

Earthquake-Resistant Design and Construction Guideline

DRAFT – 31 May 2006

For Single Story Reinforced Concrete
Confined Masonry Houses
Built in the Aceh Permanent Housing
Reconstruction Program

Elizabeth Hausler, Ph.D.
© 2006 Build Change

About Build Change

- ❑ Build Change is an international non-profit engineering company based in San Francisco, CA USA. Build Change's team of engineers, architects, and construction supervisors have completed an 11 house pilot project in Aceh Besar, Indonesia and are now providing design inputs, construction supervision, and builders training programs for other organizations building houses in Aceh.
- ❑ Build Change's house design for Aceh recently won a Structural Engineers Association of Northern California Excellence in Structural Engineering Award for 2006.



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Acknowledgements

- ❑ Build Change gratefully acknowledges funding and support from the following sources, which have made the 11 house pilot project, production of this design and construction guideline, and much more, possible.
 - ❑ Mercy Corps
 - ❑ Draper Richards Foundation
 - ❑ Echoing Green
 - ❑ Earthquake Engineering Research Institute
 - ❑ US-based engineering companies and engineers

Purpose and Disclaimer

- This design and construction guideline is intended for use in Aceh and Nias during the post-tsunami and earthquake housing reconstruction programs. It is applicable to single story reinforced concrete confined brick masonry structures on strip footings with timber truss roofs with lightweight covering.
- The focus of the design guideline is on earthquake resistance of the structure itself. Thus, it does not address issues such as siting, water and sanitation, and electrical installation.
- This guideline is in no means intended as a substitute for detailed engineering analysis. A detailed engineering analysis, including a soils investigation, is recommended prior to starting any construction project. Build Change accepts no liability. Use at your own risk.

Request for Comments and Feedback

This guideline is a DRAFT DOCUMENT. It is open for discussion. Your comments, inputs and questions are greatly appreciated.

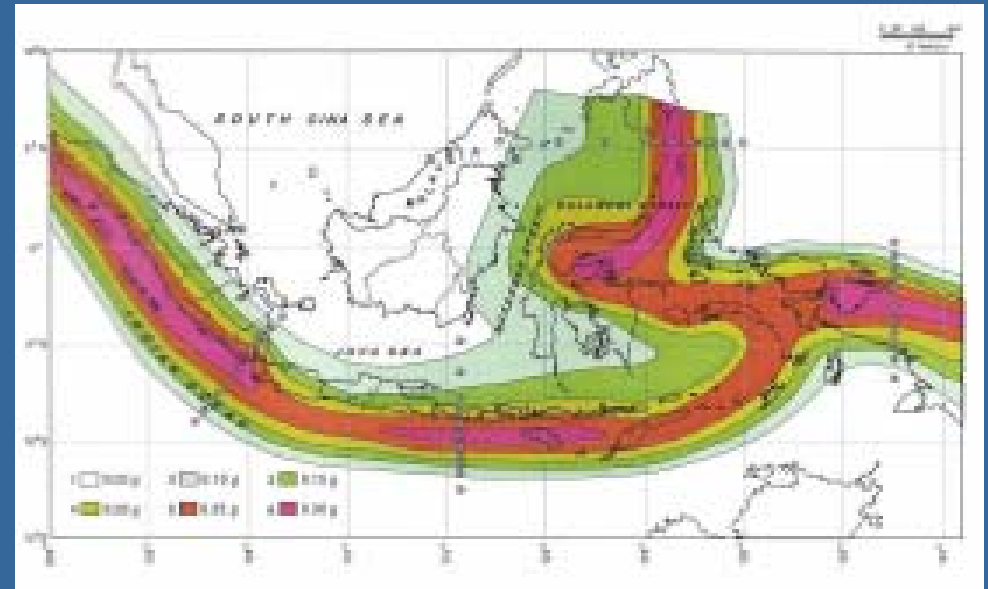
Please submit via e-mail to
info@buildchange.org

Source and Basis

This guideline is based on the following:

- ❑ Build Change's Acehnese and expatriate staff experience, prior to tsunami, in US, Indonesia, Iran, and India; an 11-house post-tsunami pilot project in Aceh, and observations of damage caused by the 27 May 2006 Central Java, Indonesia Earthquake
- ❑ Set of calculations by Build Change's team of licensed, pro bono structural engineers for 0.4g design acceleration
- ❑ BRR (Indonesia) reconstruction guideline
- ❑ Experience and posters by Teddy Boen (Indonesia)
- ❑ Eurocode 8 and City University London's guideline on confined masonry in Eurocode 8
- ❑ Construction and Maintenance of Masonry Houses, M. Blondet (Peru)
- ❑ Indian Institute of Technology, Kanpur (NICEE) Earthquake Tip Sheets
- ❑ Inputs from academic and practicing structural engineers from US and Canada

SEISMIC HAZARD IN ACEH



Build Earthquake Resistant Houses
Change Construction Practice Permanently



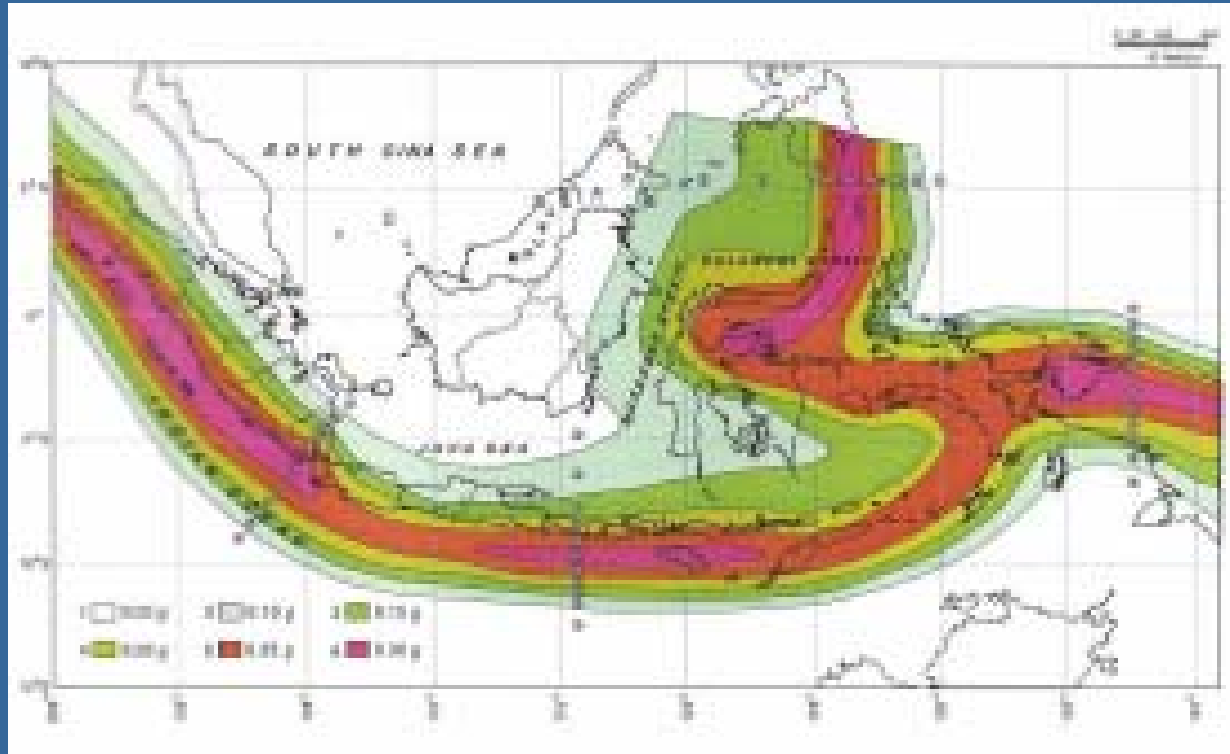
Seismic Hazard in Aceh

Indonesian Building Code SNI 03-1726-2002 specifies the following design ground accelerations based on the seismic zonation and soil type:

Design Ground Accelerations (g)

| Zone | Rock | Hard Soil | Medium Soil | Soft Soil |
|------|------|-----------|-------------|-----------|
| 6 | 0.3 | 0.33 | 0.36 | 0.38 |
| 5 | 0.25 | 0.28 | 0.32 | 0.36 |
| 4 | 0.2 | 0.24 | 0.28 | 0.32 |
| 3 | 0.15 | 0.18 | 0.23 | 0.3 |

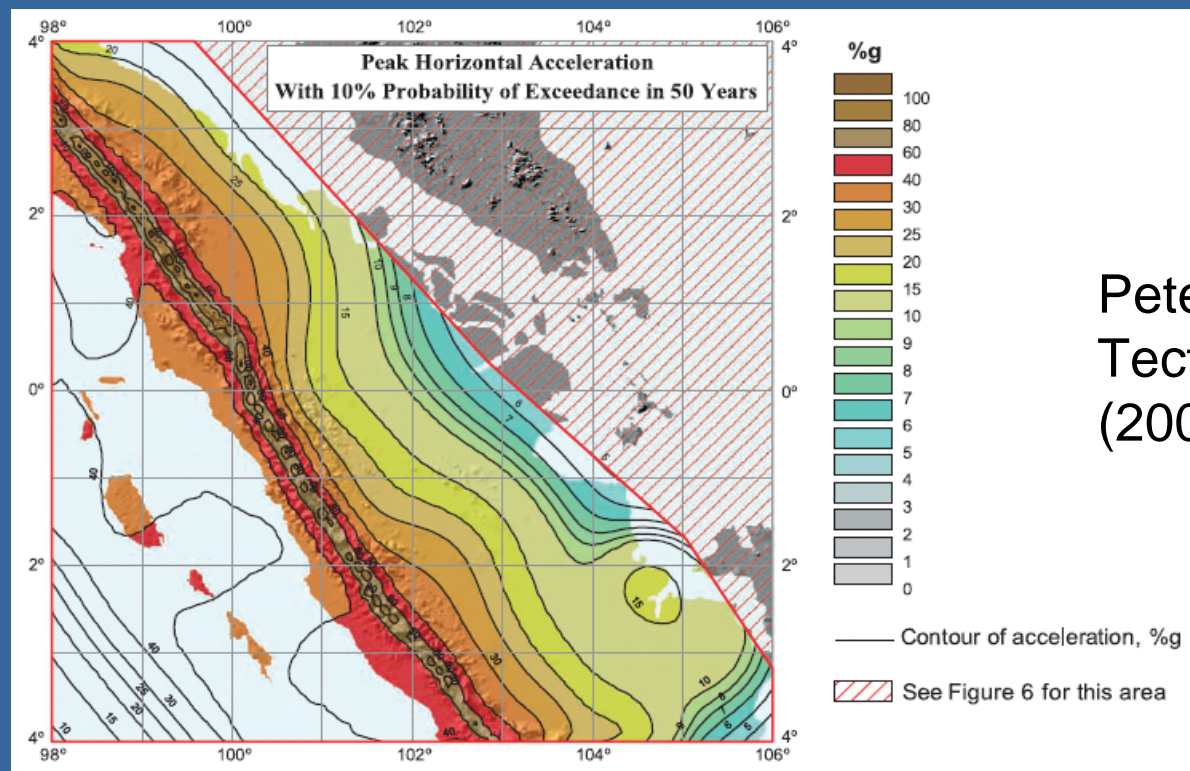
Seismic Hazard in Aceh



Seismic zonation on Sumatra Island is based on the hazard from an earthquake on the Sunda Trench
→ Banda Aceh is in Zone 5

Seismic Hazard in Aceh

However, the seismic zonation does not recognize the hazard posed by the Sumatra Fault (strike-slip fault running down the axis of Sumatra Island, a few km outside Banda Aceh)



Petersen et al.
Tectonophysics 390
(2004) 141 – 158

Build Earthquake Resistant Houses
Change Construction Practice Permanently



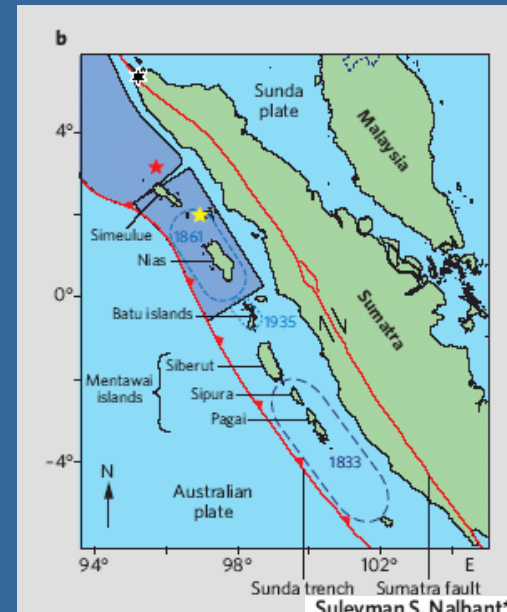
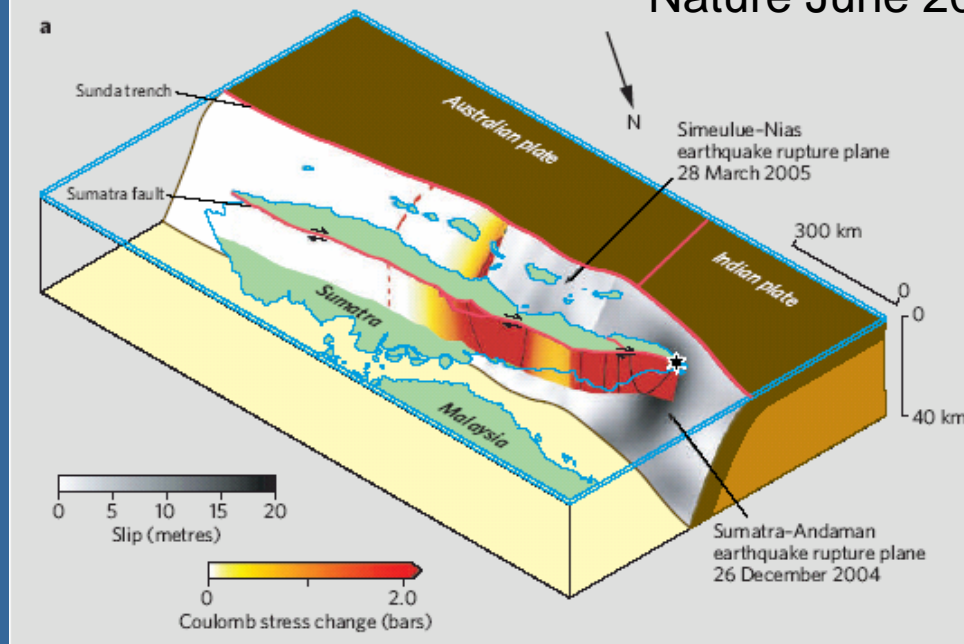
Seismic Hazard in Aceh

According to Peterson et al., Sumatra Fault could produce ground accelerations in Banda Aceh **2 – 3 times higher** than the design values in the Indonesian Seismic Code

Design Ground Accelerations (g)

| Zone | Rock | Hard Soil | Medium Soil | Soft Soil |
|----------|-------------|-------------|-------------|-------------|
| 6 | 0.3 | 0.33 | 0.36 | 0.38 |
| 5 | 0.25 | 0.28 | 0.32 | 0.36 |
| 4 | 0.2 | 0.24 | 0.28 | 0.32 |
| 3 | 0.15 | 0.18 | 0.23 | 0.3 |

Nature June 2005



Suleyman S. Nalbant*, Sandy Steacy*,
Kerry Sieh†, Danny Natawidjaja†,
John McCloskey*
*School of Environmental Sciences, University of
Ulster, Coleraine, County Derry BT52 1SA, UK
e-mail: j.mccloskey@ulster.ac.uk
†Tectonic Observatory, California Institute of
Technology, Pasadena, California 91125, USA

Other seismologists (Indonesian and international) agree, **MORE STRONG EARTHQUAKES LIKELY...**

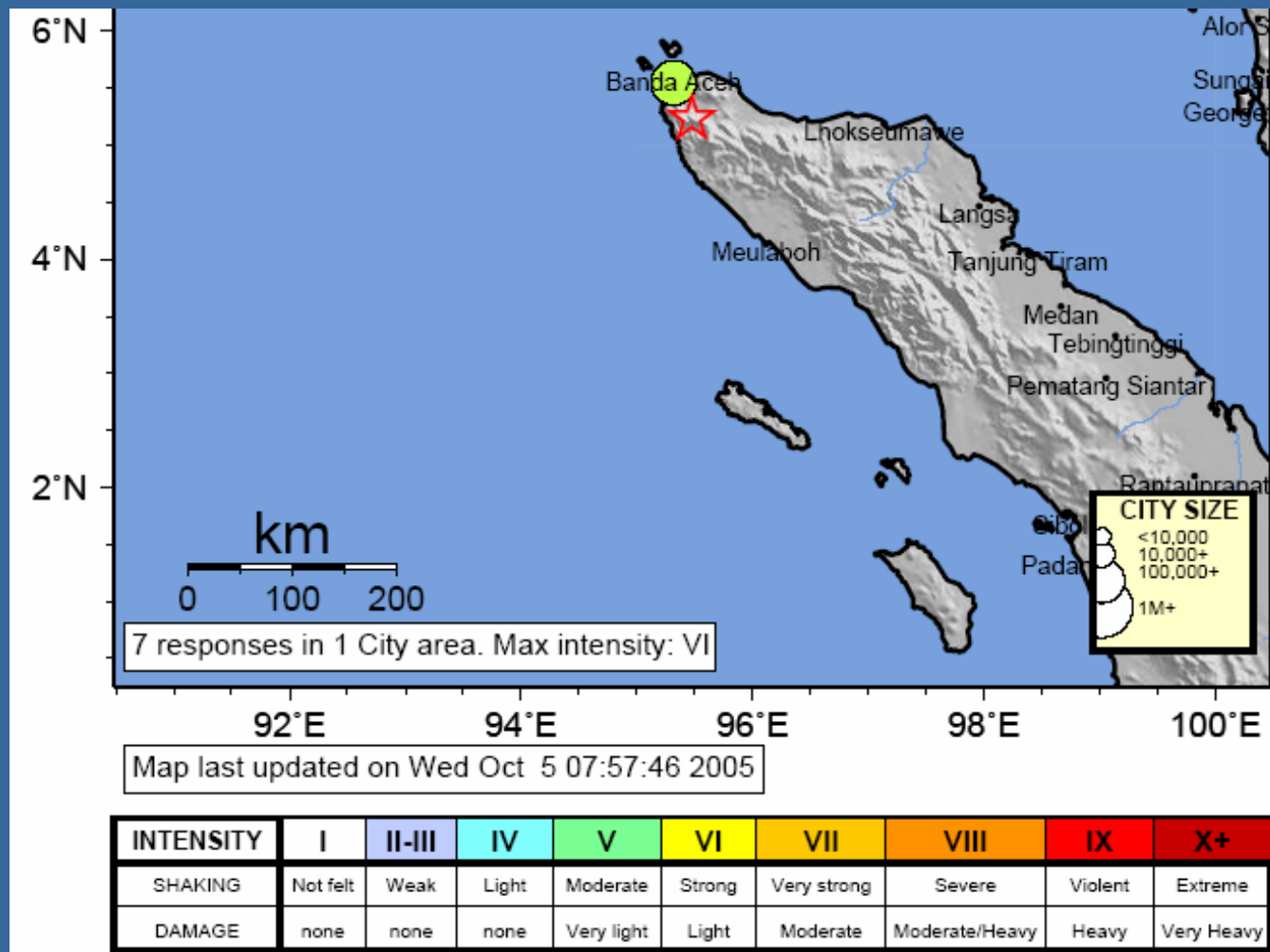
According to some seismologists, the 26 December 2004 and 28 March 2005 earthquakes resulted in

- Increased stress on Sumatra Fault near Banda Aceh and an increased likelihood of a M7-7.5 on that fault
- Increased stress in Sunda Trench under Mentawai Islands and possibility of earthquake and tsunami

Build Earthquake Resistant Houses
Change Construction Practice Permanently



M5.7 Earthquake on Sumatra Fault 5 October 2005



Build Earthquake Resistant Houses
Change Construction Practice Permanently





CONFINED MASONRY vs. RC FRAME WITH MASONRY INFILL

This Guideline is for Single Story Confined Masonry Houses with Lightweight (Flexible) Roofs

- ❑ Well-designed and built confined masonry buildings can perform well in earthquakes.
- ❑ However, if they are designed and built poorly, they can be deadly.
- ❑ Even a well built confined masonry building will probably have cracks in a strong earthquake.

