Normal to Shorter wall, θ =90	0.90	-0.40	-0.70

Here, Cp = Cpe± Cpi
(Cpe, external pressure coefficient (T-4, IS 875 (Part 3)-1987)
Cpi, internal pressure coefficient (cl.6.2.3.1, IS 875 (Part 3)-1987))

Assumptions:
All the rafters, purlins, joists, bracings, studs, beams are assumed to be simply supported i.e. torsional capacity is released at one end whereas moment capacity is released at both ends.
The support system is assumed to be simply supported.
The adjacent posts of ground floor are connected by link element at the spacing of 500 mm c/c.
The modelling of the timber frame structure is done by using ETABS 2016 Version 16.2.0. The 3D view of the building is shown below:

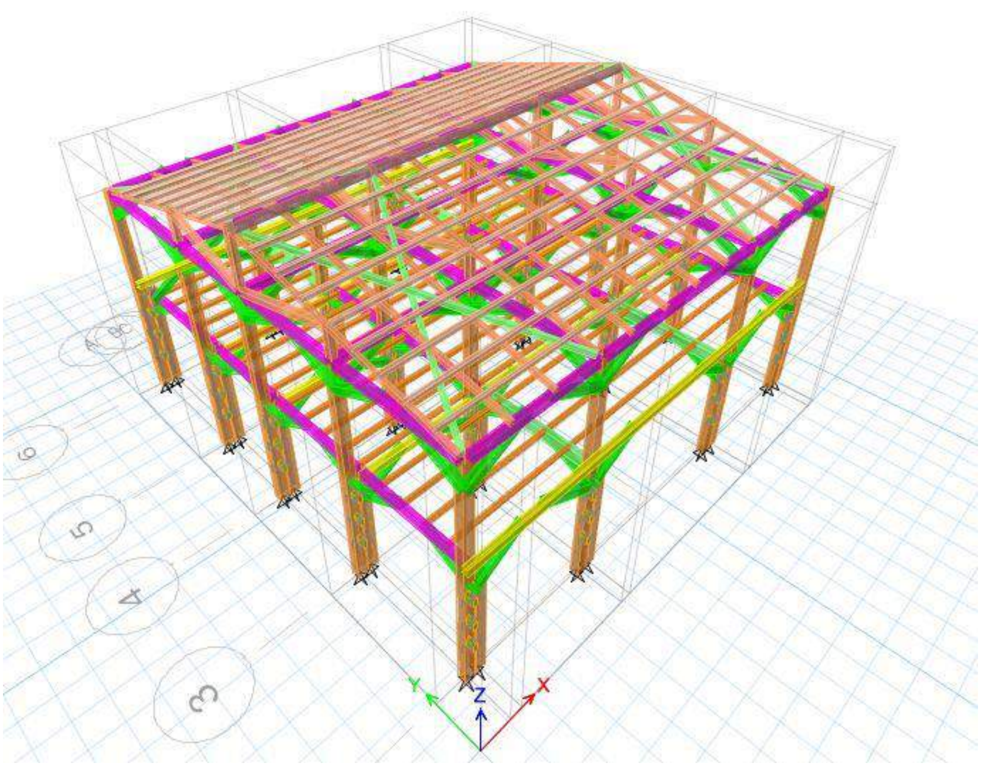


Figure 1: 3D Model

Analysis:
The analysis of the building is done by using ETABS 2016 Version 16.2.0. Seismic Coefficient Method is used to analyse the building in earthquake load.

