

You Can Keep Your Family Safe From Earthquakes

How To Build Strong
And Sturdy Houses



Build Earthquake Resistant Houses
Change Construction Practice Permanently

Handbook for Building Simple, Earthquake-Resistant Houses

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FOREWORD

Build Change is an international non-profit social enterprise that designs earthquake-resistant houses and trains builders, homeowners, engineers and government officials to build them. Build Change's work has improved the design and/or construction of over 5,700 houses in Indonesia and China.

This handbook provides simple guidelines for safe construction of the two most common structural systems for single family homes in rural Indonesia: confined brick masonry and timber frame with masonry skirt. The handbook was developed during Build Change's programs in Aceh and West Sumatra, Indonesia. It was first published in September 2008. It can be used by builders, homeowners, government officials, engineers, architects, and construction supervisors. A detailed design guideline for confined masonry is available at www.buildchange.org. Detailed drawings, bills of quantity, and construction quality checklists are available upon request.

Build Change provided hands-on technical assistance and training to 655 homeowners who lost their houses in the 2007 earthquakes in West Sumatra and Bengkulu. None of the houses that met our minimum standard were damaged in the 2009 earthquakes. It is not the earthquake that kills people, it is the collapse of a poorly designed or built building. This handbook is dedicated to homeowners and builders in Indonesia, with the hope that they can use it to keep their families safe during earthquakes.

Padang, West Sumatra, Indonesia, December 1, 2009



Elizabeth A. Hausler, Ph.D.
Founder and CEO, Build Change

ACKNOWLEDGMENTS

This booklet is the result of contributions of many individuals, including Build Change's Indonesian engineers, architects, and construction supervisors; many builders and homeowners from Aceh and West Sumatra, and Build Change's team of pro bono, licensed structural engineers from the San Francisco Bay Area.

Other primary sources of inspiration include Don Hausler Masonry Construction and the guidelines for earthquake-resistant simple masonry houses produced by Teddy Boen for Indonesia and Marcial Blondet from Peru.

Insights and hard work from all parties are greatly appreciated.

AWARDS

Build Change's house design for Aceh won a 2006 Excellence in Structural Engineering award from the Structural Engineers Association of Northern California.

Build Change is a 2008 Tech Awards Laureate (www.techawards.org) and Winner of the Katherine M. Swanson Foundation Equality Category Cash Prize for making culturally appropriate, earthquake-resistant housing solutions available to all homeowners, regardless of income level.

Build Change is a founding member of the Confined Masonry Network, an international network of academics and earthquake engineers promoting earthquake-resistant design and construction of confined masonry. CM_NET has reviewed and approved this handbook. (www.confinedmasonry.org)



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CHAPTER I: SEISMIC HAZARD IN WEST SUMATRA



Map of fault lines in Sumatra indicating previous earthquakes (California Institute of Technology Tectonic Observatory)

KENAPA BANYAK GEMPABUMI DI LEPAS PANTAI BARAT DAN DARATAN SUMATRA?

Gempabumi adalah tanah yang berguncang akibat rekahan bumi pecah dan bergeser dengan keras. Wilayah di sebelah barat Sumatra mempunyai banyak sumber gempa karena posisinya dekat dengan jalur tabrakan dua lempeng bumi, dimana lempeng Samudra

Hindia bergerak ke arah dan menunjam ke bawah lempeng (benua) Sumatra. Bagian lempeng yang menunjam di bawah Kep. Mentawai dan Nias umumnya melekat kuat pada tubuh batuan di atasnya, sehingga pergerakan ini memampatkan tubuh batuan (Gbr.1a). Akumulasi tekanan ini akan meningkat dari waktu ke waktu sampai pada suatu saat melampaui daya rekat dua lempeng tersebut. Maka ibarat

sebuah per pegas raksasa yang sudah ditekan maksimal dan kemudian dilepaskan, Kep. Mentawai akan terpental ke atas dan ke arah luar secara tiba-tiba menimbulkan guncangan bumi yang sangat keras, yaitu gempa bumi yang terjadi pada zona subduksi (lihat brosur dan poster "Pulau Kita tenggelam diantara Gempabumi").



Gbr. 1a

Gbr. 1b



APA YANG TERJADI SAAT GEMPA BESAR DI PATAHAN SUMATRA?



Gbr. 2a



Gbr. 2b

Tanah di sepanjang jalur patahan akan retak dan tanah di sekitar patahan bergeser tiba-tiba secara berlawanan arah satu sampai beberapa meter.



Gbr. 2c

- Bumi berguncang keras selama beberapa puluh detik sampai menit.
- Setelah itu selama beberapa hari-hari sampai beberapa minggu akan terjadi gempa-gempa susulan yang lebih kecil. Gempa susulan ini frekuensinya dan kekuatannya akan terus berkurang sampai berhenti.
- Gempabesar umumnya disertai oleh gerakan tanah/tanah longsor dan amblesan tanah yang dapat mengakibatkan kerusakan yang sama atau bahkan lebih besar dari kejadian gempanya itu sendiri.
- Gempabumi patahan (tektonik) ini bukan karena gunung api, tapi kadang-kadang gempa ini bisa merangsang aktifitas gunungapi disekitarnya.



Informational Poster describing the causes and effects of earthquakes in West Sumatra
(California Institute of Technology Tectonic Observatory)



Informational Poster describing the causes and effects of earthquakes in West Sumatra
(California Institute of Technology Tectonic Observatory)

KAPAN ADA GEMPABUMI LAGI?

Gempabumi adalah proses alam yang berulang-ulang. Daerah yang pernah mengalami gempa di waktu lampau pasti akan mengalami gempa lagi di waktu datang. Penelitian gempa dapat memperkirakan besarnya gempa yang sudah dan akan terjadi di suatu daerah, dan juga dapat memperkirakan kisaran waktu perulangan gempa tersebut. Sehingga kalau kita tahu kapan gempa besar terakhir terjadi dan berapa kisaran waktu perulangan gempanya, maka kita dapat memperkirakan potensi bahaya gempa besar di masa datang. Perkiraan seperti ini biasa disebut sebagai prediksi gempa jangka panjang.

Gempabumi masih sukar untuk diramalkan hari H-nya; apalagi karena kita memang belum mempunyai alat monitoring gempa yang cukup untuk melakukan prediksi gempa jangka pendek ini. Tapi yang lebih penting, dengan memahami potensi gempa di masa datang kita bisa bersiap-siap untuk mengurangi/menghindari bencana yang dapat ditimbulkan.



Gbr. 5a

APA YANG BISA KITA LAKUKAN?

- ✓ Gempabumi memang sudah takdir alam yang tidak dapat dihindari, akan tetapi pahamiilah bahwa bencana yang terjadi umumnya adalah akibat kelalaian manusia dalam menyikapinya.
- ✓ Kenali dan pahamiilah jalur-jalur gempabumi di daerah anda.
- ✓ Rumah dan bangunan (baru) sebaiknya dibuat dengan konstruksi tahan gempa yang sesuai dengan lokasinya. Pahamiilah prinsip sederhana konstruksi tahan gempa, misalnya: rumah yang terdiri dari bahan ringan dan fleksibel, seperti rumah kayu dengan fondasi kokoh ke dalam tanah akan lebih tahan gempa dibandingkan rumah tembok berkualitas rendah tanpa konstruksi penyangga yang dapat menahan goyangan ke kiri dan kanan.
- ✓ Usahakan tidak mendirikan bangunan terlalu dekat apalagi di atas jalur patahan, terutama untuk bangunan fasilitas umum, seperti: rumah sakit, hotel tinggi, dan sekolah, menimpa orang.
- ✓ Tata-lah barang-barang di dalam rumah agar tidak membahayakan kalau ada gempa, misalnya: tidak menaruh barang-barang berat di atas yang kalau diguncang akan jatuh dan menimpa orang di bawah, memaku lemari berat ke dinding agar tidak tumpah ke depan.

Untuk informasi lebih lanjut hubungi :

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Grafis & Ilustrasi: Samsul Mubajja
Fund: Betty and Moore Foundation of Caltech, NSF

Informational Poster describing the causes and effects of earthquakes in West Sumatra
(California Institute of Technology Tectonic Observatory)

CHAPTER 2: WHAT TYPE OF HOUSE SHOULD I BUILD –TIMBER OR BRICK?

Timber House: For single story house, a timber or semi-permanent house will be safer than a poorly built confined masonry house, especially if the house is built on weak or swampy soil. Buildings made from lightweight and flexible materials are safer in earthquakes than those from heavy and brittle materials.

**Safer
Cheaper
Faster**



Don't forget that a timber house is safer in an earthquake than a poorly built confined masonry or RC frame with masonry infill house. If you cannot buy enough steel to properly confine your confined masonry house, or you are not sure your builder is a good bricklayer, make sure your family will be safe by building a timber house.

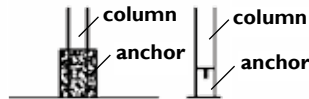
Minimum Standard for Timber House

Choose good quality timber

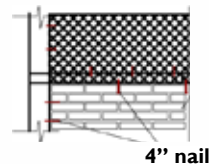
Dimensions of foundation:
25 x 40 x 50 cm



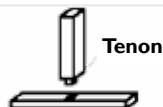
Pour concrete on column footing and give anchor



Use anchor on wall masonry



Every timber connection should have a proper joint



Every connection should have a wooden peg or nail to secure joint



Must have diagonal bracing on every corner

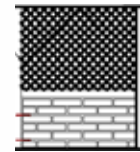


Use preservative paint

Scarf joint for beams



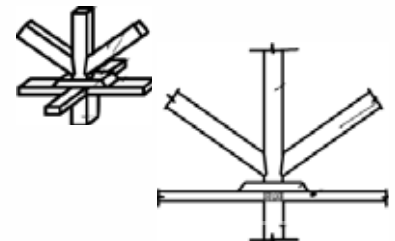
Nail the wire to the frame firmly and stretch tight



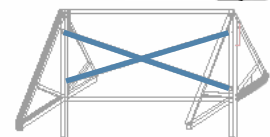
Plaster and mortar mix 1:3



Truss Connection



Wind Bracing



The Timber Frame

The first step in building a sturdy timber frame is selecting good quality wood. Choose wood that is free of knots, splits and is straight and not warped or twisted. Next, make tight fitting joints at each connection. Use these joints for connections in the timber frame.