Which structural system are you using?

| | RC Frame with Masonry Infill | Confined Masonry |
|-------------------|--|---|
| |  |  |
| Structural System | DUCTILE – frame should be flexible under seismic loading | RIGID – wall should be stiff under seismic loading |
| Gravity Load | FRAME (columns and beams) | Load bearing confined MASONRY WALL |
| Seismic Load | FRAME (columns and beams) | Confined MASONRY WALL (shear wall) |

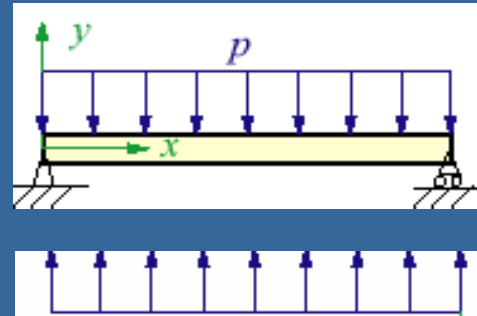
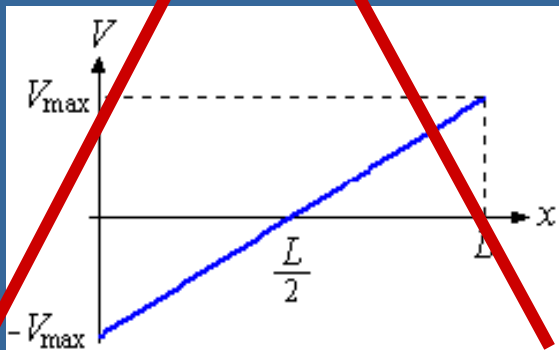
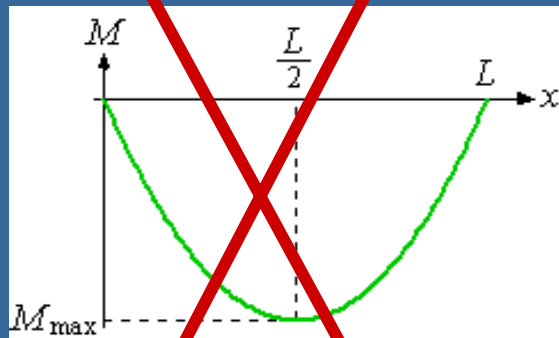
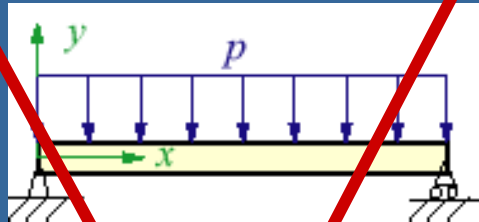
Which structural system are you using?

| | RC Frame with Masonry Infill | RC Confined Masonry |
|------------------------|---|---|
| Beam and Column Design | Ductile detailing and design required in columns and beams (larger sections, larger diameter steel bars, more stirrups at closer spacing) | Ductile detailing NOT REQUIRED in columns and beams, usually done empirically (smaller sections, smaller bar diameters, fewer stirrups) Beams and columns are confining elements acting in tension but CONNECTIONS are CRITICAL |

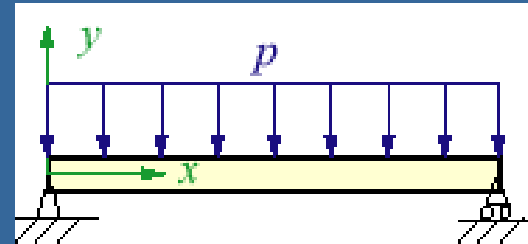
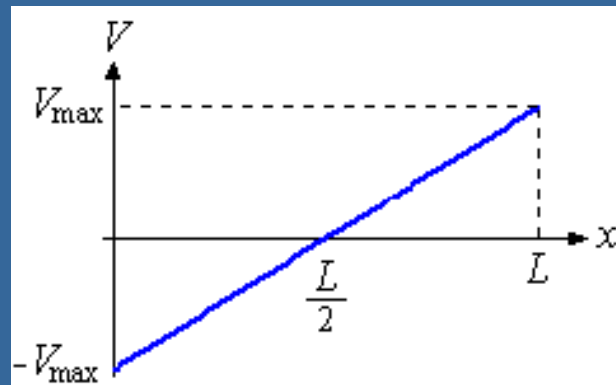
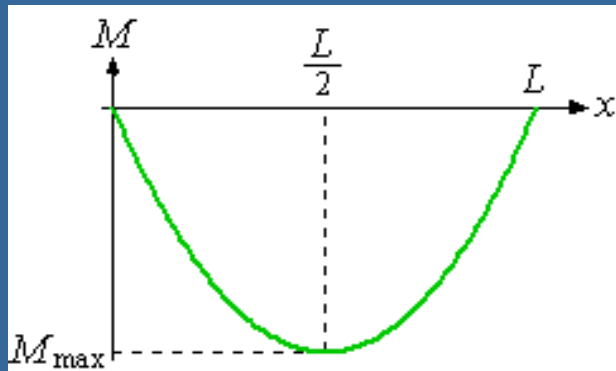
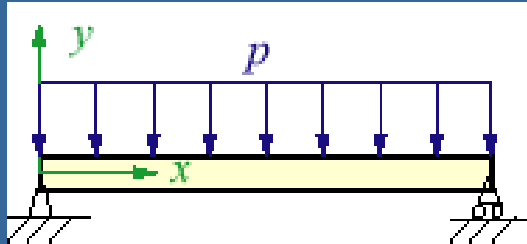
Which structural system are you using?

| | RC Frame with Masonry Infill | RC Confined Masonry |
|---------------|---|---|
| Process | FRAME (columns and beams) constructed first | MASONRY WALL constructed first |
| Infill / Wall | NONSTRUCTURAL – for space partitioning, generally not attached to frame, but should be restrained from falling out (lightweight material best – masonry infill can have a negative effect on frame) | STRUCTURAL SHEAR WALL – quality workmanship is critical, as is attachment to the tie columns and bond beams |

In Confined Masonry, “Bond Beams” are Not True Beams – they are uniformly supported by strip footing or masonry wall



Be Careful – These Beams Are Beams and Require Ductile Detailing



Build Earthquake Resistant Houses
Change Construction Practice Permanently



This Guideline Does Not Apply to RC Frame and RC Stilt Structures

- ❑ FRAME structures must be engineered, designed, detailed, and are beyond the scope of this guideline
- ❑ If you are building a frame structure, consider replacing the heavy brick masonry infill with a lighter weight material, and restrain it from falling in an earthquake
- ❑ Reinforced concrete stilt-type structures with heavy mass above the plinth beam, and those with open first floor and heavy second floor, should be avoided in earthquake-prone regions, especially where soft/loose soil conditions exist



Inadvisable designs for earthquake-prone regions



Build Change's Philosophy

Design/Build Houses which are

1. Safe (earthquake-resistant)
2. Satisfactory (culturally appropriate and comfortable for homeowners)
3. Sustainable (built with locally available materials, tools and skills, affordable)

→ "the three S's"



Which structural system are you using?

| | RC Frame with Masonry Infill | RC Confined Masonry |
|----------------------------|---|-------------------------------------|
| Uses in Indonesia | Multistory commercial buildings, schools, mosques, 2-story houses for wealthier residents | Single story houses and small shops |
| Cost | Higher | Lower |
| Engineering Input Required | More | Less |
| Skill of Workers | Higher | Lower |

Build Change's Philosophy

Make low or no-cost improvements to existing, common ways of building

→ Confined masonry is the most common method currently being used by homeowners to build single story homes in Sumatra and Java



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Basic Concept of Confined Masonry

- ❑ Masonry walls confined on all four sides by reinforced concrete members – bond beams (sloof – ring balok) and tie columns (kolom utama – kolom praktis)
- ❑ Reinforced concrete members are interconnected – connection is critical
- ❑ Masonry walls constructed first, tie columns and bond beams cast around masonry walls
- ❑ Walls assumed to carry all vertical and lateral loads.
- ❑ Contribution of tie column and bond beam to the strength and load resistance is not taken into account.

This is a GUIDELINE because no building code adequately addresses confined masonry specific to Acehnese materials and architectural preferences

- Single story: most codes and guidelines deal with multiple stories with heavy roof and floors so are overconservative for single story structures with lightweight roofs
- Tall, slender wall: most building codes recommend a lower height to thickness ratio
- Large, tall openings: most building codes recommend smaller openings
- Timber truss roof: acts as a flexible diaphragm, potential for out-of-plane failure must be mitigated in other ways

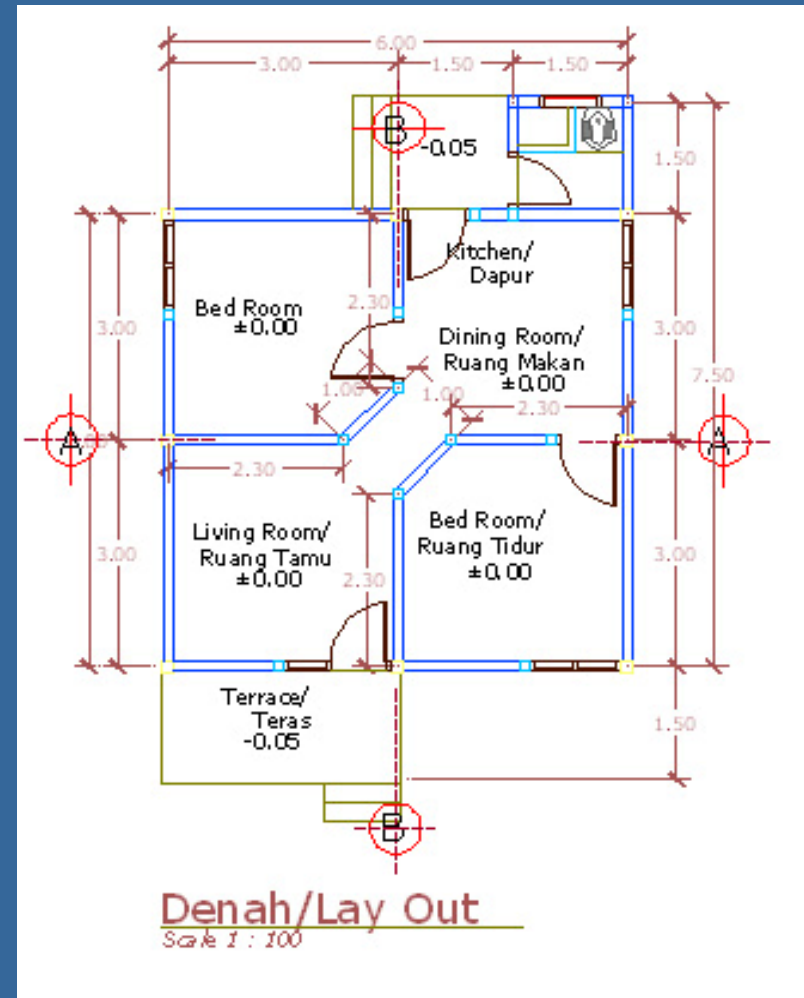
The Most Important Factors for Good Performance of Confined Masonry Buildings in Earthquakes Are

1. Configuration
2. Connections
3. Construction Quality
(Materials and Workmanship)

→ *“the three C’s”*

CONFIGURATION

- ❑ Careful thought to the plan and layout can improve earthquake-resistance at little or no extra cost
- ❑ Moving around windows, doors, shear walls

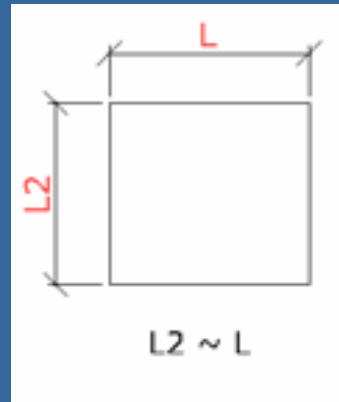


Layout Rule #1

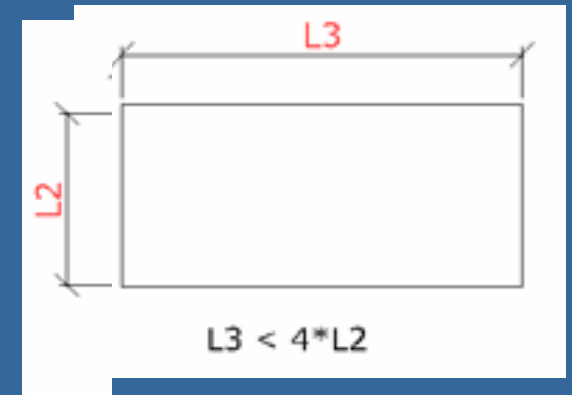
Use Simple, Square Plan

Regular in plan and elevation – uniform and symmetrical along both axes

→ Square is best



→ If rectangular, length should be less than 4 times width

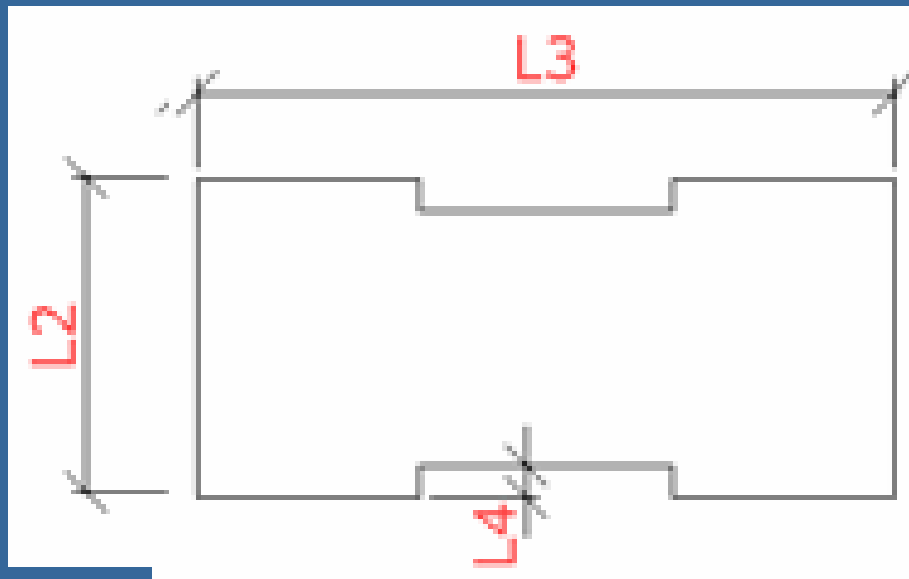


*Schematics from City University of London
Guideline on Confined Masonry and Interpretation
of Eurocode 8*

Layout Rule #2

Avoid/Limit Reentrant Corners, Recesses

Reentrant corners, projections or recesses should be less than 15% of the overall dimension in that direction



$$L4 < 0.15 * L2$$

*Schematic from City University of London Guideline on
Confined Masonry and Interpretation of Eurocode 8*

Layout Rule #3

Sufficient Wall Density

Total structural wall area divided by the floor area should be at least 3% (in each direction)

A structural wall is a confined masonry horizontal span (without an opening) with length

- 1) greater than 30% of the length of the building in the wall plane, and
- 2) greater than 30% of the clear height of the opening next to it

EXAMPLE - Layout Rule #3

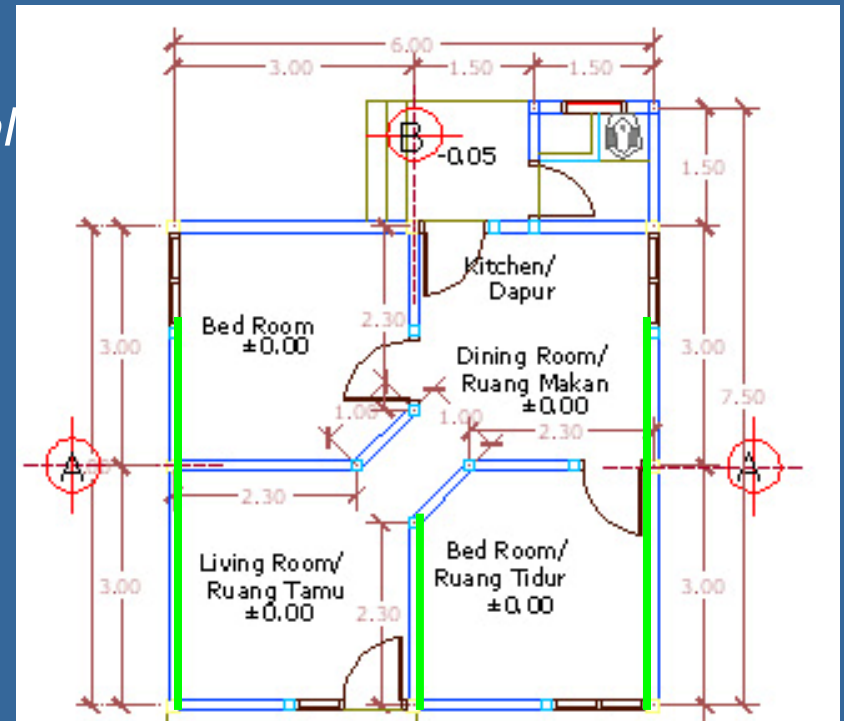
Sufficient Wall Density

→ In North – South direction,
 $(4.8\text{m} + 2.4\text{m} + 4.8\text{m}) \times 0.13\text{m} =$
 1.56m^2

length of structural walls x thickness of wall

$$1.56\text{m}^2 / 36\text{m}^2 = 4.3\%$$

wall area / total floor area = wall density



EXAMPLE - Layout Rule #3

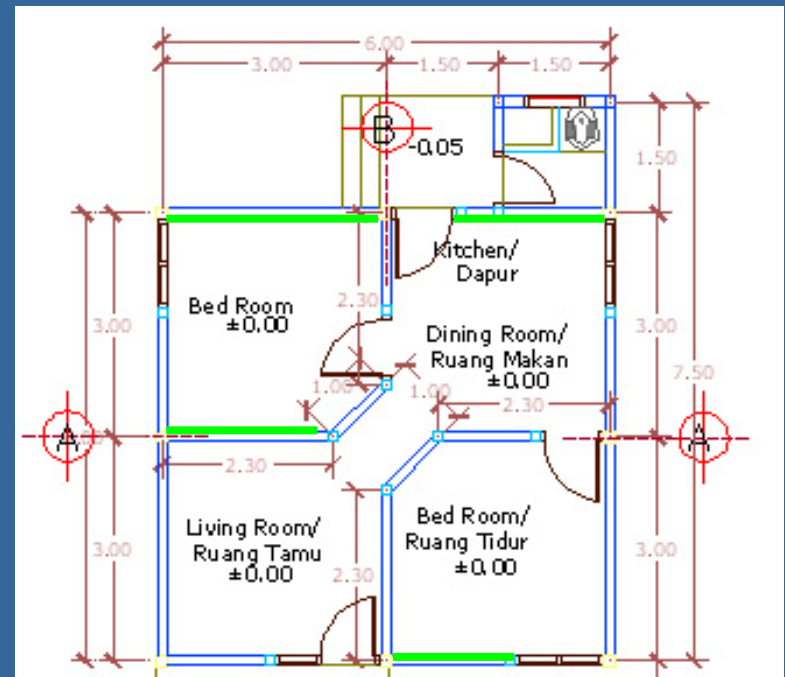
Sufficient Wall Density

→ In East – West direction,
 $(1.8\text{m} + 2.4\text{m} + 5.2\text{m}) \times 0.13\text{m} = 1.22\text{m}^2$

length of structural walls x thickness of wall with plaster = wall area

$$1.22\text{m}^2 / 36\text{m}^2 = 3.4\%$$

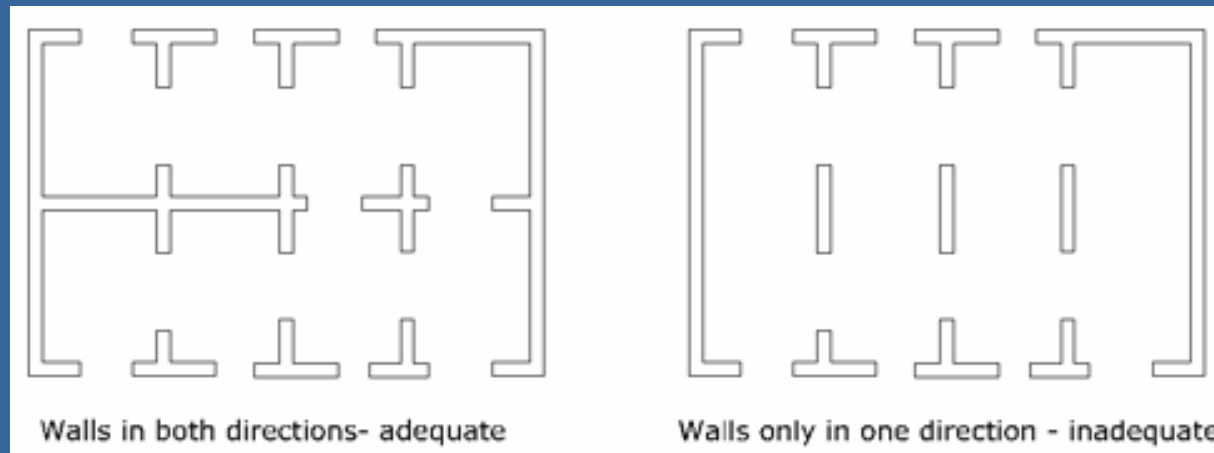
wall area / total floor area = wall density



Layout Rule #4

Symmetry of Wall Density

- ❑ Minimum of two structural walls each direction
- ❑ Structural walls approximately symmetric in plan
- ❑ Approximately same number of load bearing walls in each direction, with same stiffness
- ❑ Difference in structural wall cross-sectional area in two directions should be maximum 20%



*Schematics from City University of London Guideline on
Confined Masonry and Interpretation of Eurocode 8*

Layout Rule #5

Symmetry of Openings

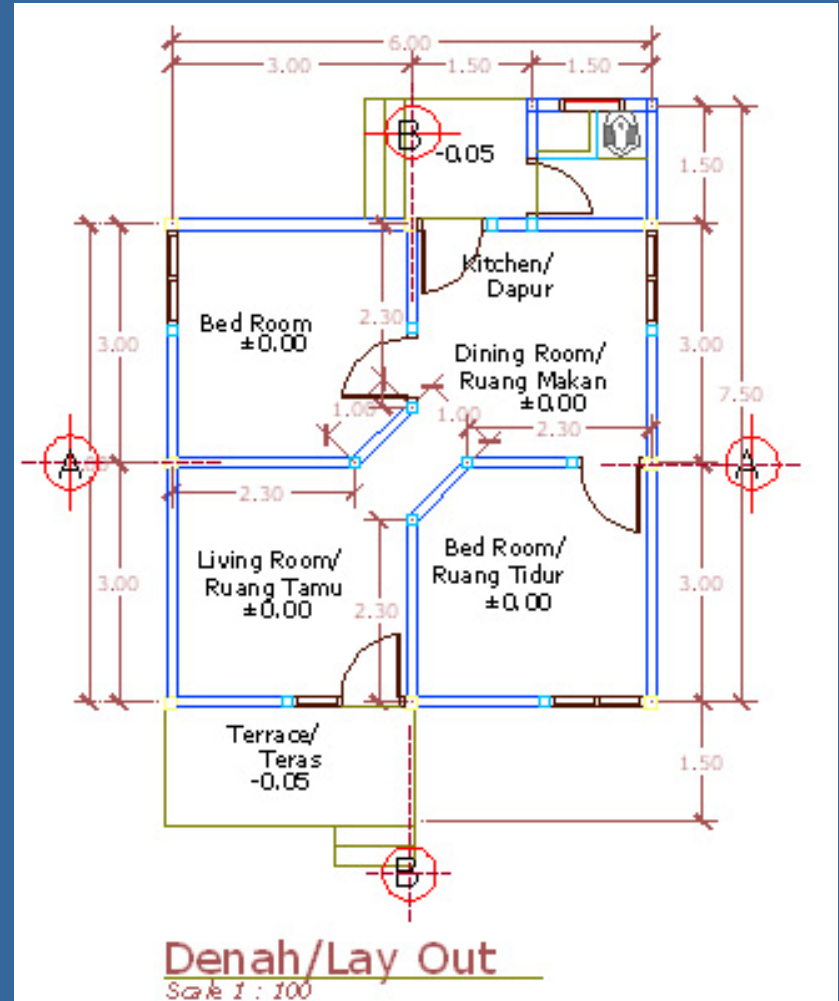
- ❑ Openings should be located symmetrically in plan
- ❑ Consolidate your openings →
- ❑ Horizontally align tops



