



1. Build a Seismic Resilient House

Guideline for Seismic Resilient House Construction

Joint Research Project on
Evaluation and Mitigation of Seismic Risk for Composite Masonry Buildings in Bhutan

in the framework of SATREPS
(Science and Technology Research Partnership for Sustainable Development)
2017-2023

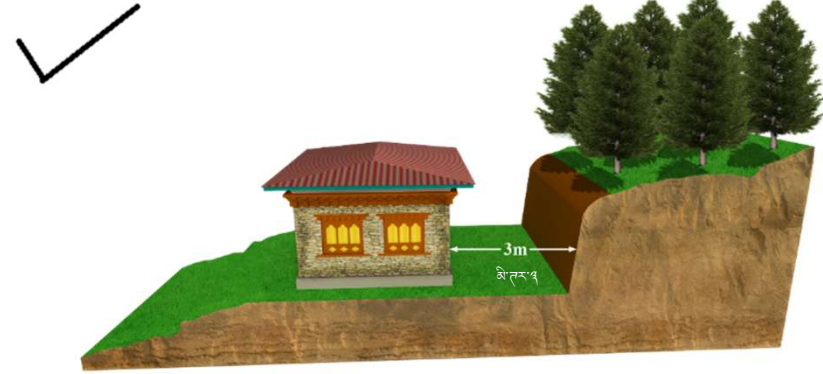
Department of Culture
Ministry of Home and Cultural Affairs

Department of Engineering Services
Ministry of Work and Human Settlement

1. Site Selection

Where shall a house be built ?

བྱིམ་རྒྱབ་པའི་ས་གོ་གདམ་ཁ།

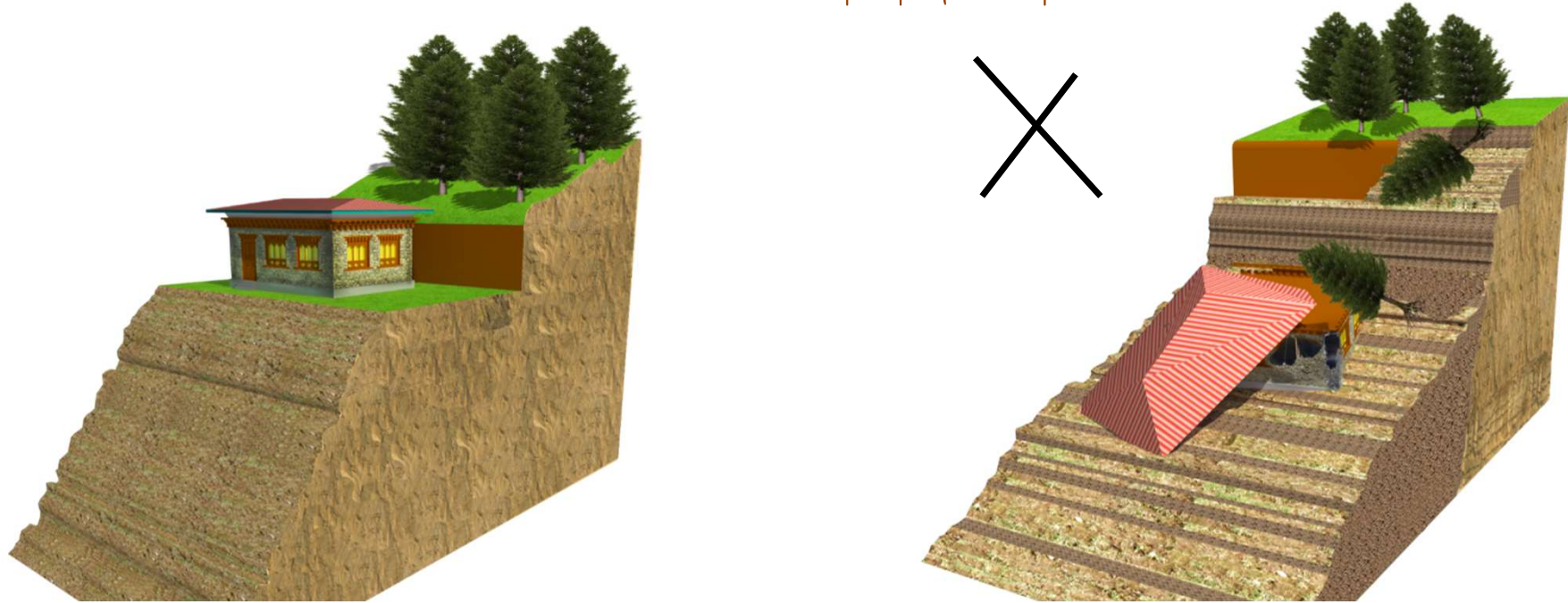


གྲུབ་གཟུང་དྲག་བཅད་དེ་བྱིམ་རྒྱབ་པའི་སྐབས་ གྲུབ་གཟུང་དྲག་བཅད་བཅད་པའི་མཚམས་དང་བྱིམ་གྱི་བར་ན་ ཉུང་ཤོས་མི་ལྷན་གྱི་འཇོག་སྟེང་གི་འཇོག་སྟེང་ ལྷན་གྱི་འཇོག་སྟེང་གི་འཇོག་སྟེང་ གྲུབ་ཆད་འོང་སྟེ་ བྱིམ་ལུ་གཞོན་པ་འབྱུང་ནི་ཡིན།

The house should not be constructed 3m within the cut slope, as the horizontal forces of the earth might cause the adjacent walls to collapse.

Where shall a house be built ?

བྱིམ་རྒྱབ་སའི་ས་གོ་གནམ་ལ།



བྱིམ་འདི་ གྲེན་གྱི་མཐའ་མར་ལུ་སྐྱུར་ཏེ་ རྒྱབ་ནི་མི་འོང་ འདི་ཡང་ས་ཆད་འགྱོ་བའི་སྐབས་ བྱིམ་ལུ་གནོད་པ་འབྱུང་ནི་ཨིན།

The house should not be constructed near or on top of the edge of slopes as it might collapse due to earth avalanches.

Where shall a house be built ?

བྱིམ་རྒྱབ་སའི་ས་གོ་གཤམ་ལ།



བྱིམ་རྒྱབ་ནི་དོན་ལུ་ས་དམར་སུ་ཡོད་ས་ལུ་ས་གསར་པ་ ལྷགས་ཏེ་ འདྲན་འདྲ་བཟོ་བའི་སྐབས་ས་གསར་པ་ ལྷགས་སའི་ས་གོ་འདི་ བྱིམ་གྱི་
སྤྱིང་ཚད་འབག་ཚུགས་ ནི་གི་དོན་ལུ་ས་འདི་བརྟུང་སྟེ་ རང་བཞིན་གྱི་ས་དང་ དབྱེ་བ་མེད་པ་སྟེ་ སྤྱིང་སྤྱིང་བཟོ་དགོ། དེ་སྟེ་མ་བཟོ་བ་
ཅིན་ས་གསར་པ་གི་ ཐོག་ཁར་བཟོ་སྐབས་འབད་བའི་ བྱིམ་འདི་མར་བསམ་འགྱུ་ནི་གི་ཉེན་ཁ་ཡོད།

Buildings should not be constructed on the loose fill, as its low bearing capacity might cause differential settlement of the foundation.

Where shall a house be built ?

བྱིམ་རྒྱུ་བ་སའི་ས་གོ་གཤམ་ལ།

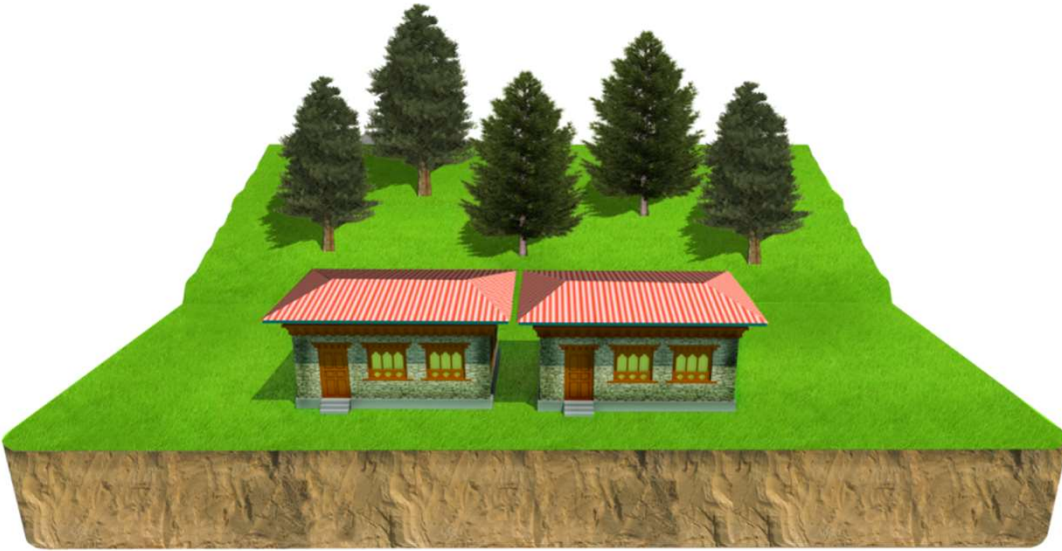


གྲེན་བརྟན་རྟོག་རྟོ་མེད་སའི་ས་གོ་ནང་ལུ་ས་གཞོལ་འགྲོ་ནིའི་ཉེན་ཁ་ཡོད་པ་ལས་བྱིམ་རྒྱུ་ནི་མི་འོང་། པར་ནང་ལུ་བརྟན་དོ་བཟུམ་གྱིང་འདི་ཚུ་གཡོ་གྲ་སྐྱེ་སྐྱེས་འདི་ཡོད་པ་ཅིན་ས་འདི་བརྟན་རྟོག་རྟོ་མེད་པའི་རྟག་མཚན་ཨིན།

The house should not be constructed on the unstable slopes as it might slide down.
The slopes where the trees are bent as shown in the picture are not stable.

Where shall a house be built ?