For more information on truss connections see page 72

Column-Beam



Beam-Beam Splice



Fasten each joint with 2 pins



Use a starter column to get timber off the ground and away from water.



Install frame elements using level or plumb bob.



Paint entire frame with preservative before installing walls or windows

For more information on timber see page 38

Semi Permanent House: Masonry Skirt Wall

The base of the house needs to be tougher than the rest of the wall. Build a masonry skirt for the first 80 cm.



Soak bricks and blocks in water before laying



Use nails to connect masonry with frame



Use bricks, blocks, or stone masonry to build masonry skirt wall. Fasten masonry skirt wall to timber columns with nails.

Wall Material Options

You can use wood planks, plastered bamboo mat, or plastered chain link fence for the wall.



Install verticals first
then weave long
horizontal strips



Stretch chain link
tightly and bend nail
over to tighten.



Install backing boards
and plaster with 1:3
mix.

Whatever wall material you use, make sure you fasten it securely to the timber frame.

REINFORCED CONCRETE FRAME, OR CONFINED MASONRY?

Confined Masonry House: It is possible to build a confined masonry house that will withstand an earthquake. But if you can't follow the minimum standard for confined masonry, then your house may be destroyed by the next earthquake.

Important Features of an Earthquake-Resistant Confined Masonry Home

Lightweight roof cover on timber truss connected to the walls



Lightweight timber in the gable

Simple, square, symmetric layout

Reinforced concrete symmetric layout tie columns and bond beams "confine" the masonry wall together

Steel reinforcement in between the bricks, connects the walls to the columns



Masonry wall built with locally available, good quality materials and workmanship

Good quality steel tied together



WINNER
2006 Excellence
in Structural
Engineering Award
Structural Engineers
Association of
Northern California



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Kaki Kuda-kuda/ Truss Foot S/10

Problems with Poorly Built Confined Masonry

Qoring/Punih S/7

Heavy masonry gable



Very tall, slender walls with gable, with overturning failure

Heavy clay tiles



TOTAL LOSS
2006 Central Java
Earthquake

Homeowner
must tear down
and rebuild

Weak masonry
without
reinforcement,
lintel beam, or
connection to tie
column



Poor, weak
connections
between tie
columns and
bond beams



EARTHQUAKES DON'T KILL PEOPLE, POORLY BUILT BUILDINGS DO

Earthquakes cannot be prevented, but they don't have to be feared. We can anticipate and plan for an earthquake by building a strong and safe house. If we do so, we can prevent the house from collapsing in an earthquake. It is not the earthquake that kills people, but the building collapsing. You can keep your family safe in an earthquake by following the Three C's.

FIRST C: Use a simple, symmetric **CONFIGURATION** and

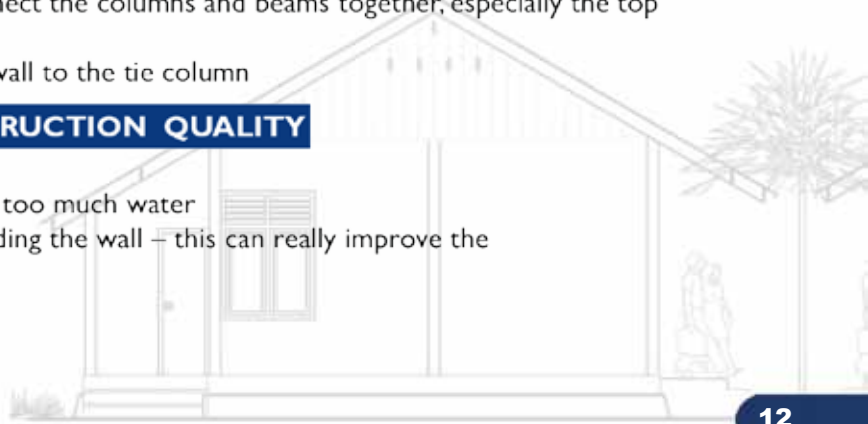
- Build a house in a common shape, such as a square, short rectangle, or circle
- Avoid long and narrow structures that have a length more than three times the width
- Use steel reinforcement in walls, crosswalls, and/or bracing for walls that are 4m long or longer
- Don't put bricks in the gable wall. Use either timber or another lightweight material
- Use smaller openings, or use a lintel beam above the opening and minor columns next to openings
- Use lightweight material for terrace and make sure the terrace columns are connected together
- Build a single story only

SECOND C: Use strong **CONNECTIONS** between the structural elements

- Follow the barbending and anchoring rules to connect the columns and beams together, especially the top of the column and the ring beam
- Use steel reinforcement to connect the masonry wall to the tie column

THIRD C: Use good quality materials and **CONSTRUCTION QUALITY**

- Use good quality materials
- Use the correct mix for concrete, and do not use too much water
- Make sure to soak the bricks in water before building the wall – this can really improve the strength for your house.



FIRST C: CONFIGURATION

Using a simple, square, symmetric layout, building a one story house instead of two, avoiding heavy material in the gable wall, and avoiding or mitigating for large openings can make a big difference in earthquake resistance. Most of these changes are free or easy to make.

a. Use Simple, Symmetric Layout

Layout is one of main points in creating earthquake resistant houses, because an irregular shape can result in damage during an earthquake. For example, mosques are usually built with a simple, square, symmetric and redundant form, using lightweight material above for the dome. Most mosques have survived recent earthquakes in Indonesia, but sometimes poor construction quality has caused collapse.

Please consider these points in choosing your house layout:

- Choose a uniform and symmetric layout
- Build a house in a common shape, such as a square, short rectangle, or circle
- Avoid long and narrow structures where length of the wall is more than 4 times the width
- Every length of wall more than 4 m should be a crosswall or brace.



Here's a comparison of good and not so good layouts for earthquake resistant houses

No	BUILDING FORM	
	Good	Poor
1		
2		
3		
4		
5		

b. Do Not Use Masonry in the Gable Wall

Gable walls made of masonry can easily collapse or crack during an earthquake because they are so tall and often stand alone without any support or bracing. If you build the gable wall from masonry, make sure to confine it with reinforced concrete. This is difficult and expensive. It is easier, cheaper, and safer to build the gable wall with timber or use a hipped roof.

PROBLEM

27 May 2006 Central Java Earthquake

**Poor**

No steel connections

SOLUTION**Option 1:**

Use lightweight material such as timber, CGI sheet, or calciboard in the gable to increase safety in an earthquake

SOLUTION**Option 2:**

Use a hipped roof, which is less expensive than a pitched roof with masonry in the gable wall and better for strong wind

c. Use Smaller Openings or Confine Openings

Using many large openings at the front of the house, which is common in Indonesia, means that the front wall will be very weak in an earthquake. Walls with openings that are not confined by reinforced concrete columns and beams are very vulnerable, with many cracks at the corners. These walls are much more vulnerable than walls without windows and doors. Take a look at pictures below that show failures of walls with large windows and doors in earthquakes in West Sumatra and Bengkulu:

PROBLEM



12-13 September 2007 Bengkulu Earthquake

PROBLEM



4 March 2007 West Sumatra Earthquake

PROBLEM



12-13 September 2007 Bengkulu Earthquake

PROBLEM



12-13 September 2007 Bengkulu Earthquake

The pictures above show the damages which are caused by large openings and the absence of connections to the walls. To reduce the damage, you can follow several options on the following page.

SOLUTION



- Use smaller openings or consolidate the opening so there is more continuous wall of masonry

SOLUTION



- Reduce the weight above the opening by using lightweight material for the gable wall (see the pictures in the previous section)

SOLUTION



- Put horizontal steel reinforcement in every 7 course bricks, on top and below the frame

See pages 62 & 63 for more information on steel reinforcement

SOLUTION



- Use a lintel beam on top and below frame. Make sure it is connected well to the columns

See pages 48-50 for more information on steel bar-bending

SOLUTION



- Use minor column on each side of the frame. Make sure it is connected well to the plinth beam and ring beam



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Kaki Kuda-kuda/ Truss Foot 5/10

d.Reduce the Weight and Improve Connections on Covered Veranda

The covering over the front veranda can also be dangerous in an earthquake if it is not built correctly. A covered veranda that has a heavy mass made of bricks supported by small columns not connected to the beams and the main house can collapse. Many people run out of their house when they start to feel the earthquake. If they run out of the front door under the covered veranda and it collapses, they can be injured or killed.

Reasons for failures include:

- Masonry gable is too heavy and it collapses
- Connection between column and beam is not strong enough
- Use of prefabricated columns which may be strong but cannot connect well to the ring beam
- Beam separates from the main building
- Veranda is too tall or far away from the main building

Here are some recommendations for building a safe covered terrace:

- Build the covered part not too far forward from the main building
- Do not use the prefabricated, decorative column if there is not enough steel to connect to the ring beam
- Use a light weight material for above the veranda like timber
- Reduce the height of the covered terrace (maximum 3 meters)

PROBLEMS



12-13 September 2007 Bengkulu Earthquake



12-13 September 2007 Bengkulu Earthquake

SOLUTION



e. A Single Story Building is Safer than a Two Story Building

If you think a two-story house is safer in an earthquake than a single story house, you are wrong! But it is possible to build a safe two-story house. You really have to know how to design and build it, so you should hire an experienced structural engineer. If you would like to build a two story building, consider these alternatives:

SOLUTION



Option 1:

Build the second story out of timber



Option 2:

Use confined masonry, but with a full-brick wide wall



Option 3:

Build the structure from steel frame. Be careful to use a lightweight infill for the walls



Option 4:

Use reinforced concrete frame with masonry infill. But, be **VERY CAREFUL**. Multi-story RC frame with masonry infill buildings, especially with open ground floor, can be very dangerous in earthquakes. Consult a qualified structural engineer.