Better to consolidate

CONFIGURATION

- ❑ Careful thought to the plan and layout can improve earthquake-resistance at little or no extra cost
- ❑ Moving around windows, doors, shear walls

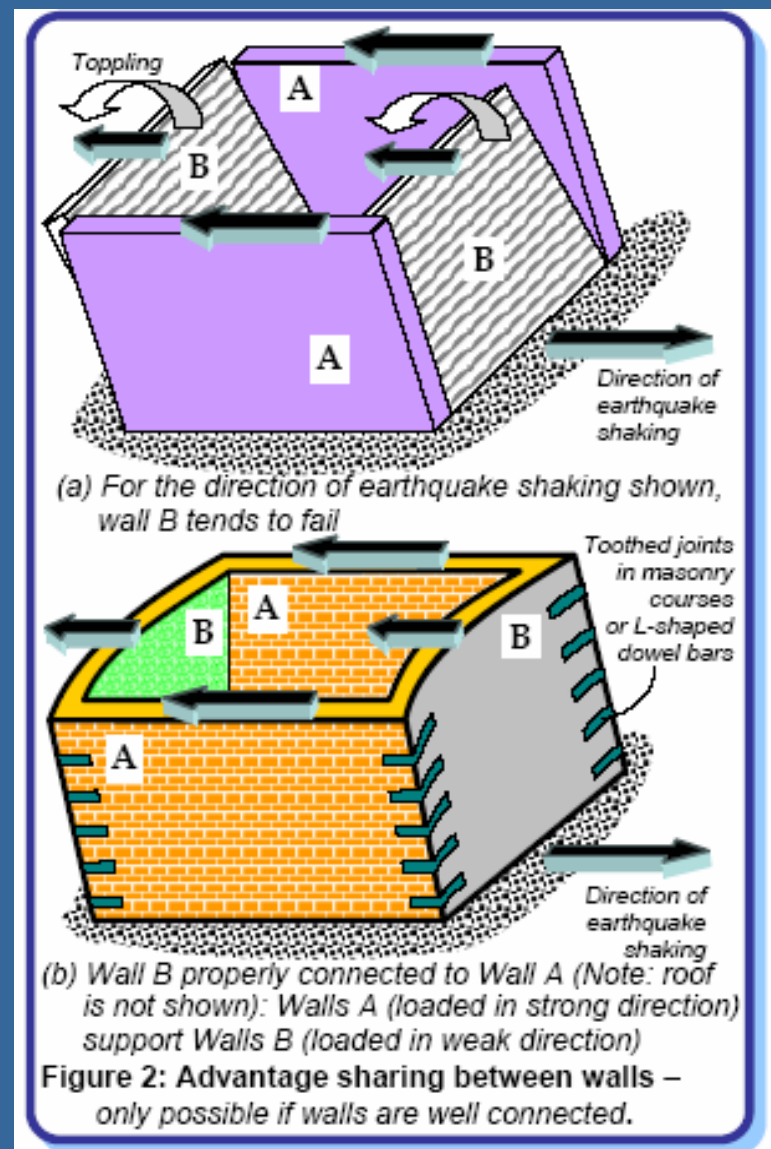
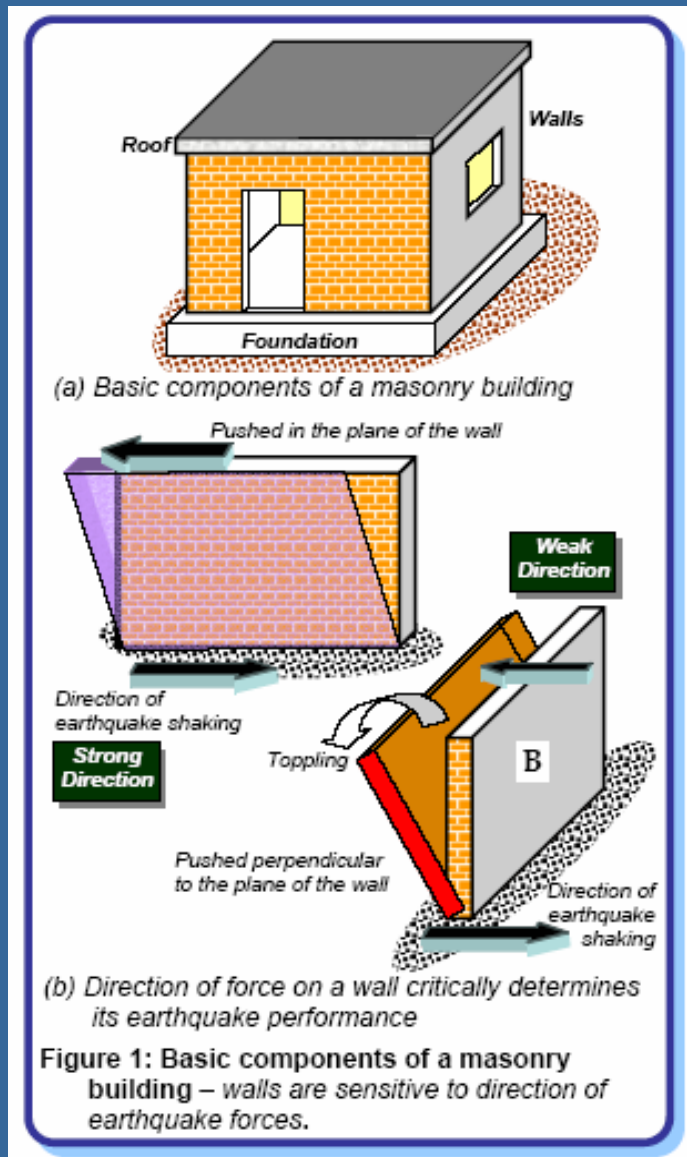


CONNECTIONS

Good connections are critical for good performance of confined masonry buildings in earthquakes. Unreinforced or unconfined masonry walls fail in earthquakes. Good connections are necessary between

- All masonry walls
- All confining elements
- Foundation and walls
- Tie columns and walls
- Bond beam and walls
- Bond beams and tie columns
- Ring bond beam and roof





from IITK-bmtpc Earthquake Tip #12

Build Earthquake Resistant Houses
Change Construction Practice Permanently




Function of Bond Beams (Sloof, Ring Balok)

Bond Beams – required at foundation and on top of all structural walls. WHY:

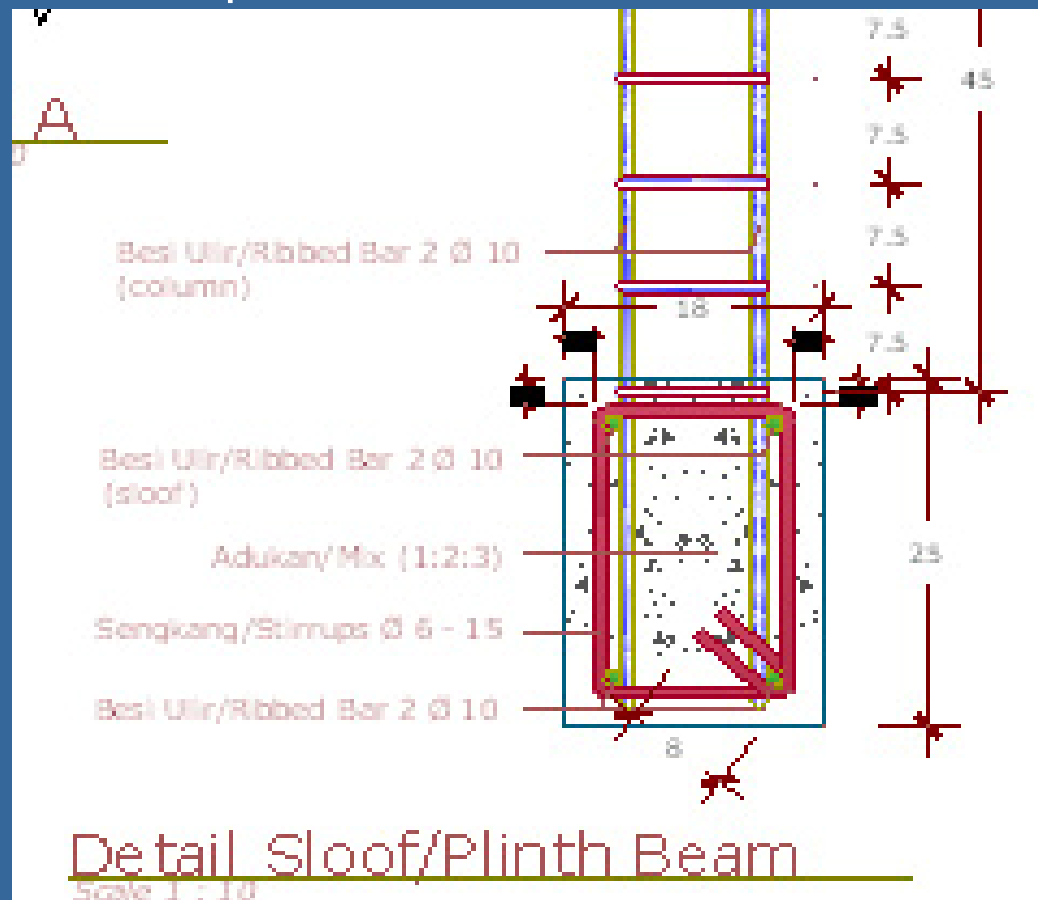
- ❑ Tie the walls together at the roof and floor level
- ❑ Anchors the RC tie columns
- ❑ Ring beam confines the walls from vertical movement and makes it more difficult for wall to tip over or fail out-of-plane
- ❑ Confining action results in better initial stiffness, shear crack strength, and ultimate lateral load capacity of the wall




Design for Aceh: Plinth Tie Beam (Sloof)

| | BRR |  | Why We Deviate |
|-----------------|---------------|---|---|
| Section | 15 x 20 | 18 x 25 | → Uncertainty in soil conditions → Too difficult to fit 15 x 15 column with 15 x 20 plinth beam |
| Long bars | φ12mm smooth | φ10mm ribbed | → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 8cm long hook | → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 15 cm | → Calcs indicate spacing could be increased to 30 cm away from joint |
| Cover | Not specified | 2.5 cm | USE BETON TAHU (concrete spacer) |

With a 15 x 20 sloof and a 15 x 15 column, it is very difficult to fit column steel inside beam steel and at the same time maintain sufficient cover over the concrete in the sloof, and at the same time maintain sufficient space between the long bars in the column, so as to be able to bend a stirrup that is square, not round!



Design for Aceh: Plinth Tie Beam (Sloof)

| | BRR |  | Why We Deviate |
|-----------------|---------------|---|---|
| Section | 15 x 20 | 18 x 25 | <ul style="list-style-type: none"> → Uncertainty in soil conditions → Too difficult to fit 15 x 15 column with 15 x 20 plinth beam |
| Long bars | φ12mm smooth | φ10mm ribbed | <ul style="list-style-type: none"> → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 8cm long hook | <ul style="list-style-type: none"> → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 15 cm | → Calcs indicate spacing could be increased to 30 cm away from joint |
| Cover | Not specified | 2.5 cm | USE BETON TAHU (concrete spacer) |

Smooth vs. Ribbed? 10mm vs. 12mm?

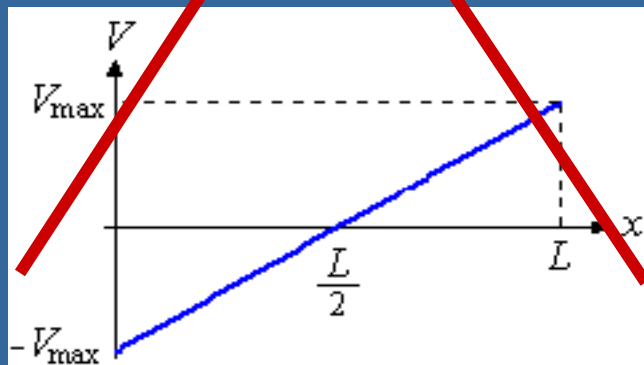
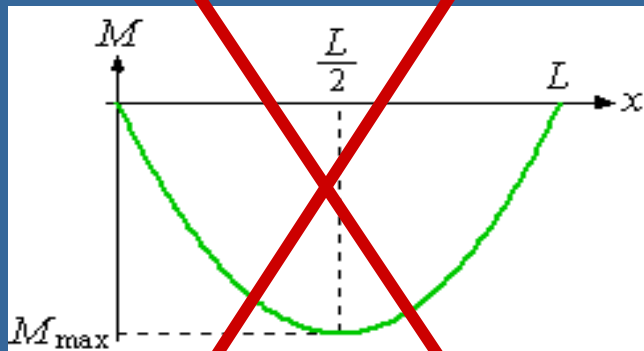
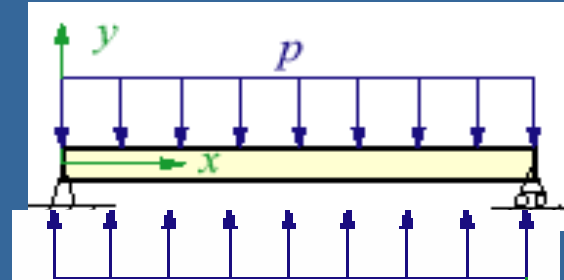
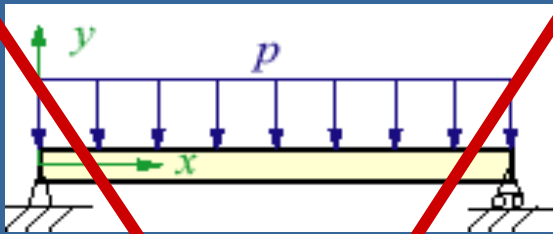
IN THEORY:

- ❑ 12mm bar provides greater strength in tension than a 10mm bar *if the steel is the same and both bars are properly developed and covered with sufficient concrete*
- ❑ Ribbed bar provides greater strength in tension than a smooth bar *if the steel is the same and both bars are properly developed and covered with sufficient concrete*

IN PRACTICE:

- ❑ (Our limited) test data does not show a significant difference in tensile strength between ribbed vs. smooth bars
- ❑ (Our limited) test data does not show a significant difference in tensile strength between 12mm vs. 10mm diameter bars
- ❑ (Our limited) test data indicates a significant variation in strength of steel on the market in Aceh
- ❑ (Our limited) test data indicates that actual bar diameter is 0.5 – 1mm smaller than claimed

“Tie Beams” are Not Beams – they are uniformly supported by strip footing or masonry wall



Build Earthquake Resistant Houses
Change Construction Practice Permanently

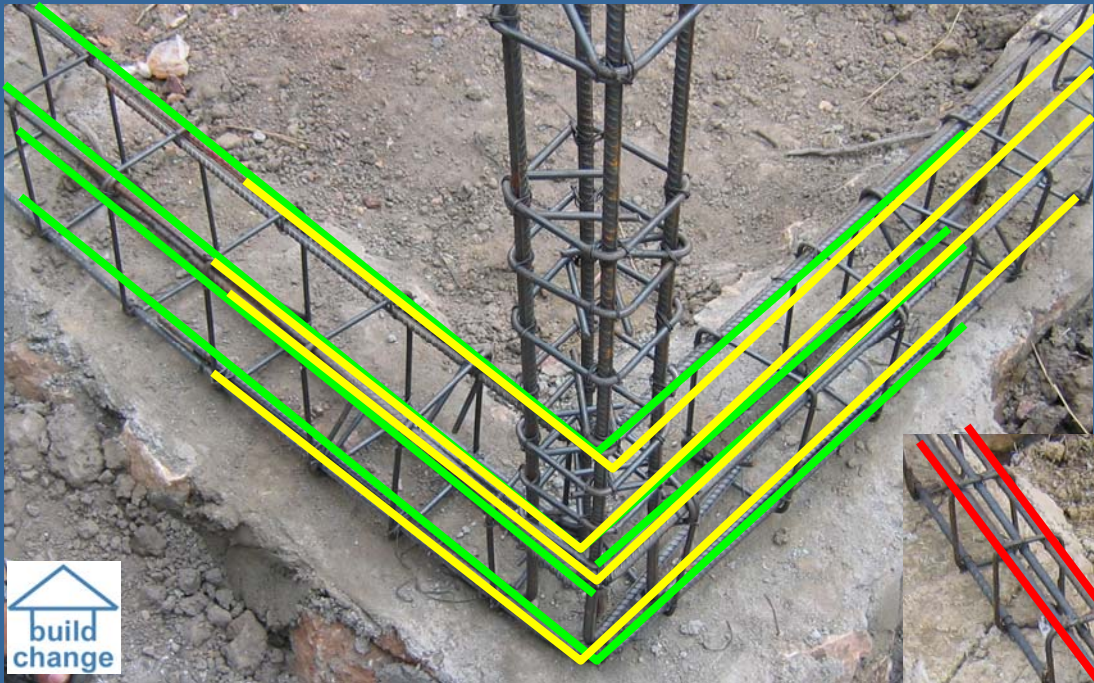


Connections, Laps are CRITICAL

No matter what size bars you are using!!

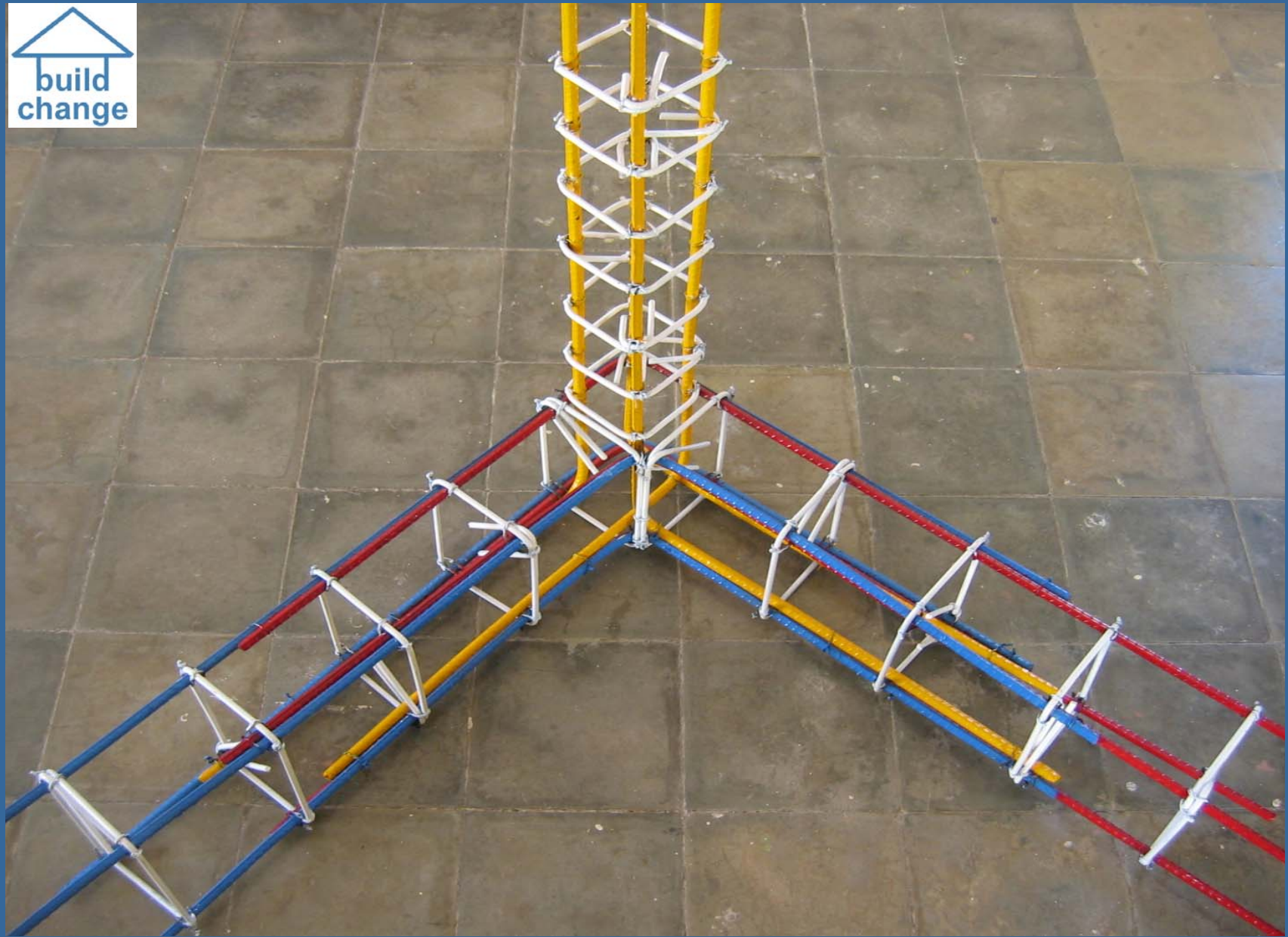
Bad Practice (Buruk)

→ *Long bars terminate in the joint*



Good Practice (Baik)

→ *Long bars pass through corner and overlap 40-50 times diameter of rod for ribbed bars, twice that for smooth*




Build Earthquake Resistant Houses
Change Construction Practice Permanently

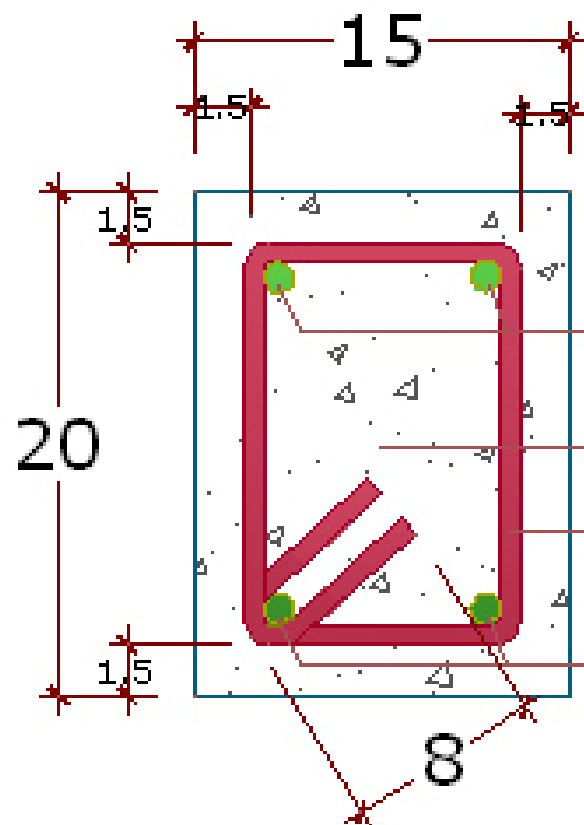


The image displays three architectural drawings related to a sloof (foundation) structure:

- Tampak Atas Sloof / Plan View Plinth Beam:** A top-down view of the sloof structure. It shows a central rectangular area with dimensions 600x600. The outer dimensions are 750x750. The drawing includes a scale of 1:50 and a north arrow pointing upwards.
- Detail A:** A cross-section view of the sloof, showing the internal structure and reinforcement. It includes a scale of 1:10 and labels for materials like "Senggang/Stirrups Ø 6 - 15" and "Besi Ulir / Ribbed bar 2 Ø 10".
- Detail Sloof/Plinth Beam:** A cross-section view of the sloof, showing the internal structure and reinforcement. It includes a scale of 1:10 and labels for materials like "Besi Ulir/Ribbed Bar 2 Ø 10 (column)", "Besi Ulir/Ribbed Bar 2 Ø 10 (sloof)", "Adukan/Mix (1:2:3)", "Senggang/Stirrups Ø 6 - 15", and "Besi Ulir/Ribbed Bar 2 Ø 10".