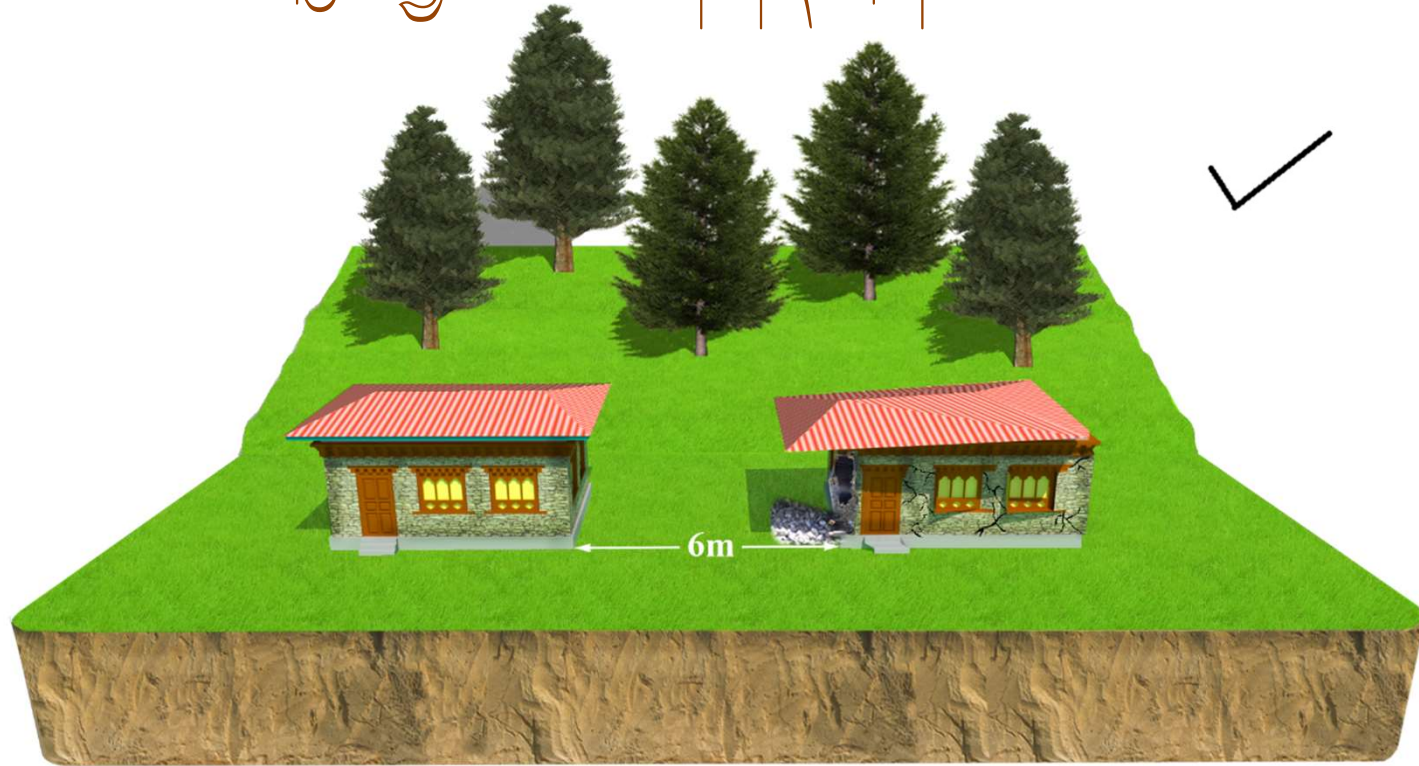
བྱིམ་རྒྱབ་སའི་ས་གོ་གནམ་ལ།



བྱིམ་འདི་ཚུ་ སློ་ལོགས་ཁར་སྐྱར་ཏེ་ རྒྱབ་ནི་མི་འོང་། གལ་སྲིད་ ས་ཡོམ་རྒྱབ་པའི་སྐབས་ བྱིམ་གཅིག་འགྲེལ་འོང་པ་ཅིན་ འདི་གིས་ སློ་ལོགས་ཁའི་ བྱིམ་གཞན་ཚུ་ལུ་ཡང་ གནོད་སྐྱོན་རྒྱབ་ནི་ཨིན། བྱིམ་གཉིས་ཀྱི་བར་ན་ རྒྱང་ཐག་ ཉུང་ཤོས་ མི་ཧུ་ བཞག་དགོས་ མ་ཚད་ རང་སའི་ས་ཁོངས་དང་བསྐྱུན་ དེ་བ་ལྷག་པ་སྟེ་བཞག་རུང་བཏུབ།

Where shall a house be built ?

བྱིམ་རྒྱབ་སའི་ས་གོ་གནམ་ལ།



Where shall a house be built ?

བྱིམ་རྒྱབ་པའི་ས་གོ་གནས་ལ།



ས་ཡོམ་རྒྱབ་པའི་སྐབས་ལུ་ ཤིང་འདི་ཚུ་འགྲེལ་ནི་གི་ཉེན་ཁ་ཡོད་པ་ལས་ བྱིམ་འདི་ཚུ་ ཤིང་སྤོམ་ཚུ་གི་སྤོམ་ལོགས་ཁར་རྒྱབ་ནི་མི་འོང་། ཤིང་
དང་ བྱིམ་གྱི་བར་ནའི་རྒྱང་ཐག་འདི་ བྱིམ་ ཡང་ན་ ཤིང་དེ་གི་རིང་ཚད་ ག་མཐོ་ཤོས་ཡོད་མི་དང་འབྲེལ་ཏེ་རྒྱབ་དགོ།

Where shall a house be built ?

བྱིམ་རྒྱབ་སའི་ས་གོ་གནམ་ལ།

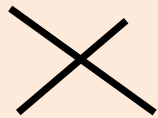


2. Basic Planning

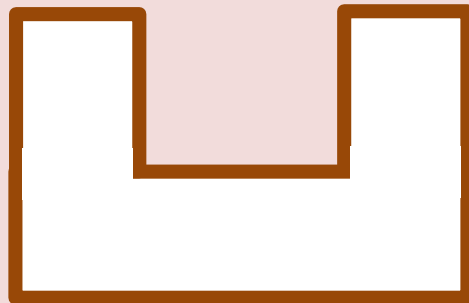
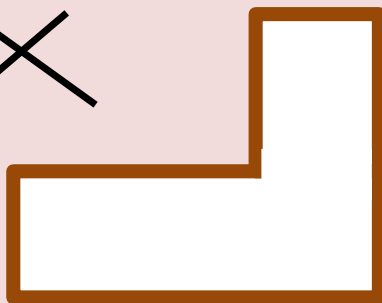
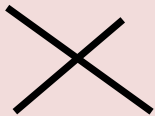
Planning: Building Shape བྱིམ་བཟོའི་སློབ་གསོའི་བཀོད་ཀྱི་



Simple and Symmetrical shape



Too long



Asymmetrical shape



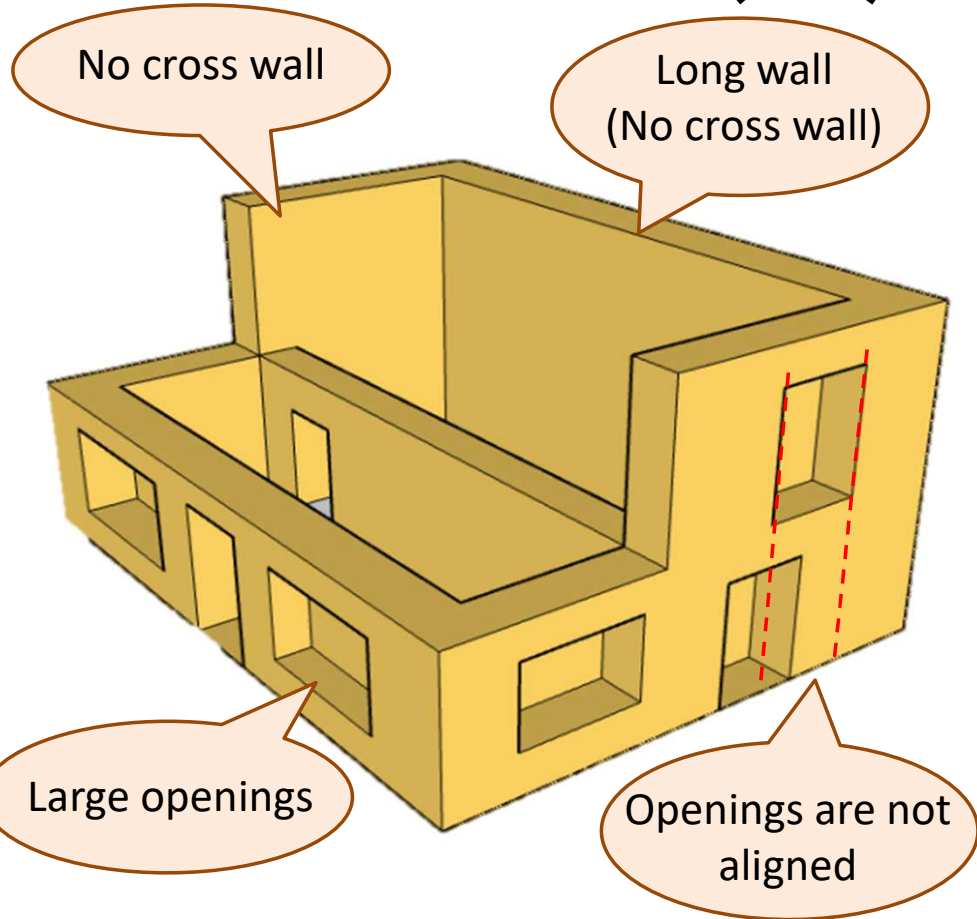
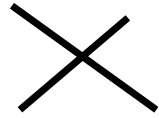
A typical house in rectangular shape



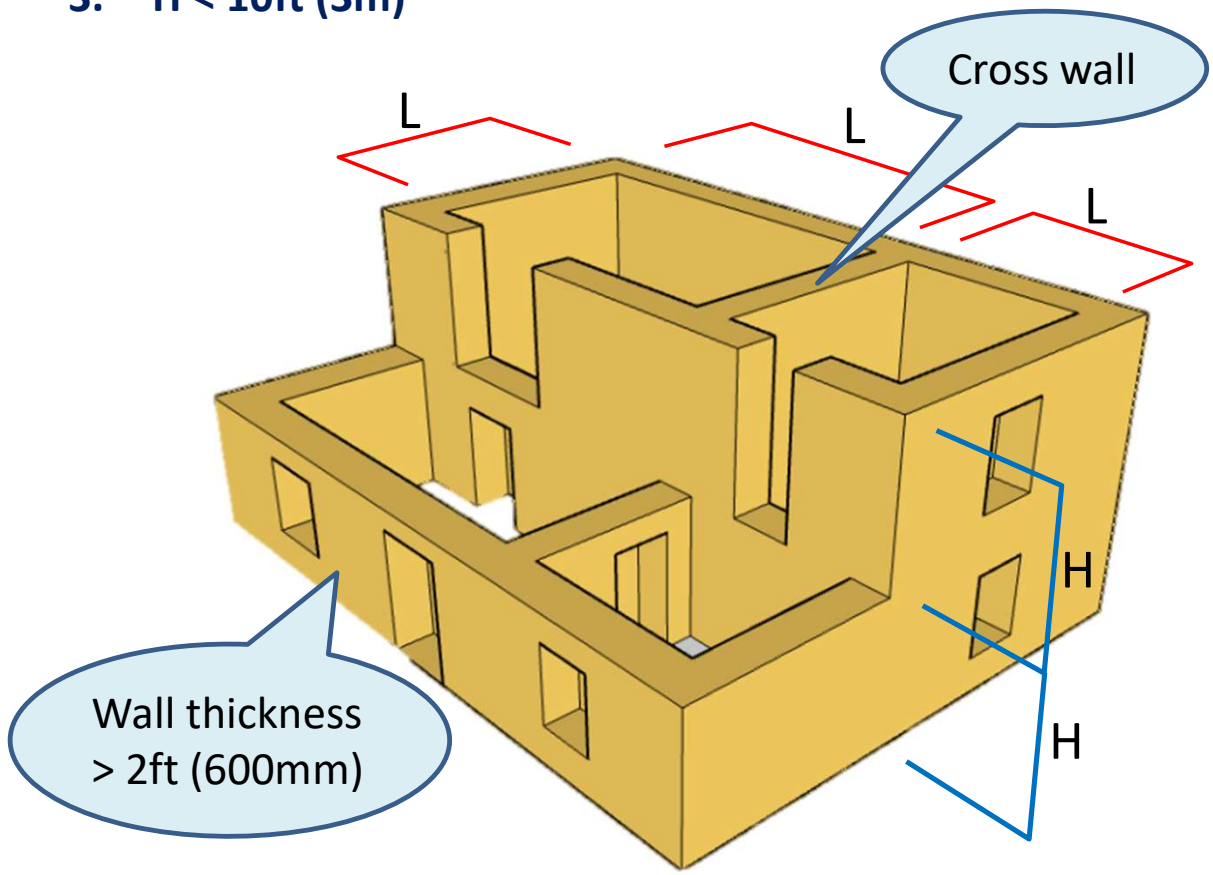
The two buildings are structurally separated

Planning: Wall Length and Openings གུང་གི་རིང་ཚད་དང་ གློ་དང་གློ་ཅུང་གི་རིགས།

Why not good?