SECOND C: CONNECTIONS

After choosing a good configuration, focus on connections between structural elements, such as:

- Anchor the foundation beam to the foundation
- Overlap and tie the steel together at the joints between the tie columns and bond beams and at the corners and T-junctions
- Connect the masonry wall to the column
- Connect the bricks to the frames using nails
- Tie the truss down to the ring beam using plate and bolt

Strong connections are critical in helping the house survive an earthquake. If the parts are not connected, the house may collapse and kill or injure your family.

a. Anchor the Foundation Beam to the Foundation

The foundation beam should be anchored to the stone masonry foundation. This can be done in one of two ways – by using the S-shaped anchor every 1 m and at locations of each column, or by anchoring the tie column bars into the stone masonry foundation.



b. Join and Overlap the Steel in the Tie Columns and Bond Beams

Poor connections between tie columns and bond beams are responsible for many failures in earthquakes in Indonesia. The common method of terminating the bars in the joint with a hook can fail very easily in an earthquake. Poor connections can be very dangerous. Here are some examples of failures at connections in earthquakes in Indonesia:

PROBLEMS



Good Connections Save Lives



Strong steel reinforcement connections will save our lives and families



If we hold together tightly, we will stand against earthquake shaking; we won't separate or release easily



Weak connections will endanger our lives and families

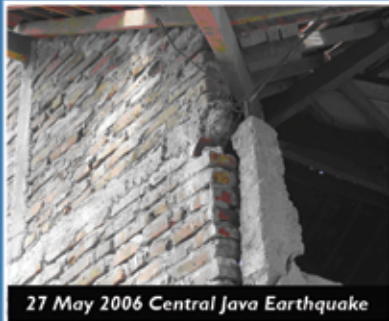


A loose grip will not withstand earthquake shaking; it will separate easily

c. Connect the Masonry Wall with the Tie Column

A strong connection between the masonry wall and the tie column is also very important. The connection will be stronger if we pour the column after we build the masonry wall.

PROBLEMS



27 May 2006 Central Java Earthquake



27 May 2006 Central Java Earthquake

Separation between wall and column

SOLUTION



Option 1:
Use toothing

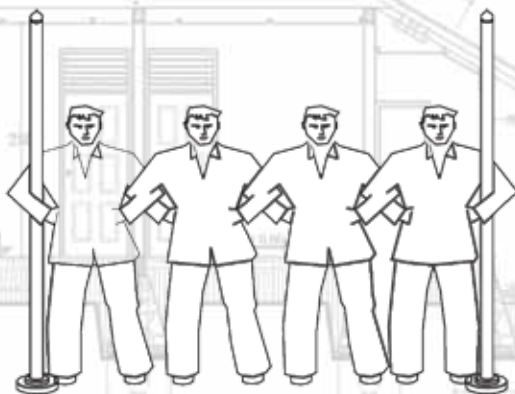
There are two options for improving the connection between the wall and the column. One is to use toothing in the masonry by leaving out the half bricks. This option requires extra formwork and sometimes it is difficult for the concrete to flow into the gaps. If this option is not used, it is necessary to use steel reinforcement. For more information see pages 62 & 63

Kaki Kuda-kuda Truss Foot S10

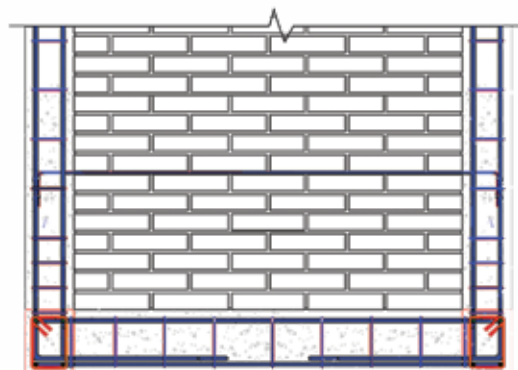
SOLUTION



BEST



Using steel reinforcement in the wall will strengthen the wall itself and connect the wall to the tie columns, like linking arms together against the earthquake.



Use steel reinforcement in the horizontal bed joint every 7 courses of masonry and above and below all window and door openings.

For more information see page 62-63

Option 2:

Use steel reinforcement in the horizontal bed joint

THIRD C: CONSTRUCTION QUALITY

Even the best design will not perform well in an earthquake if it is not built properly. Extra care should be taken in building a confined masonry or RC frame house because poor quality materials and workmanship can have a devastating effect during an earthquake. Good construction quality is made up of:

- Good quality materials, such as clean sand and strong bricks
- Mixing concrete and mortar with enough cement and not too much water
- Building a good quality masonry wall – even in a simple single story confined masonry house, the first thing to crack and collapse will be the masonry wall, so it is very important to build it well
- Skills and will of the builder – it is hard work to build a house! Make sure you pay your builder enough money so that he can slow down and make sure he does a good job building your house. But if he doesn't, fire him and hire a new builder.

Examples of poor construction quality

PROBLEMS



Poor



- No concrete at the connection
- Concrete not poured in one day, resulting in cold joints
- No connection between ring beam and ring beam
- Poor quality concrete



Poor



- Exposed steel
- Large spacing between ties
- Poor quality masonry: spacing between the bricks is too large and not filled with mortar



Poor



- Columns are not uniform in section
- Columns are not plumb
- Poor quality masonry

WHICH IS BETTER, RC FRAME OR CONFINED MASONRY?

There are two ways of building a brick and concrete house in Indonesia. The first way is to build the masonry wall first, and then cast the column around the walls. This method is called confined masonry. This way is more common for a house because it is easier and uses less formwork. Also, by casting the column after building the wall, the connection between the wall and the column will be stronger. This method is simpler and less expensive to build, so it is more common for single story house.

The other way is called reinforced concrete frame with masonry infill. In this method, the column is built first, and then the masonry wall is built. This method is more common for a building with many stories and commercial buildings in which it is really important that the column is large and strong.

The advantage of building RC frame with masonry infill is that the column can be poured all at one time, which will make the column itself stronger. However, for a single story house with a lightweight roof, the strength of the column doesn't matter as much as the connection between the columns and the ring beam, the connection between the columns and the wall, and the quality of the wall itself. After all, if the wall collapses but the columns are still standing, you or your family may still be injured.

Confined masonry is better than reinforced concrete frame with masonry infill for a simple, single story house

PROBLEMS



6 March 2007 West Sumatra Earthquake



6 March 2007 West Sumatra Earthquake

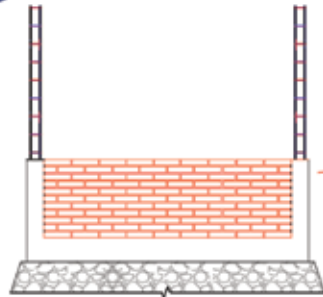


12-13 September 2007 Bengkulu Earthquake

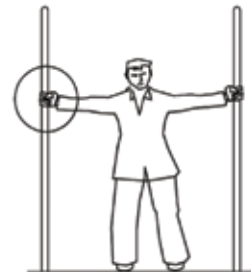
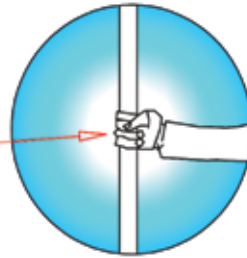
BE CAREFUL! If the wall is not connected to the columns and beams, the wall may collapse.



BEST



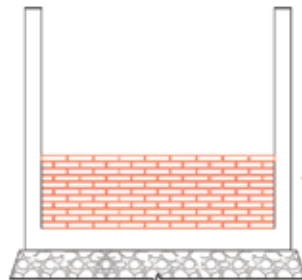
If the concrete for the column is poured **AFTER** the wall is built, the wall and the column will have a strong connection



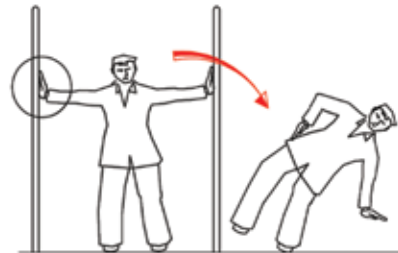
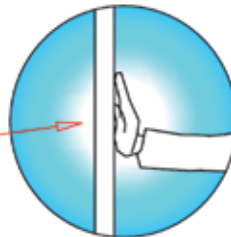
The man can stand strong against the earthquake because he can hold on to the flagpoles



NOT SO GOOD



If the concrete for the column is poured **BEFORE** the wall is built, the connection between the wall and the column will be weak



The man can tip over easily during the earthquake because he can't hold on to the flagpoles properly

If you want to build a two story reinforced concrete house with masonry infill, consult a qualified structural engineer. Here's what you need to know:

- Make a foundation that can hold the weight from above, such as isolated footing
- Bar diameter should be bigger than simple house
- More stirrups and ties should be used than simple house
- Number of major bars should be more than 4 (6 or 8 pieces of bars)
- Bars should be connected properly so they will not separate easily in an earthquake
- Concrete should be poured continuously
- Concrete quality should be very high
- Load in upper stories should be lower than load in lower stories
- Opening should not be too big and every opening should be confined with minor column or lintel beam
- Use steel stick / anchor to connect masonry to column

Be Careful!
Poorly built RC frame
can be very dangerous
in an earthquake



Banda Aceh, 26 December 2004 Earthquake



Banda Aceh, 26 December 2004 Earthquake



27 May 2006 Central Java Earthquake

CHAPTER 3: HOW TO CHOOSE GOOD QUALITY MATERIALS

Major material used:

Mountain stone

Sumatra Island has 3 kinds of the mountain stone:

1. Black mountain stone – best
2. Red mountain stone – good
3. Yellow mountain stone – not so good

If we compare the quality of each stone, black mountain stone is stronger, denser, and has almost no pores or cracks. But, it is more expensive and more difficult to find. Red mountain stone is more common and it is stronger than yellow mountain stone. Using yellow mountain stone is not recommended because it is weaker. It is clayey sand-stone so it looks more like soil, and can have fibers in the cracks.

The size or the diameter of the mountain stone should be between 15 and 30 cm. If we use stones which are too small, we will spend a lot of money on cement, and the mixture may not be able to support a heavy load. If we use stones which are too big, it is more difficult work for the builder. It will be difficult to arrange the stones so that they interlock, do not touch, and allow enough space in between for the mortar. If the stones are touching but there is no mortar in between, it will reduce the strength of the foundation.

River stone

It is better to use mountain stone than river stone because the mountain stone is angular and it can lock together. But, if mountain stone is not available in your area, you can use river stone. Because of the smooth surface and rounded shape, river stone does not bond as well to concrete and create an interlock between the stones, like mountain stone does. The size is same as mountain stone; 15–30 cm. If you use river stone, try to break up the river stone so that they have some rough edges.