Calculation of Base Shear

Load Pattern	Type	Direction	C	Weight Used	Base Shear
				kN	kN
EQx	Seismic	X	0.2	188.601	30.1762
EQy	Seismic	Y	0.2	188.601	30.1762

Load combinations for the analysis of the building:
The design loads for the Working Stress Method as per NBC 105:1994 are:
Including the Earthquake Load
a. DL+LL+Eqx
b. DL+LL-Eqx
c. DL+LL+Eqy
d. DL+LL-Eqy
e. 0.7DL+Eqx
f. 0.7DL-Eqx
g. 0.7DL+Eqy
h. 0.7DL-EQy
Including the Wind Load
a. DL+LL+Wind X+
b. DL+LL+Wind X-
c. DL+LL+Wind Y+
d. DL+LL+Wind Y-
e. 0.7DL+Wind X+
f. 0.7DL+Wind X-
g. 0.7DL+Wind X+
h. 0.7DL+Wind X-

After subjecting the building to aforementioned load combinations, checking of all the elements as well as of the building were done. The conclusions of the analysis are listed below:
Many beams were failed in both shear and bending moment.
All existing sized columns were passed in both interaction check (axial and bending moment) and shear check.
Global deformation of the building is under control of codal guidelines.

Additions:
After performing successive iterations following elements were added to strengthen the performance of building:
Beams of existing size (130 mm X 100 mm) were added in the next direction in the ground floor i.e. at the first floor level. In field, it is difficult to install these beams at the same level of existing beams; thus, the outer beams were modelled slightly above the existing model whereas inner beams were modelled below the level of existing beams (For detail refer below: figure 2, 3).
Knee bracings (130 mm X 100 mm) were added in each and every beam column joints to improve the joint performance (For detail refer below: figure 2,3 and 4).
Wooden roof truss (100 mm X 100 mm) were improved at each vertical plane where beams exist (For detail refer below: figure 4). Moreover, bracings (100 mm X 100 mm) were added as shown in figure 3 to control the deflection of ridge beam.
Diagonal Roof Bracings of size 80 mm X 50 mm were provided in end bays to improve the roof diaphragm (For detail refer below: figure 5).

