Environment, Man and Building’ series

A manual of earthquake-resistant building practice

Heinz Frick
Tri Hesti Mulyani

English language translation by Colin Small

Penerbit Kanisius

Lembaga pendidikan lingkungan-manusia-bangunan

A manual of earthquake-resistant building practice
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PENERBIT KANISIUS
Jl. Cempaka 9, Deresan,Yogyakarta 55281
Post box 1125/Yk,Yogyakarta 55011
Phone +62-274-588783
Fax +62-274-563349
E-mail:office@kanisiusmedia.com
Website:www.kanisiusmedia.com

UNIKA Soegijapranata, Lembaga Pendidikan LMB
Jl. Pawiyatan Luhur. IV/1 Bendan Dhuwur,Semarang 50234
Telephone (024)8316142-8441555(hunting),fax (024)8415429
E-mail :info@LMBunika.com
Website: www.LMBunika.com

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Publishers note

Earthquakes happen in series, usually spread over several years. This latest event was very strong and resulted in many casualities. It is frightening that many victims died alone inside their houses, struck by collapsing building materials.

We cant deny that the region where we live is repeatedly affected by earthquakes. We must accept that at some unknown time in the future another quake will happen in our area. Our only choice is to continue to introduce this information to our children and grandchildren, and take precautions so that we are protected from danger.

One of the ways we can achieve this is to build our houses to resist earthquakes. Is there, we ask, an inexpensive way to build earthquake resistant buildings, which does not require sophisticated machinery or materials, and which can be achieved by the general public?

Happily, the answer is Yes! Heinz Frick and Tri Hesti Mulyani from the Environment-man-building center of education (LMB) give practical guidelines for us in the pages of this small book.

Our greatest thanks to both writers who prepared this book in such a short time, and to the Liechtenstein Development Service Foundation who subsidized the publishing.

We dedicate this book to all communities in Indonesia.

Our hope is that it will be useful.

Yogyakarta, August 2006

Publisher

Foreword

An earthquake in the Yogyakarta-Bantul-Klaten region of Central Java, on May 27th, 2006 resulted in thousands of victims, killed, injured or terrified. The death toll and widespread serious damage is a great concern because the earthquake was only moderate in size, magnitude 5.8 on the Richter Scale (8.0 MMI), and should not have had such serious consequences. In many cases the large scale destruction brought by earthquakes is a consequence of careless and unsafe community standards.

It is the developing countries that are most frequently affected by earthquakes. In these areas, where houses are built by families and communities, education, about the science of earthquakes, about earthquake resistant construction, and about community organization in anticipation of, and in response to earthquake, is very important.

This education helps communities understand the consequences, and construct earthquake resistant buildings to reduce the risks. This knowledge must be applied each time a building owner wants to change, extend or improve a building, so that these activities wont weaken or destabilise it. Also, as a safety precaution, the structural condition of every existing building should be checked.

The authors were asked by Kanisius (publisher and printer, Yogyakarta) to prepare this manual as an aid to the construction of earthquake resistant buildings, as soon as possible in order to assist the recovery process.

The Environment-Man-Building Center of education (LMB) was created to improve the quality of life and the environment in Indonesia, where earthquakes regularly threaten human life and disrupt society.

The damage to buildings and infrastructure, the expense of repairs and the consequential damage to the environment caused by reconstruction activities are significant problems.

We thank the many people who helped with this work, especially Anggara Agung Pire, the illustrator, and the team from LMB – Soegijapranata Catholic University - Semarang for their critical input during the finishing stages, and many others who cannot be mentioned individually.

The authors apologize for any oversights in the acknowlegement of copyright and ask that the importance of an early publication date be considered.

Any suggestions or advice which might improve this manual are welcome, and may be submitted to the publisher, Kanisius and to the author, at LMB, Soegijapranata Catholic University Semarang, for inclusion in following editions.

This English language translation was supported by funding from Colin Small, Sydney, Australia.

Semarang, July 2006

Dr.Ir. Heinz Frick, dipl.arch. FH/SIA
Ir. IM. Tri Hesti Mulyani, MT

Contents

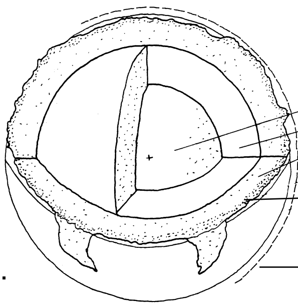
1. The Problem[1]

Every year seismographs record about a million ‘tremors’ in the outer crust of the earth. About 20 of these events are considered as ‘strong’ earthquakes, and two might be considered ‘very strong’. There are only one or two severe earthquakes each year. While these earthquakes can be measured all over the planet they are only dangerous close to the epicenter.

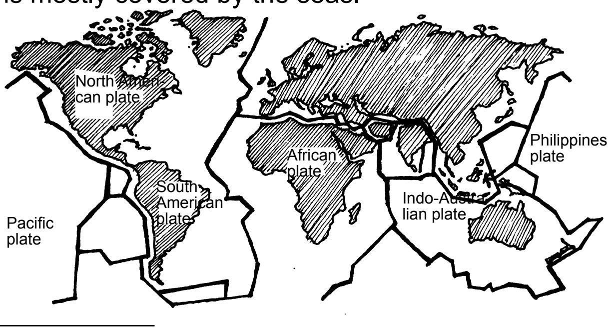
The areas of most concern, adjacent the edges of tectonic plates, experience the affects of plate movement. According to the science of Plate Tectonics, the earths’ crust is divided into 16 large and several small tectonic plates. These plates are in constant movement (up to 10cm/yr) on the mantle, layers of semi-solid rock up to 280km thick. These movements are caused when the heat from the earths’ core is distributed unevenly to the surface, causing movement in the crust.

The structure of the earth

The predominately iron ore, molten inner core of the earth is approximately 2400 km in diameter. An outer core of molten nickel and iron is a further 2300 km thick. This outer-core rotates around the inner core at a speed of approximately 90m/day generating a powerful magnetic field, the magnetosphere.



The outer-core is surrounded by an iron and magnesium mantle up to 2900 km thick and then an 11 km thick layer of lighter material, containing silica and aluminum. The continents are part of the outer crust, which is mostly covered by the seas.

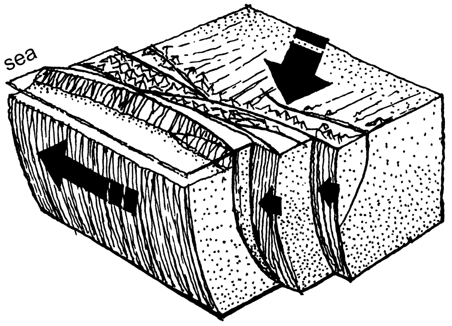


Tectonic plates

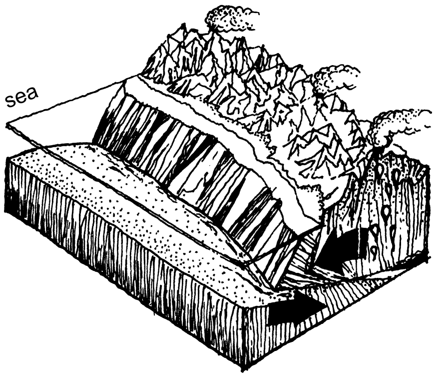
1 This chapter quotes from: Frick, Heinz. *Baukonstruktionslehre*. University lecture notes. Vaduz: Institute of Technology,1990 p 6.62-6.64