Black mountain stones



Red mountain stones



Yellow mountain stone



River stones



Build Earthquake Resistant Houses
Change Construction Practice Permanently

Sand

To build a strong house, it is best to use good quality sand, because in construction, sand is used for many important parts of the house, including the foundation, concrete for the tie columns and bond beams, and mortar in between the bricks.

Good quality sand is

- Clean and free from mud
- Not mixed with rubbish, wood bits or roots
- Not too fine (not small particles)

FIELD TEST:


You can check the quality of gravel the same way you check the quality of sand.

 **Good**



 **Not Good**



 Avoid using canyon sand or sand with too much mud or fines. This sand will absorb water from the cement before it has time to hydrate and create a good bond.

Gravel

Gravel is used in the concrete for the plinth beam, tie columns, ring beam and the floor. For concrete, it is important to have the right relative proportion of cement, sand and gravel in the mix. This is easier to do if the sand and gravel are purchased separately. Otherwise, it is a lot of work for the builders to separate the sand and gravel. An explanation about the mixing and pouring concrete will be provided later the section on concrete.

Good quality gravel:

- **Clean and free from mud**
- **Not mixed with rubbish, wood bits or roots**
- **Not larger than 3 cm in diameter**

And, it is better to use crushed gravel which is angular than rounded gravel from the river.

FIELD TEST:

You can check the quality of gravel the same way you check the quality of sand.



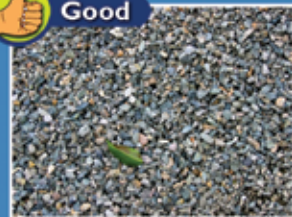
Good



Poor



Good



CRUSHED GRAVEL



Not so good



ROUNDED RIVER GRAVEL



Not so good



MIXED SAND AND GRAVEL

Bricks

For a simple, single story house built with masonry and reinforced concrete, the strength of the masonry walls is very important. A strong masonry wall is the first line of defense in strong earthquake shaking.

So, in addition connecting the wall to the column by using lintel beam or horizontal reinforcement to strengthen connection*, we must pay attention in choosing the good quality bricks.

*See pages 62 & 63 for more information

FIELD TEST: Take a sample of 10 bricks and test one by one using the test set up below. Have a person who weighs about 60 kg slowly step on the bricks (without bouncing).

Good



If:
At least 7 do not break
and 3 or less break,
the result is good,
you can use the bricks

Poor



If:
More than 3 break,
the result is bad and you
should send the bricks
back to the manufacturer
and ask for stronger bricks

Not so good



NOT ACCEPTABLE
Bricks erode in the rain

Not so good



NOT ACCEPTABLE
Bricks erode in the rain

FIELD TEST:

Check the following about the bricks

- No crack and no chips
- No part that is not mixed well, no clumps of earth
- Brick is square, not warped or curved
- The brick's size is the same for every 10-20 bricks, and the size does not vary more than 10 mm in length or 5 mm in height or width
- When two bricks are hit together, the sound is a metallic clunk, not a dull thud
- If the bricks are soaked in water for 24 hours, they do not crumble or break apart

Cement

There are two types of cement available in Sumatra. The first type, Type I, is straight Portland cement. It sets up faster and cures faster and is better for foundation and concrete elements, such as the plinth beam, columns, and ring beam. The second type is PPC (also known as PCC), which is Portland cement with an additive that slows down the setting time. This makes it easier to work with, especially for masonry and plaster. It sets up slower, and we don't have to use it up as quickly.

Differences between Type I and Type PPC are shown in the table below:

DESCRIPTION	TYPE OF CEMENT	
	Type I	Type PPC
Price	Expensive	Cheaper
Weight	50 kg	40 kg
Quality	Good	Good
Hardening Process	Faster	Longer
Time to reach design strength	28 days	More than 28 days
Setting time after mixing	45 minutes	90 minutes
Workability	More difficult	Easier
Usage	Foundation Concrete casting for • Foundation beam • Ring beam • Columns • Floor	Masonry wall and plaster

Type I cement becomes stronger faster than Type PPC (or PCC), but this is not as important for a single story house which does not have a heavy mass. Over time, the strength will be the same no matter if we use Type I or Type PPC (or PCC).



Type I



PPC

Concrete Spacers

Concrete spacers are really helpful for separating the steel from the formwork so that there is enough space for the concrete to cover the steel. If the steel is not covered up by concrete, it will get rusty and lose strength. Using a concrete spacer also helps to straighten out the bars.



Concrete spacers can be made from sand and cement at a ratio 1 : 3 (1 part cement to 3 parts sand) with maximum size of 5x5 cm and thickness according to the amount of cover required over steel (see the drawings in the section on steel detailing). Concrete spacers are easiest to use if they are cast with a binding wire, so they can tie to the bars. Concrete spacers can be square or round.

Steel

One of the critical components for an earthquake resistant house is the steel reinforcing bars. It is better to use the ribbed bar. If you use the smooth bar, you should use a larger diameter bar. Using a 12mm smooth bar is the same price as a 10mm ribbed bar. The 10mm ribbed bar will be easier to cut and bend, and provide a stronger bond with the concrete, assuming the steel is the same in both bars. So, we recommend to use a ribbed bar.



Ribbed steel



Smooth steel



Not Acceptable

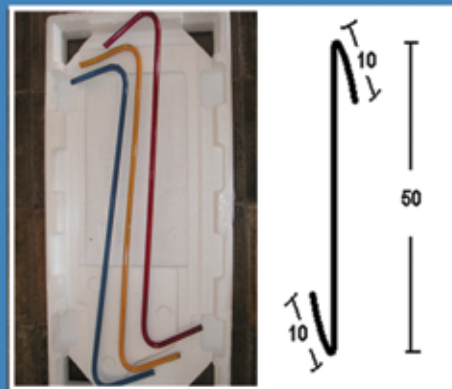


Don't use recycled steel!

For more information see pages 48-51

Foundation

Steel anchors should be placed in the foundation at intervals of 1.5m and at the locations of all columns. The anchors help to reduce sliding between the foundation and the foundation beam, and they reduce uplift of the columns. You can use waste bar, \varnothing 10 mm ribbed bars or smooth bars.

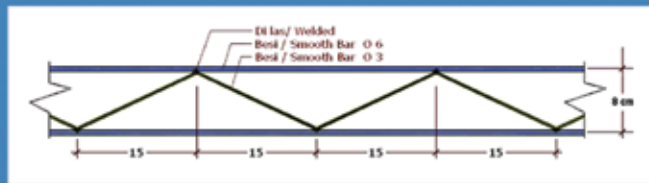


Steel Reinforcement for the Masonry Wall

Steel reinforcement should be included in the masonry wall, especially above and below the window and door frames. This steel reinforcement is nicknamed “bed joint” because it is placed in the bed joint of the masonry wall, or in the horizontal mortar joint between the bricks. Bed joint can be prefabricated in a welding shop or made in the field using binding wire. See the examples below.

Bed Joint functions:

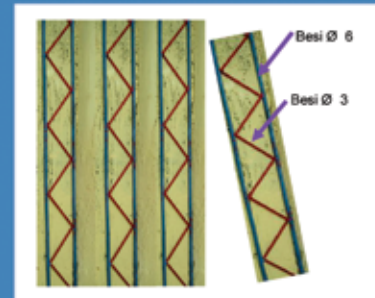
- To strengthen the masonry wall
- To connect wall with tie column



Bed joint prefabricated in welding shop



Bed joint made in field with binding wire



For more information see page 62 & 63

U-Shaped Steel Plate and Bolts

Using U-shaped steel plates to bind the ring beam with the bottom chord of the truss is helpful so the truss and roof won't easily shift in an earthquake or strong wind. The truss can also provide some bracing of the walls, so it is important that the trusses are connected tightly to the ring beam. You can ask your local welding shop to make this U-shaped plate by welding together a steel plate that is at least 4mm thick and 4 cm wide.



U-shaped plate in the ring beam



U-shaped plate in the ring beam



Poor



Bad practice –
using the column steel
to tie to the truss

Although it's very common to use the column bars to tie the ring beam to the timber truss, it would be better to tie the column bars to the ring beam, so that there is a good connection between the column and ring beam. If the column bars are left exposed to the air, they will corrode and become rusty. This corrosion is like cancer; it will spread into the column and weaken the structure.

Timber

In choosing timber for your building construction, the type of timber must be matched to the function of the timber element. Choosing timber elements efficiently and choosing the appropriate type and dimension will reduce the cost of the house.

In selecting good timber, look for the items below:

- No splits or cracks
- No knots
- No warped or curved
- Timber grade I or II



Make sure the timber is dry enough before you start to build with it. It is no problem to use recycled timber, as long as it is in good condition and not decayed.

HOW TO STORE MATERIALS

Materials like steel and timber should be stored inside, up off the ground so that they do not get warped or rusted by rain or flooding. Good air circulation is especially important for timber.



Cement should also be stored up off the ground and in a covered area. If the cement bag gets wet, the cement will get hard. Cement should be used up within 90 days of being purchased.

CHAPTER 4: HOW TO BUILD AN EARTHQUAKE RESISTANT HOUSE

1 Choose a Safe and Stable Location

Do not build ON TOP OF a steep slope



Do not build AT THE BASE OF a steep slope



Do not build IN THE RIVER BED



"Guidelines for Building Earthquake Resistant Houses Simplified," courtesy of Dr. Adi Jatmika Suryabrata, M.Sc., Ph.D. and IFRC

2 Check that the Soil is Strong Enough to Support the House

Even if you follow all of the rules about good construction in this booklet, your house could develop cracks or collapse in an earthquake if the soil under it is weak. For a simple, single story house, there are two types of **SOIL YOU SHOULD AVOID**:

- **Clayey soil or peat, that is very sticky.**

This type of soil is usually found near the coast and sometimes in the rice paddies or fish ponds. This type of soil is easy to identify because it

- Sticks to your hands and is difficult to wash off
- Smells musty and rotten
- Dries out slowly
- Shrinks when it dries out
- Breaks up or crumbles easily when it is dry
- Contains organic matter such as small fibers or seashells

- **Sandy soil that is loose and saturated with water, like quicksand.**

This type of soil is usually found near the beach or near the river bed. It is not so common in the hilly areas of West Sumatra. But if you think you may have this type of soil, try pushing a 12mm diameter steel bar into the ground. If you can push it in more than 30 cm by hand, the soil may not be strong enough to support your house.