Design for Aceh: Plinth Tie Beam (Sloof)

| | BRR |  | Why We Deviate |
|-----------------|--------------|---|---|
| Section | 15 x 20 | 18 x 25 | <ul style="list-style-type: none"> → Uncertainty in soil conditions → Too difficult to fit 15 x 15 column with 15 x 20 plinth beam |
| Long bars | φ12mm smooth | φ10mm ribbed | <ul style="list-style-type: none"> → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 8cm long hook | <ul style="list-style-type: none"> → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 15 cm | → Calcs indicate spacing could be increased to 30 cm away from joint |
| Cover | | 2.5 cm | USE BETON TAHU (concrete spacer) |



Besi Ulir/Ribbed Bar 2 Ø 10

Adukan/Concrete Mix (1:2:3)


Begel/Smooth Bar Ø 6 - 15

Besi Ulir/Ribbed Bar 2 Ø 10


Detail Ring Balk/Ring Beam

Scale 1 : 10

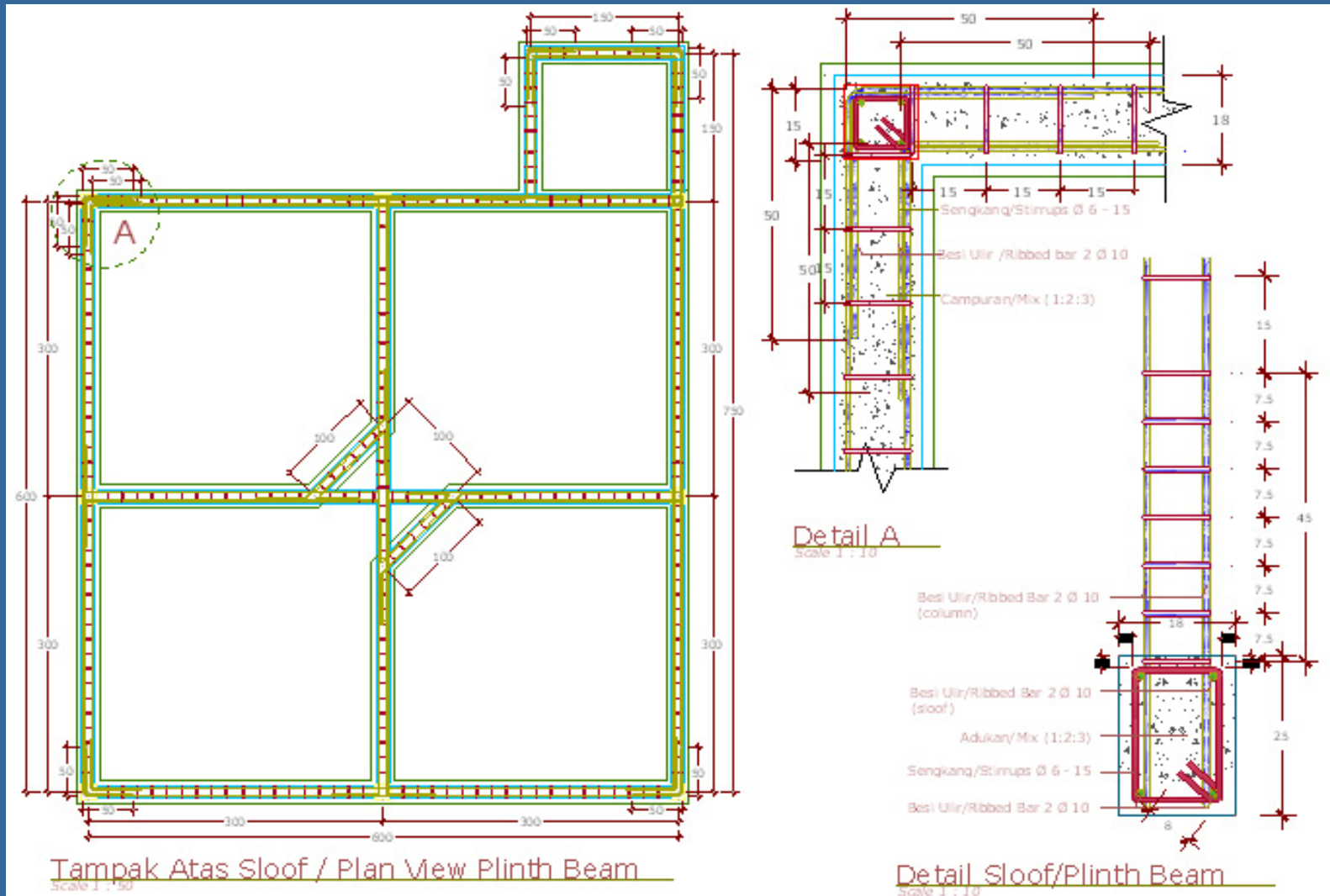
Design for Aceh: Plinth Tie Beam (Sloof)

| | BRR |  | Why We Deviate |
|-----------------|---------------|---|---|
| Section | 15 x 20 | 18 x 25 | → Uncertainty in soil conditions → Too difficult to fit 15 x 15 column with 15 x 20 plinth beam |
| Long bars | φ12mm smooth | φ10mm ribbed | → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 8cm long hook | → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 15 cm | → Calcs indicate spacing could be increased to 30 cm away from joint |
| Cover | Not Specified | 2.5 cm | USE BETON TAHU (concrete spacer) |

Design for Aceh: Ring Bond Beam (Ring Balok)

| | BRR |  | Why We Deviate |
|-----------------|--------------|---|---|
| Section | 15 x 20 | 15 x 20 | |
| Long bars | φ12mm smooth | φ10mm ribbed | → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 8cm long hook | → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 15 cm | → Calcs indicate spacing could be increased to 30 cm away from joint |
| Cover | | 1.5 cm | USE BETON TAHU (concrete spacer) |

Overlaps of 40-50 Times Diameter of Rod at all Joints (for Ribbed Bars)



Build Earthquake Resistant Houses
Change Construction Practice Permanently

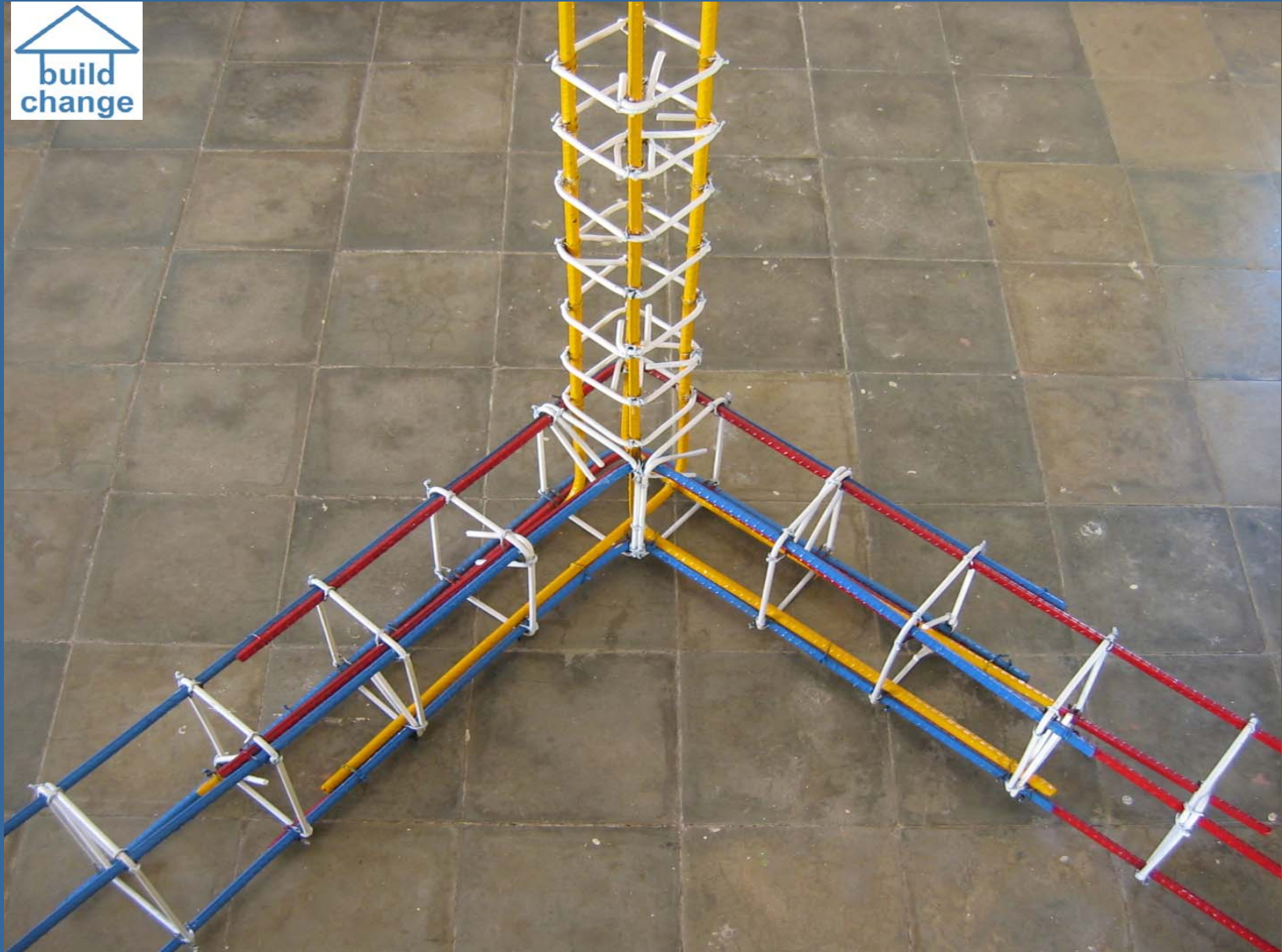


Connections, Laps are CRITICAL



Bad Practice (Buruk)

- *Long bars terminate BEFORE the joint*
- *Column bars not bent and lapped with ring beam bars*
- *Missing stirrups at the joint*



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Function of Tie Columns

Tie columns

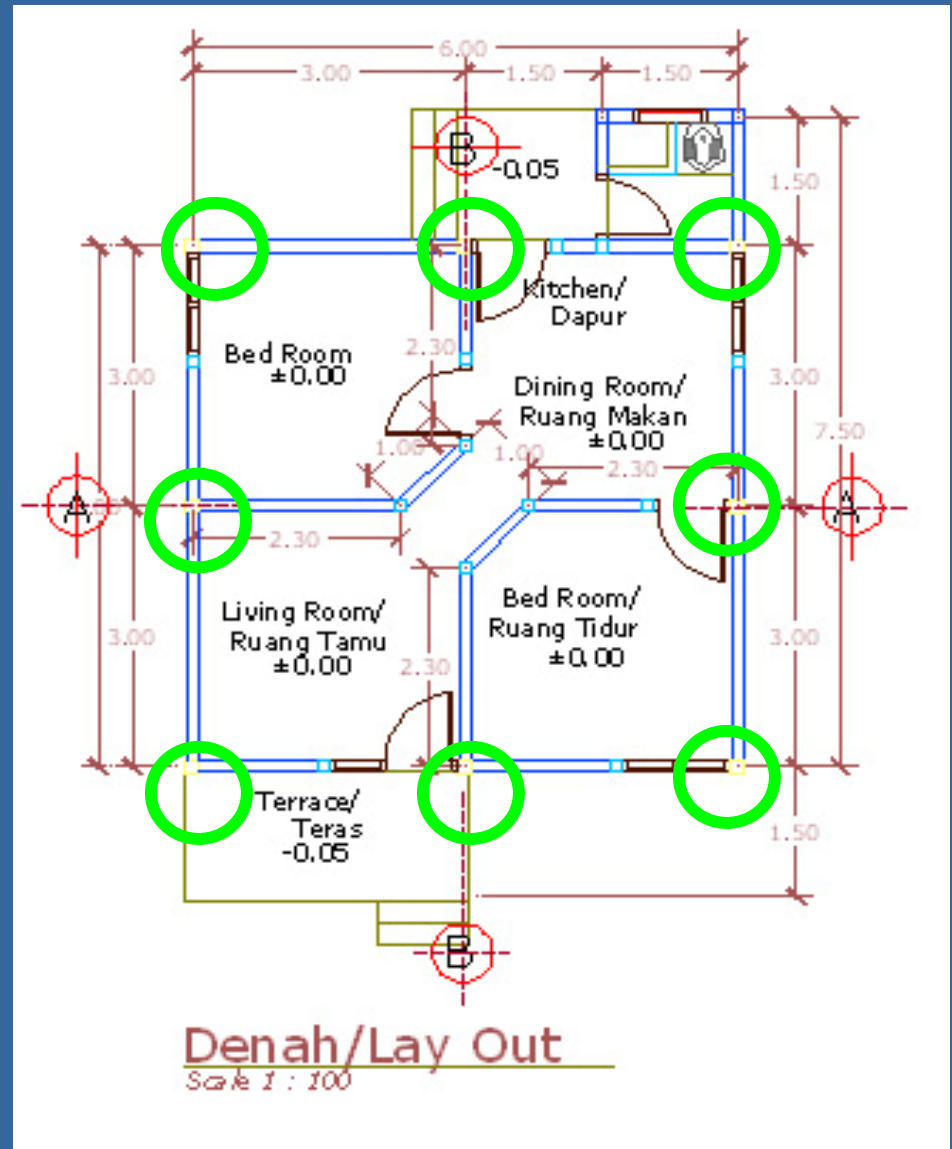
- ❑ Unreinforced or unconfined masonry walls will crack and may collapse in large earthquakes. Tie columns improve the ability of the wall to crack but not collapse.




Locations of Major Tie Columns

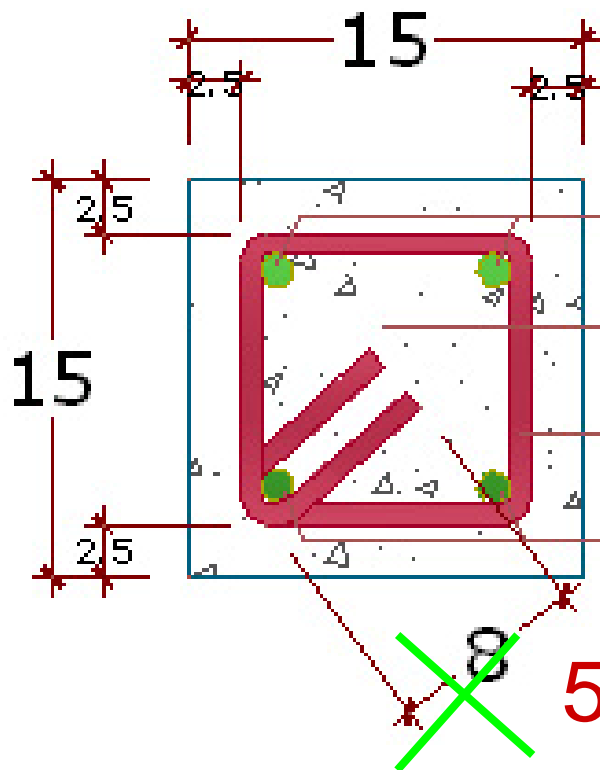
Major columns
(kolom utama) should
be used at

- All major corners
- All major joints and
wall intersections



Design for Aceh: Major Columns (Kolom Utama)

| | BRR |  | Why We Deviate |
|-----------------|--------------|---|---|
| Section | 15 x 15 | 15 x 15 | |
| Long bars | φ12mm smooth | φ10mm ribbed | → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 5cm long hook | → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 7.5 cm 15 cm | → First 7 stirrups at joint → Away from joint |
| Cover | | 2.5 cm | USE BETON TAHU (concrete spacer) |



Besi Ulir/Ribbed Bar 2 Ø 10

Adukan/Mix (1:2:3)

Begel/Smooth Bar Ø 6 - 15

Besi Ulir/Ribbed Bar 2 Ø 10

~~8~~ 5 → 8 cm was too long (aggregate would get stuck)

Detail Column Utama (K1)

Scale 1 : 10



Good Practice (Baik)


→ *Stirrups have square corners, sufficient hook lengths, hooks alternating between long bars*



Bad Practice (Buruk)

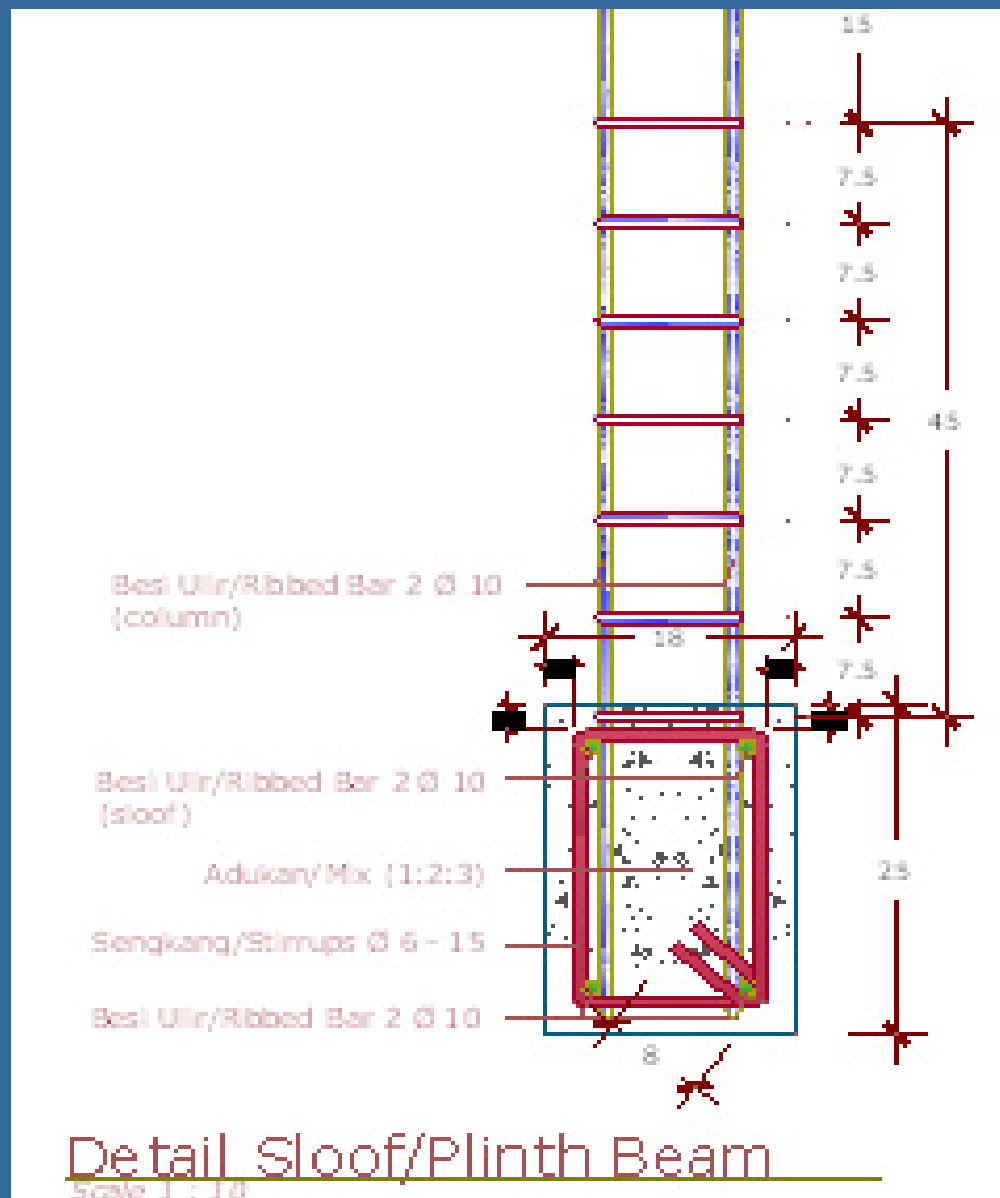
→ *Stirrups have insufficient hook lengths*