Introduction to seismology

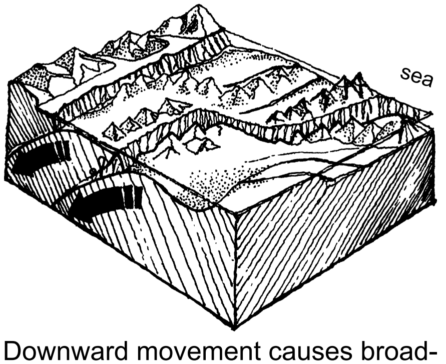
Movement of the earths’ tectonic plates causes 4 types of earthquake trauma.[2]



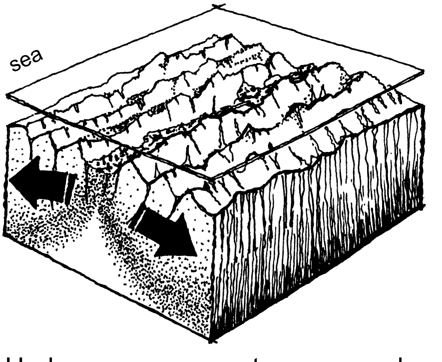
Horizontal movement (sideways) causes cracks in the earths surface.



Upward movement can increase the flow of magma and the activity of nearby volcanos.



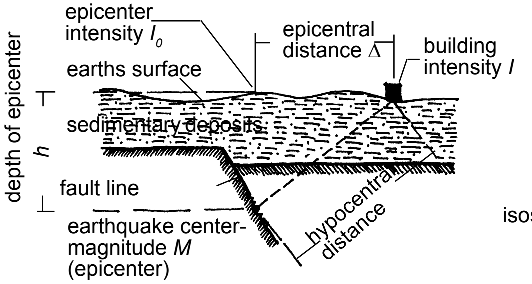
Downward movement causes broadening of low lying areas accompanied by sedimentation



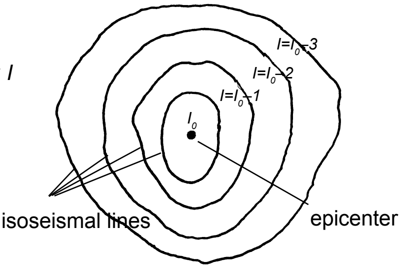
Undersea movement opens cracks, allowing magma to escape and accumulate on the seabed.

An earthquake under the seabed can result when ‘stored’ tectonic pressure, (between tectonic plates) is released as kinetic energy, felt as seismic shocks (earthquake). In these circumstances the seabed often has a fractured appearance.

2 drawings from:Gray, William R./Kogod, Charles/Payne,Barbara A.(ed.) *Restless Earth.* Washington: National Geographic Society.1977 p 152-153



Detail of typical earthquake dislocation[3]



Isoseismal lines on a map, connecting places of similar earthquake intensity

Earthquakes are caused variously when:

- Erosion or sedimentation gradually changes the form of the outer crust (earths surface), and as a consequence, its weight. A 25 cm change in the profile of the earths surface through erosion is equivalent to the weight of 127,500 cubic kilometers of rock. Recent research shows that earthquakes may also be caused by the weight of water in large concentrations.
- Decomposition of radioactive material in the earths mantle releases heat energy, causing the mantle to warm up and melt. As the tensions are balanced the crust moves horizontally and vertically, or cracks.
- Cracks occur on the earth's crust caused by cooling and shrinking processes

Earthquakes under the seabed may generate dangerous tsunami. Tsunami can travel great distances, far from the epicenter of the earthquake. When they reach land, the energy is dissipated quickly but can cause great damage, as in Banda Aceh in 2004.

The power of an earthquake and its influence on construction determines its scale. The magnitude (M), Richter scale, of an earthquake is determined by measuring the maximum seismic movement (using a seismograph), while the Intensity (I) measures the impact of an earthquake on human beings, buildings, and the landscape. The modified Mercalli intensity scale (MMI) describes the impact in grades.

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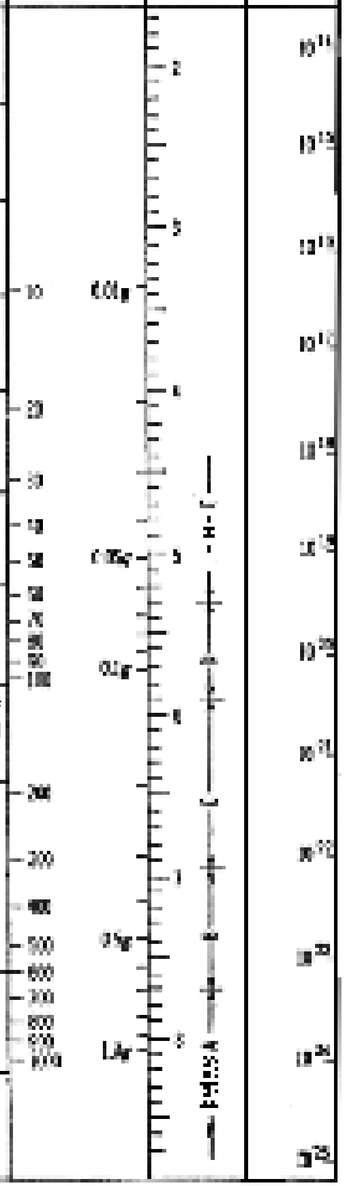
[3] Muller,F.P./Keintzel,E. *Erdbebensicherung von Hochbauten.*2[nd] edition Berlin: Muller,1984

MMI scale	Modified Mercalli Intensity scale (MMI) of physical effects.	Movement Velocity cm/s² gaya-berat	Richter-scale	Shaking Energy
1	Detected only by sensitive instruments			
2	Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing			
3	Felt noticeably indoors; but not always recognized as earthquake; standing autos rock slightly; vibration like passing truck			
4	Felt indoors by many; outdoors by few; at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably			
5	Felt by most people; some breakage of dishes, windows, and plaster, disturbance of tall object			
6	Felt by all; many frightened and run outdoors; falling plaster and chimneys; damage small			
7	Everyone runs outdoors, damage to buildings varies depending on quality of construction; noticed by drivers of automobiles			
8	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed			
9	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken			
10	Most masonry and frame structures destroyed; ground cracked; rails bent; landslides			
11	Few structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent			
12	Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown up into air			

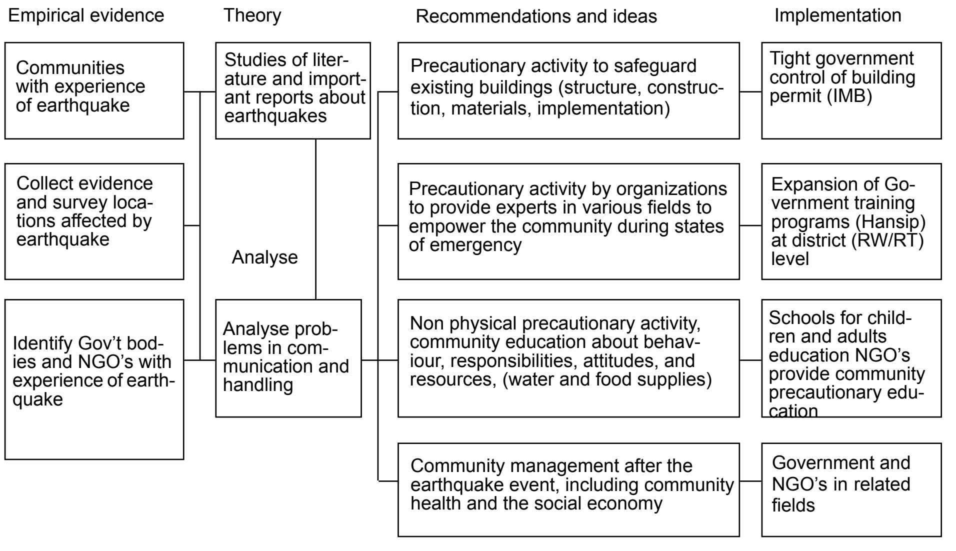


2. Principles of earthquake resistant construction [4]

Overview

Large scale earthquake damage to buildings is common because the danger is often underestimated, or the likely costs of prevention exaggerated. This need not be the case, since the additional construction cost to provide earthquake resistance is only about 2%-5%.