If you find either type of soil, you should move to a different location. But if it that is not possible, you may be able to dig out the soil and replace it with compacted fill. Or, consider building a lightweight timber structure instead of a masonry and concrete structure. A timber house will be more flexible, so if the house settles a little bit, there will be no problem, or it will be easy to repair.



Poor



3 Take Care for Drainage and Grading

Make sure the rainwater can drain away from your house, and the graywater from your bathroom does not drain into the foundation.



Poor



INADEQUATE DRAINAGE
Poor grading and site selection



Poor



INADEQUATE DRAINAGE
Graywater drains into foundation



Poor



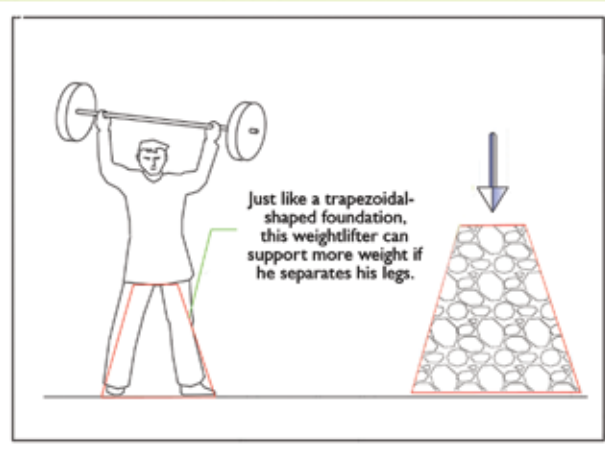
Drain pipes should not pass through any reinforced concrete elements like the foundation beam or column because this will weaken these elements. Put the pipe through the wall or the foundation.

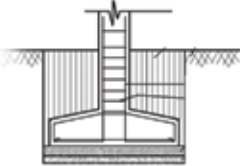
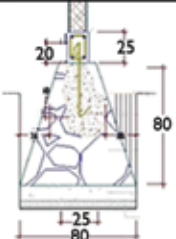
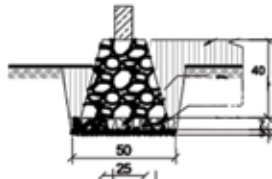
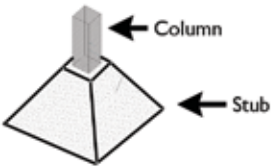
4 Build a Strong Foundation

The foundation is the main support for carrying the weight of the building. The size and type of foundation depend on the type of building, the weight of the building, and the type of soil. For a simple, single story confined masonry house, the best type of foundation is a well-built, trapezoid-shaped stone masonry strip footing. For a single story, semi-permanent house, a strip footing is also best, but it can be smaller and shallower. For a traditional timber house, a stub footing is sufficient, but a simple masonry strip footing will provide a good, firm platform for the structure and reduce stress from settling. For a multi story building using a reinforced concrete frame (RC Frame), a square footing is best, but it must be designed by a qualified engineer.

Stone Masonry Strip Footing for a Permanent House

Description	Weak Soil	Hard Soil
Depth of excavation	45 – 70 cm	35 – 50 cm
Width at base of foundation	70 – 80 cm	60 – 70
Total height of foundation	60 – 90 cm	50 – 70 cm
Width at top of foundation	30 cm	30 cm
Foundation height from the ground surface	15 – 20 cm	15 – 20 cm
Base layer	Screed (weak concrete)	Small stone
Base layer thickness	10 – 15 cm	10 cm

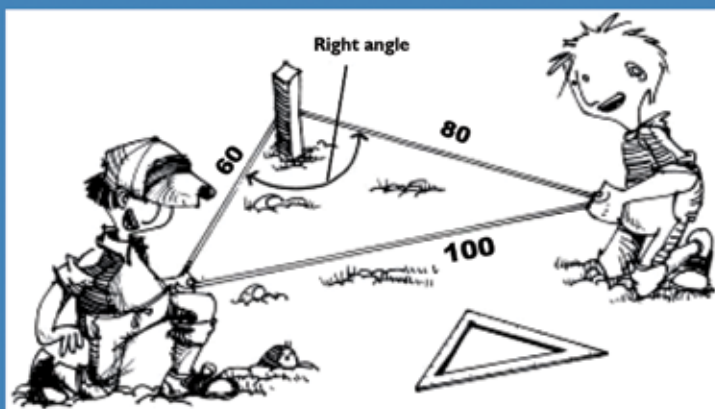


Type of Building	Type of Foundation	Explanation
Multi-Story Reinforced Concrete Frame Building		Square, isolated footings are used for multi story building in which the load is concentrated in the columns and the soil is strong. If we use this type of footing for simple one story house, we will waste more money which we can use to strengthen another part of the house such as reinforcing the masonry wall or ensuring good connection between tie columns and bond beams. Also, if we use this type of foundation for confined masonry house in which the soil is not so strong, the house might settle and have cracks.
Single Story Confined Masonry House		Stone masonry strip footing is the most common and we recommend to use it for confined masonry. It is easy to build, and it supports the weight of the wall evenly. Also, if the soil is not so strong, it can distribute the weight over a larger area. For more information see pages 46 & 47
Single Story Semi-Permanent House and Timber House		The same type of stone masonry strip footing can be used for semi-permanent house. It can be smaller, though, because the weight of the house is less. This is also a good foundation for a timber house and will increase the life of your timber house.
Single Story Timber		Although the above masonry strip footing is recommended for a timber house, a stub foundation can be used for a timber house so that the timber is separated from the ground. This can help to prevent rotting and insect infestation.

Line Out and Batterboard

Right angles are very important in building a house. Without these the house will not stand straight. A right triangle can be used to find right angles when laying out the building. This simple method can be used for a simple house. When each string is laid out in a triangle as shown below, and each string is the exact length indicated, then we have a right angle.

- String with length 60 cm can be described as "dead thread" which means this thread is immobile. Both ends of the thread are nailed to both sides of the batterboard, right and left, with length of 60 cm
- String with length 80 cm can be described as "living thread". This means, one end can be moved inwards or outwards until the diagonal has length 100 cm. The other end is nailed to the batterboard.
- String with length 100 cm is diagonal thread. When the length is 100 cm, then we have a right angle.



"Construction and Maintenance of Confined Masonry Houses:
For Masons and Technicians", Marcial Blondet, Editor

Foundation Excavation



Poor



Remove water, organic component, and remain excavate soil from the foundation area and make a flat surface



Good



Minimum width of excavation should be 80 cm. Depth of excavation depends on soil type*; if weak soil is found, you may have to dig deeper to find the strong soil

* For more information on soil types see page 41



Good



Use a lean concrete mix (1:3:6) to make a screed floor. This will create an even working surface. Thickness of screed floor is 10 cm with mix 1 : 3 : 6 (1 cement : 3 sand : 6 gravel)



Good



CAUTION!!

Do not build a confined masonry house in a swampy or watery area, or on soil that is spongy and soft. If the soil is weak, the building may settle and crack. It is better to build a semi-permanent or timber house.

Build a strong foundation using mountain stone/river stone

In making foundation using mountain stone or river stone, it is important that the spacing between the stones is filled with mortar, and the stones don't touch each other.



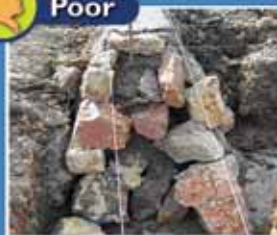
Good



Use a trapezoidal-shaped stone masonry strip footing for a permanent, confined masonry house with minimum width at the bottom of 70 cm and top 30 cm



Poor



- Stones laid vertical
- Stones touch each other
- Gaps are not filled with mortar



Good



- Lay the stone horizontally and fill all the gaps with mortar
- Corners and T junctions should be built continuously so that there is a connection between perpendicular walls



Good



Use steel anchors every 1 m and at the locations of the columns as the connection between foundation and plinth beam



Good



If the work has to stop, do not add mortar on the top



Good

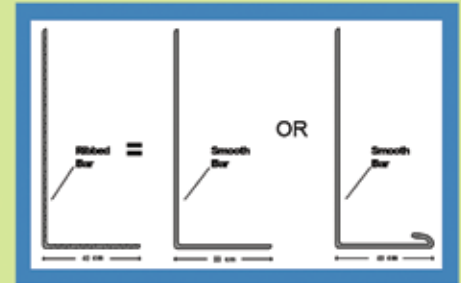


Don't forget to scarify the top for good contact with the foundation beam

5 Connect the Tie Columns and Bond Beams

Good connections and anchoring of the steel in the reinforced concrete is critical to prevent collapse in an earthquake.