1. $L < 18\text{ft}$ (5.5m)
2. Smaller openings are recommended
3. $H < 10\text{ft}$ (3m)



3. Construction Work

I. Material བཞོ་སྐྱོན་རྒྱ་ཆས།

Stone Masonry རྩོམ་སྐྱེ་བྱིན།

Stone རྩོམ་	Cement mortar རྩོམ་འདམ། <ul style="list-style-type: none">• Cement• Sand བྱེན།• Water ལྷ།
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Rammed Earth རྩོམ་སྐྱེ་བྱིན།

Soil རྩོམ་	Water ལྷ།
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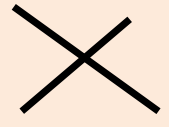
Seismic Reinforcement

Steel ལྷགས།	Concrete རྩོམ་འདམ། <ul style="list-style-type: none">• Cement• Sand བྱེན།• Stone aggregate རྩོམ་རྒྱ་ཆས།• Water ལྷ།
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I. Material: Stone རྩོམ་པོ།



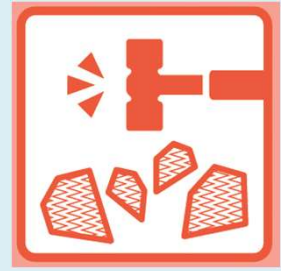
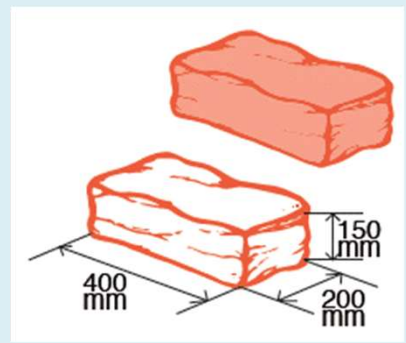
- Granite, Limestone, Sandstone རྩོམ་པོ་ཅན་གྱི་ཕྱི་ལོ།
- Hard, Tough, Compact grained, Crack-free ལྷན་གྲག་གྲ་དང་ རྩིང་རྩིང་ དམ་ཞིབ་ཅན་དང་ ལར་ཆག་དགུམ་མེད་པའི་ རྩོམ་པོ།
- Uniform in Texture and Color རྩིས་དང་ ཚོན་མདོག་ཆ་སྟོམས་ **without chizeling** རྩོག་རྩོ་ཡོད་པའི་ལར་ ཆག་དགུམ་མེད་པའི་ རྩོམ་པོ།



- Round stones རྩོམ་པོ་རྩོག་རིལ་རིལ་འབད་ཡོད་མེ་
- River stones without chiseling work རྩོམ་པོ།



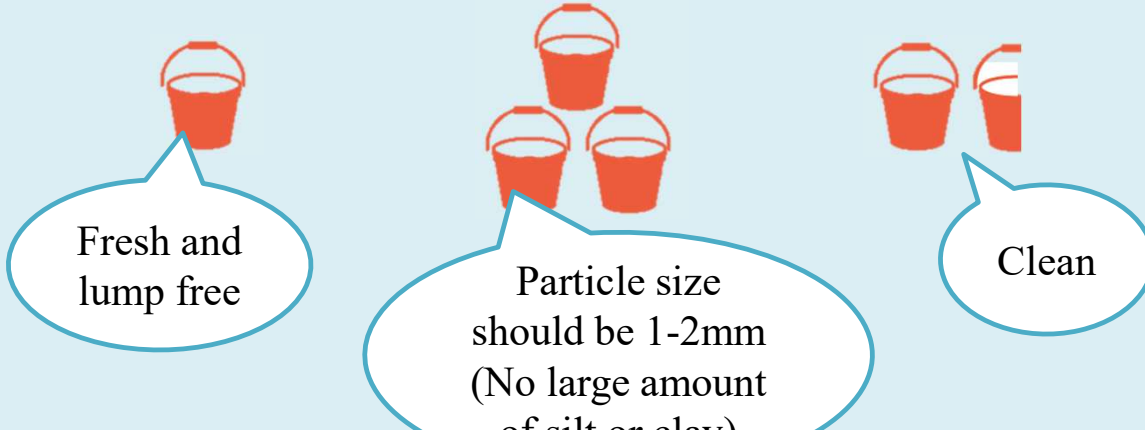
- A minimum of 200mm boulder is recommended.
རྩོམ་པོ་ཚད་གཞི་འདི་ཡང་ *མི་ལེ་མི་ཏར་ ༢༠༠ ལས་ རྩུང་ནི་མི་འོང་།



I. Material: Cement Mortar རྩི་འདམ་

Ratio (Volume)

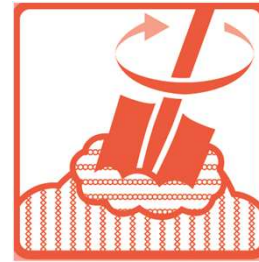
Cement	:	Sand	:	Water
1		3		1.5



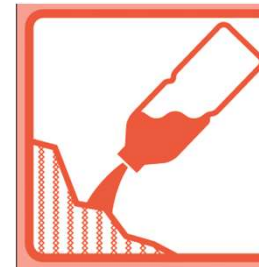
Fresh and lump free

Particle size should be 1-2mm (No large amount of silt or clay)

Clean




i. Mix the dry ingredients together before adding water



ii. Mix clean water
* Do not add water running, but from a container

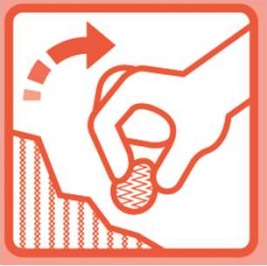
Hardness Test



10

> 4

I. Material: Soil for ramming



Remove pebbles larger than 1 cm



Well mixed soil



If too dry: Add water little by little from a bottle and not directly from a bucket.



If too clayey: Add sand little by little from a scoop.

Soil test



If a ball collapses, the soil is not appropriate

Lump test



Make a ball



Drop a ball



suitable for use



I. Material: Concrete (M20)

Ratio (Volume)

Cement : **Sand** : **Aggregate** : **Water**
1 : 1.5 : 3 : 1.5



Fresh and lump free



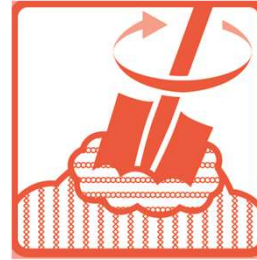
Particle size should be 1-2mm (No large amount of silt or clay)



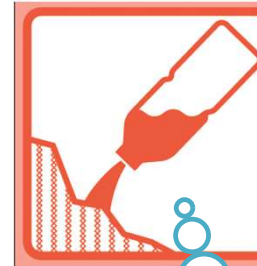
High gradation, Tough, Uniform texture & colour Free from mud and other foreign materials



Clean



① Mix the dry ingredients together before adding water



② Mix clean water
* Do not add water running, but from a container

Slump Test



Excess water makes concrete poor quality.

Poor quality of concrete reduces durability of structure

I. Material: Steel Rebar |

- Yielding strength: 415 MPa or higher (HYSD)
- Plain bars should not be used.

ལྷགས་དུམ་ཚུ་ ལྷགས་ཚད་ཤིང་པེ་ཤི(MPa) 415 ལས་མངས་སྡེ་ ཡོད་མི་ལག་ལེན་ འཐབ་དགོས་ད་ ལྷགས་ཤུགས་སྐྱིང་སྐྱིང་ཡོད་པའི་(HYSD)
ལྷགས་དུམ་ཚུ་ ལག་ལེན་འཐབ་ནི་མ་གཏོགས་ གཞན་ལག་ལེན་འཐབ་ནི་མི་འོང་།

I. Material

Check List

Stone Masonry House

- Is stone size appropriate?
- Was the mortar mixture found appropriate by the test?

Rammed Earth House

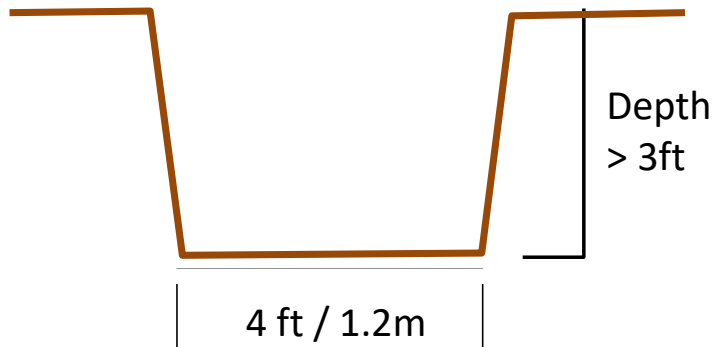
- Was the soil mixture found appropriate by the tests?

II. Foundation

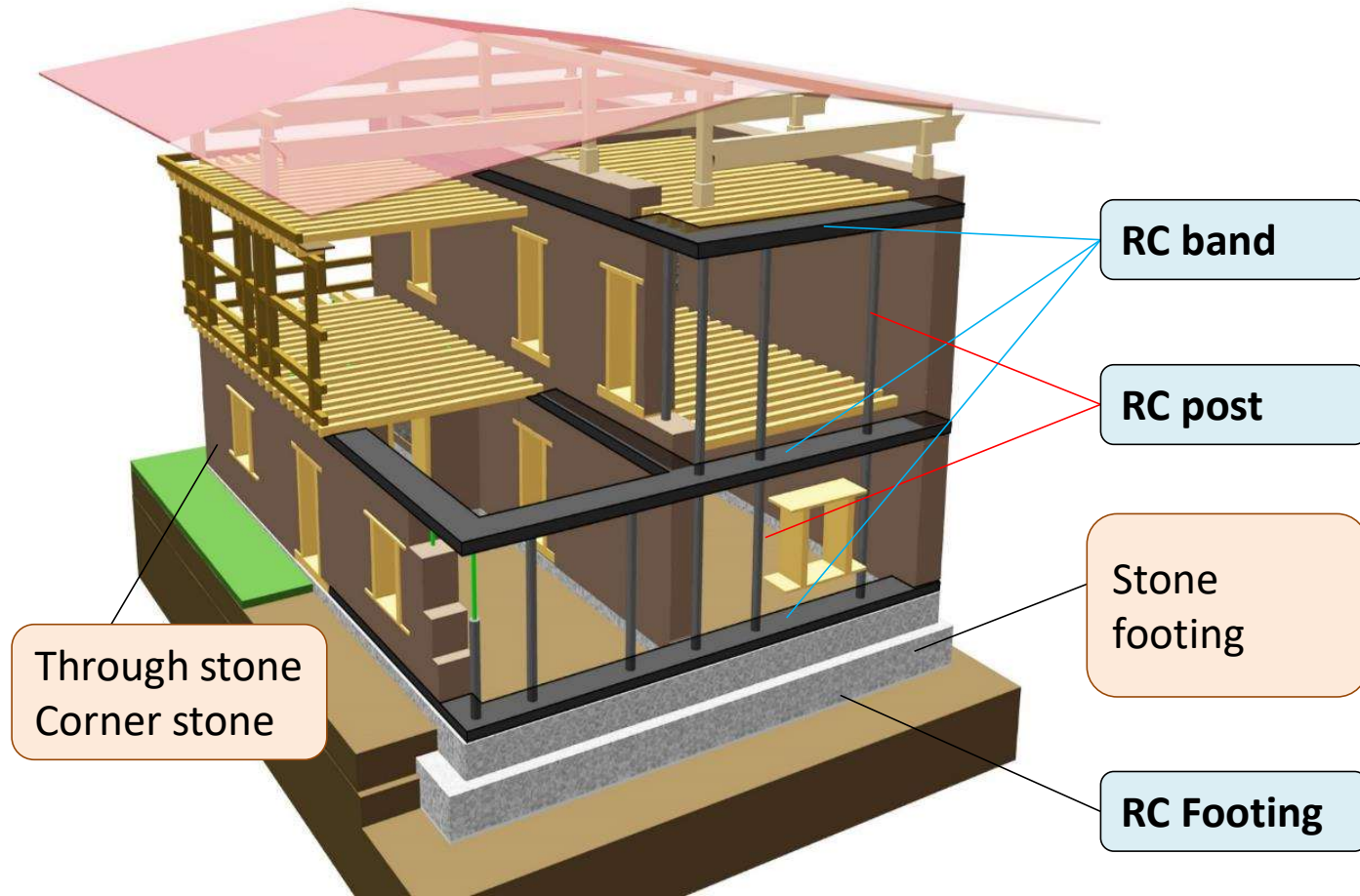
1. Earth work



Dig a trench 3ft deep and 4ft wide.