Design for Aceh: Major Columns (Kolom Utama)

| | BRR |  | Why We Deviate |
|-----------------|--------------|---|---|
| Section | 15 x 15 | 15 x 15 | |
| Long bars | φ12mm smooth | φ10mm ribbed | → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 5cm long hook | → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 7.5 cm 15 cm | → First 7 stirrups at joint → Away from joint |
| Cover | | 2.5 cm | USE BETON TAHU (concrete spacer) |

How To Prevent Shear Failure in Columns

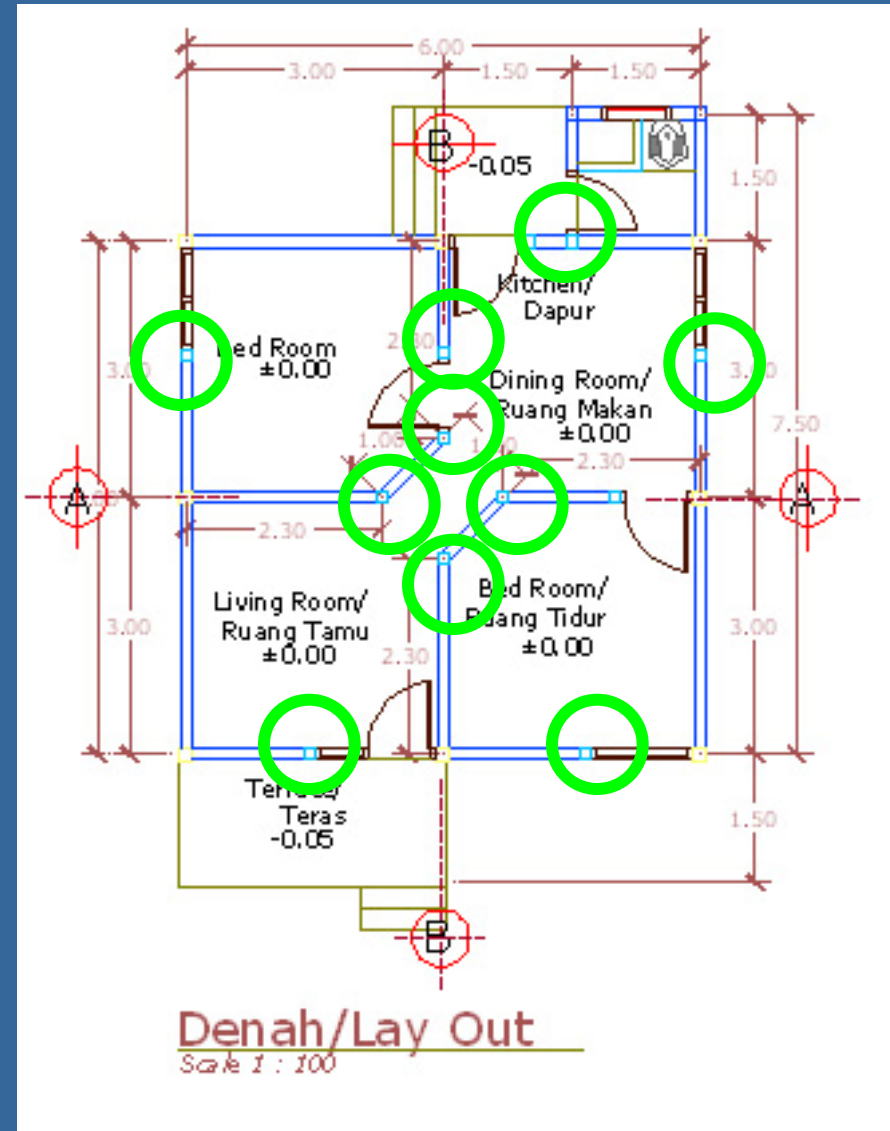
1. Increase size of the column
2. Increase number or size of long bars (doesn't have a big effect and expensive)
3. BEST → Increase the number of stirrups at the top and bottom of the joint in the columns.




Locations of Minor Tie Columns

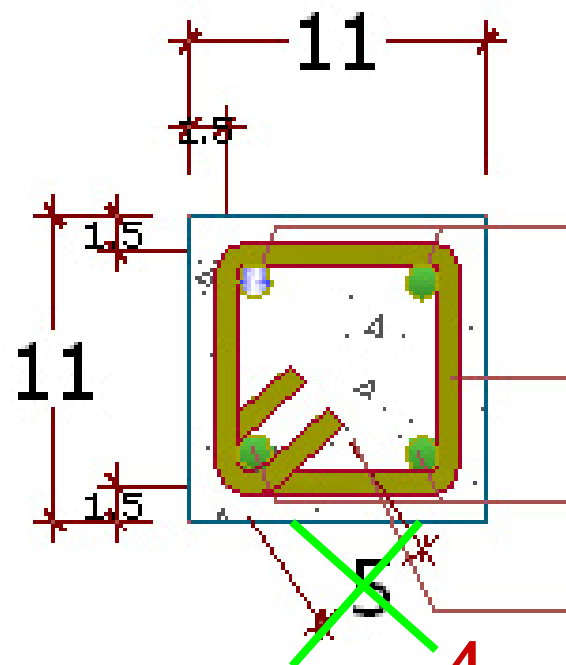
Minor columns (kolom praktis) should be used at

- ❑ All free ends of masonry walls
- ❑ All changes in wall contour
- ❑ Adjacent to any opening with area greater than 2.5m^2
- ❑ All wall spans longer than 4m



Design for Aceh: Minor Columns (Kolom Praktis)

| | BRR |  | Why We Deviate |
|-----------------|--------------|---|---|
| Section | 11 x 11 | 11 x 11 | |
| Long bars | φ12mm smooth | φ8mm ribbed | → Too difficult to cut and bend → Space for cover, confinement → Justified with engineering calcs |
| Stirrups | φ8mm | φ6mm 4cm long hook | → Too difficult to BEND → Justified with engineering calcs |
| Stirrup spacing | 15 cm | 7.5 cm 15 cm | → First 7 stirrups at joint → Away from joint |
| Cover | | 2.5 cm | USE BETON TAHU (concrete spacer) |



Besi Ulir/Ribbed Bar 2 Ø 8

Begel/Smooth Bar Ø 6 - 15

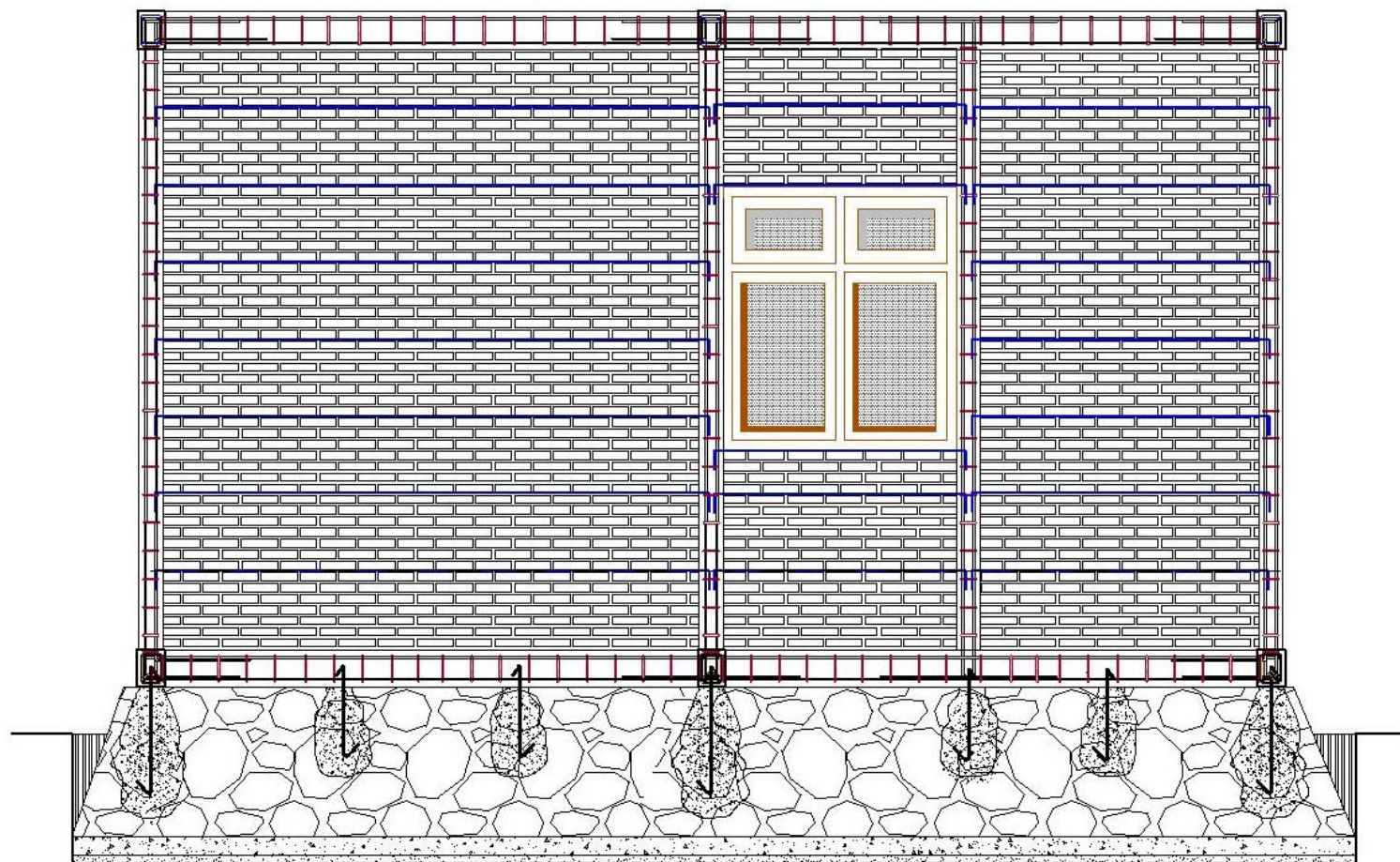
Besi Ulir/Ribbed Bar 2 Ø 8

Adukan/Mix (1:2:3)

4 → 5 cm was too long (aggregate would get stuck)

Detail Column Praktis (K1)

Scale 1 : 10



PEMASANGAN BED JOINT PADA DINDING 3

Scale 1 : 30

Build Earthquake Resistant Houses
Change Construction Practice Permanently



Newly Built Confined Masonry Buildings Generally Performed Well in the 27 May 2006 Central Java Earthquake



→ *Confined masonry house without damage or cracks, on the edge of heavy damaged Pleret*



→ *Confined masonry house with only minor (hairline) cracks, Bambang Lipuro*

Build Earthquake Resistant Houses
Change Construction Practice Permanently



POOR CONNECTIONS BETWEEN BEAMS AND COLUMNS → Major Cause of Failure of newly built houses in 27 May 2006 earthquake in Central Java



Build Earthquake Resistant Houses
Change Construction Practice Permanently



POOR CONNECTIONS BETWEEN BEAMS AND COLUMNS → Major Cause of Failure in newly built houses in 27 May 2006 earthquake in Central Java



Build Earthquake Resistant Houses
Change Construction Practice Permanently

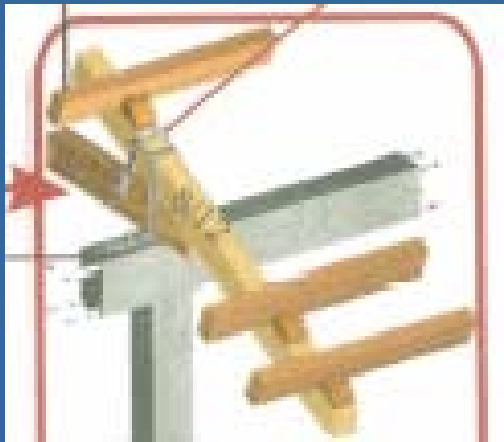


Connection Between Ring Beam and Roof Trusses

Important for earthquakes and high winds

If done correctly,

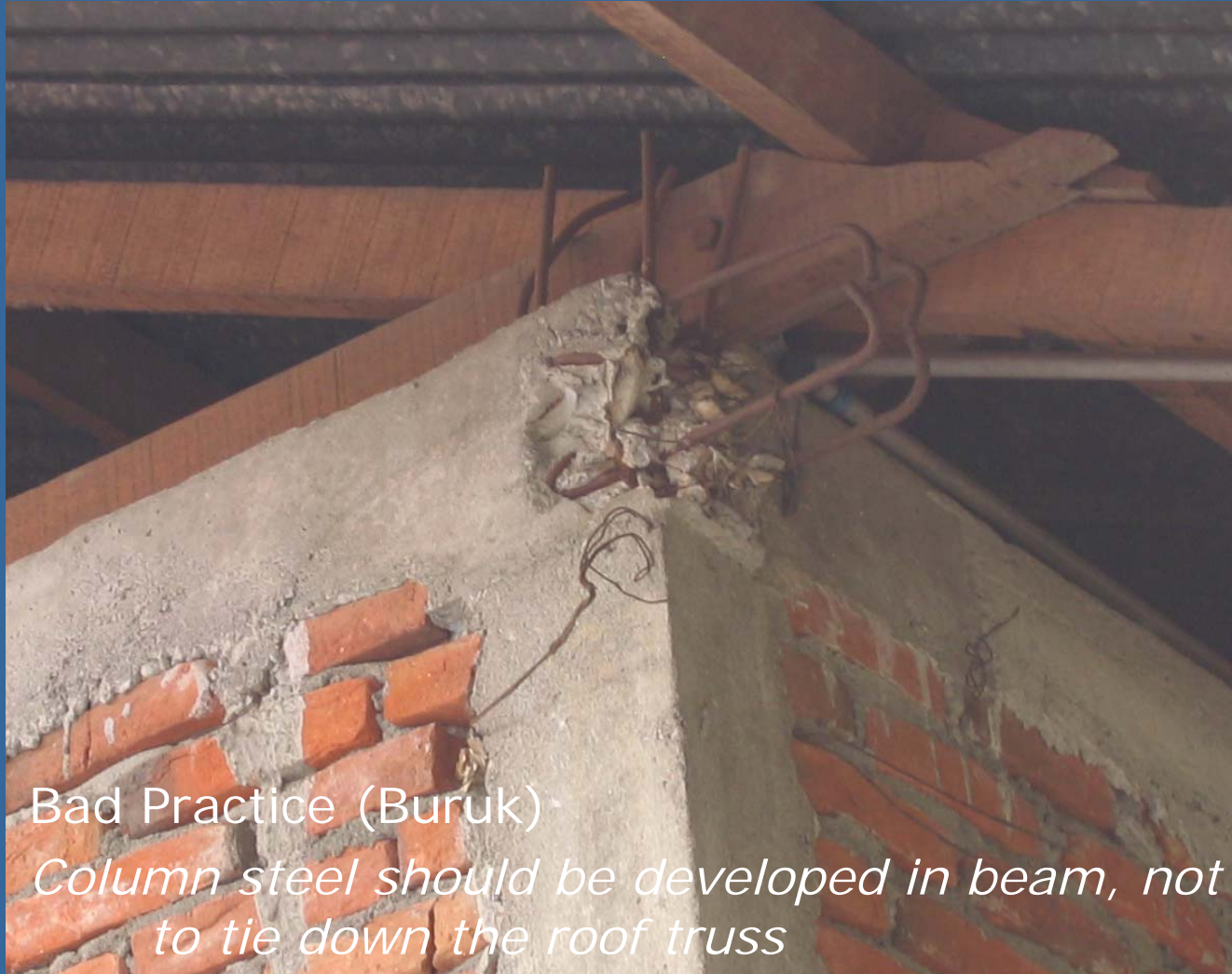
- ❑ Prevents the roof from lifting off in high winds
- ❑ Provides some bracing of walls against out-of-plane failure



Teddy Boen and YIPD



Do Not Use Column Steel for Connection to Timber Truss!



Do Not Use Column Steel for Connection to Timber Truss. WHY?

1. Tie column steel should be overlapped and connected to bond beam steel to provide good connection and confinement as discussed previously
2. Exposed steel will rust. As it rusts, it increases in volume which will cause cracks in the column and beam
3. Although not a rigid diaphragm, fixing the truss joists to the walls provides some bracing of the walls against out of plane failure
4. Simply wrapping column steel around truss members is not sufficient to resist wind loads in Aceh

CONNECTIONS

Good connections are critical for good performance of confined masonry buildings in earthquakes. Unreinforced or unconfined masonry walls fail in earthquakes. Good connections are necessary between

- All masonry walls
- All confining elements
- Foundation and walls
- Tie columns and walls
- Bond beam and walls
- Bond beams and tie columns
- Ring bond beam and roof



HOW CONFINED MASONRY BUILDINGS FAIL IN EARTHQUAKES



Build Earthquake Resistant Houses
Change Construction Practice Permanently



DIGRESSION: How Confined Masonry Buildings Fail in Earthquakes

- ❑ Overturning (collapse) of masonry gable wall
- ❑ Out-of-plane failure of masonry wall
- ❑ In plane shear failure (diagonal cracking) of masonry wall (sliding shear and bending)
- ❑ Instability of interior walls and failure of unconfined walls and frames
- ❑ Shear failure of confining elements
- ❑ Bond failure between masonry and concrete elements
- ❑ Buckling of tie columns

List Courtesy Prof. Ken Elwood, UBC

Elevation Rule # 2

Allowable Slenderness

Slenderness is the height of wall divided by thickness of wall (h/t)

If the wall is tall and slender, it will be able to resist lower earthquake forces before failing

Most building codes allow a maximum $h/t = 15$

Architectural preference in Aceh is for a 3m tall wall.

For wall thickness with plaster of 0.13m, $h/t = 23$

BUT, if wall has a longer continuous shear walls (not interrupted by openings) and structural cross-walls it will perform better in earthquakes

Failure Mode #1: Overturning (Collapse) of Masonry Gable

- In an earthquake, the most vulnerable part of the single story confined masonry buildings being built in Aceh is the masonry in the gable (above the ring beam)

WHY

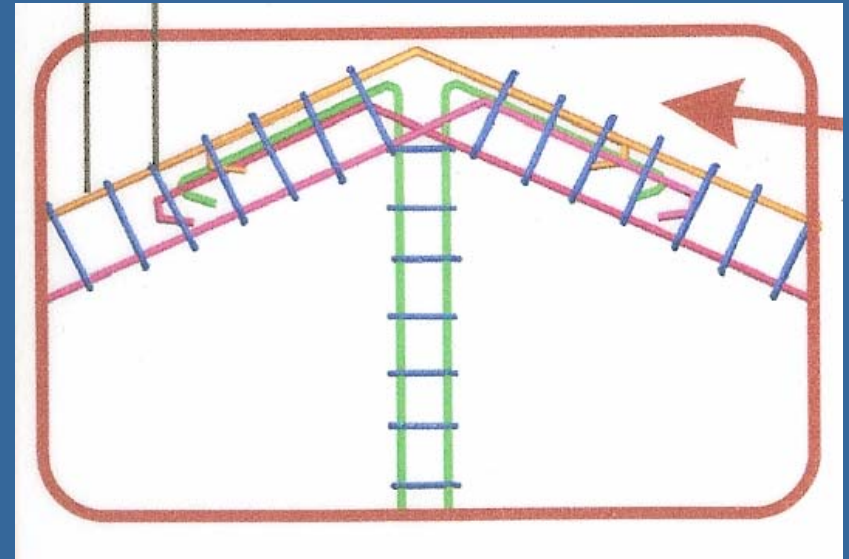
- ☐ Very high slenderness ratio
- ☐ High center of gravity (tendency to overturn)
- ☐ Very difficult to confine properly (poor connections between RC elements)
- ☐ Poor masonry and RC workmanship



Damage to gable walls in 27 May 2006 Central Java earthquake

To Prevent Collapse of Masonry in Gable: Don't Use Masonry Above Ring Beam

→ Steel detailing and connections is inadequate



Bad Practice (Buruk)

→ *Steel bars in center column not long enough to tie into diagonal beam, diagonal not connected at top or at column*

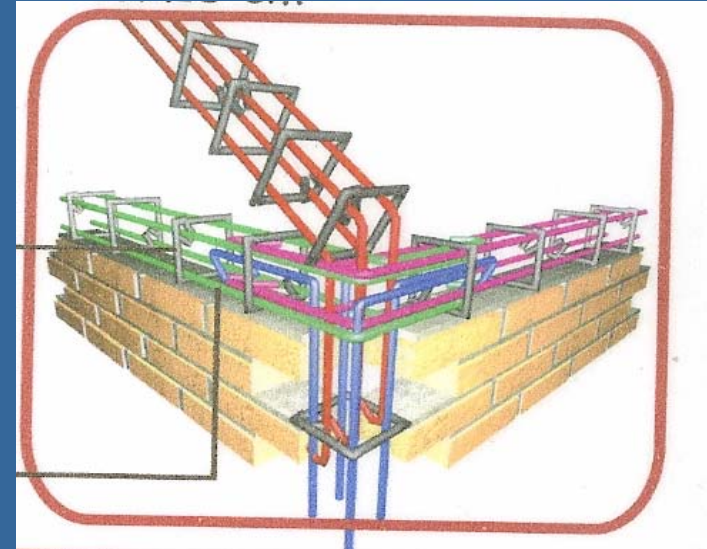
Teddy Boen and YIPD

Good Practice (Baik)

→ *Steel bars in center column developed in gable beam*

To Prevent Collapse of Masonry in Gable: Don't Use Masonry Above Ring Beam

- Very difficult to get an adequate connection between the gable beam and ring beam



Teddy Boen and YIPD



Alternatives To Masonry Above Ring Beam

(1) Use Timber or other lightweight material



(2) Use Rabung Empat or Rabung Lima (Hipped Roof)



Build Change houses in Lampisang and Keunue ue, Peukan Bada Subdistrict of Aceh Besar



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Alternatives To Masonry Above Ring Beam