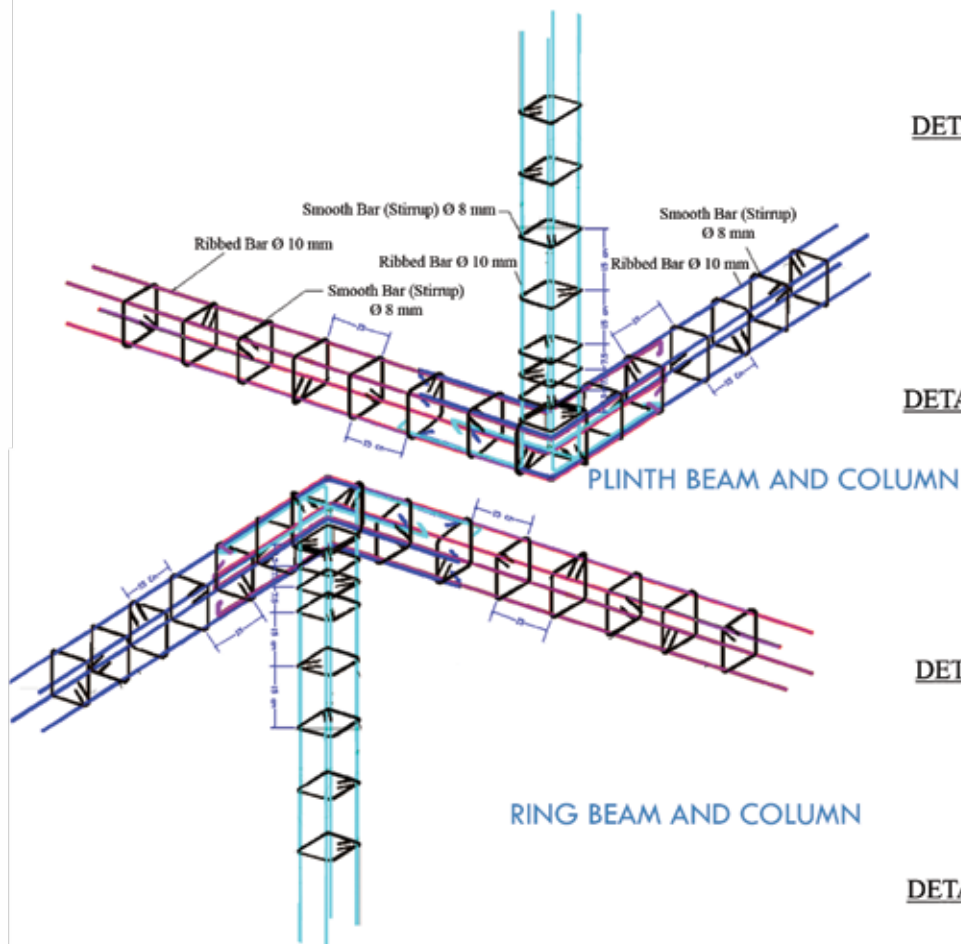
To make the steel reinforcement earthquake-resistant, we need to improve the barbending technique and make better connections. The old way - using a small hook at the end of the bar - is not sufficient to prevent collapse in an earthquake. Here we will introduce a stronger and easier way of connecting the steel reinforcing system.



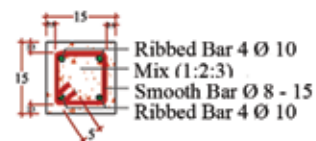
For a simple, single story confined masonry house, we recommend to use 10mm diameter ribbed bars for the long bars in the tie columns and bond beams. The length of overlap should be 40 times the diameter of the bar, or 40 cm. If you use smooth bar, you can either double the length of the overlap to 80 times the diameter of the bar, or use an overlap of 40 times the diameter of the bar plus a hook at the end.

Earthquake-Resistant Steel Anchoring

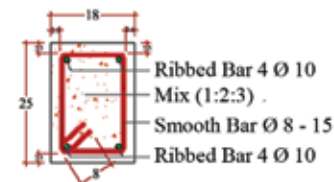




DETAIL RING BEAM



DETAIL MAJOR COLUMN

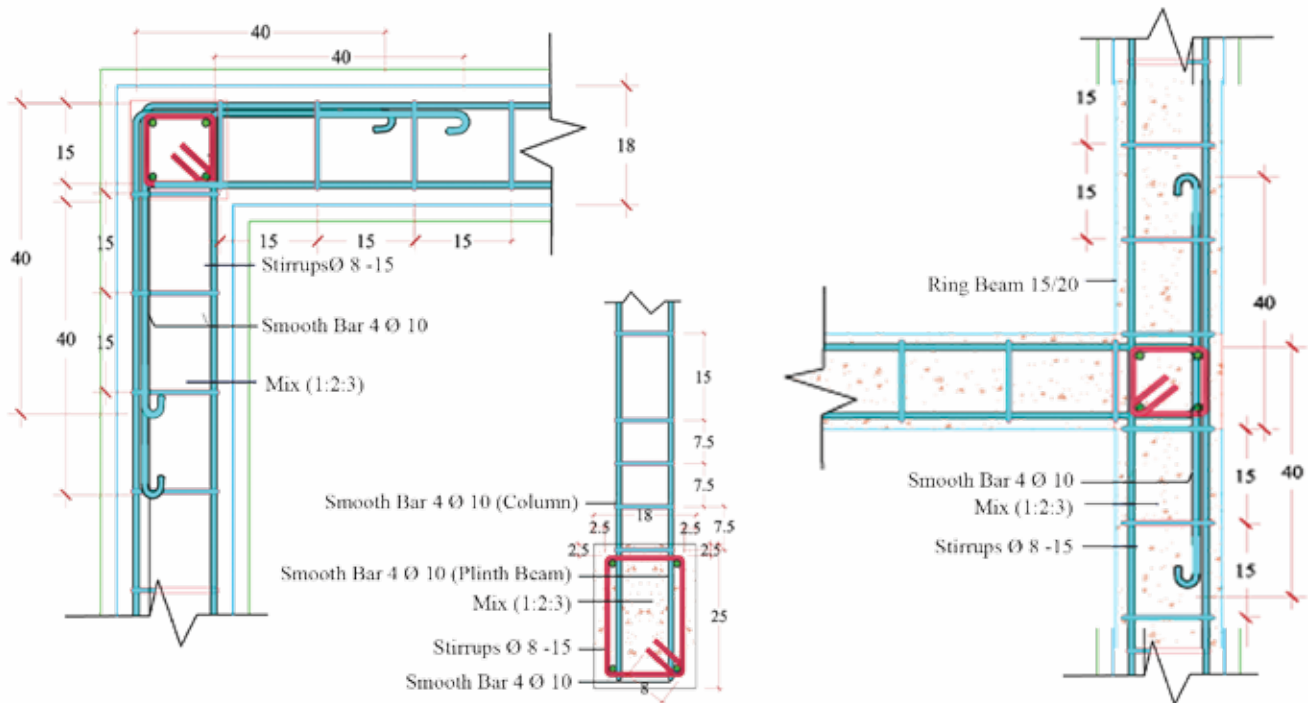


DETAIL PLINTH BEAM



DETAIL MINOR COLUMN

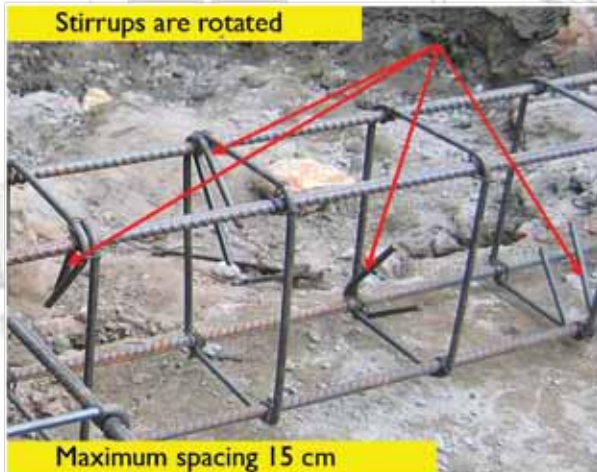
STEEL REINFORCEMENT CONNECTION DETAIL: L AND T JUNCTION



How to Bend and Assemble Stirrups or Ties:

- Use \varnothing 8 mm smooth bars for stirrups and ties
- Bend the hooks at 135 degrees
- Check the stirrups are at right angles with the long bars

Stirrups are rotated



Maximum spacing 15 cm

- Rotate the stirrups so that the hooks do not all line up on the same long bar
- Maximum distance between stirrups should be 15 cm



Good



Hooks bent at 135 degrees, long enough, tied tightly to the long bars with binding wire, and at right angles with long bars



Poor



Hooks not long enough



Stirrups not at right angles or tied tightly to long bars

6 Mix, Pour and Cure Good Quality Concrete

Concrete Mix
Use 1:2:3 Mix



- You can mix concrete either by hand on the ground or using a mechanical mixer. If you mix by hand on the ground, use a paved surface that is clean from trash and soil.
- Mix the dry ingredients first (cement + sand + gravel) and keep mixing until the color is uniform
- Make hole in the corner of materials and add clean water and mix it well
- Use the concrete within 90 minutes of adding water



MIXING SAND GRAVEL AND CEMENT
Not completely mixed until the color is uniform



MIXING SAND GRAVEL AND CEMENT
Thoroughly mixed dry ingredients.



MIXING IN WATER.
Mix in water gradually and use up within 90 minutes of mixing with water



BE CAREFUL! When mixing concrete using a mechanical mixer, it's easy to use too much water. If you use too much water, the concrete will be weaker



Poor



TOO MUCH WATER!
This concrete has too much water – it is like soup and will not be strong enough

SIMPLE TEST



Not so good

Mix has too much water



FIELD TEST:

You can check the water content in the concrete in a simple way. Just pick up a handful of mixed concrete and if there is a lot of water running out between your fingers, leaving only sand and gravel behind, the mix is too wet.

BETTER TEST



Poor



Good



FIELD TEST:

A better way of testing the concrete mix is to use a slump test. Fill the cone, turn it over, and measure the slump. It should be between 8 and 12 cm.

Formwork and Concrete Spacer



Good



Make the formwork using good quality timber that will not bulge or bow



Good



Wet the formwork and foundation before pouring concrete so the cement won't be absorbed by the formwork



Good



Place concrete spacers on the bottom and both sides of the steel to separate the steel from the formwork so that the concrete can completely cover the steel

Pouring Concrete

Ram the concrete with a rod and tap the formwork with a hammer to make sure the concrete is compacted and all voids are filled.



Good



To make the concrete compacted and ensure all voids are filled, ram the concrete with a rod and tap the formwork with a hammer



Good



CAUTION! If using a vibrator, do not vibrate it for too long because it will separate the mix (gravel will go down to the bottom)

Kaki Kuda-kuda Truss Foot S10



Good



Do not forget to scratch the surface for good bond with masonry wall



Good



Cure the concrete by pouring clean water on it 3 to 5 times a day for 7 days



Good



Good



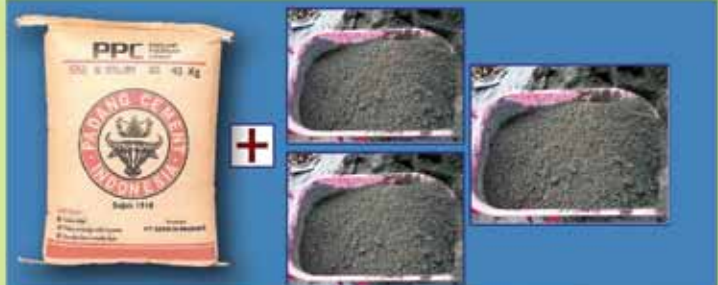
7 Build a Strong Masonry Wall

Mortar Mix

For masonry and plaster, use cement type PPC



1:2 mix for damp proof course and bathroom
(1 sack cement and two wheelbarrows sand)



1:3 mix for interior walls and exterior walls
above damp proof course (1 sack cement and
three wheelbarrows sand)



Good



IMPORTANT!! If you soak the bricks in water before you build the wall, the wall will be much stronger. **WHY?** The bricks in Sumatra are very porous and dry, so they absorb the water from the mortar before the cement has time to hydrate and stick the bricks together.