The following ideas may help communities avoid the disasterous experiences of Banda Aceh (2004) and Bantul/Yogyakarta (2006)[5]



Definitions and objectives:

Earthquakes in the earth's surface have the following effects;

– Tremors or shakes in the earth, caused by seismic waves;
– movement of the earth, causing cracking, changes in profile, landslides, changes to drainage patterns and waterways; and
– liquification that results in changes to the lands ability to support load.

4 this chapter quotes from: Rosman, Riko. *Erdbebenwiderstandsfähiges Bauen.* Berlin: Ernst. 1983 p 4-12

5 expansion based on: PT Saranabudi Prakarsaripta. *Proposal teknis: Pedoman praktis, bantuan teknis, penanganan pembangunan/perbaikan perumahan di daerah bencana alam.* draft. Semarang 1998/1999. p. 11

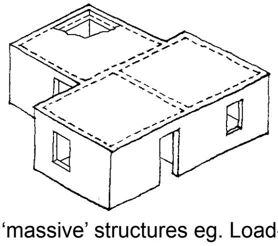
Earthquakes can destroy buildings, overturn dams, fracture pipelines, and endanger peoples lives. Secondary damage caused by flood, tsunami and fire can magnify the problems.

Earth tremors can be categorized as follows:

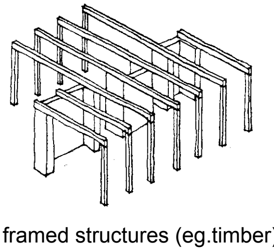
– single shocks in hard ground close to the epicenter. Uni-directional with frequencies less than 0.2 seconds and small amplitudes (only centimeters);
– tremors with a duration 20–30 seconds, in many directions. The tremors have unequal frequencies, between 0.05–6 seconds, and higher amplitudes (up to 20 cm). This kind of earthquake is the most common.
– Slow moving tremors, with a duration up to 5 minutes and amplitudes up to 30 cm, uniform in direction, in soft ground,

For buildings, the velocity of earthquake generated movement is important because maximum values can generate forces equal to the earths gravitational effect ($g = 981\ cm/s^2$). Generally, buildings are designed for vertical loadbearing strength only, ignoring the horizontal forces caused by earthquake - particularly dangerous for the stability of buildings. Resonance between the movements of buildings and movements of the earth makes the frequencies between 0.1 and 6 seconds the most dangerous. Small frequencies generally affect 'stiff buildings', whereas large frequencies affect buildings that are more flexible.

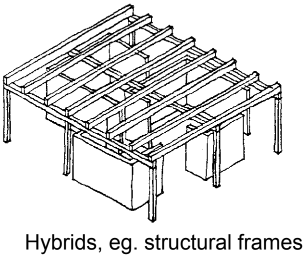
Ductility in the structural system of a building affects the buildings stability and ability to endure earthquake shock.



'massive' structures eg. Load-bearing reinforced concrete and brickwork in boxlike forms, are very 'stiff' and can withstand earthquakes



framed structures (eg.timber) easily change shape, accommodating shock through the elasticity (movement) of connections



Hybrids, eg. structural frames supporting the roof, with non loadbearing 'massive' walls enclosing space

Massive, boxlike structures, don't easily change shape, so they are very stable. In contrast to massive structures, jointed timber structures are flexible (ductile), and can accommodate earthquake shocks.

Where the soil is already wet, or wet as a result of an earthquake, earth tremors can decrease the water pressure in the soils pores, leading to soil saturation and liquifaction. Liquified soil has little loadbearing ability. If the soil under only one side of a building becomes liquid, that side of the building will collapse.

Objectives in building earthquake resistant houses are as follows:

– to avoid cracking or structural damage in low intensity earthquakes (MMI < 8.0), which may happen several times in the life of a building.

– In high intensity earthquakes (MMI > 8.0) to avoid damage that will endanger the lives of occupants.

These objectives can be achieved by paying attention to the stiffness, stability and ductility of a buildings' structure. Note also that deflection or buckling in beams can stress parts of a building not directly receiving shocks, and that neighbouring, attached structures can receive transmitted earthquake shocks. Although not affecting the building's stability the cracks and shakes may cause panic for occupants.

Not all buildings need the same earthquake resistant characteristics. The community should ensure that important buildings, like hospitals, power stations, communications, fire fighting and administration facilities, can resist damage, enabling these functions to continue in the aftermath. Because it is so expensive and difficult to construct a building to withstand a 9.0 MMI intensity earthquake, priority should be given to important buildings.

Buildings resistant to low intensity scale earthquakes can be achieved in principle by choosing an advantageous form (shape) and structure, and a simple method of construction which separates loadbearing and non loadbearing parts. This 'in principle' approach can be inexpensive and doesn't require complex calculations.

Guidelines

The following guidelines give directions about the design of plans, foundations, and building structures, for architects and civil engineers.

1 Foor plans must be simple and compact.(see illustration p. 19-20). Load-bearing and non load-bearing parts should be designed as parts of a 'whole', where the parts mutually influence and support each other.

2 Structures should be as light as possible. The heavier a structure the more it is influenced by earthquake shock. The higher a building is the greater the earthquake effect. Heavy structures high in the building can damage those underneath.

3 Supporting structures must be as simple as possible, allowing vertical and horizontal load transfer pathways to be easily recognized. Simple structures are more able to endure large-scale earthquakes.

4 Floor plans should be regular and as symmetrical as possible. Square and circular shapes are ideal, simple rectangles are also effective.

5 Vertical load-bearing structures must be placed to take the heaviest vertical load. Structural elements carrying the greatest downforce are most able to resist the horizontal forces and twisting moments characteristic of earthquakes. A vertical loadbearing element's contribution to a structures' overall torsional 'stiffness' increases as its distance from the centre of the structure increases.

6 Vertical connections such as stairs, lift shafts, and other shafts should be located in the center of the floor plan.

7 Vertical sections through the structure should be rectangular (in principle). Floors which are smaller or larger introduce asymmetric loadings and endanger the stability of buildings.

8 The height of a building should not be more than four times its width.

9 Multi-storied buildings with open ground levels, (shop, office, parking lot, etc.) are thought to be weaker, because the box formed by the upper floors may fall if an earthquake occurs. Lower floor structures should not be comprised of columns or parallel shear walls only.

10 Building structural systems react to earthquake forces in different ways. A buildings' structure should be monolithic, ie, built entirely

with the same material system so that it will all react to an earthquake in the same way.