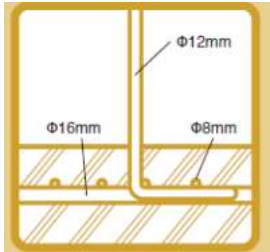


Seismic Reinforcement: What are the new components to be adapted?



II. Foundation

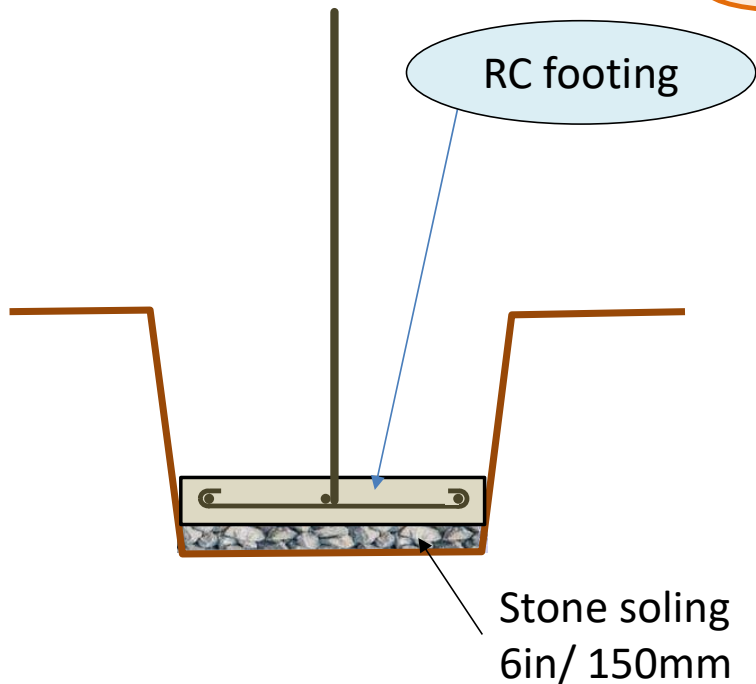
2. RC Footing



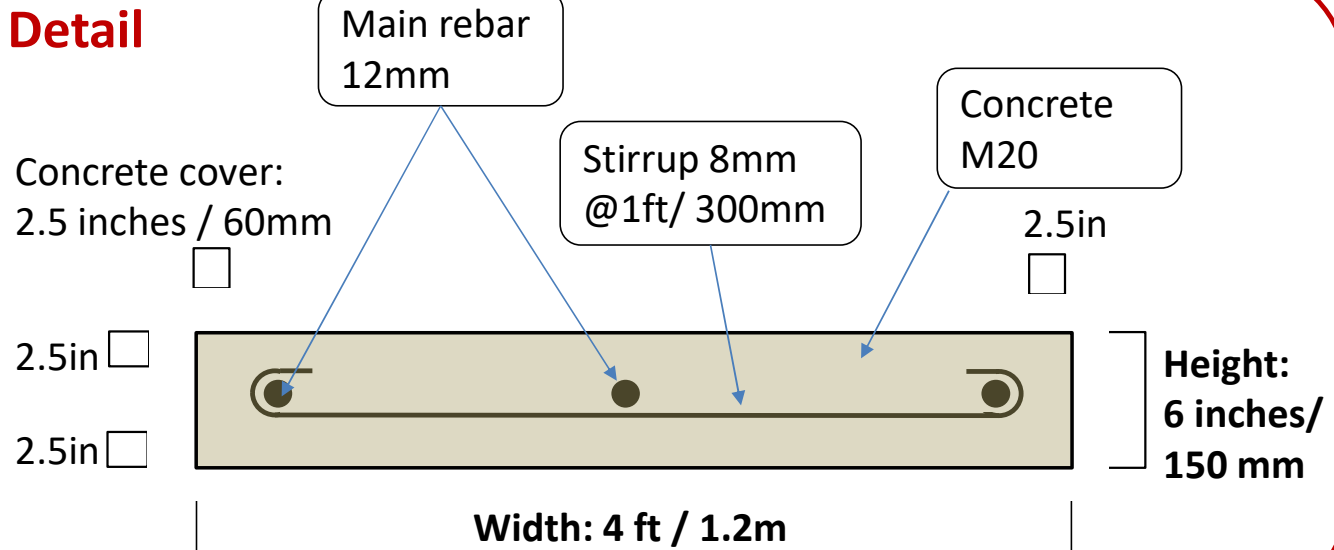
- Provide stone soling
- Place main rebars with stirrups.
- Erect vertical rebars.
- Cast M20 concrete 6 inches thick.

Erect vertical rebar before concrete casting (see the next slide about the rebar)

Cure the concrete minimum for a week



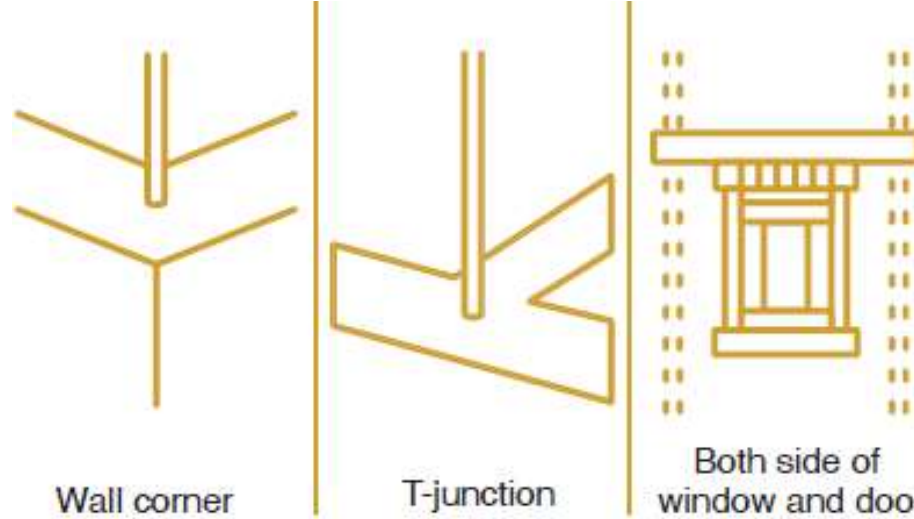
Detail



II. Foundation

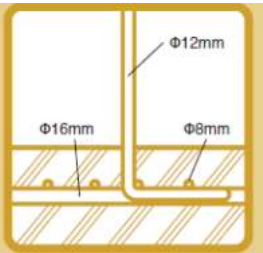
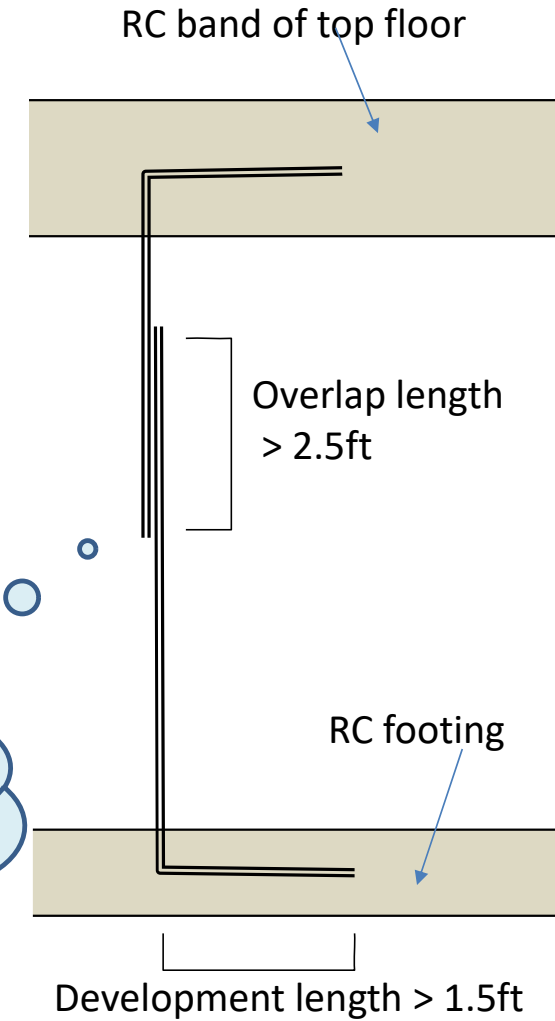
2. RC Foundation

Where to install the vertical rebar?