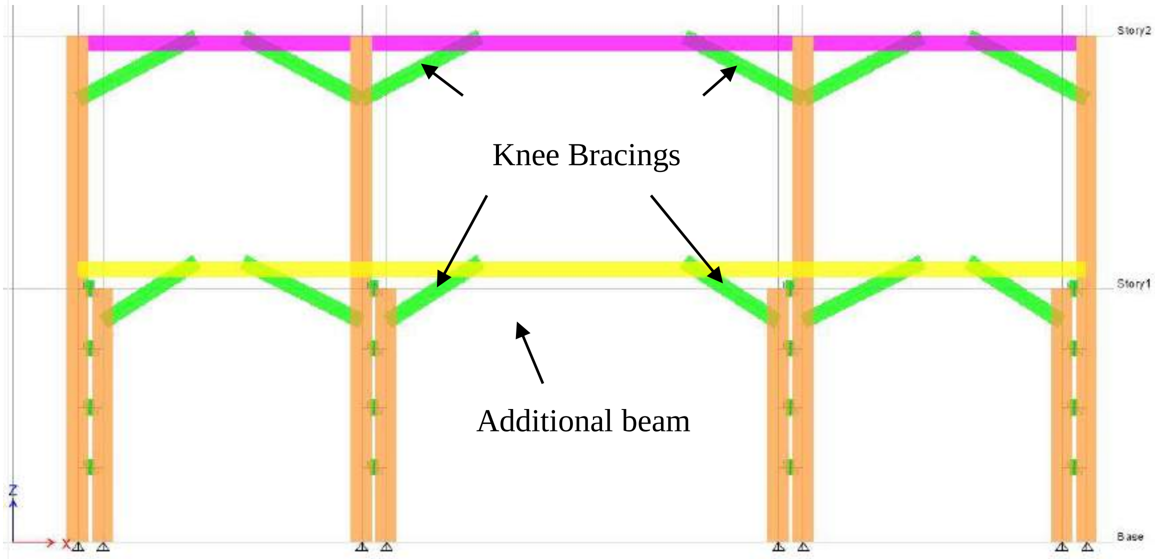


Figure 2: Additional beam above the level of existing beam

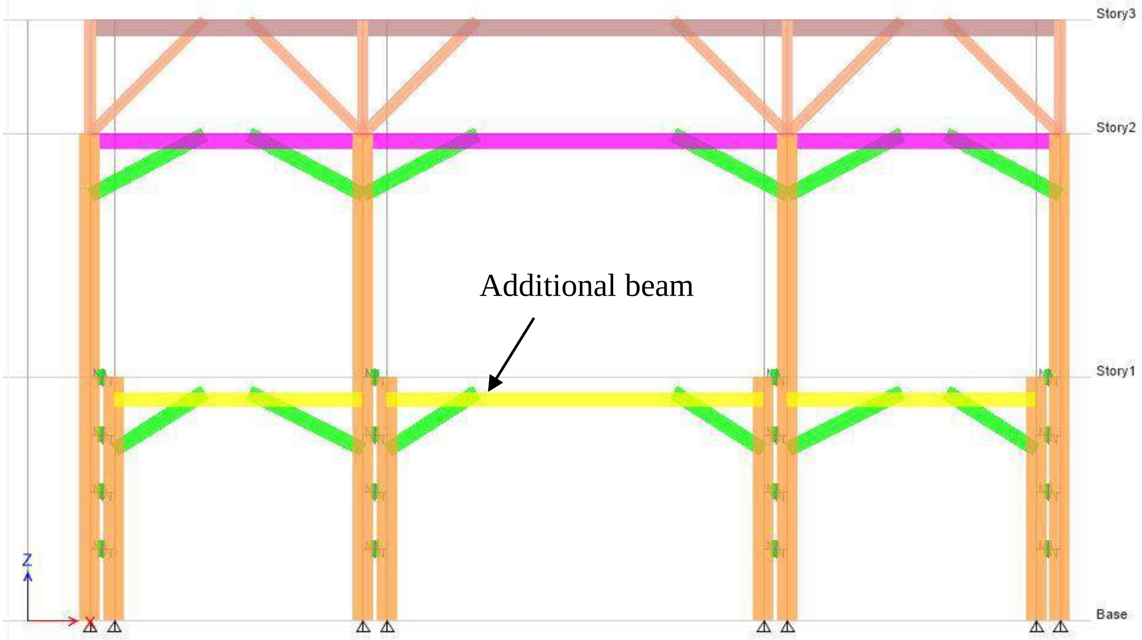


Figure 3: Additional beam below the level of existing beam

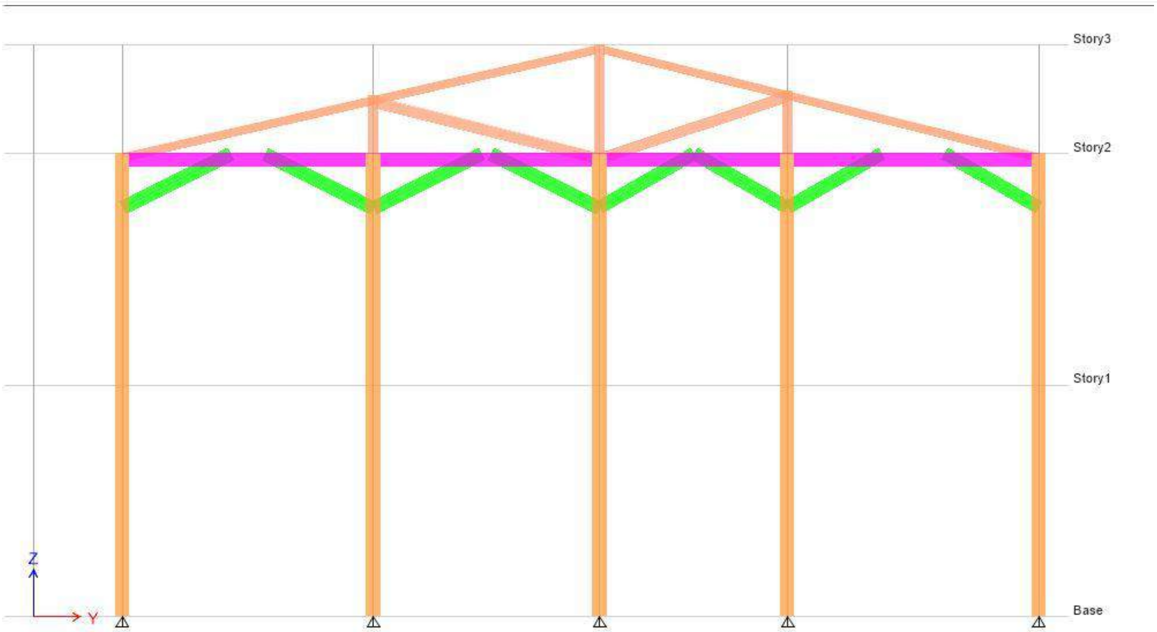


Figure 4: Improved Roof Truss System

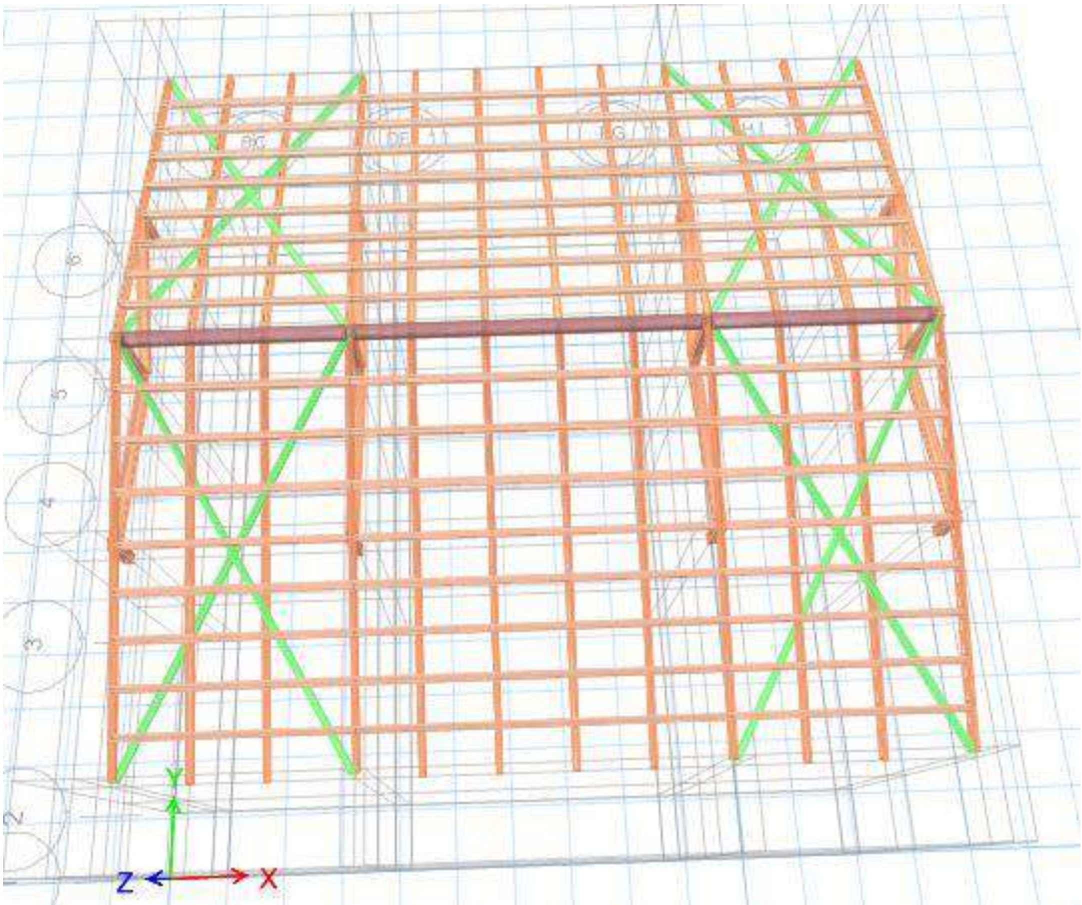


Figure 5: Diagonal Roof Bracing

After adding aforementioned members, the analysis of the building is carried out. In this case, all the members of the building had satisfied the codal requirements except few intermediate existing beams with span 2.31 m. These intermediate beams had failed in shear as well as in the interaction (axial and bending) check. Thus, the depth of only these beams were increased and back-to-back trials were carried out. The depth satisfying all the codal requirements is 200 mm. One of the frames consisting these beams is depicted in figure 6.