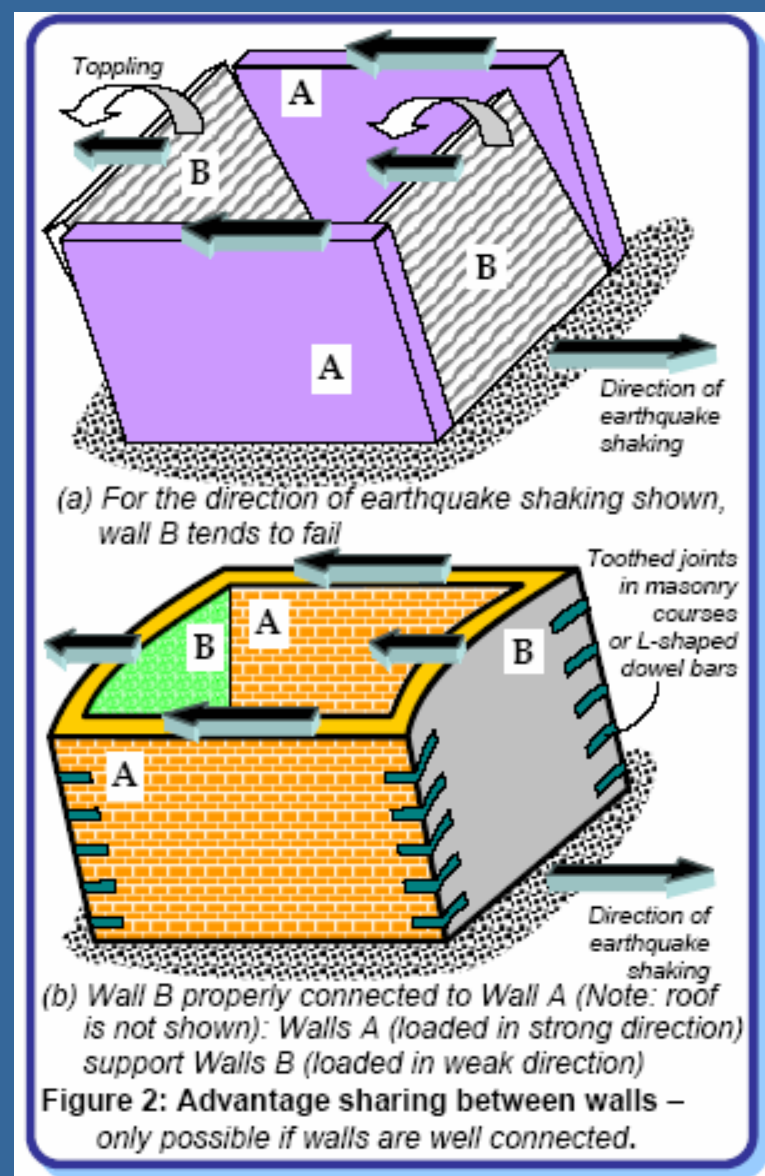
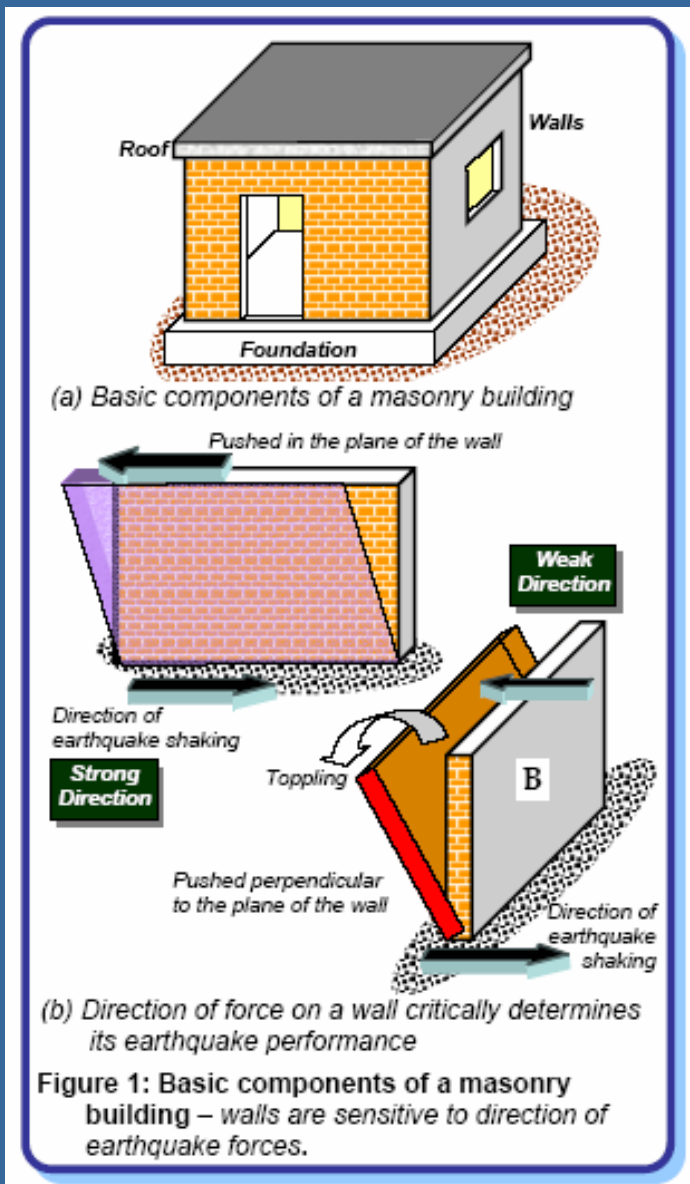
| Roof Type | Materials Cost (circa April 2006) |
|--|--------------------------------------|
| Masonry in Gable, Full Timber Truss | Rp. 11.6 million |
| Papan Gable ← (Pitched) | Rp. 10.6 million |
| Masonry in Gable, Partial Truss | Rp. 10.2 million |
| Rabung Empat ← (Hipped) | Rp. 8.8 million |

Failure Mode #2: Out-of-Plane Failure of Masonry Wall



Build Earthquake Resistant Houses
Change Construction Practice Permanently





from IITK-bmtpc Earthquake Tip #12

Build Earthquake Resistant Houses
Change Construction Practice Permanently



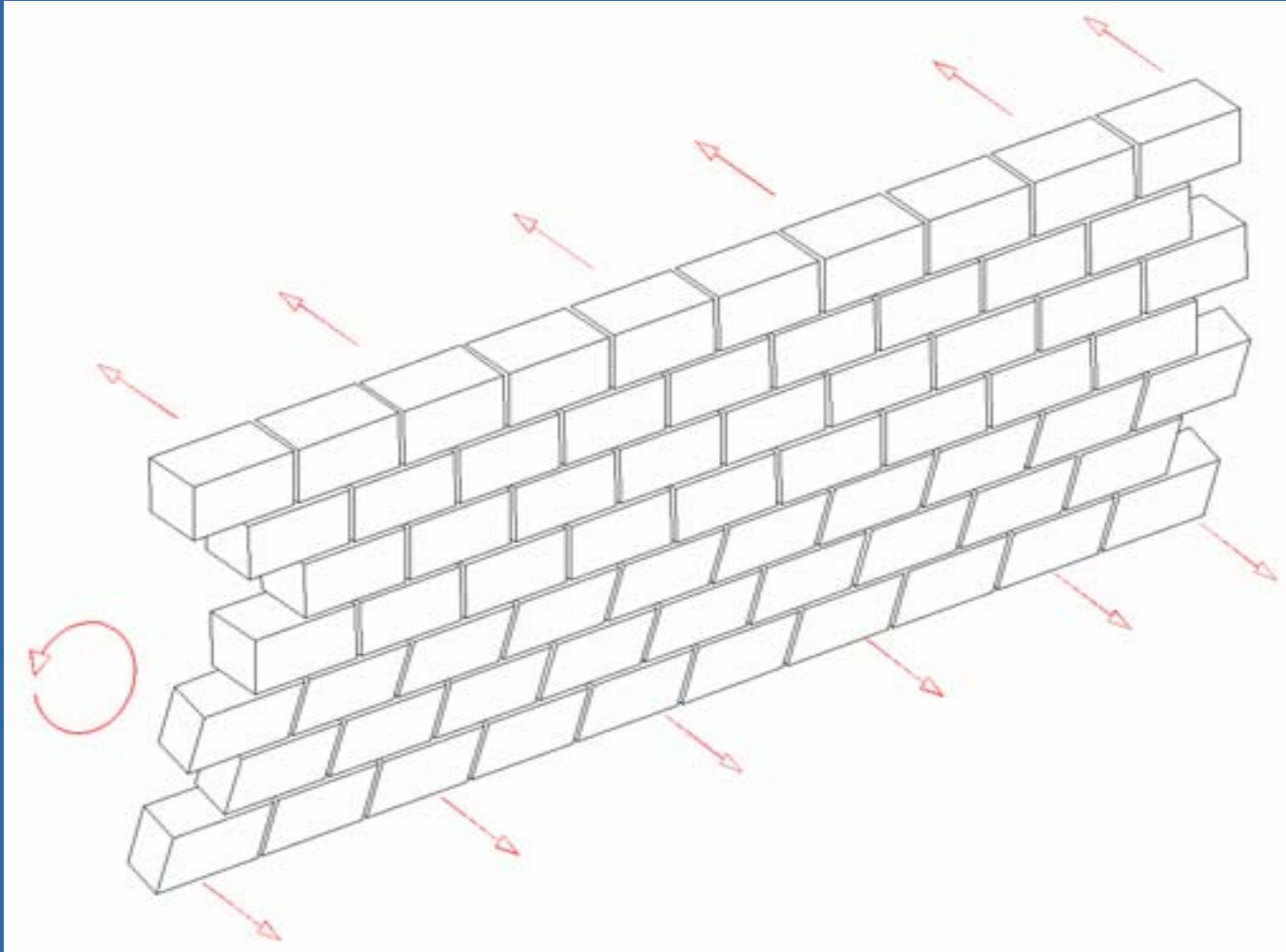


Out-of-Plane Failure Mechanism #1 Overturning as Rigid Body

Build Earthquake Resistant Houses
Change Construction Practice Permanently



Out-of-Plane Failure Mechanism #2



Horizontal cracking along masonry bed joint

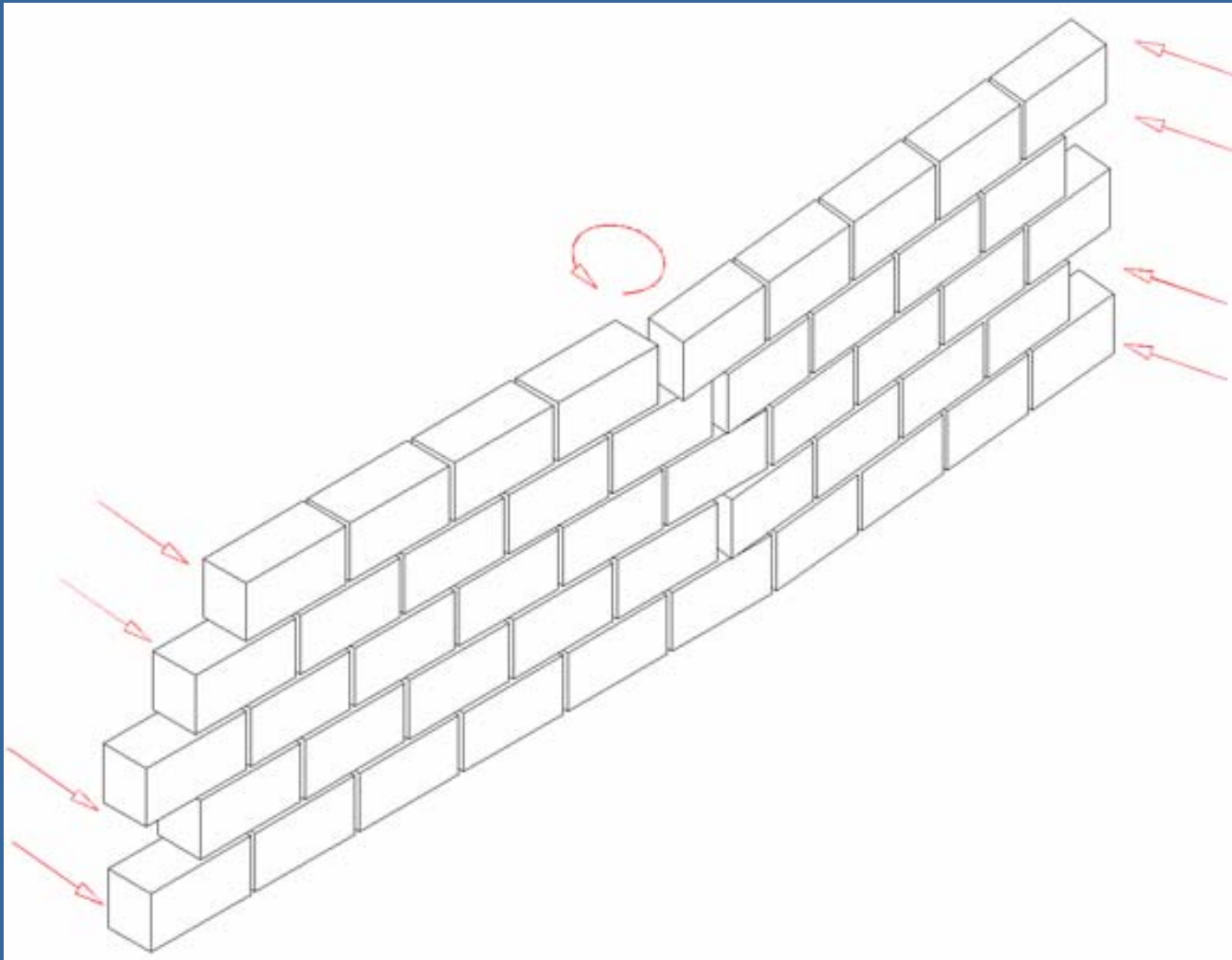
Schematic from City University of London Guideline on
Confined Masonry and Interpretation of Eurocode 8



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Out-of-Plane Failure Mechanism #3



Vertical cracking at center or edge of masonry

Schematic from City University of London Guideline on
Confined Masonry and Interpretation of Eurocode 8

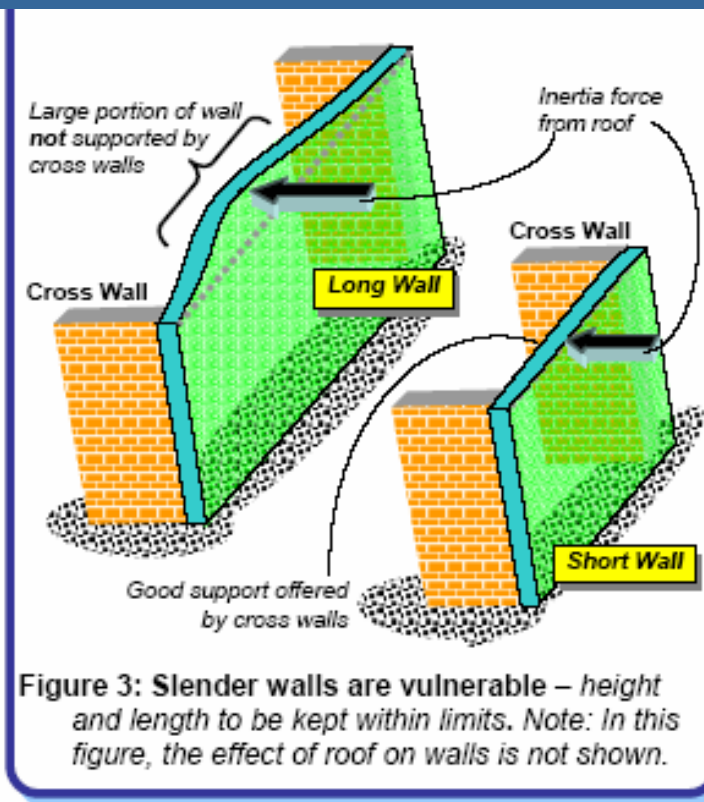
How To Limit Out-of-Plane Failure

1. Follow configuration rules and add bracing at the ring beam level and/or add cross walls
2. Restrain the masonry by tying it to the tie columns and bond beams or covering it with mesh
 - a. Add horizontal reinforcement in the masonry wall, tied into tie columns, or
 - b. Lay wire mesh across wall when plastered
 - Must be on both sides, tied into foundation beam and ring beam, and have loops or ties through the brick wall. NOTE: we haven't tried this yet and have concerns about durability!
3. Reduce slenderness ratio, h/t
 - a. Use a different masonry bond to make a wider wall
 - But heavier wall will be more likely to crack in shear, and more deadly if it collapses; bricks in Aceh are the wrong shape, people don't want
 - b. Or add a second horizontal bond beam (lintel level)
 - But top of opening is already within 0.5m of the ring beam, so very little to gain

How To Limit Out-of-Plane Failure

1. Follow configuration rules and add bracing at the ring beam level and/or add cross walls

- Follow the configuration rules
- Add cross walls every at minimum spacing of 4m
- Add bracing at the ring beam level for wall spans 4m long or greater

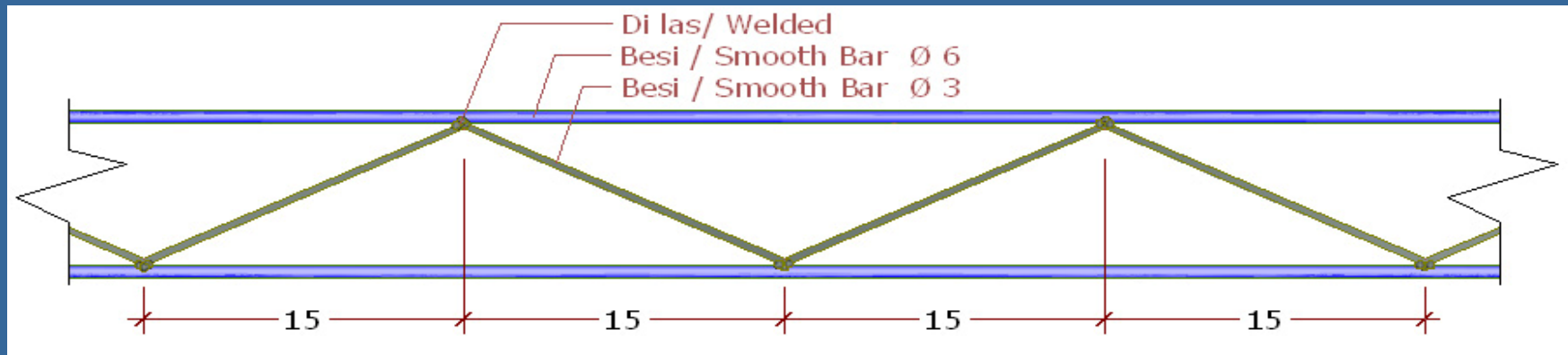


from IITK-bmtpc Earthquake Tip #12

How To Limit Out-of-Plane Failure

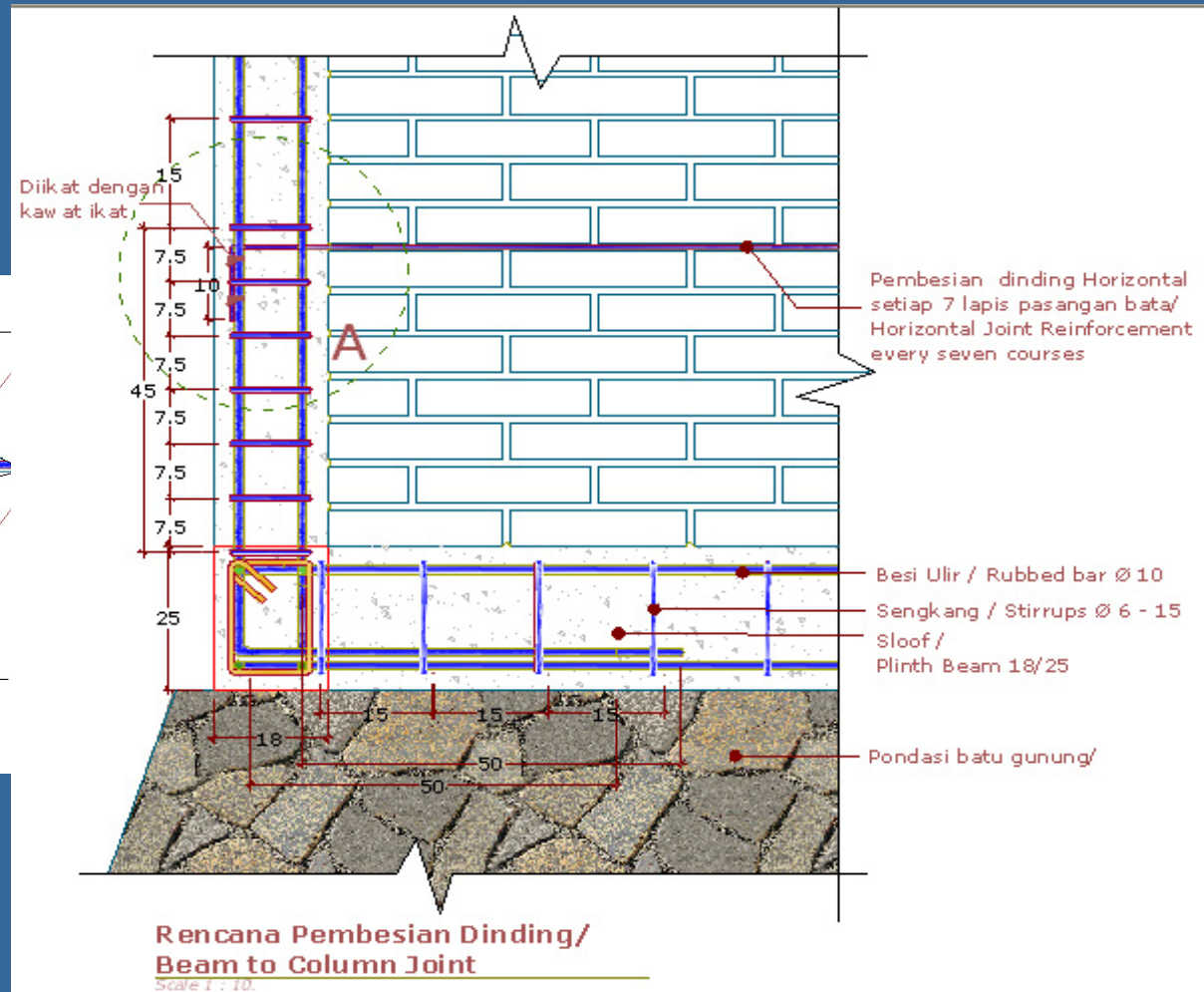
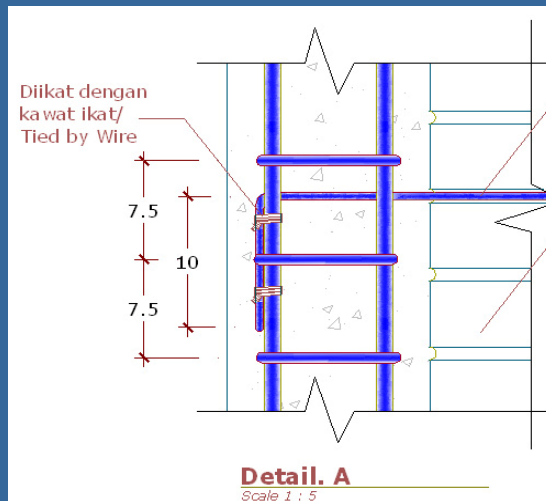
2. Restrain the masonry by tying it to the tie columns and bond beams or covering it with mesh
 - a. Add horizontal reinforcement in the masonry wall, tied into tie columns, or
 - b. Lay wire mesh across wall when plastered
 - Must be on both sides, tied into foundation beam and ring beam, and have loops or ties through the brick wall. NOTE: we haven't tried this yet and have concerns about durability and ease of construction!