11 The thickness of concrete floor slabs and the depth of beams should be thicker than normal to avoid vertical ‘shake’ or ‘flutter’. To avoid additional torsional (twisting) forces, beams should not be wider than the columns they are carried on.

12 Horizontal ring beams with diagonal cross-bracing in the floor slab on each floor can enhance the stability of a building.

13 Foundations must be simple and strong to resist earthquake forces. A reinforced concrete floor slab or a reinforced concrete ring beam at floor level (sloof) are recommended for residential buildings. Isolated pad footings should be avoided.

14 The way a building reacts to earthquake depends as much on the way it is built as on the way it is designed. Site management and site and work practice supervision during construction are necessary to guarantee the earthquake resistance of a building.

15 Subsequent to its construction, poor maintenance, local excavations, poor on site drainage, unrepaired damage to pipework, etc, can affect a buildings stability during an earthquake. Alterations, such as renovations or additions may alter a buildings ability to resist earthquake.

Problems which can be prevented and those that can’t

As previously mentioned, only about 20 of the millions of earth movements each year cause damaging earthquakes. With a variety of causes including changes in the weight of the earths crust and displacement of tectonic plates, earthquake events can harness massive amounts of energy, changing the shape of the landscape, causing massive damage to structures and buildings and endangering human lives.

Damage to buildings/structures can be avoided or reduced in the following ways:

- *It is prohibited to build over an active faultline. Lists and maps of known active faultlines can identify fault lines which might move in the future.* By not building on top of, or close to fault lines or cracks caused by tectonic plate shift. It is not possible to build safely directly over a fault line. Further seismic activity along that fault line will cause damage to structures built in that area. So don't build over known fault lines, or cracks in the grounds surface. Such fault lines or cracks are not often visible on the surface, being filled or covered with sediment. They can be identified on a terrestrial seismic map. Large fault lines can be identified with radiation level surveys. (Cracked or faulted areas have higher radiation levels compared to normal).

- By constructing earthquake resistant buildings in areas where the problem is known. (see the following earthquake map).
- By choosing to build in quake-free areas such as Central Kalimantan or South Papua (Merauke).

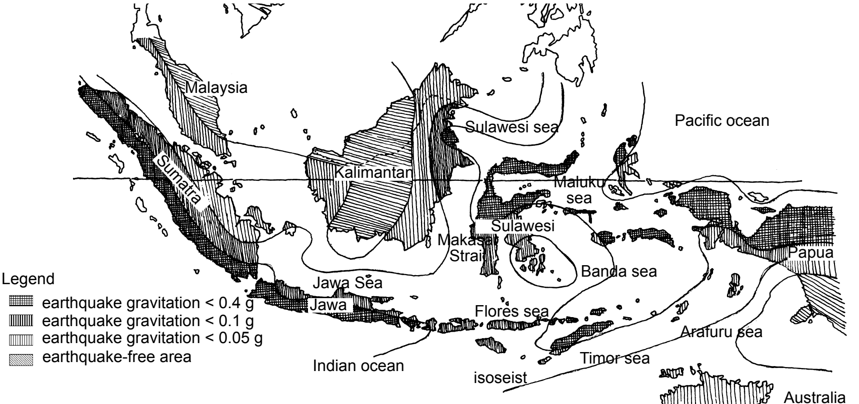


Illustration: Indonesian Earthquake Map from 1935[6]

Damage to buildings cannot be avoided when:

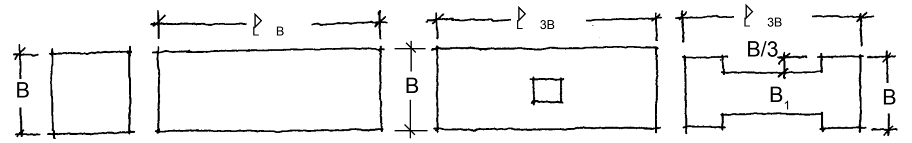
- The earthquake strength exceeds 8.0 MMI (>0.1 g) which can cause major damage and cause weak buildings to collapse. Because of the expense and difficulty of building to resist very strong earthquakes, only important buildings should be constructed in this way.
- The ground becomes saturated due to the earthquake. While its not good practice to erect buildings on wet ground, industrial and trading cities with harbors have been developed on swampy ground all over the world.

6 drawing from: Wangsadinata, Wiratman. *Perencanaan bangunan tahan gempa.* 2nd edition. Bandung: Direktorat penyelidikan masalah bangunan. 1971 map 1 p. 34

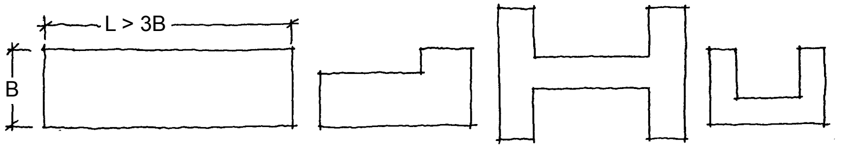
3. Designing an Earthquake Resistant Building

Plan shape

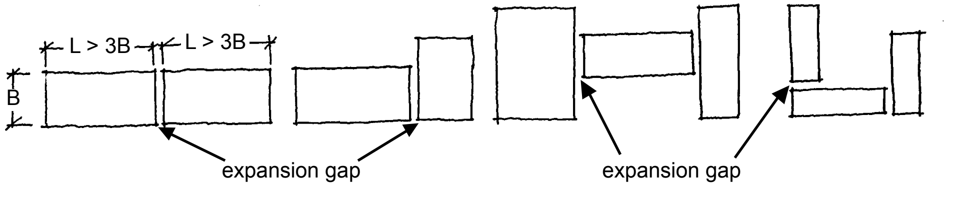
The Indonesian regulations for the design of earthquake resistant buildings[7] requires; The plan shape should be as simple as possible; rectangle, square, etc. as follows;



Avoid shapes that are very long or asymmetrical.



If a very long or asymmetric shape cant be avoided, the building must be divided into simple complete parts. The gaps should be at least 3 cm wide for buildings up to 3 stories high, as illustrated below.

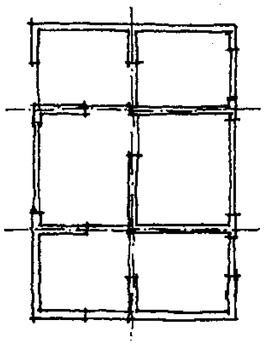


On plan, the gaps should *extend* from one side to the other, as shown in the illustration.

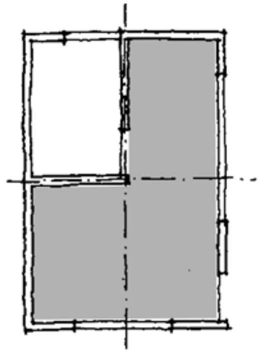
Structural plan, layout

The plan is to be developed from a simple overall shape (eg. a square or rectangle). Room plans should avoid asymmetric or overly long shapes (see the following illustration).