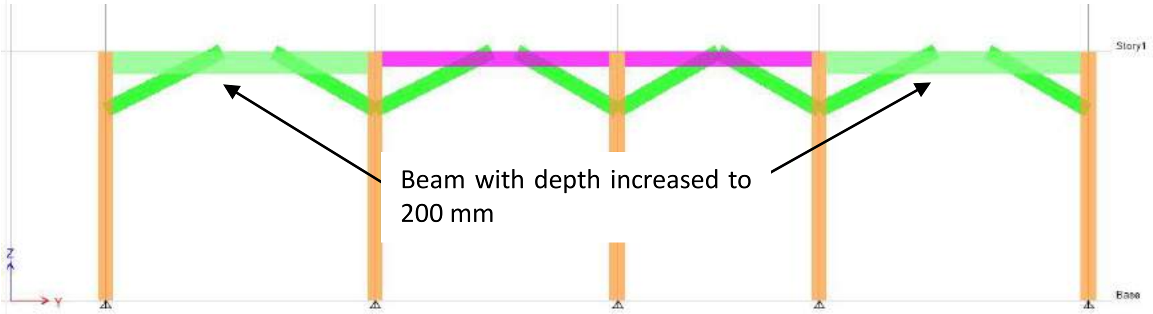


Figure 6: Beams with depth increased to 200 mm

Design of Structure:

Design of all the members were carried out in the envelope load. Working stress philosophy is used for the design of the different elements of the building.

Check of beam

The beams are checked in interaction of axial and bending as well as in shear. The interaction……………
The check of all the beams were tabulated in the Annex ……whereas, only the sample calculation (Beam Identity: B8) is shown below.

Interaction check:					
Maximum Moment=	M	3.53	KN-m		
Corresponding Axial force =	P	25.99	KN		
Depth of Beam =	d	0.200	m		
breadth of beam =	b	0.100	m		
Section Modulus =	Z	0.000667	m^3		
Form factor, a reduction constant for Z =	K	1	As, D	<	0.3 m
Bending stress = M/Z =	σb	5.29	N/mm^2		
Axial stress = P/A =	σt	1.30	N/mm^2		
For Inside location, bending Permissible stress =	σpb	16.5	N/mm^2		
For Inside location, axial Permissible stress =	σpt	10.4	N/mm^2		
σt/σpt + σb/σpb		0.446	<	1	OK
Shear Check:					
Shear Stress = (1.5V)/(b X d)	Ʈv				
Shear force =	V	9.61	KN		
Permissible Shear Stress	Ʈc	0.90	N/mm2		
$Ʈ_v$ =		0.72	N/mm^2 < 0.9 N/mm2		OK
Depth required to satisfy deflection criteria:	-				
dmin=> (50*Fb/E)*L			(Ref. NBC 112 Cl.6.4)		
Length =	L	1.72	m		
Modulus of Elasticity =	E	12500000	KN/m2		
dmin =		0.04	m	< 0.2 m	OK

Where,
σt is calculated average axial compressive stress in N/mm^2
σb is calculated bending stress in extreme fibre in N/mm^2
σpt is permissible stress in axial compression in N/mm^2
σpb is permissible stress in bending in N/mm^2

Check of columns:
The columns are checked in interaction of axial and bending as well as in shear. The interaction……………
The check of all the columns were tabulated in the Annex ……whereas, only the sample calculation (Column Identity: C12) is shown below.