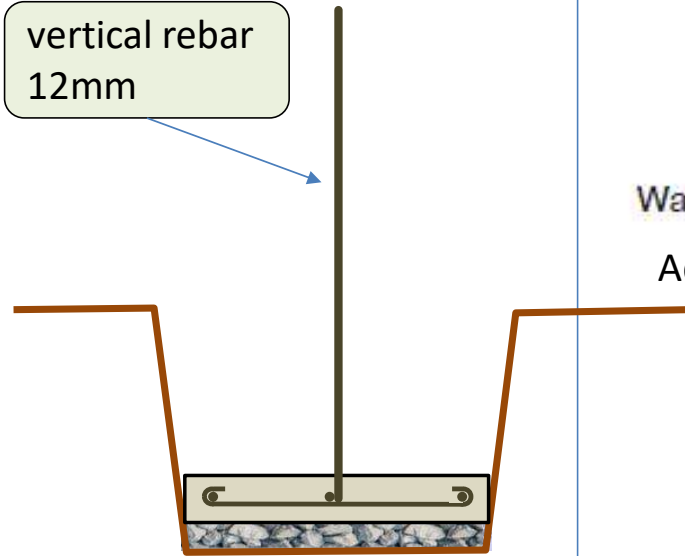


Addition to the above, install at every 4ft/ 1.2m

lapping zone shall be the mid height of the two floors

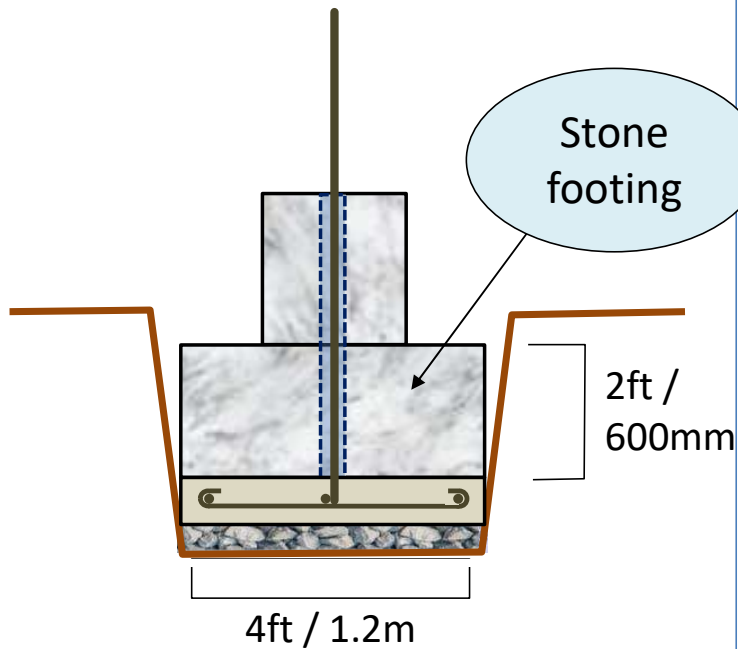


vertical rebar 12mm



II. Foundation

3. Stone Foundation

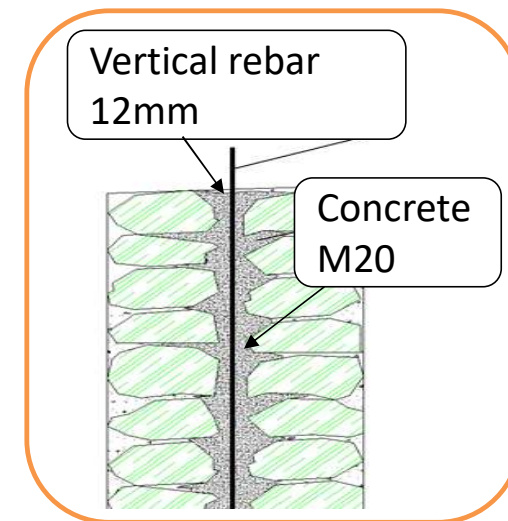
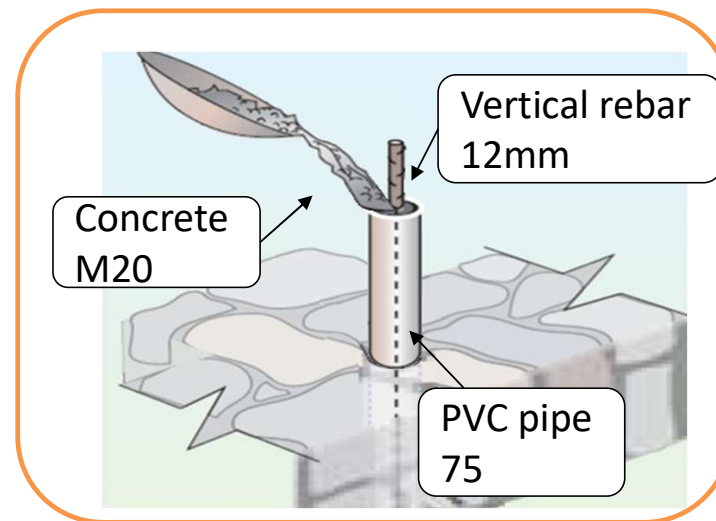


- Place a PVC pipe around the vertical rebar
- Lay stones in single lift.
- Cast M20 concrete in the pipe.



- Right after casting concrete, pull out the pipe.

Use a tamping rod to properly fill the pipe with concrete



II. Foundation |

Check List

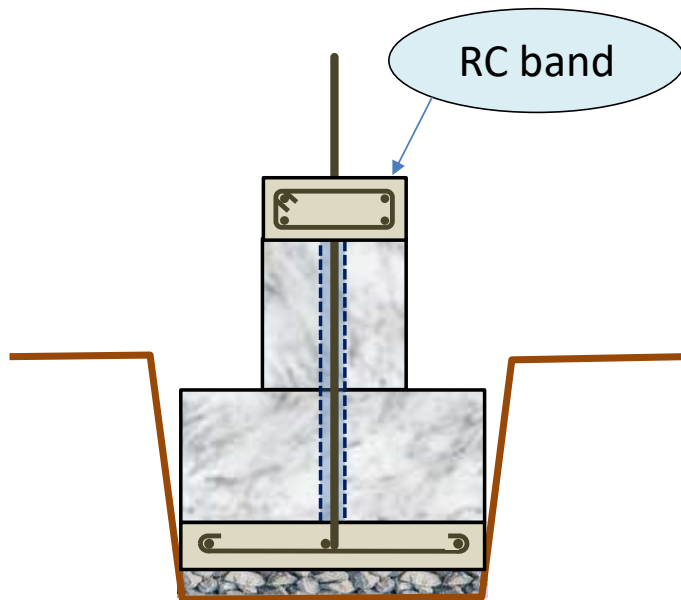
- Excavated 1 meter trench to construct a foundation?
- Maintained appropriate overlapping length? (It shall be more than 3ft for main rebar of the RC foundation; more than 2ft for the vertical rebar)
- Erected vertical rebars at all the necessary location?
- Maintained enough concrete cover for the RC foundation? (It shall be more than 2.5 inches)
- Was concrete filled up properly around the vertical rebar?
- Kept the adequate concrete curing period ?

III. RC Post & Band

1. RC Band



Cure the concrete minimum for a week



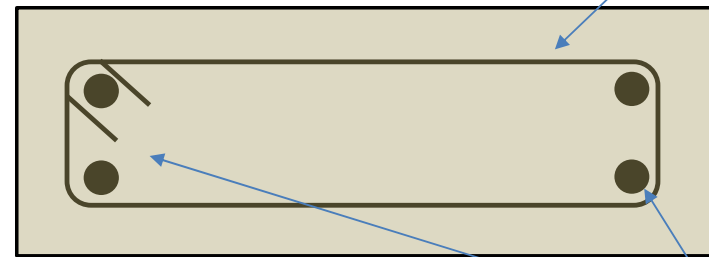
Detail

Concrete M20

Width: 2 ft / 600 mm

Stirrup 8mm @150mm

1.5in
Stirrup 120mm
1.5in



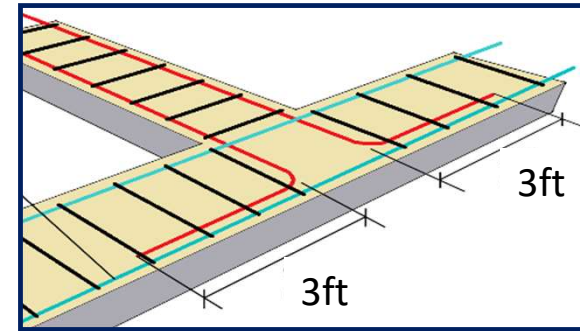
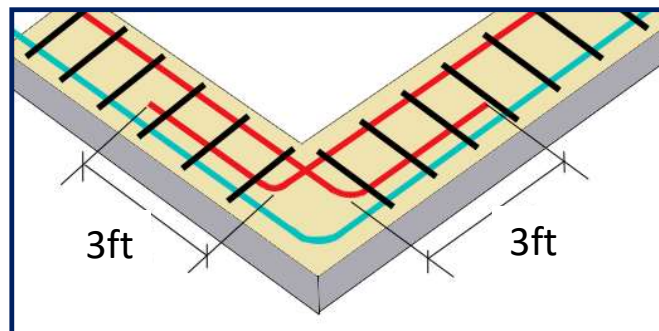
Height: 8 inches / 200 mm

Concrete cover: 1.5 inches / 50mm

Stirrup 500 mm

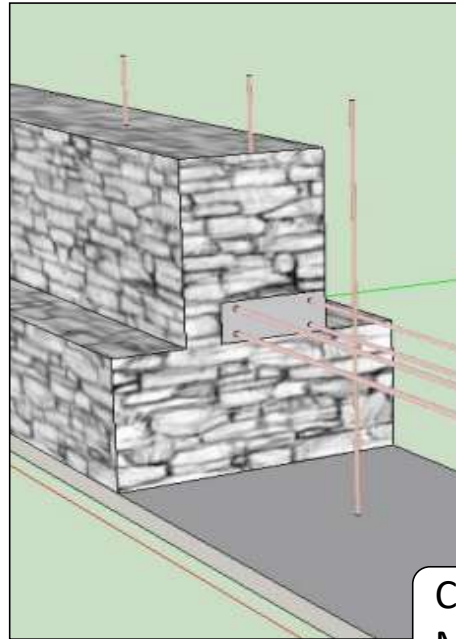
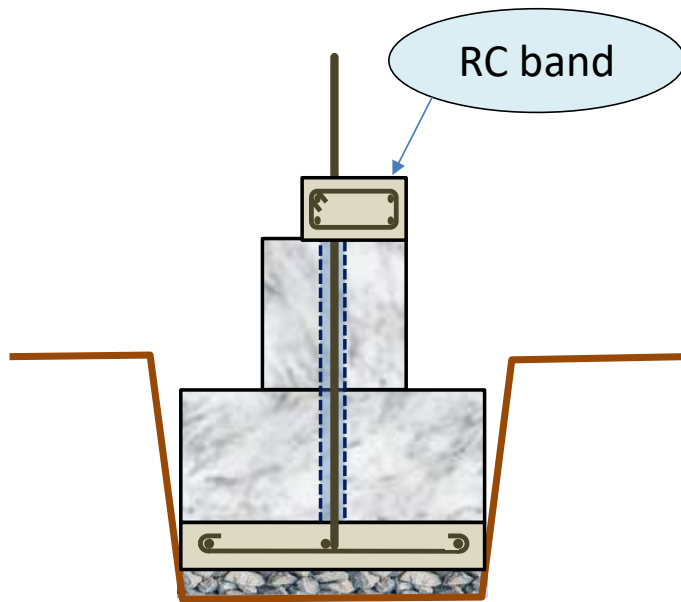
1.5in
Main rebar 16mm

Overlapping of rebar



III. RC Post & Band

1. RC Band



If a RC band needs to be concealed from aesthetic reason, construct the band 1.5ft /450mm wide.