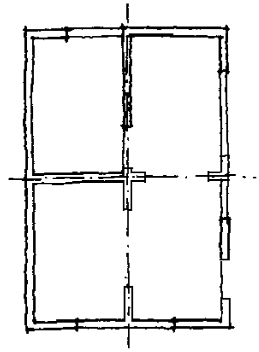
7 see: Badan pembina penelitian teknik gempa (ed.) *Peraturan perencanaan tahan gempa Indonesia untuk gedung.* Bandung: Departmen PU. 1983, and: Pusat penelitian dan pengembangan teknologi permukiman (ed.) *Standar perencanaan ketahanan gempa untuk struktur bangunan gedung.* SNI-1726. Bandung 2002



Planning which is earthquake resistant



Planning which is less earthquake resistant

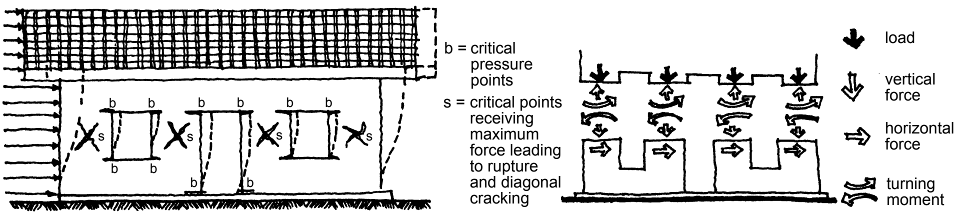


…and improved.

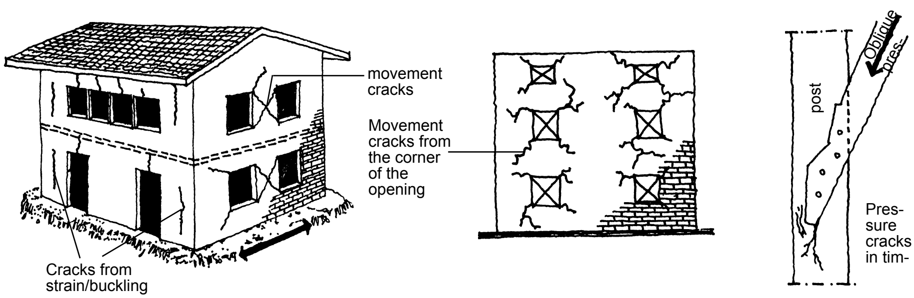
Long or asymmetric rooms can be made more earthquake resistant by introducing regular dividing walls (with openings for functionality). Such openings should be located symetrically, allowing wall space either side of and above the opening.

Building Structure

Ground floor structures, without a loadbearing frame, can move, and are the most threatened. Damage always occurs at the weakest points, eg, around openings. See illustration.



Forces working on one wall of a house.

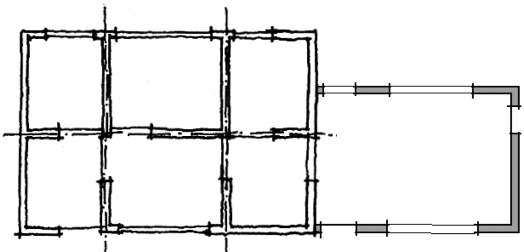


Cracking in masonry and timber construction as a result of ageing of the structure.

In ‘concrete post and beam’* *(beton rangka)* structures, the most common form of residential construction, the brickwork panels, not adequately tied into the concrete framework, cannot transfer horizontal forces, causing cracking in the brickwork, and compromising the stability of the reinforced concrete frame. [8]

Stability and alterations and extensions.

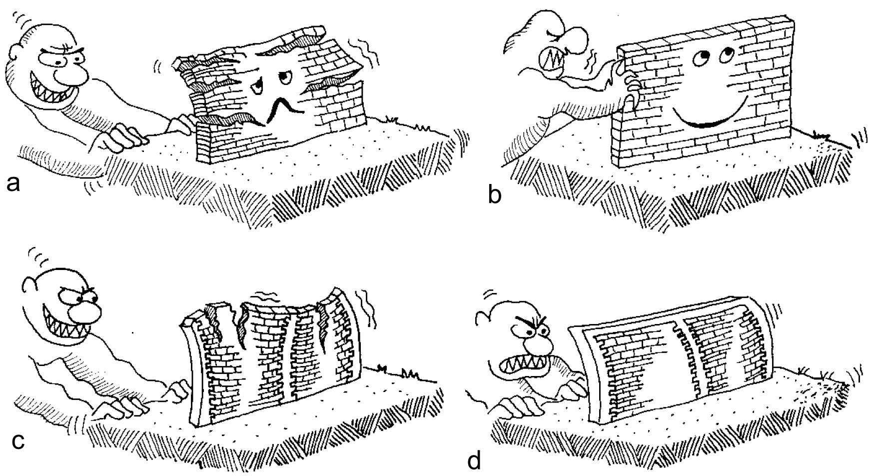
The **overall shape** of a building influences its ability to withstand earthquake.



Changes that alter the shape or weaken the buildings structure will detract from its ability to withstand earthquake. Every change should consider the structure as a whole.

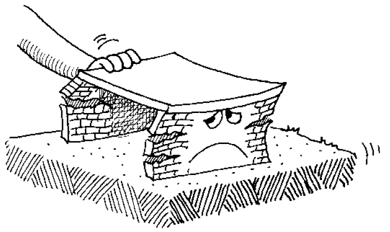
4. Constructing Earthquake Resistant Buildings

Prerequisites and arrangements



8 see also: Rosman,Riko. *Op.cit*. p. 45, 53

* see also page 24



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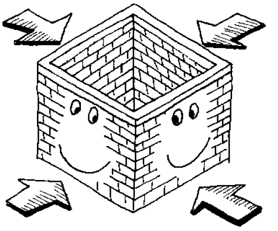

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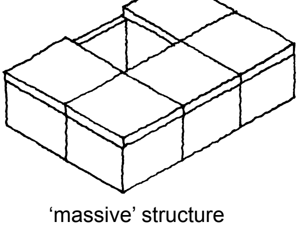
For a building to withstand earthquake, consider the following:[9]

Simple brickworkwalls can only withstand horizontal forces in the same direction as the wall plane, not perpendicular to the wall plane.(a,b); simple columns, tied in well to concrete structures at floor and ceiling level (eg. at footing beam and ringbeam) will resist horizontal forces but simple columns, not tied in well at floor and ceiling level have little strength to resist horizontal forces and will fail during earthquake events. (c,d); floor slabs (or roof construction) will be unable to resist horizontal forces if the structures that support them do not have such strength (e); 'massive' structures, where all walls are tied to one another, are most able to resist horizontal forces (f).

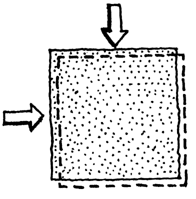
'Massive' structures

A technical term for a structure in which all walls are loadbearing.