2a. Horizontal Reinforcement in Masonry, Tied into Columns



- Frequency depends on spacing between columns
- Use above door and window frames
- 2 cm mortar below
- 2 cm mortar below
- Adds ~Rp. 2.2 million to cost of 36m² house

2a. Horizontal Reinforcement in Masonry, Tied into Columns



2a. Horizontal Reinforcement in Masonry, Tied into Columns



Build Earthquake Resistant Houses
Change Construction Practice Permanently



3a. Reduce h/t by Using Different Masonry Bond (Full Brick Thick)

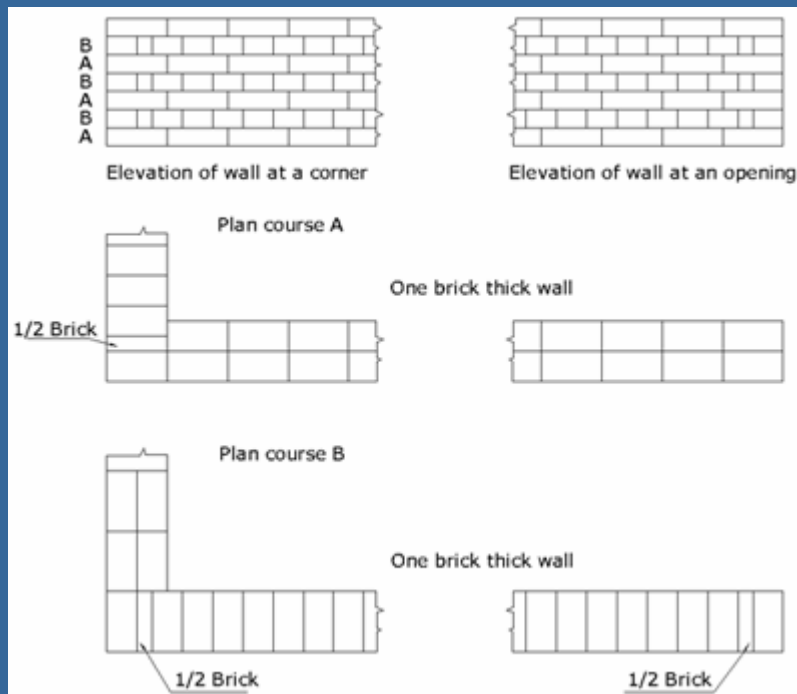
But,

- ❑ Creates heavier wall more prone to shear failure
- ❑ Common window and door frames in Aceh are too narrow
- ❑ Bricks in Aceh are wrong proportion to use a proper masonry bond
- ❑ Aceh homeowners prefer tall, slender wall (based on limited sampling)

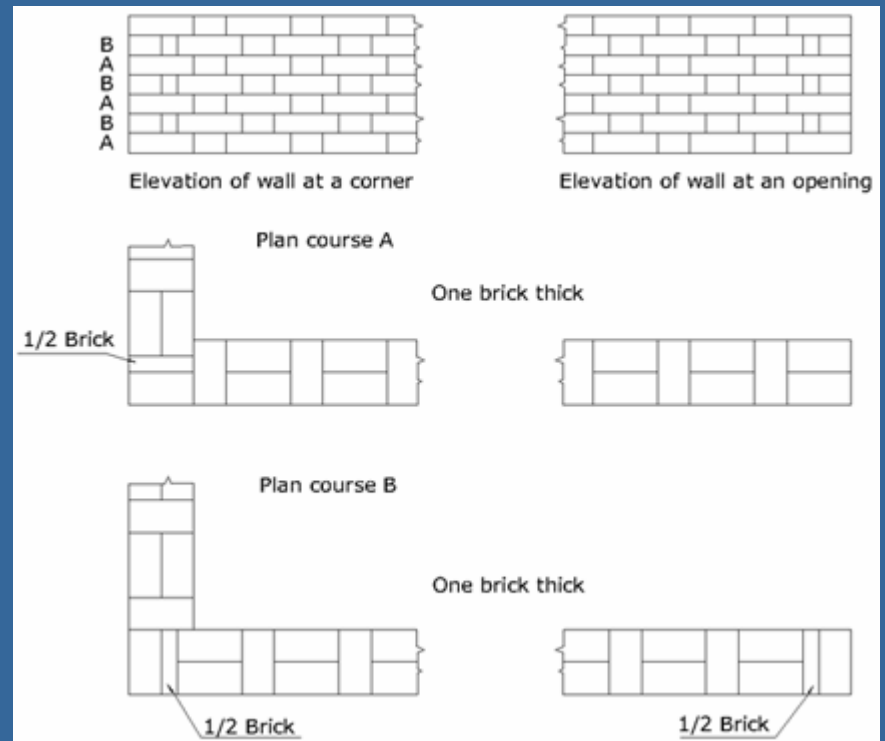


Acceptable Bonds for Full Brick Wide Wall

English Bond



Flemish Bond



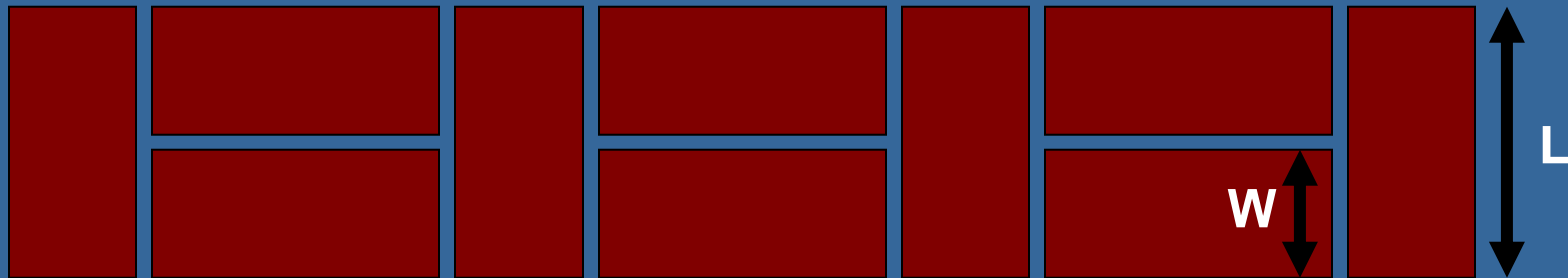
*Schematics from City University of London Guideline on
Confined Masonry and Interpretation of Eurocode 8*

Bricks Common in Aceh are the Wrong Proportion for Full Brick Bonding

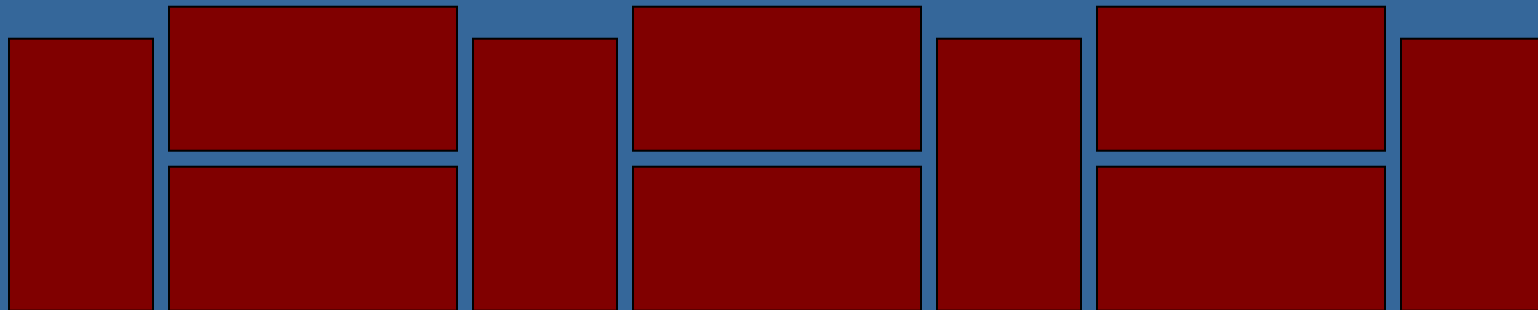
Length of brick must be at least twice the width plus width of joint

$$L > 2W + 1.5 \text{ cm}$$

Flemish Bond using bricks with correct proportion (top view)



Flemish Bond using Aceh bricks with wrong proportion (top view)



This Bond is Not Recognized/Acceptable



Build Earthquake Resistant Houses
Change Construction Practice Permanently



3b. Add a Second Horizontal Beam at Lintel Level

- ❑ Must be at least 0.5m between top of lintel tie beam and bottom of ring beam for any gain, cultural preference for a tall opening with vent on top doesn't accommodate this



How To Limit Out-of-Plane Failure

1. Follow configuration rules and add bracing at the ring beam level and/or add cross walls
2. Restrain the masonry by tying it to the tie columns and bond beams or covering it with mesh
 - a. Add horizontal reinforcement in the masonry wall, tied into tie columns
 - b. Lay wire mesh across wall when plastered

Best solution is combination of 1 and 2a → Must be on both sides, tied into foundation beam and ring beam, and have loops or ties through the brick wall. NOTE: we haven't tried this yet!

3. Reduce slenderness ratio, h/t
 - a. Use a different masonry bond to make a wider wall
→ But heavier wall will be more likely to crack, and more deadly if it collapses; bricks in Aceh are the wrong shape, people don't want
 - b. Add a second horizontal bond beam (lintel level)
→ But top of opening is already within 0.5m of the ring beam, so very little to gain

CONSTRUCTION QUALITY: MATERIALS and WORKMANSHIP

FOUNDATION EXCAVATION



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Foundation Excavation

- ❑ Make bottom flat, level
- ❑ Remove any organics, tree branches
- ❑ Remove loose soil
- ❑ Remove rainwater
- ❑ Don't build below the water table
- ❑ Don't build on expansive soil!



CONSTRUCTION QUALITY: MATERIALS and WORKMANSHIP

STONE MASONRY STRIP FOOTING



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Mountain Stone



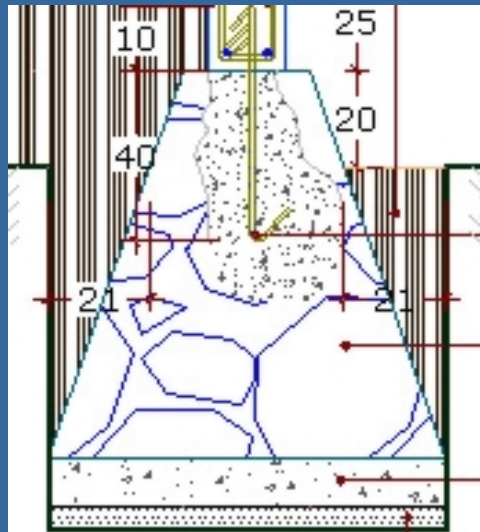
← Use red or black
(batu gunung merah
atau hitam)

Avoid yellow →
(batu gunung kuning)
weathered (clayey)
and weak



Stone Masonry Strip Footing

- ❑ Shape should be trapezoidal
- ❑ Build corners and cross walls at the same time
- ❑ Use long stones at the top, corners, wall junctions



Stone Masonry Strip Footing

- Lay stones flat, not vertical
- Fill the gap between stones completely with mortar
- Use of pasir cor ok for mortar (sand gravel mix)
- If good stone masonry workmanship cannot be ensured, consider a reinforced concrete strip footing



Bad Practice (Buruk)

CONSTRUCTION QUALITY: MATERIALS and WORKMANSHIP

REINFORCING STEEL



Build Earthquake Resistant Houses
Change Construction Practice Permanently

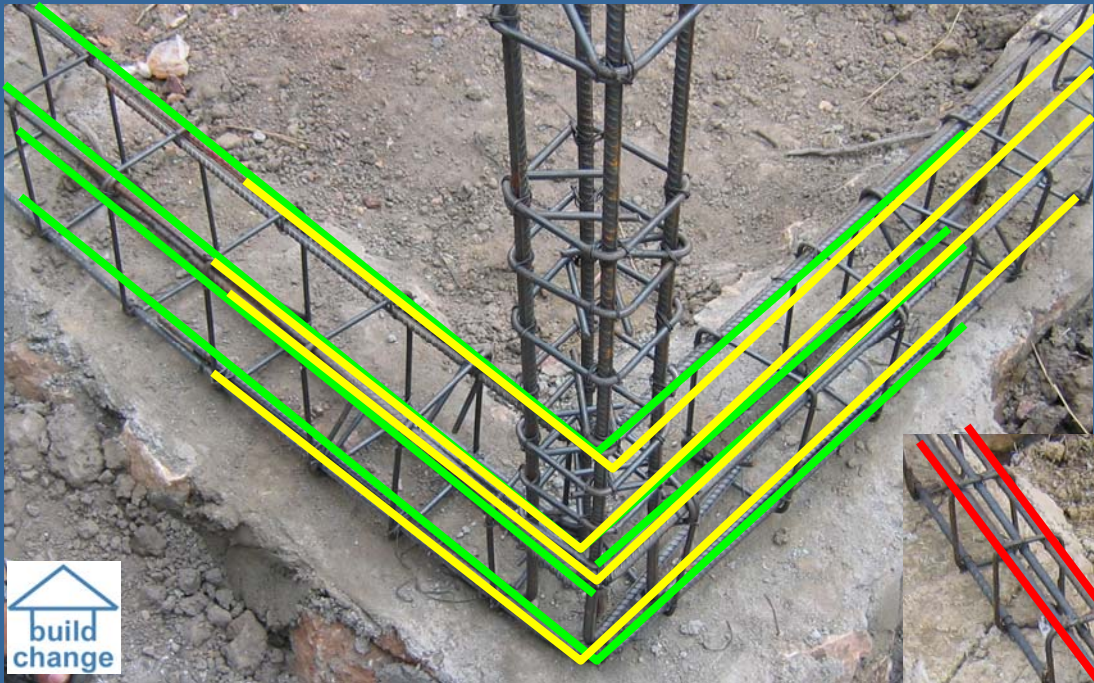


Connections, Laps are CRITICAL

No matter what size bars you are using!!

Bad Practice (Buruk)

→ *Long bars terminate in the joint*



Good Practice (Baik)

→ *Long bars pass through corner and overlap 40-50 times diameter of rod for ribbed bars, twice that for smooth*



Steel Detailing and Connections



Bad Practice (Buruk)

- *Long bars terminate BEFORE the joint*
- *Column bars not bent and lapped with ring beam bars*
- *Missing stirrups at the joint*

Steel Detailing and Connections



Good Practice (Baik)

- *Stirrups have square corners, sufficient hook lengths*



Bad Practice (Buruk)

- *Stirrups have insufficient hook lengths*
- *Bars are rusty*

Steel Detailing and Connections

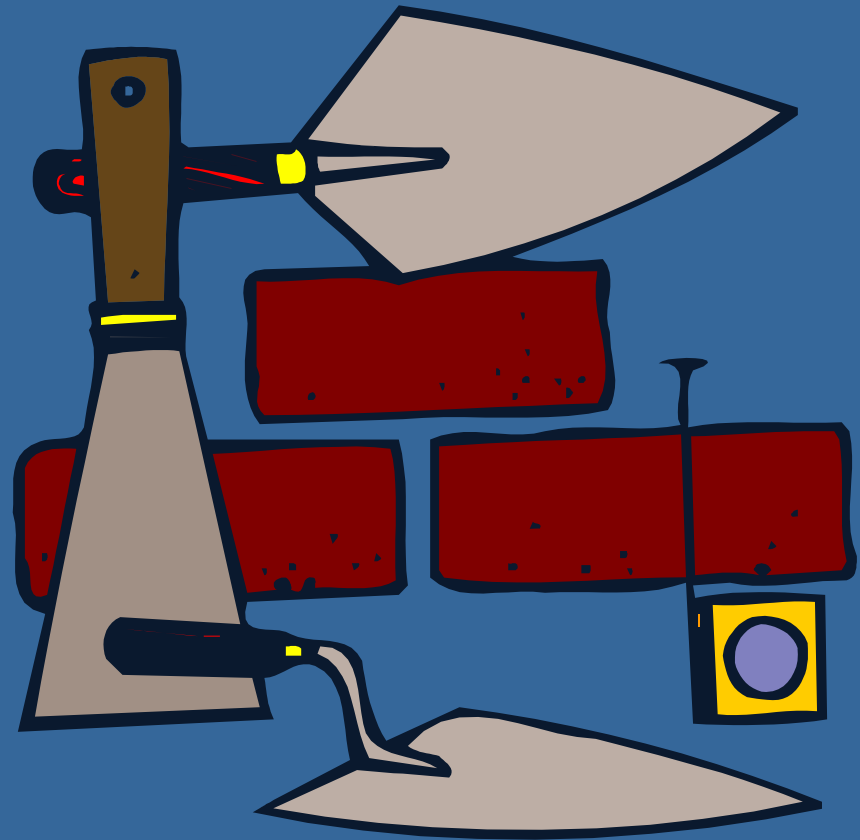
- Rotate stirrups so they do not line up on the same long bar →
- Tie with double binding wire
- Attach stirrups perpendicular to the long bar →



Bad Practice (Buruk) →
*Stirrups not at right angles
with the long bars*

CONSTRUCTION QUALITY: MATERIALS and WORKMANSHIP

FIRED BRICK MASONRY WALL



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Many Factors Affect Strength of Masonry Wall

Masonry Unit (Brick)

- ☐ Compressive, bending, rupture, tensile strength
- ☐ Dimensions and variations in dimensions
- ☐ Rate of absorption of water

Mortar

- ☐ Compressive, bending, rupture, tensile strength
- ☐ Type of cement and cement: sand mix
- ☐ Rate of drying

Workmanship and Curing

- ☐ Wetting bricks prior to laying
- ☐ Curing the wall
- ☐ Joint thickness and variation in joint thickness
- ☐ Filling and raking out of joints
- ☐ Plumb, level, straight, and true to a line

Masonry Panel

- ☐ Shear, bending, rupture strength of bricks and mortar combined

Wall Shape and Size

- ☐ Width, height, length, slenderness ratio

Plaster

- ☐ Increases the thickness and shear strength of the wall

Clean Water for Masonry and Concrete

- ❑ Salty water can reduce the strength of concrete by ~20% and corrode steel faster
- ❑ Use water that is at least clean enough to wash and bathe with
- ❑ Do not use swamp, tidal pond or ditch water →



Clean Sand for Masonry and Concrete

- ❑ Avoid beach sand
- ❑ Make sure sand is clean from dirt (fines), leaves, tree roots
 - Take a handful of sand, pour some water on it, if the water runs out dirty, reject it

→ Good Quality Bricks

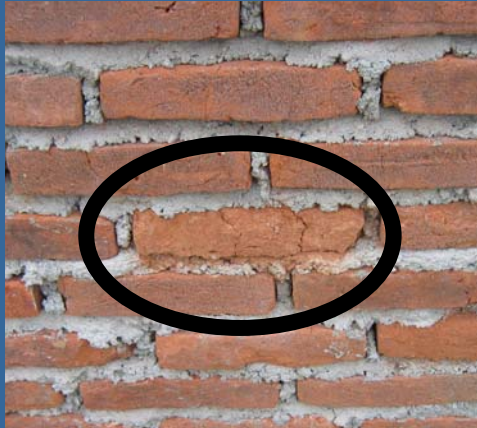
- ❑ No cracks or chips
- ❑ No visible unmixed portions or divits
- ❑ Brick is square, not warped or curved
- ❑ Dimensions are consistent among sample of 10-20 bricks → they do not vary by more than 1 cm in long direction and 5mm in width and height
- ❑ When two bricks are hit together, the sound is a metallic clink not a dull thud
- ❑ When left out in the rain or soaked for 24 hours, bricks do not crumble

→ Use Only Fully Fired Bricks



❑ *Bad practice → weak (not fully fired) bricks used and eroding in the rain*

→ Use Only Fully Fired Bricks



Bad Practice – chisel out and replace →



Three-point bending: a non-quantitative, simple test → 80% pass with an average size Indonesian male, no bouncing

Mortar Mix

- ❑ 1:2 for WC (kamar mandi) and damp proof course on bottom 40 cm (approximately 7 courses) of exterior walls



- ❑ 1:3 above damp proof course and interior walls



- ❑ Use clean water (clean enough for washing and bathing)
- ❑ Use enough water to be loose and flowable but not weep out of joints
- ❑ Use up the mix within 90 minutes of mixing with water



→ Soak Bricks in Clean Water Prior to Laying



Good Practice (Baik)
Bricks soaked prior to laying



Bad Practice (Buruk)
Bricks laid dry

Typical Aceh bricks are too porous: they absorb water from the mortar. This dries out the mortar before the cement has time to hydrate and create a strong bond between the bricks.