Concrete M20

Width: 1.5 ft / 450 mm

Stirrup 8mm @150mm

1.5in
Stirrup
120mm
1.5in

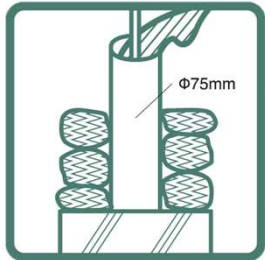
Height:
8 inches
/200 mm

1.5in Stirrup 1.5in
350 mm

Main rebar
16mm

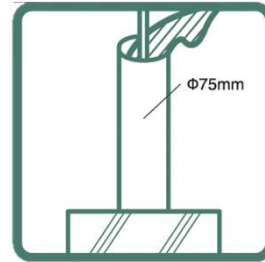
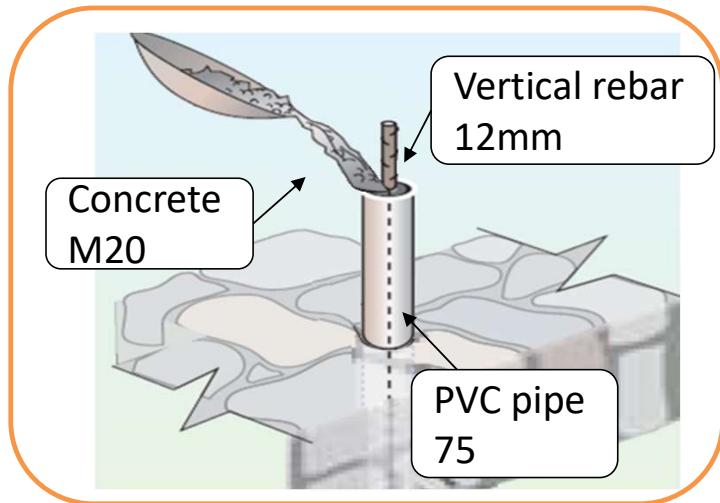
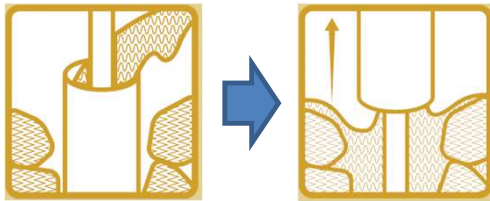
III. RC Post & Band

1. RC Post



For Stone Masonry wall

Follow the same process for the stone footing



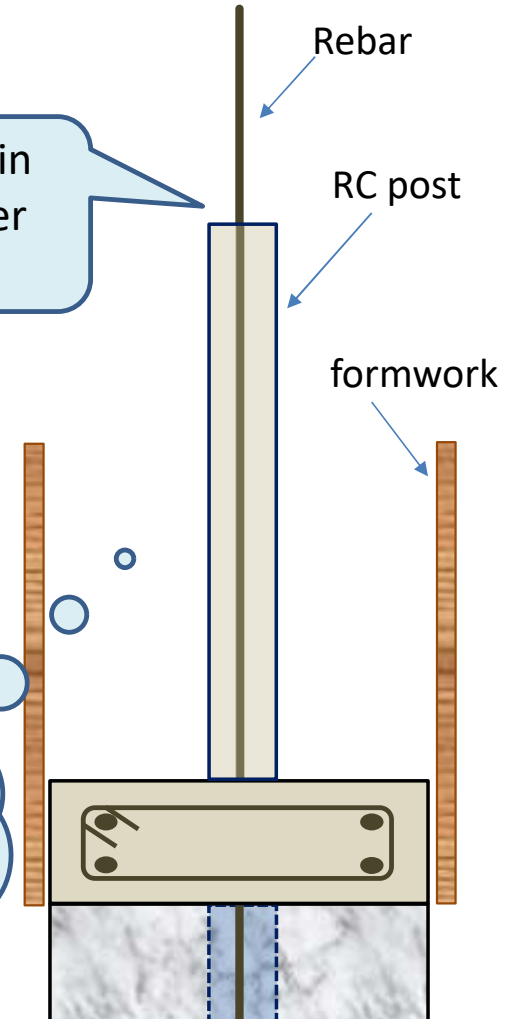
For Rammed earth wall

The post constructed in one time shall be taller than the formwork

- Place a PVC pipe vertically cut into two around a rebar
- Cast M20 concrete
- Remove the pipe 24hrs after casting
- Cure the concrete minimum for a week

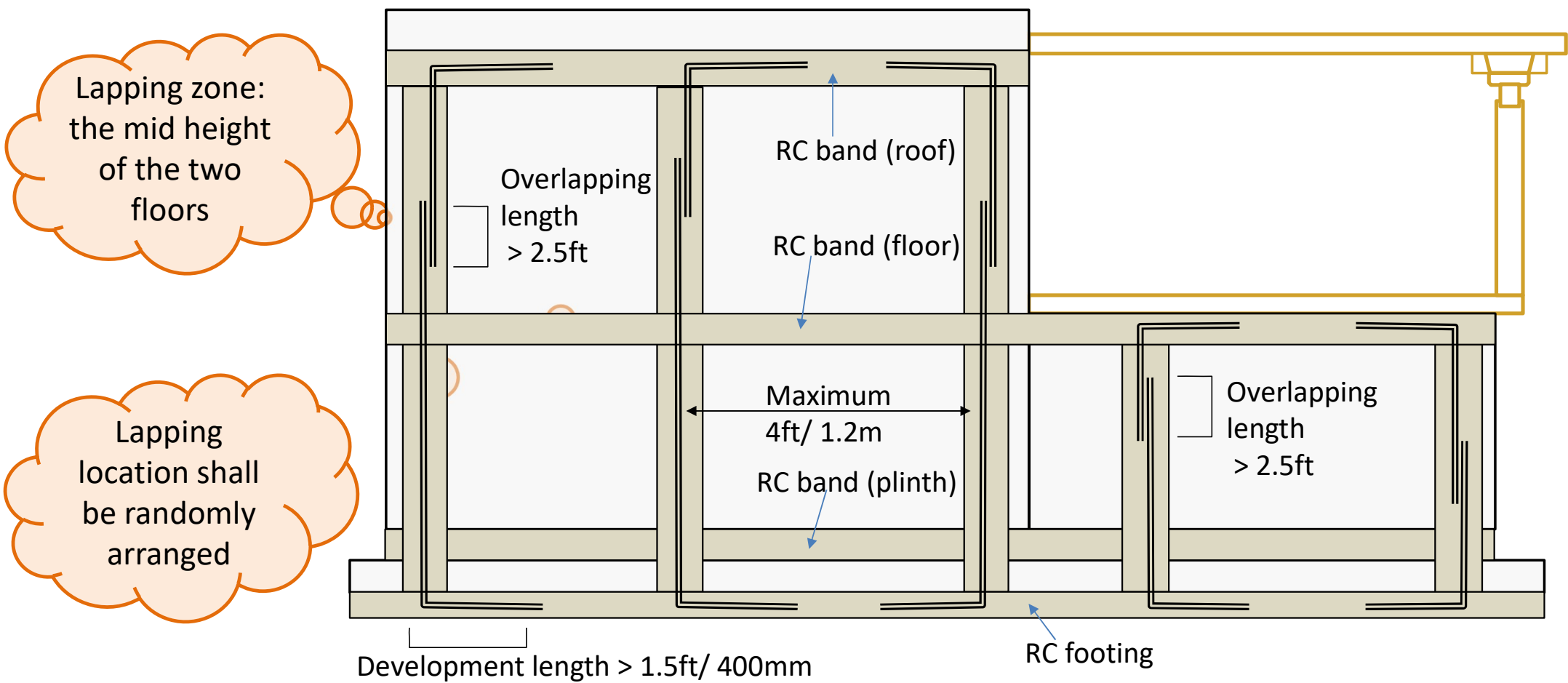
In order to maintain enough concrete cover

Maintain a rebar in the centre of the pipe



III. RC Post & Band

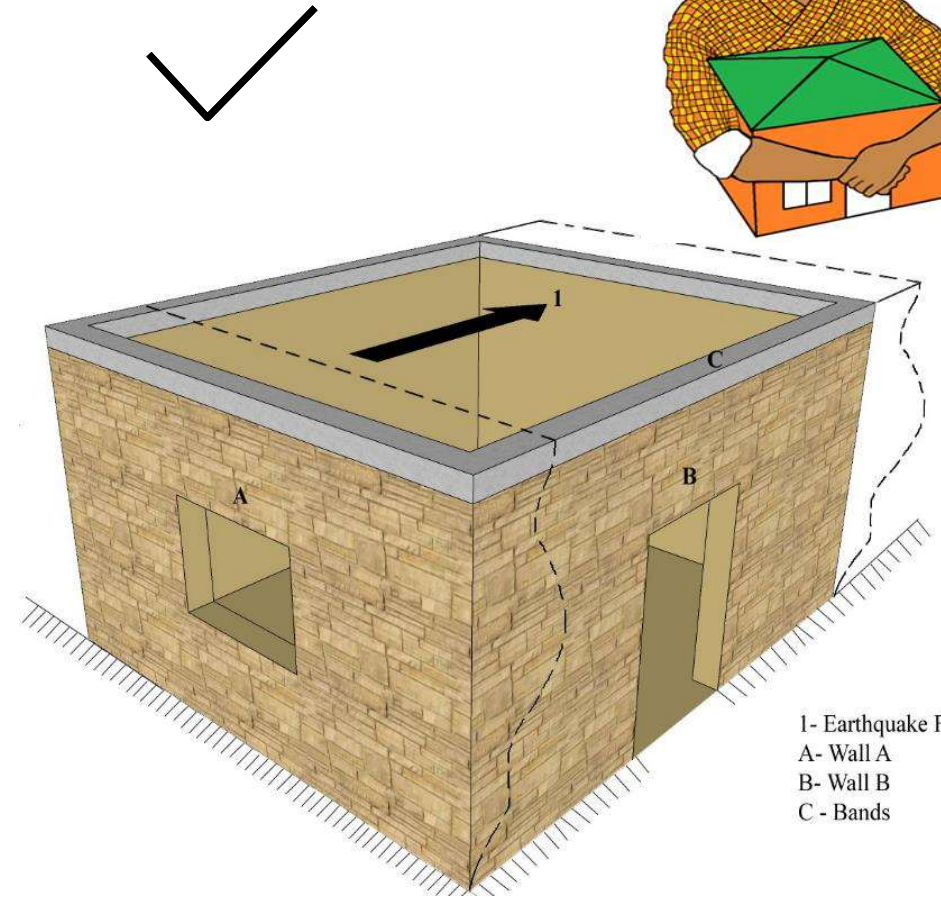
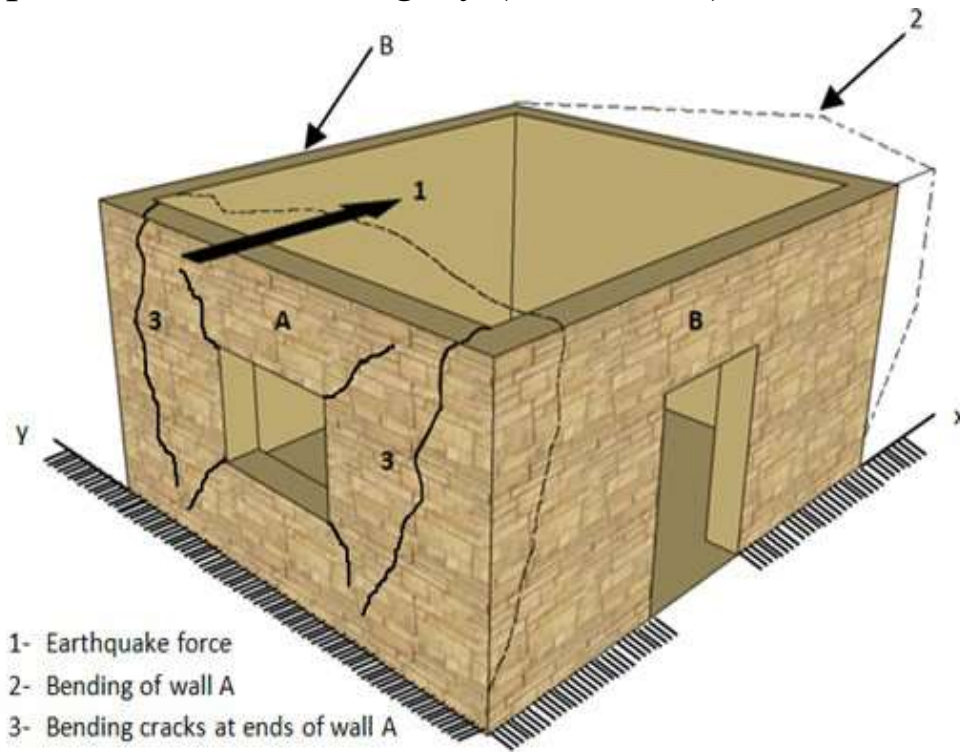
When the vertical rebar need to be jointed:



III. RC Post & Band

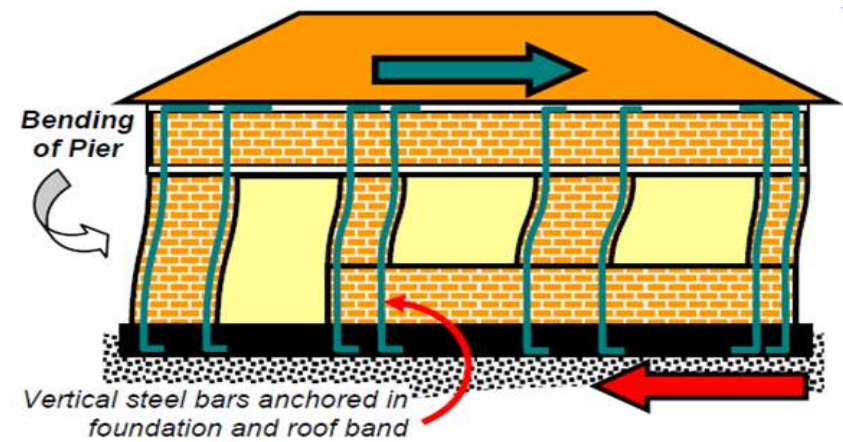
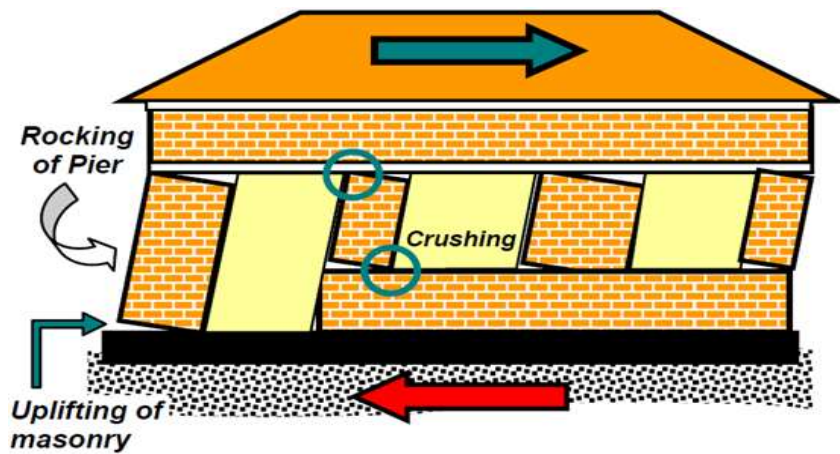
How the adaptation of RC band improve seismic resilience?

Improve Structural Integrity (Box Effect)



III. RC Post & Band

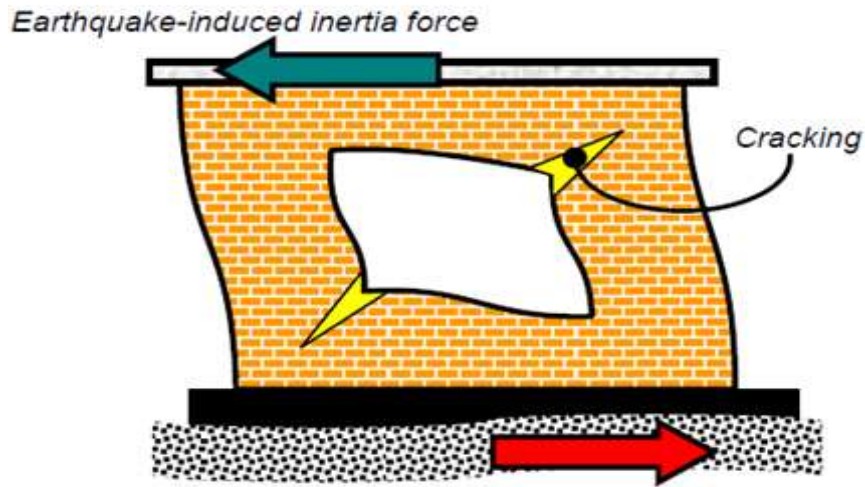
How the adaptation of RC post improve seismic resilience?



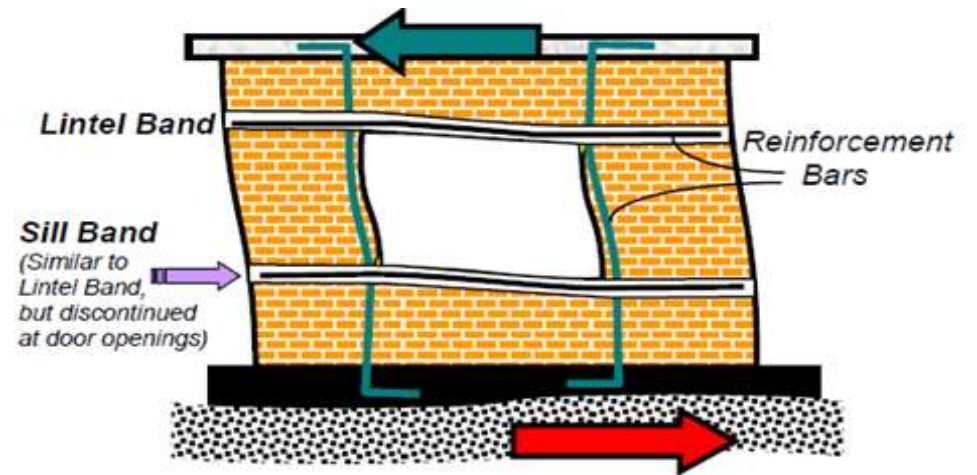
Vertical reinforcement causes bending of masonry piers
Sliding is resisted by vertical reinforcement

III. RC Post & Band

How the adaptation of RC post improve seismic resilience?



Cracking in the building with no corner reinforcement



Prevention of X-cracks due to vertical reinforcement and RCC bands

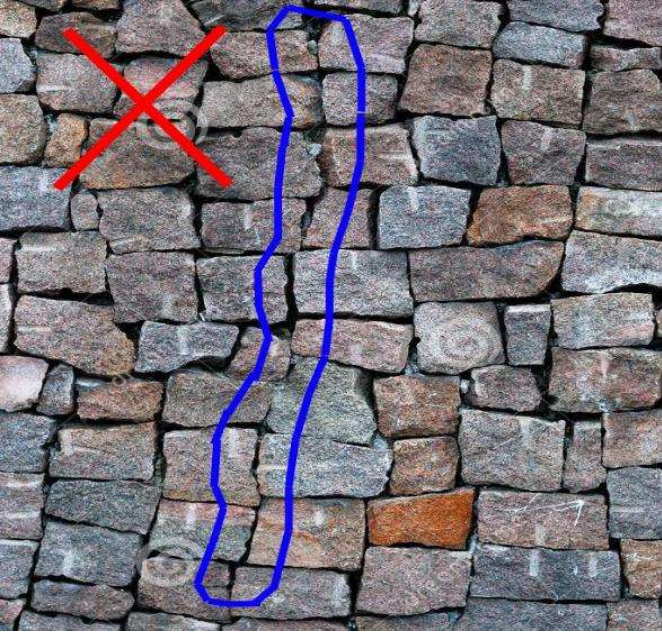
III. RC Post & Band

Check List

- Maintained appropriate overlapping length?
(It shall be more than 3ft for main rebar of RC band; more than 2ft for RC post)
- Maintained enough concrete cover for RC band? (It shall be more than 1.5 inches)
- Was concrete filled up properly around a vertical rebar?
- Kept the adequate concrete curing period ?

IV. Stone Work

Course work རྩོམ་ལྗོངས།



There should not be vertical mortar lines.

རྩོམ་ལྗོངས་ཀྱི་ ཡར་མར་འཕྲང་སྟེ་གྲུལ་ཅིག་སྟེ་བརྩིག་ནི་མི་འོང་།

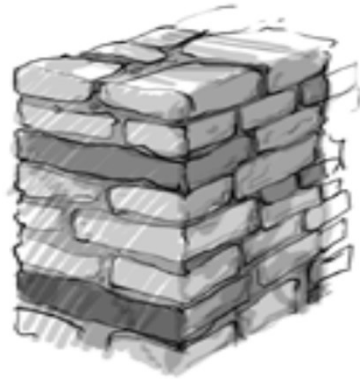
Maximum 2ft / 600mm in single lift.

གྲུང་བརྩིག་ཐངས་གཅིག་ལུ་ མཐོ་ཤོས་ཕི་ཏེ་ ༢ ཡང་ན་ མི་ལི་མི་ཏར་ ༦༠༠

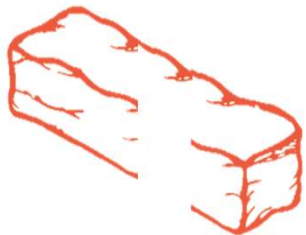


IV. Stone Work

1. Through stone གཙང་རྫོ།



Recommended Size:
0.5x0.5x2ft (150x150x600mm)

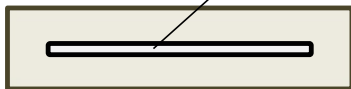


Stone

If long stones aren't available

གཙང་རྫོའི་ཐབས་ཤེས་གཞན།

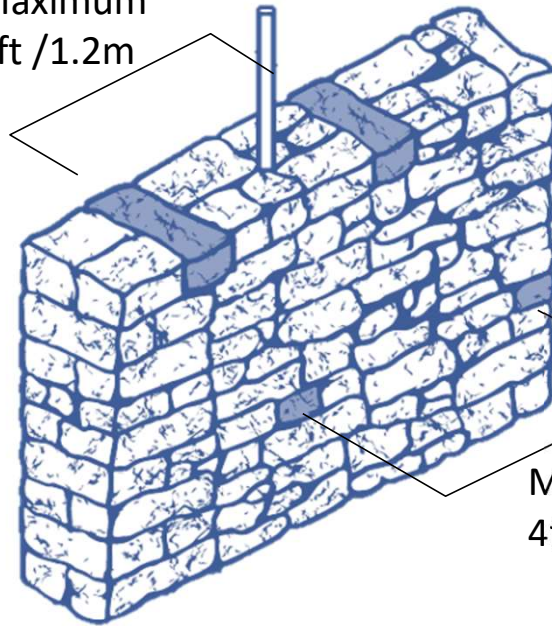
Rebar 8mm



M20 Concrete

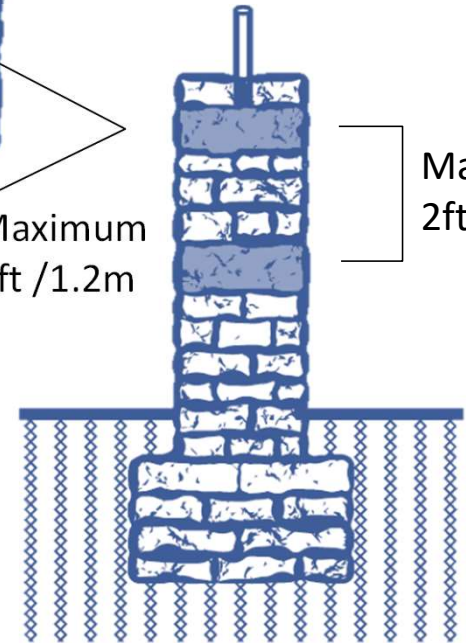
Where to use the through stones?