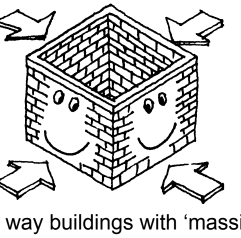
The 'structure' of a building normally includes its foundations, walls, columns, floor slabs, and roof framing. Building structural types can be identified according to the relationship between loadbearing elements (foundations, walls, columns, floor slabs, and roof framing) and non-loadbearing elements (partition walls, doors, windows, etc.) as follows:[10]



'massive' structure



The way horizontal (earthquake) forces work *(plan)*

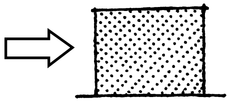


The way buildings with 'massive' structures receive horizontal forces

9 according to: Doat,P.et al. *Construire en terre.*Paris: edition alternatives 1979 p 132

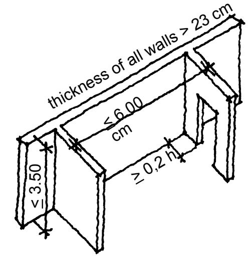
10 see: Ronner, Heinz.*Kontext 78: Baustruktur.*2nd edition. Zurich: ETH, 1986 p 8-9

Structural systems which accept earthquake forces



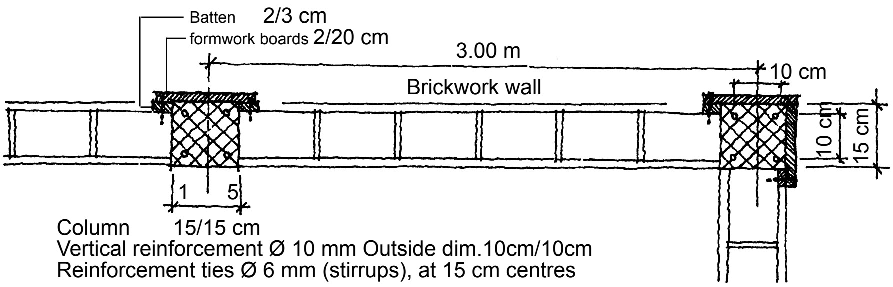
A wall best resists earthquake forces parallel to its length

To increase the stability of a wall which faces an overturning force



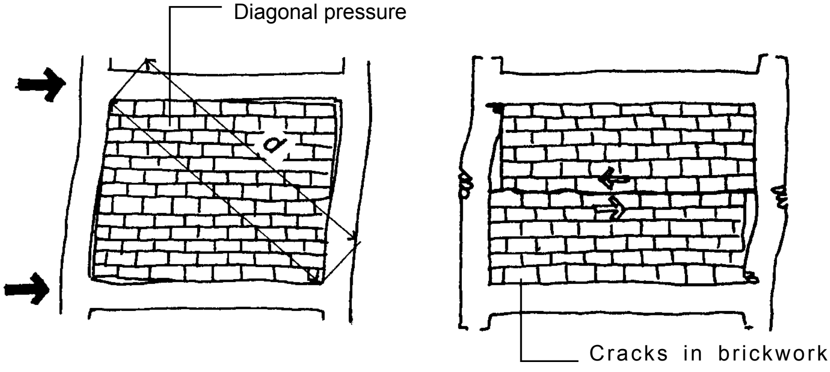
‘Massive’ structures are space enclosing systems, in which all walls of the building are loadbearing. They are usually built of brickwork, *batako* (trass-lime blocks), or concrete block.

In ‘massive’ and ‘sheer wall’ structures, loadbearing walls must be at least 23 cm thick (maximum height 3.50 m and length to cross wall 6.0 m), see above illustration. In Indonesia, single skin brickwork walls (about 11cm thick) are preferred, for economy of construction. To withstand earthquakes, these require strengthening with a concrete framework, usually a reinforced concrete ringbeam at floor-level (sloof), reinforced concrete columns in particular locations, and a ring beam at ceiling level. This is a hybrid structure, which includes both framework and massive masonary elements. With typical minimum member sizes as follows, (floor level ring beams 15 cm x 20 cm, columns 15cm x 15 cm) the structure must be detailed and built carefully if it is to withstand earthquake.

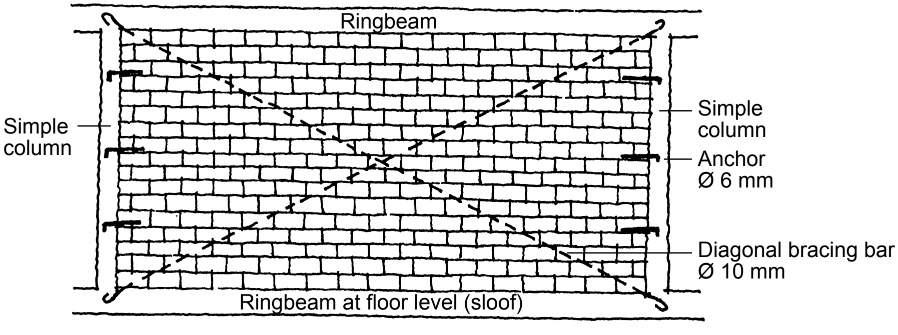


How to build 15cm/15cm simple r/c columns in 11 cm-brickwork walls (or concrete block). Simple columns are finished flush, with plastered or rendered internal and external finishes.

According to the Indonesian regulations for reinforced concrete, to withstand earthquake simple columns must be 15/15 cm minimum plan dimensions.



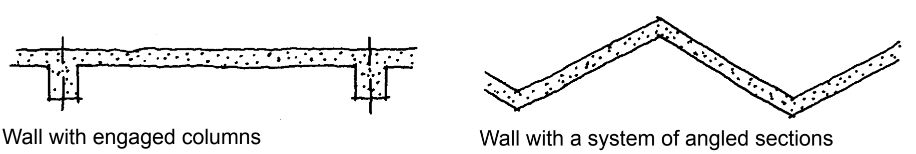
In an earthquake, brickwork walls may be forced to move resulting in diagonal cracks or (if the quality of brickwork is high) horizontal fractures.



System of diagonal cross bracing to stiffen a brick wall

Movement due to horizontal forces (earthquake, wind, etc.) can be prevented with a diagonal cross bracing system, using steel rods, 10 mm Ø min and at least 3 steel anchors, min Ø 6 mm, built into the practical columns.

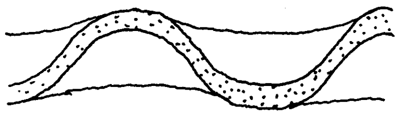
Vertical loads help to resist horizontal forces. The weight of a building contributes to the firmness of its foundations and generally serves to resist the tendency for elements to shake when subjected to horizontal force.



Wall with engaged columns

Wall with a system of angled sections

Wall with a system of parallel sections



Wavelike wall

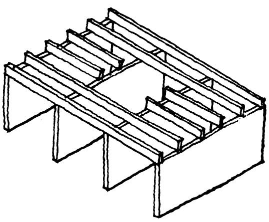
Wall stiffness can also be improved with non-linear shapes as illustrated above, without the need for reinforced concrete columns.

Shear wall structures

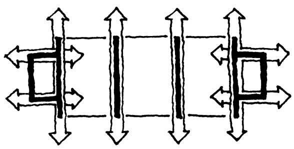
Shear wall structures *utilize* parallel loadbearing walls. They are usually made from brick, *bataco* (a javanese pressed brick), or concrete block.

Shear wall structures are very efficient, but are weaker in resisting horizontal forces perpendicular to the direction of the parallel shear walls. This can be seen in the following illustration.

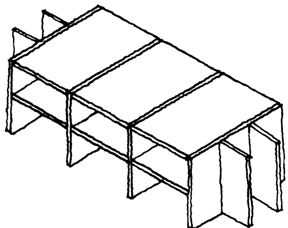
This problem can be avoided by using a portal-frame construction, integrated with the floor slab and roof construction.



Shear wall structural systems

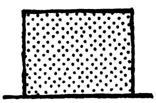


How horizontal forces (eg, earthquake) work.