Poor



Here's what happens if you don't wet the bricks; there is no bond between the bricks and mortar, and the wall will crack easily in an earthquake.

**Building a Strong
Masonry Wall
is one of the Most
Important Things
You Can Do to
Keep Your Family
SAFE**

Kali Kuda-kuda Truss Foot 5/10



Good



Lay the bricks out first to check the spacing.
It should be maximum 1.5 cm



Good



Distance between column steel
and bricks is 3 cm



Poor



Bricks are too close to
the column steel



Good



Use line and deadman to make bricks straight



Good





Good



Lay the bricks at same time horizontally



Poor



Good



Maintain a uniform joint thickness of maximum 1.5 cm

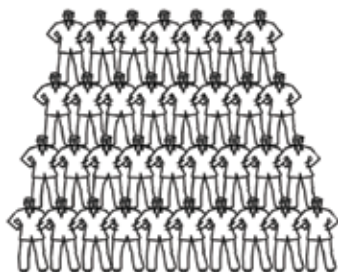


Poor

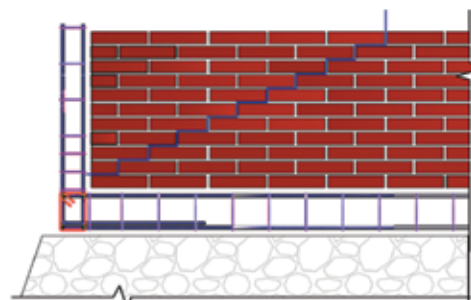




BEST



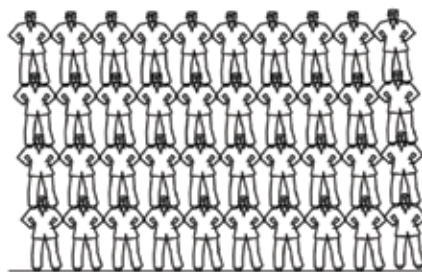
When people stand in a pyramid shape, with one leg on two people below, the load from one man above is shared by two men below. If one man is weak, another man can carry the weight. The pyramid is more stable. It has redundancy.



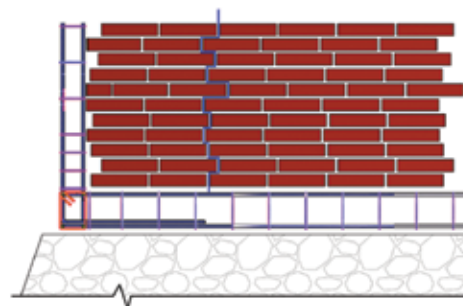
A good example of brick laying. When the joints between the bricks are staggered, the load from one brick above is shared by two bricks below. When there is a crack, this crack will not continue in a vertical direction along the spaces between the bricks.



NOT SO GOOD



When people stand one on top of the other, the load is taken all by one man. If that one man is weak, the line will collapse. There is no redundancy.



A bad example of brick laying. The joints between the bricks are not staggered, and if there is a crack, this crack will easily continue in a vertical direction. The bricks are not laid neatly either, the spaces between



Good



Stagger the vertical joints



Poor



Stagger the vertical joints and don't use broken bricks



Good



Fill the joints completely with mortar



Poor



Joints are not completely filled. We can see through the wall!

Kaki Kuda-kuda/ Truss Foot 5/10

Gording/Purlin 5/7



Good



Always cure the bricks and sprinkle with water before laying the next course



Poor



Many bricks are weak because they are not fully fired. They erode in the rain. They should be replaced.



Poor

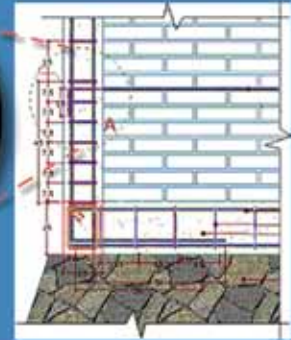


Don't use patterned bonding over the window frames. It is too difficult to make a proper arch.

8 Connect the Wall to the Column Using Steel Reinforcement



Good



Put bed joint in every 7 layers of bricks and above and below the window and door frames



Good



Use 2 cm of mortar above and below the steel



Poor



Bed joint reinforcement hook is too short and not tied to column steel

Alternative Method for Reinforcing Walls and Openings

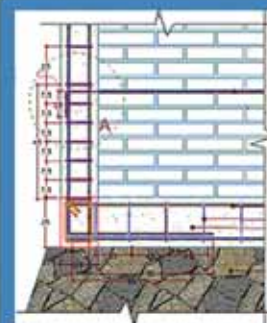
If you do not use the bed joint horizontal reinforcement described on [page 62](#) you can use a reinforced concrete lintel beam above openings and install a single steel bar every 1 meter of masonry.



Use reinforced concrete lintel beams above windows and doors. Connect reinforcing steel from lintel beams into tie columns.



Install steel bar every 1 meter of masonry wall height and extend steel bar at least 50 cm into masonry wall.



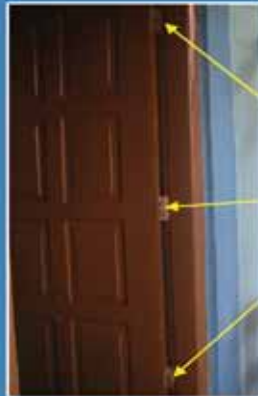
Tie the steel bar into tie columns as shown above.

9 Install Frame, Doors and Windows

- Check frames, doors and windows for the following things:
 - Good quality timber with no splits or fibers
 - Frame is square and straight (not warped)
- Install frame vertical and make sure the doors open inward and windows open outward
- Use the putty and sand paper to smooth the doors and windows before painting.
- Use three coats of oil-based paint on the doors and frames



- Coat with sealant
- Use timber nails in a cross pattern to connect the frame with the column



Use 3 hinges for doors and 2 hinges for windows



Put concrete starter bars at bottom of door frame



Fill the space under the windows completely with mortar

10 Concrete Cast for Column



Good



Clean the bottom of the column



Bad



Bottom of column is filled with loose mortar



Prepare the formwork and cover with sika or oil inside formwork



Pour columns after 1-1.20 m wall built

CAUTION!

After pouring concrete, use steel rod and hammer to compact concrete as shown on

page 54

- Cure 1-5 times per day for 3 days after pouring concrete by sprinkling with water
- Open formwork after minimum of 3 days
- If the weather is hot and dry sprinkle more often with water and wait longer before removing formwork



Good



Good



Poor quality concrete and exposed steel reinforcement can greatly reduce the strength of your house in an earthquake



Poor



Poor



11 Connect the Top of Tie Columns to the Ring Beam

A ring beam is essential for good performance in an earthquake. The connection between the top of the column and the ring beam is one of the most important connections in the house, so don't make this same mistake shown below!

For more information see pages 48-51



Poor



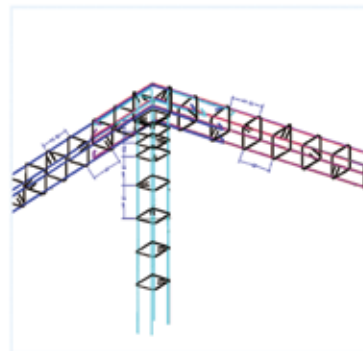
Steel is not long enough to make a strong connection for the ring beam



Poor



Good



Place concrete spacers below, to the left, and to the right of the stirrups, and follow the instructions about mix and concrete pouring. For more information see pages 52-56



Good



Before pouring the concrete, do not forget to install U plate to connect ring beam and truss



Good



Pour the entire ring beam in one day to avoid cold joints and increase the strength



Poor



If the quality of construction is poor, demolish and rebuild

After removing the formwork, check for cracks, spalls and holes. If there are big holes, demolish the concrete and rebuild.



Good



Poor



Don't leave the column steel sticking out of the top. It is better to bend it in to the ring beam.



Poor



Exposed steel

12 Plaster the Wall

Many people think that plaster is just for finishing and for the aesthetics of the building. The fact is that plaster increases the strength of the masonry wall and protects the masonry wall from exposure to weather and moisture that can weaken the wall. However, if the masonry and concrete are poor quality, good finishing with plaster will not improve the strength enough. So, it is really important to follow the instructions in this guideline on good quality construction.

Keep in mind these points when plastering:

- Better to plaster the wall after the roof is finished
- Wait at least 7 days after finishing the masonry wall before starting the plaster
- Plaster the interior walls first. This will help the plaster bind to the wall by using the heat on the outside of the wall
- Minimum thickness of plaster is 1.5 cm
- Use the same mix as for the mortar [see page 56](#)
- Start the plaster from the top of the wall and plaster downwards.



Wet the wall before applying plaster



Use pressure to apply the plaster to the wall; do not just throw the plaster against the wall



Finish the wall with cement-water slurry

13 Connect the Truss to the Ring Beam



Good



Install U plate at locations where the truss cord can tie to the plate



Good



Install U plate so that it sticks out above the ring beam approximately 10 cm



Good



Poor



Use bolt diameter $\frac{1}{2}$ " to tie U plate with truss

Kaki Kuda-kuda Truss Foot S/10

Gooding/Purin S/7



Good



Residu

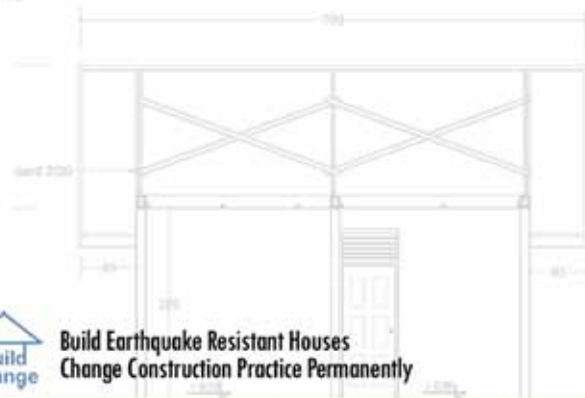


Make truss frames from hard wood, as follows:

- Use good quality of wood (timber Class I or class II):
- Make tight connections – no space between the timber elements
- Fasten truss connections with bolt, washer, and steel connection plate. Nails are not strong enough for the truss connection.