Maximum
4ft / 1.2m



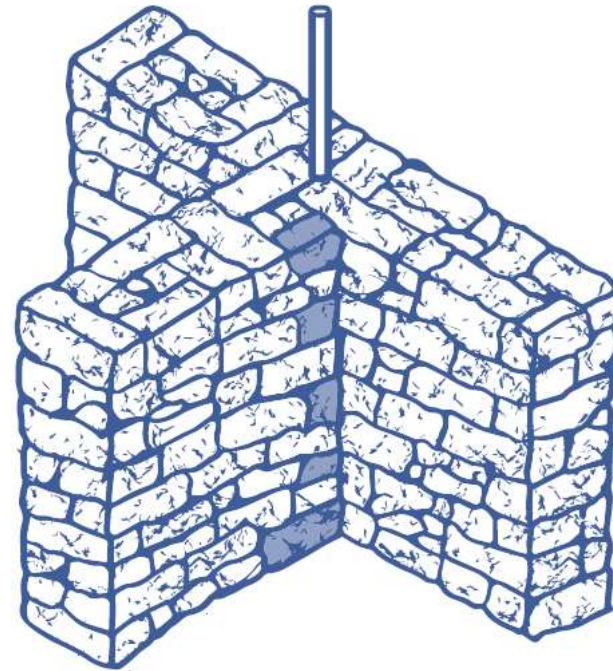
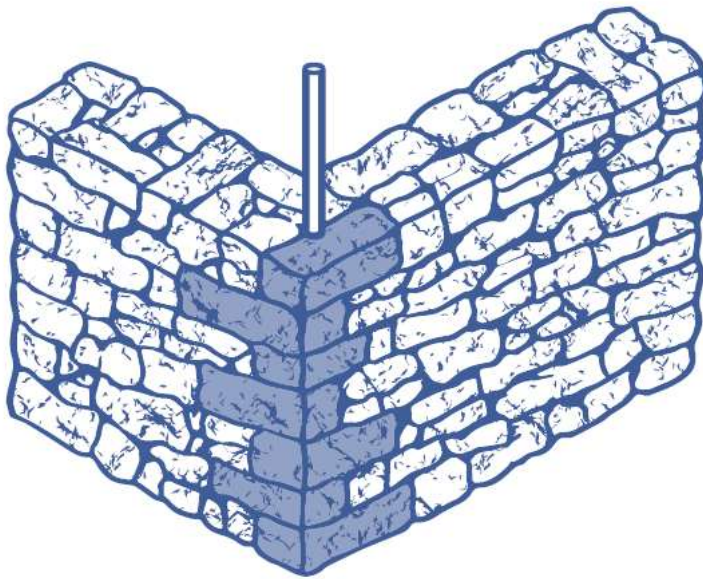
Maximum
4ft / 1.2m

Maximum
2ft / 600mm



IV. Stone Work

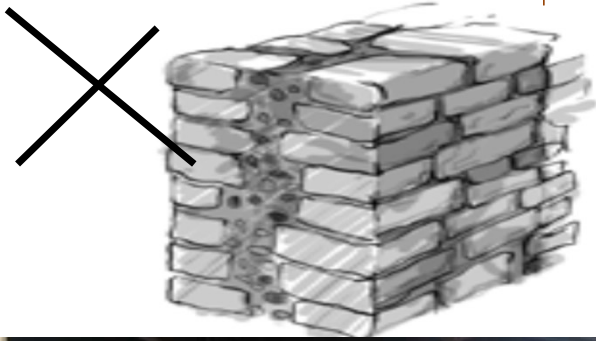
2. Corner stone ལུས་རྩོ།



Provide corner stones inner and outer corners

IV. Stone Work |

Without through stone གཙང་ཚོ་མེད་པར།



Without corner stone ཟུར་ཚོ་མེད་པར།



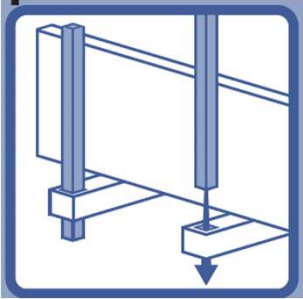
IV. Stone Work

Check List

- Was the stone work done with good bonding?
- Were through stones and corner stones located in appropriate spacing?
- Were the gabion boxes arranged in a staggered pattern?

V. Ramming Earth

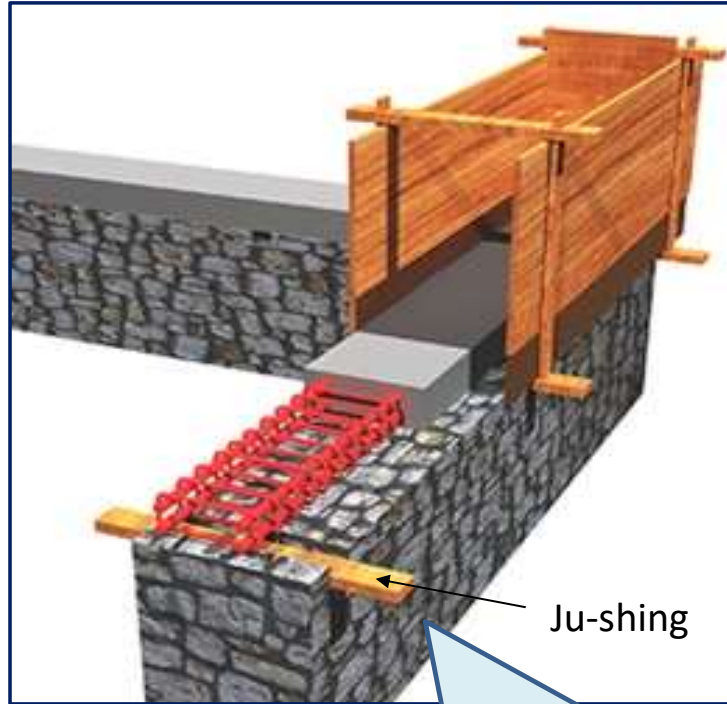
1. Formwork



Keep provision to set Ju-shing

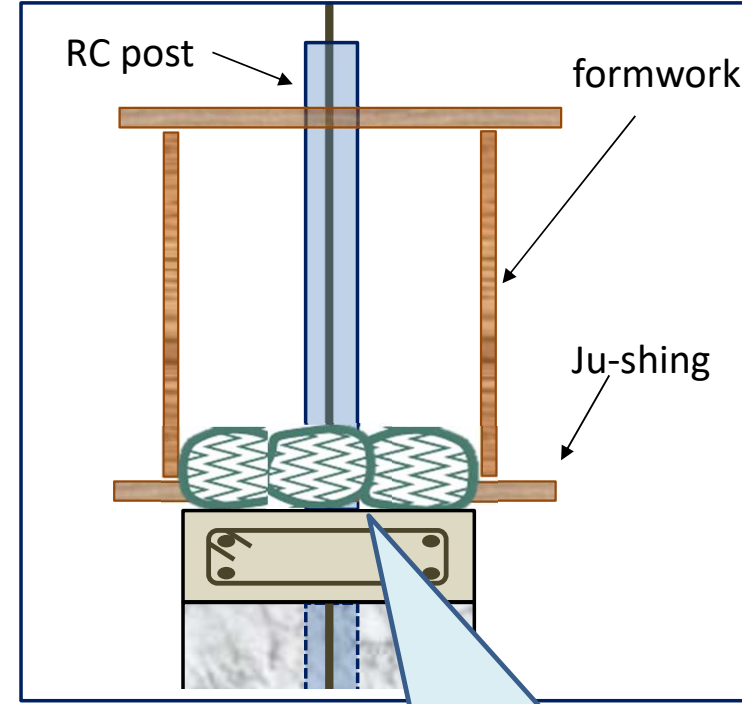
Do Not chip a RC band

Idea 1:



Make a space to set a ju-shing, before construct a RC band

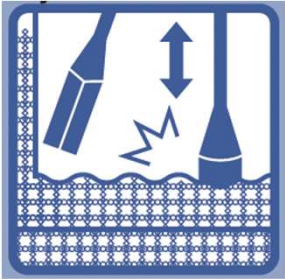
Idea 2:



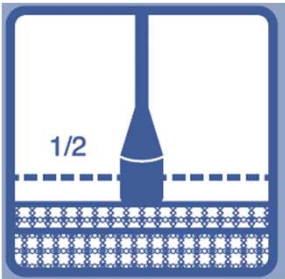
Lay a lift of stones on the RC band to fix a ju-shing

V. Ramming Earth

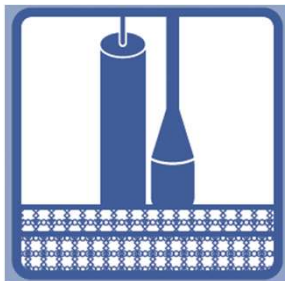
2. Ramming of one layer



- i. Fill the formwork with 4 inches/ 100mm of soil
- ii. Use right tool to compact edge and plane



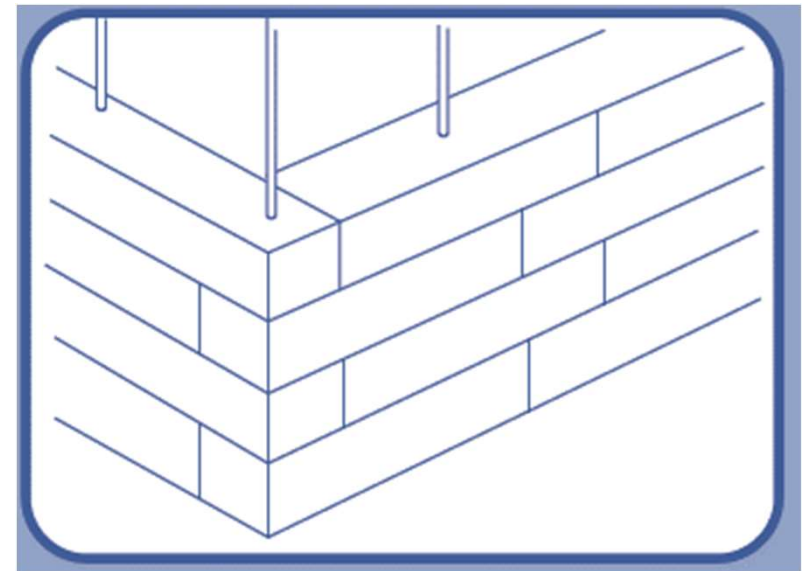
- iii. Compact the soil until it is 2 inches thick (Half of 4 inches)



- iv. Compact well around the RC post

3. Construction of wall

- i. Repeat the same process of ramming to complete in the formwork
- ii. Repeat the same process to set a formwork and complete ramming
- iii. The formwork shall be provided in a staggered pattern



V. Ramming Earth

Check List

- Was any provision kept for fixing ju-shings?
- Was the soil compacted until it is 2 inches thick?
- Was the soil around the RC post compacted well?
- Were the formworks arranged in a staggered pattern?