Interaction check			
Depth of Column=	d	0.18	m
Width of Column=	b	0.13	m
Length of Column =	L	2.13	m
Density of Wood=		8.65	KN/m^3
Axial load =	P	21.12	KN
Bending Moment =	M	5.27	KN-m
For timber member subjected to both bending and axial compression shall be designed to comply with the following formula:			
σc/σpc + σb/σpb <1			
σc = P/A		0.90	N/mm^2
σb = M/Z			
Section modulus = $bd^2/6$ =	Z	702000.00	mm^3
σb=		7.51	N/mm^2
σpc =		10.40	N/mm^2
σpb=		16.50	N/mm^2
σc/σpc + σb/σpb =		0.54	< 1 OK
Check of Shear Stress:	-		
Shear force =	V	4.83	KN
Permissible Shear stress=	Ʈc	1.3	N/mm2
Shear stress =	Ʈv	0.21	N/mm2 < 1.3 N/mm2 OK

Check of ridge beam

The beams are checked in interaction of axial and bending as well as in shear. The interaction…………..

The check of all the beams were tabulated in the Annex ……whereas, only the sample calculation (Ridge Beam Identity: B40) is shown below.

Interaction check:					
Maximum Moment=	M	3.74	KN-m		
Corresponding Axial force =	P	2.27	KN		
Diameter of Beam =	d	0.150	m		
Section Modulus =	Z	0.000331	m^3		
Form factor, a reduction constant for Z =	K	1	As, D	<	0.3 m
Bending stress = M/Z =	σb	11.30	N/mm^2		
Axial stress = P/A =	σt	0.13	N/mm^2		
For Inside location, bending Permissible stress =	σpb	16.5	N/mm^2		
For Inside location, axial Permissible stress =	σpt	10.4	N/mm^2		
σt/σpt + σb/σpb		0.697	<	1	OK
Shear Check:					
Shear Stress = (4/3V)/(A)	Ʈv				
Shear force =	V	1.14	KN		
Permissible Shear Stress	Ʈc	0.90	N/mm2		
$Ʈ_v$ =		0.06	N/mm^2 < 0.9 N/mm2		OK
Depth required to satisfy deflection criteria:	-				
dmin=> (75*Fb/E)*L			(Ref. NBC 112 Cl.6.4)		
Length =	L	1.72	m		
Modulus of Elasticity =	E	12500000	KN/m2		
dmin =		0.12	m	< 0.2 m	OK

Where,

σt is calculated average axial compressive stress in N/mm^2

σb is calculated bending stress in extreme fibre in N/mm^2

σpt is permissible stress in axial compression in N/mm^2

σpb is permissible stress in bending in N/mm^2

Drift Check:

Drift of the building is checked as per the requirement suggested by Clause 9, NBC 105. The design lateral deformations resulting from the application of the forces is increased by the factor 5/K as specified by Clause 9.1. Then the obtained inter-story deflection is checked against 60 mm as specified by Clause 9.3. Furthermore, the inter-story drift ratio is calculated and checked against 0.01 as specified by Clause 9.3. The detail of drift check is tabulated below:

Direction of loading	Load Case	Deformation from Etabs	Design lateral deformation (5/K* d)	Inter Story deflection	Check	Inter story drift ratio	Check
		d	D'	a	(a<60mm)	b	(b<0.01)
		m	mm	mm			
X	EQX	0.016	41.10	6.39	OK	0.003	OK
		0.014	34.71	14.25	OK	0.007	OK
		0.008	20.46	20.46	OK	0.007	OK
		0.000	0.00	0.00	OK		OK
Y	EQY	0.033	81.75	1.37	OK	0.001	OK
		0.032	80.39	34.44	OK	0.006	OK
		0.018	45.95	45.95	OK	0.009	OK
		0.000	0.00	0.00	OK		OK

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