Use preservatives (called "Residu" in Sumatra) or oil based paint on all timber for the truss. This will protect the wood from insects and decay.

Use 8 bolts of 1/2 inch diameter installed in a zig-zag pattern on truss joints



14 Timber Joinery for Truss



1. Simple Scarf Joint

This connection can be used for the purlin but it can only resist the compression (pushing) load. It cannot resist the tension (pulling) load.

2. Hooked Scarf Joint

This connection is better because it can resist both compression (pushing) and tension (pulling).



3. Hooked (Half Lap) Scarf Joint

This connection is also good because it can resist both compression (pushing) and tension (pulling), and it is easy to make.



4. Flared Tennon Butt Joint

This connection is common for fascia board because it can hold compression (pushing) and tension (pulling) loads.



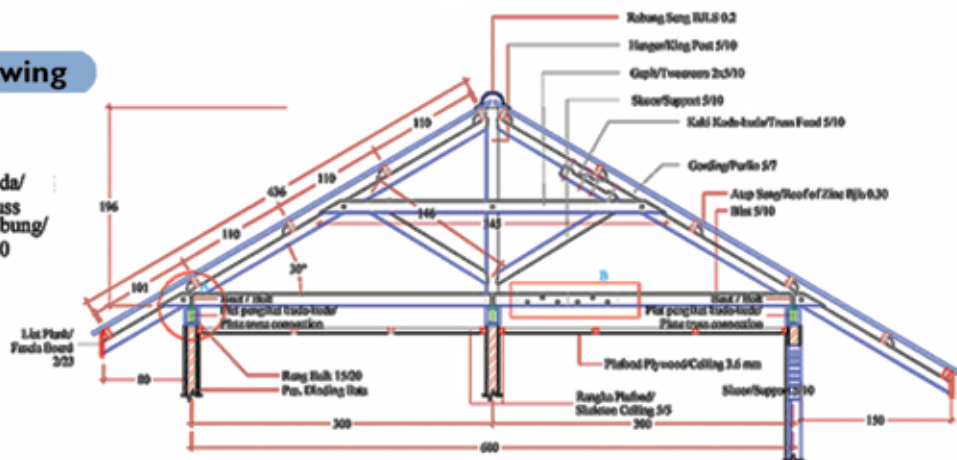
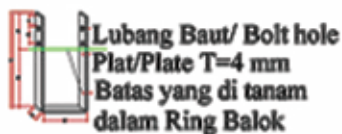
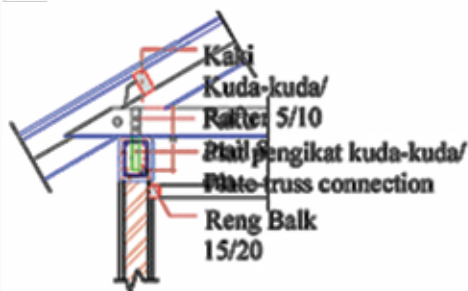
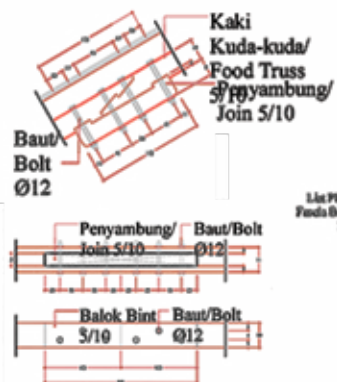
5. Scarfed Butt Joint

This kind of connection is also common for the fascia board because it is also capable of resisting both compression (pushing) and tension (pulling) loads.

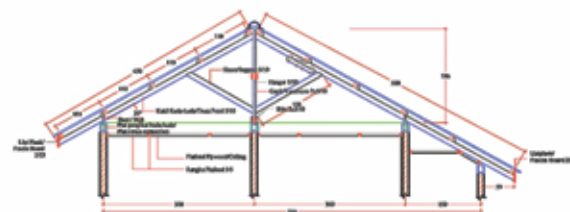


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15 Timber Truss Detail Drawing

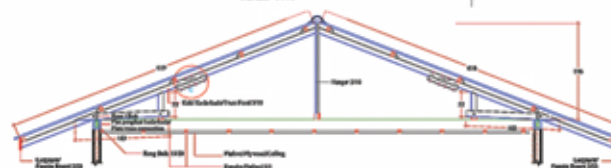


KUDA - KUDA / TRUSS 1



KUDA - KUDA / TRUSS 2

SCALE 1:70



KUDA - KUDA / TRUSS 3

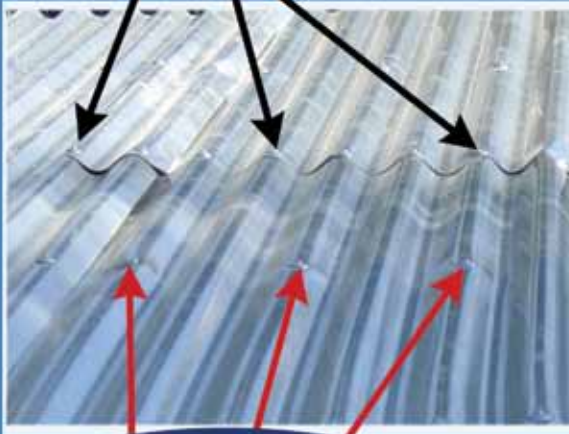
SCALE 1:70

16 Installing the Ridge Sheet

Use special galvanized nails for CGI sheets



Overlap CGI sheets at least 15 cm and nail at purlin



Nail CGI every 2 waves at high point also at purlin



Minimum thickness of CGI sheet is 2 mm but 3 mm sheet will last longer



Start CGI sheet from the bottom



Build Earthquake Resistant Houses
Change Construction Practice Permanently

Kali Kuda-kuda Truss Foot S10

Good connection, waves straight



Bad connection, waves not straight



Thickness of CGI ridge sheet should be minimum of 2 mm

MINIMUM STANDARD FOR SINGLE-STORY CONFINED MASONRY HOUSE

1 Foundation

- Soil must be strong enough to support the weight of the house
- Fill all the spaces between foundation stones with mortar

2 Tie Columns and Ring Beams

- Stirrups must have hook and hooks are rotated
- Use good quality sand and gravel
- Use a mixture of 1:2:3
- Good casting: there is no exposed steel
- No cavities
- Compact with a steel rod and tap with hammer
- Must have a connection between the ring beam and column
- Do not use recycled or rusty reinforcing steel

3 Masonry Wall

- Use confined masonry
- Soak the bricks before laying
- Spacing between bricks should be maximum 1.5 cm
- Distance brick with columns 3cm
- Cast column after height of the wall reaches 1 to 1.2 m
- Use good quality bricks, sand, and concrete
- Fill all joints between bricks

4 Walls Without Openings

- Use steel bed joint every 7 courses, tied into tie columns, or
- Use a single steel bar every 1 m of masonry, tied into tie columns, extending at least 50 cm into the wall
- Add minor column to walls of more than 4 m

5 Walls With Openings

- Use steel bed joint every 7 courses and above and below openings, tied into tie, or
- Use a lintel beam above openings and a single steel bar every 1 m of masonry, tied into tie columns, extending at least 50 cm into the wall

6 Connection Between Ring Beam and Truss

- Tie steel bars from overlap from ring beam to truss or
- Use bolts and steel plate / strong nails in truss

7 Gable

- Do not use masonry for gable wall. Use wood, CGI sheet, or other lightweight material



CITATIONS

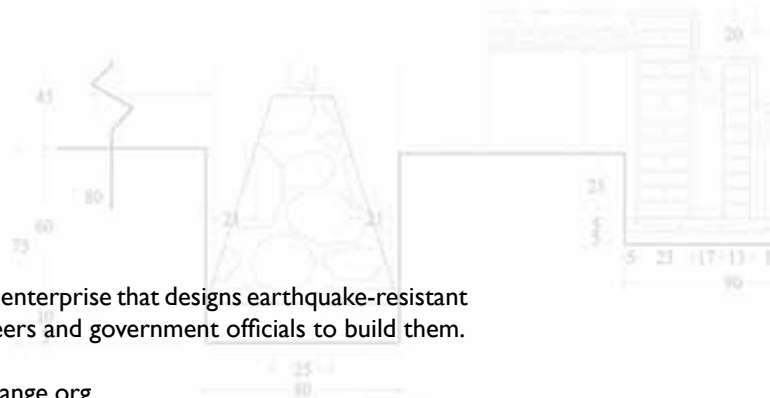
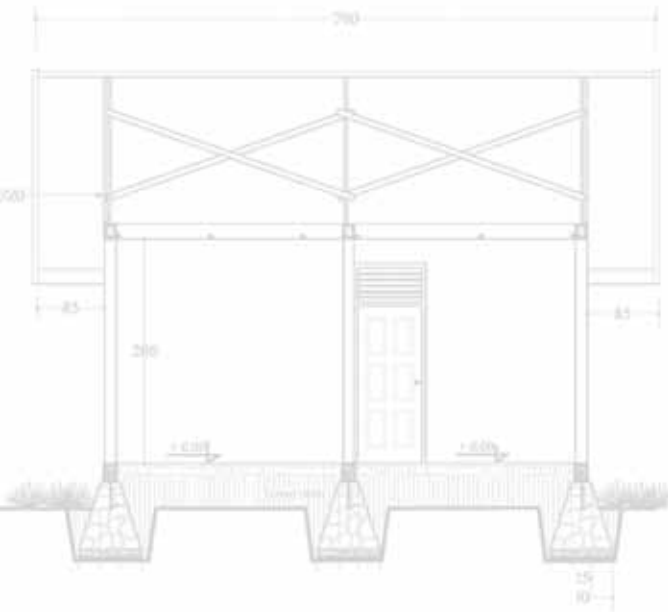
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