If Bricks Are Laid Dry...



Bad Practice (Buruk)

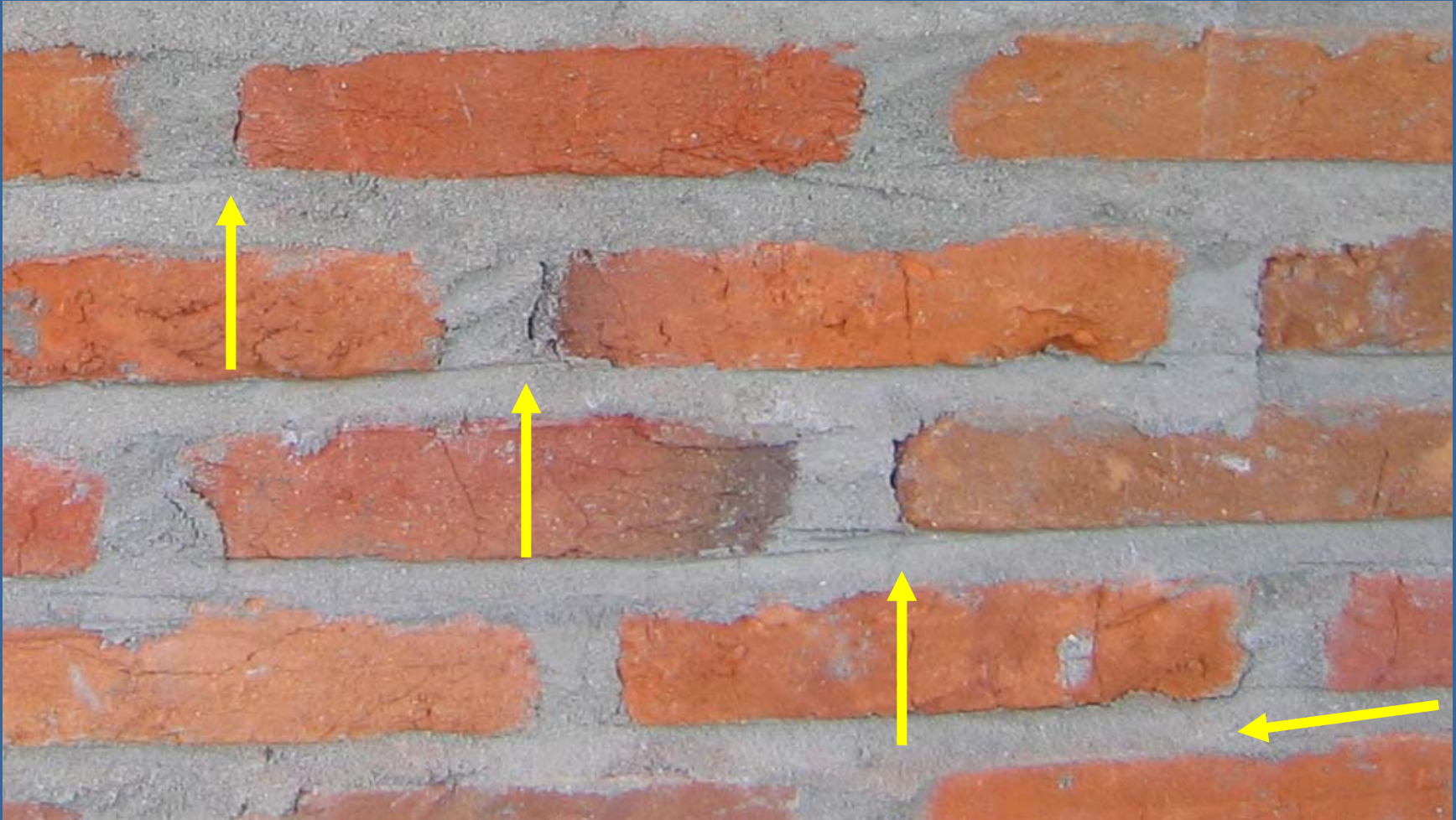
Wall will be weak

Easy to crack or overturn wall by striking with a fist

Build Earthquake Resistant Houses
Change Construction Practice Permanently



If Bricks Are Laid Dry...



Bad Practice (Buruk)
Hairline shrinkage cracks

Soaking Bricks in Clean Water Prior to Laying



is one of the most important steps you can take to improve the strength of masonry walls built in Aceh, and their performance during earthquakes

→ Lay Bricks Horizontally (One Course at a Time)



Good Practice (Baik)

- *Bricks laid horizontally one course at a time*
- *Use a line and deadman*



Bad Practice (Buruk)

- *Difficult to maintain horizontal continuity, plumb and level when bricks are laid several courses at a time*

→ Maintain Uniform Joint Thickness



Good Practice (Baik)

- *Bricks laid horizontal*
- *Joint thickness maximum 15 mm*
- *Joint thickness varies by less than 4mm*



Bad Practice (Buruk)



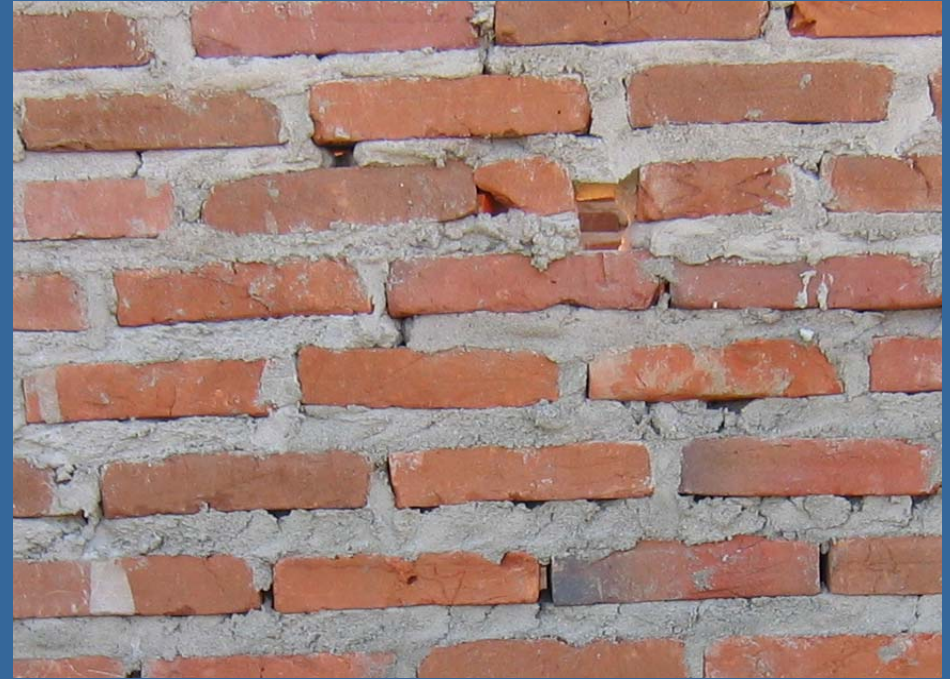
Bad Practice (Buruk)

→ Fill Joints Completely



Good Practice (Baik)

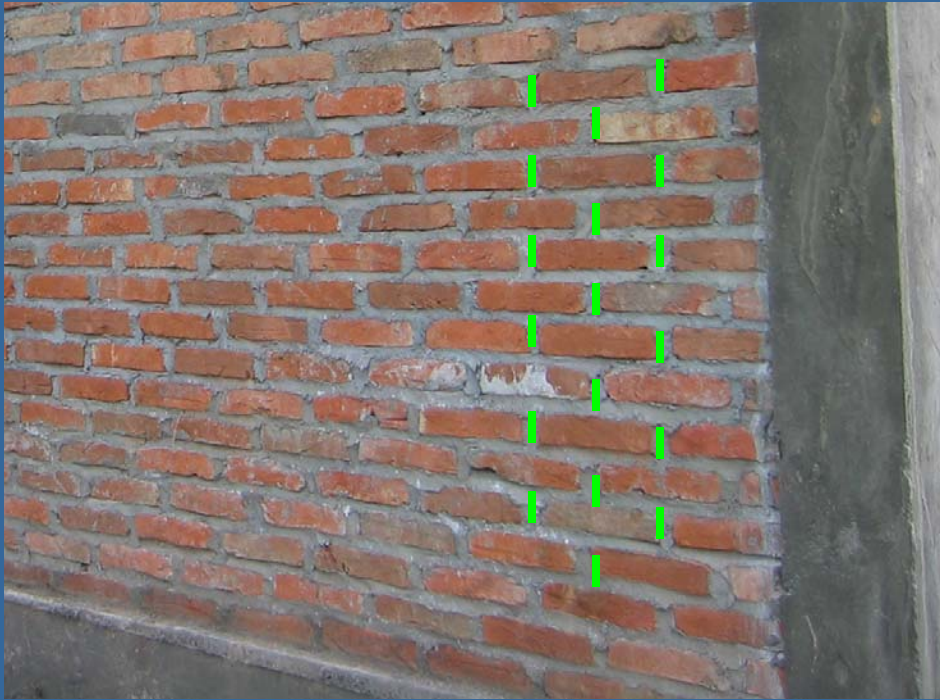
→ *Joints filled*



Bad Practice (Buruk)

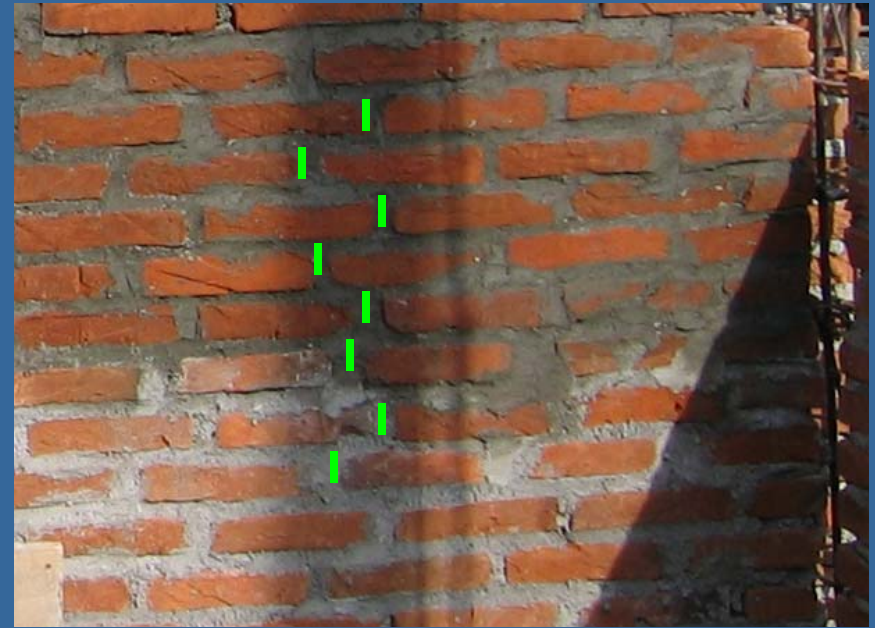
→ *Joints not fully filled with mortar (some head joints don't have any mortar; it is possible to see through the wall)*

→ Stagger Vertical Joints



Good Practice (Baik)

- *Bricks laid end-to-end*
- *Bond staggered*



Bad Practice (Buruk)

- *Bond inconsistent*

→ Maintain Consistent Spacing Between Bricks and Column Steel

2 – 3 cm depending on size of column



Bad Practice (Buruk)

Gap between bricks and steel too large - check steel remains plumb



Gap between bricks and steel too large at bottom, too small at top – no space for concrete cover over steel

→ Avoid Bond Discontinuities Avoid Small Panels



Bad Practice (Buruk)

- *Discontinuous bond between column and window frame*
- *Small masonry panels between column and window frame*



Photo Courtesy R. Willison, UNDP

→ Avoid Patterned Bonding Over Frames

WHY? No arch effect in practice



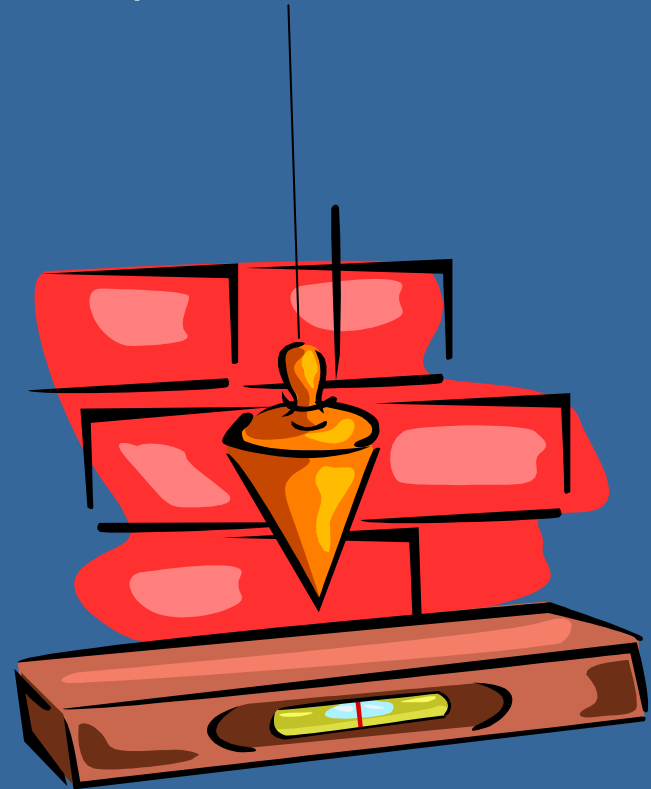
Better to use horizontal steel reinforcement (tied into adjacent columns) and running bond

→ Regularly Check Plumb

If the variation from plumb is more than 2 cm over 3m height, tear down and rebuild (bonkar)



Use a plumb bob or level



Build Earthquake Resistant Houses
Change Construction Practice Permanently



→ Cure the Wall

Sprinkle water on the wall for at least three days
(depending on the type of cement and weather)



Build Earthquake Resistant Houses
Change Construction Practice Permanently



→ Plaster the Wall
Good quality, cement-based plaster will increase the strength and thickness of a fired brick masonry wall



Build Earthquake Resistant Houses
Change Construction Practice Permanently



CONSTRUCTION QUALITY: MATERIALS and WORKMANSHIP

CONCRETE



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Gravel for Concrete (Kerikil Beton)

- Avoid coral
- Crushed aggregate is best
- Rounded river stone is ok if it is
 - ❑ Smaller than 3 cm diameter
 - ❑ Mixed with proper proportion sand
 - ❑ Clean from dirt (fines)



Concrete Mixing

It is possible to achieve the BRR-required strength (K175) for 1:2:3 concrete by mixing by hand on the ground.

1. Use a clean (preferably paved) surface so that the mix does not absorb sulfates from the ground: this will weaken concrete
2. Thoroughly mix the dry ingredients first

AND MOST IMPORTANTLY:

3. DO NOT USE TOO LITTLE OR TOO MUCH WATER



→ Do Not Use Too Much Water!!



Bad Practice (Buruk)

Cement and sand run through fingers leaving only gravel



Bad Practice (Buruk)

Do a Slump Test



Between 8 and 12 cm
(ideal = 10 cm)

Photo P. Tennis

Build Earthquake Resistant Houses
Change Construction Practice Permanently



→ Do Not Use Too Much Water

Mechanical mixing does not solve the water problem



Bad Practice (Buruk)

Too much water

Build Earthquake Resistant Houses
Change Construction Practice Permanently



→ Use Beton Tahu (Concrete Spacer)

Bad Practice (Buruk)

Exposed Steel

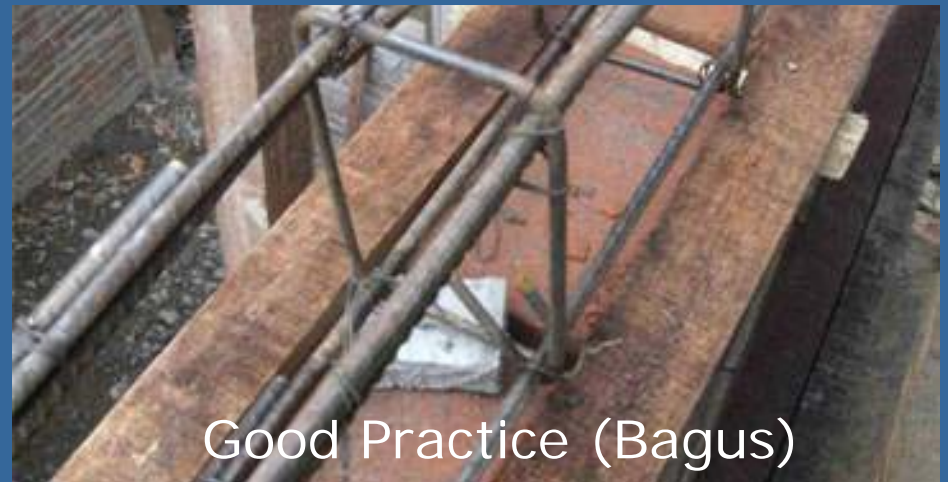
Lack of Cover

On sides and under stirrups – to ensure adequate cover over concrete

→ Maximum size 5 cm by 5 cm (square) or 5 cm diameter (round)

→ Thickness equal to the amount of cover over steel required

→ Use binding wire to tie to stirrups



Good Practice (Bagus)

Build Earthquake Resistant Houses
Change Construction Practice Permanently



Concrete Cover over Steel



Good Practice (Baik)

No exposed steel



Bad Practice (Buruk)

*Exposed steel – tie columns
should be demolished and
rebuilt*

→ Pour Clean Water on Forms and Steel Before Pouring Concrete



Good Practice (Baik)

Wetting formwork, steel, and existing surface

→ For Beams, Avoid Cold Joints by Pouring Entire Beam at Same Time



← Bad Practice (Buruk)
Main span of bond beams
poured days before joints

Good Practice (Baik) →
Entire ring beam poured in
same afternoon



→Clean Out the Bottom of the Tie Column Before Putting Formwork



Good Practice (Baik)

*Bottom surface clean
(should take a wire brush
to the steel)*



Bad Practice (Buruk)

*Loose mortar at the
bottom of the column*

→ Before Pouring Tie Columns,

→ Plumb the Door Frames



→ Coat With Sealant
(cat menie)

→ Connect with Nails



→ Pour Columns in Increments Between 1m and 1.2m Height



If pour shorter columns, too much work, too many cold joints, poor quality

If pour much taller, aggregate separates out when it hits the bottom



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Cure for 7 Days, Check for Spalling



Good Practice (Baik)

No spalling or exposed steel



Bad Practice (Buruk)

*Concrete stuck to formwork –
demolish and rebuild*

Check Concrete Cover over Steel



Good Practice (Baik)

No exposed steel



Bad Practice (Buruk)

*Exposed steel – tie column
should have been
demolished and rebuilt*

SITING, DRAINAGE, SOILS and FOUNDATIONS



Build Earthquake Resistant Houses
Change Construction Practice Permanently



Siting and Drainage

Poor choice of site and drainage issues can lead to differential settlement of the house before an earthquake. This may lead to cracking of masonry walls, and the wall will be weaker when the earthquake strikes.



Bad Practice (Buruk)
No drainage



Bad Practice (Buruk)
Graywater draining into foundation

Soils Investigation

- ❑ A detailed soils investigation is strongly recommended prior to starting any construction project (e.g., CPT, SPT, vane shear)
- ❑ If budget is limited, can still do simple tests
 - ❑ Dig a pit (such as for the septic tank) to determine soil type, depth to water table
 - ❑ Do a sedimentation test – to estimate the percent clay, sand, silt
 - ❑ Do an expansion test – used to determine how much the clay shrinks when it dries
 - ❑ Push a 12mm diameter rod in the ground
- ❑ FOR MORE INFORMATION ON ANY OF THESE METHODS, PLEASE ASK

Avoid Soft and Expansive Clays

→ If soil is expansive clay (peat, black cotton soil – soil that shrinks and cracks when it dries), do not build a masonry structure!!

Three options:

1. Find a new site
2. Build from lightweight, flexible materials (timber)
3. Excavate the expansive clay and fill with compacted fill soil



Avoid/Mitigate Liquefiable Sand

→ If soil is loosely compacted, sandy and water table is high → biggest hazard is liquefaction during the earthquake → causes settlement of house, which can result in cracking or collapse.
Four options:

1. Find a new site
2. Build from lightweight, flexible materials (timber)
3. Improve the soil using densification or cement addition (expensive)
4. Distribute the building load evenly and span loose spots using a reinforced concrete mat or raft foundation – avoid isolated footings



1964 Niigata, Japan Earthquake

Closure: Confined Masonry for Aceh



Build Earthquake Resistant Houses
Change Construction Practice Permanently



MAJOR RECOMMENDATIONS for Aceh Confined Masonry Housing Construction

1. DESIGN and BUILD GOOD CONNECTIONS between reinforced concrete elements and keep steel covered
2. AVOID USING MASONRY ABOVE THE RING BEAM
3. USE MORE WATER on the bricks and curing masonry wall
4. USE LESS WATER in the concrete

MAJOR RECOMMENDATIONS

- ❑ PLEASE SUPERVISE YOUR CONSTRUCTION
- ❑ POORLY BUILT CONFINED MASONRY HOUSES WILL COLLAPSE AND KILL PEOPLE IN THE NEXT STRONG EARTHQUAKE
- ❑ IF YOU CAN'T SUPERVISE, BUILD A TIMBER HOUSE (but also with timber, design, quality workmanship, and quality materials are critical)

WHAT BUILD CHANGE OFFERS...

- ☐ Repeat this seminar in Bahasa or English
- ☐ Put the design guideline in handbook form
- ☐ Put the construction guideline in handbook form
- ☐ Share our design drawings, bill of quantities, construction quality checklist
- ☐ Check your design drawings
- ☐ Train your construction supervisors
- ☐ Train your skilled and semi-skilled builders

CONTACT US

❖ Dr. Elizabeth Hausler

elizabeth@buildchange.org

HP in Indonesia: 081315905072