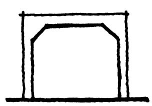


How shear wall structures resist horizontal forces

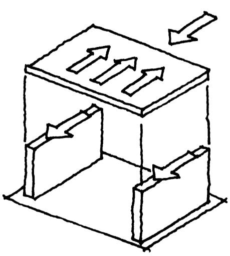
Structural systems that resist earthquake forces

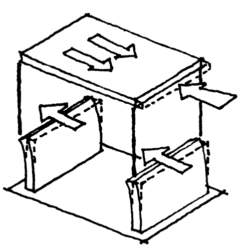


a wall can resist forces



portal frame construction





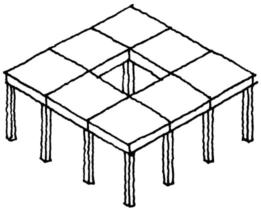
The stability of shear wall systems is not uniform, it differs according to the direction of the received force.

Framed structures

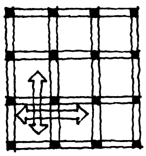
In framed structures *vertical* loads are carried by a regular pattern (grid) of columns. Framed structures are usually made from reinforced concrete, timber, or steel.

The frame provides both vertical and horizontal stability. Vertical loads are carried by horizontal beams and distributed to the column grid by connections to posts. Horizontal loads are redirected into both vertical and horizontal components via diagonal braces, or infilled wall plates. The main horizontal loadbearing beams should be braced on each structural grid in two directions by:

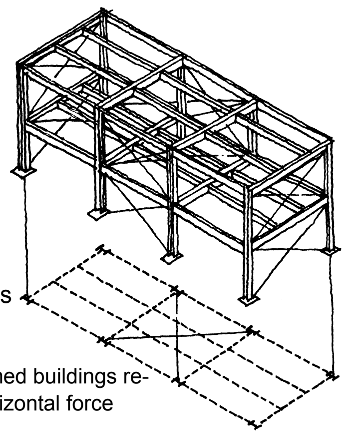
- diagonal braces or struts, in timber, concrete, or steel construction;
- plywood panels, layers of diagonal boards, or timber struts/timber construction;
- reinforced concrete portal frames with fixed connections to reinforced concrete footings.



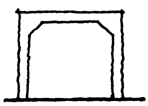
The basic form of a framed structure



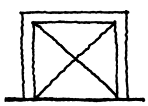
horizontal forces (eg. from earthquake)



Structural systems which accommodate earthquake forces



portal frame



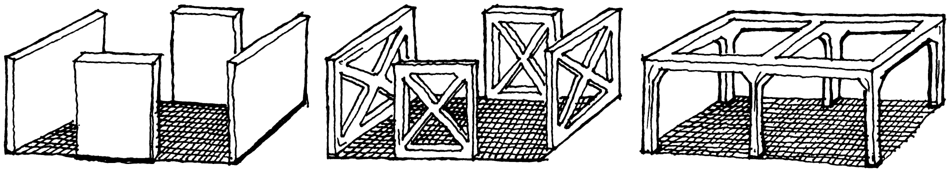
framed structure with diagonal brace as a main element

How framed buildings receive horizontal force

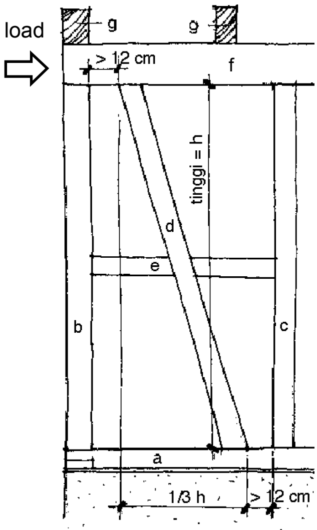
Stiff framed systems resist horizontal forces.

Horizontal stability can be achieved in floor slab construction (and also roof construction) with:

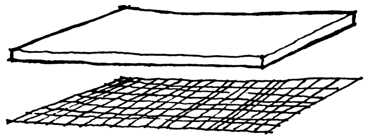
- diagonal braces in timber, concrete and steel;
- plywood flooring, and layers of diagonal boards in timber construction;
- reinforced concrete slabs in buildings with a reinforced concrete frame.



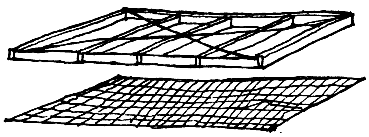
Vertical stability can be achieved *with* shear walls, framed walls, or framework structures with *bracing* in each structural axis.[11]



The placement of a strut to resist horizontal load in a typical timber wall frame:[12] a) floor plate; b) corner post; c) post; d) timber strut; e) rail; f) head beam; g) bearers or joists.



Horizontal stability can be achieved with a floor slab of reinforced concrete receiving and distributing horizontal forces.



Horizontal stability can be achieved by using timber *beams, bearers and joists* and plywood, diagonal boards or diagonal steel braces.

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11 drawing from: Arnold,Christopher/Reitherman,Robert. *Building configuration and seismic design.* New York: John Wiley & Sons, 1982 p.37

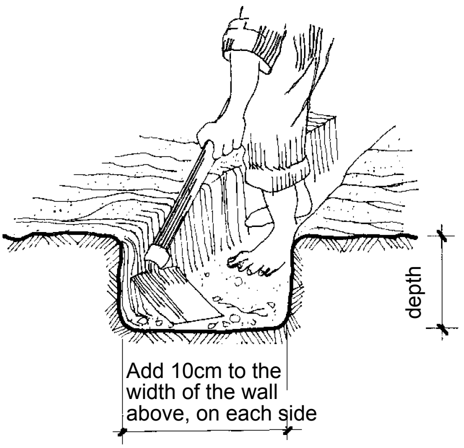
12 Frick, Heinz/Moediartianto. *Ilmu konstruksi bangunan kayu.* Yogyakarta: Kanisius, 2004 p.60

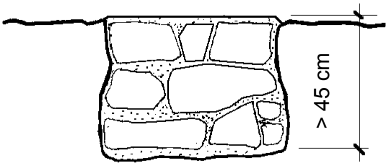
5. Earthquake resistant building practice

Foundations

Excavate to the required profile. For all buildings the excavation should reach at least the underlying hard layer of ground.

Please note. When the soil is hard enough to provide adequate bearing close to the surface, the excavation need not be deeper than 45cm.The excavation is then filled with rubble, concrete etc. as described later. In this way the overall mass of the building will be kept to a minimum.

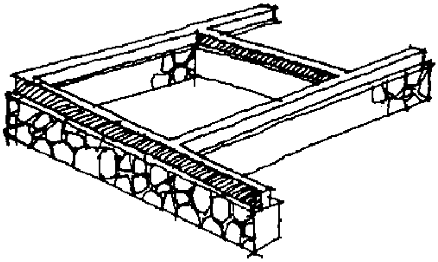




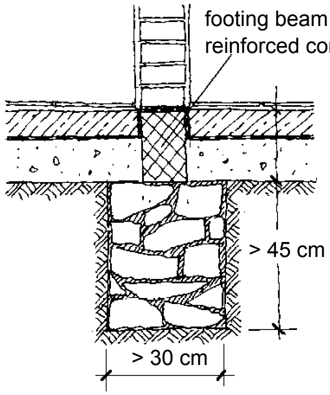
Cyclopean concrete foundations are made from river stones or *rubble*, well compacted in a slurry of concrete (min K125).The stones are to be placed evenly and regularly without cracks or holes, so as to prevent termite infestation. The minimum foundation width is equal to the thickness of the wall above plus 10 cm each side. The minimum height should be twice the width.[13]

13 Dancy, H.K. *A manual of building construction.*3rd edition. London:Intermediate technology, 1978. p. 64

Ring beams at floor level *(sloof)* distribute the building load evenly onto the foundation, at the same time tying the foundation together. A sloof could be constructed from timber, steel or reinforced concrete.



foundation from cyclopean concrete
with reinforced concrete footing beam



Ringbeam *(sloof)* **from reinforced concrete**. For a single storey residential building with simple columns spaced approximately 3 m apart, a reinforced concrete ring-beam should be built above the stone foundation. The width/depth of the ring-beam should be at least 15 cm x 20 cm.

A ring-beam can ensure the stability of a wall effected by an earthquake. A reinforced concrete ring-beam also acts as a tie between columns.

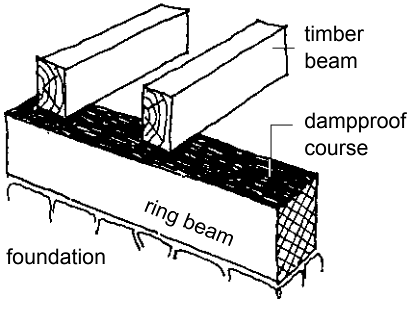
Dampcourses are horizontal waterproof layers preventing rising damp. Through hygroscopic action, rising damp can damage the structure of masonry walls in the long term, and impact on the health and comfort of occupants in the short term. If the damp-proof course is made of metal sheet, it can also function as a termite-proof barrier.

So that the damp-proof course can fulfill its function to prevent rising damp, care must be taken to ensure that almost all of the building materials used are hygroscopic, ie, allow the passage of damp. Hygroscopic materials receive and pass on moisture; ie, they absorb, store, and release water as a liquid or a gas.

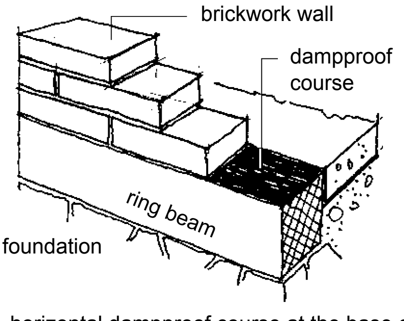
In the past (before 1950s) damp-proof courses consisted of several layers of bricks in a cement rich mortar, but this kind of damp-proof course isn’t effective. Based on the building materials which are commonly available, effective damp-proof courses can be made in the following ways:

-

  Layered asphalt (or roofing felt) can be used above a concrete ring-beam (allow the concrete ring-beam to dry for 14 days), or under a timber *floor* plate (on a flat cement surface layer over the stone filled foundation). The thickness of the asphalt layer should be approximately 2 mm (two or three painted layers of heated liquid asphalt, bitumen or an emulsion of latex rubber).
- Rubber damp-proof course. Rubber or PE *(polyethylene) sheets)* are cut the same width as the ring-beam and placed on the beam with joints overlapping at least 10 cm. Where there are anchors and column reinforcing steel, make holes in the rubber material matching the diameter of the steel bars. It is more difficult using PE pieces; if the holes are too big the damp proofing function is compromised
- Flat galvanized iron sheet damp proof-course. The sheets must be rustproof, ie. galvanized (minimum BWG 24). *Joints, and all holes for screws, anchors, etc must be soldered with care*. The sheets should extend 2 cm from the outer wall face and 5 cm down at an angle of 45°. Used in this way, the damp-proof course also acts as a termite barrier.
- Synthetic resin emulsion damp-proof courses are made from cement with synthetic additives (eg. cal-black) to make the damp-proof course crackproof and waterproof.



Floor beams and joists resting on the horizontal dampproof course

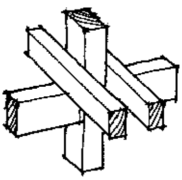
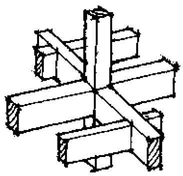
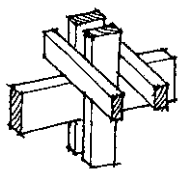
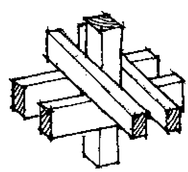


horizontal dampproof course at the base of a brickwork wall

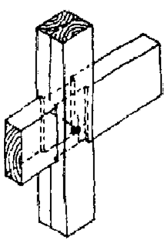
Except for the synthetic resin emulsion damp-proof course, anchors are required to tie the base of the wall and the footing beam together, because the dampproof course of asphalt, rubber, or galvanized iron sheets effectively separates them.

Post and beams

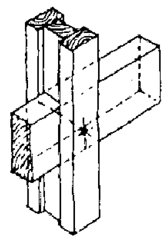
Timber post and beam structures are based on traditional craftsmanship, and can generally be classified as follows:

Through post continuous post	Through beam continuous beam	Paired post double post	Paired beam double beams & joists
			

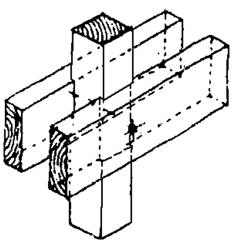
For earthquake resistant buildings, use a paired system, either double posts or double beams with joists on either side of the post.



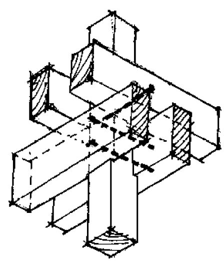
Paired, notched posts
With a continuous beam



Paired posts with filler piece
and continuous beam



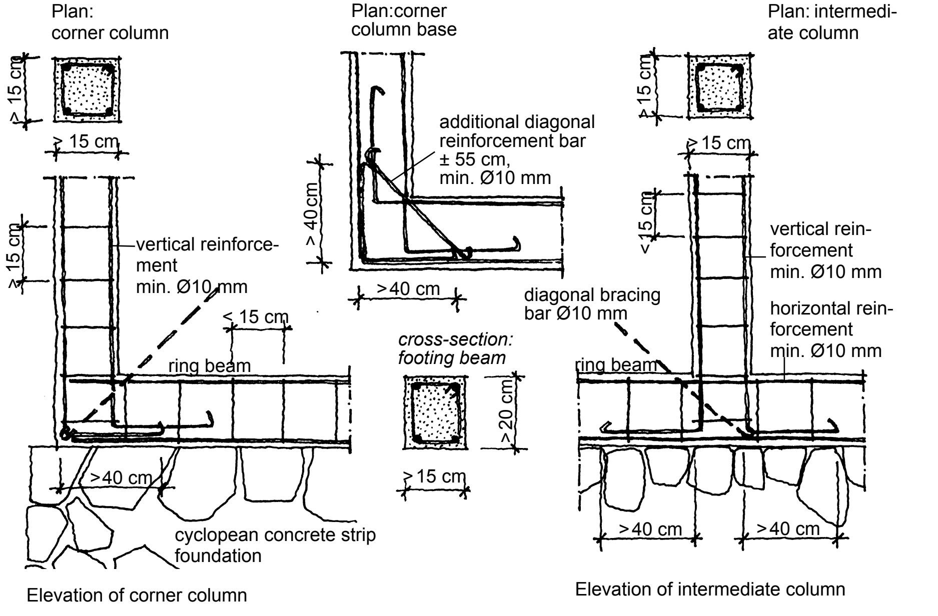
Continuous notched post with
double beams



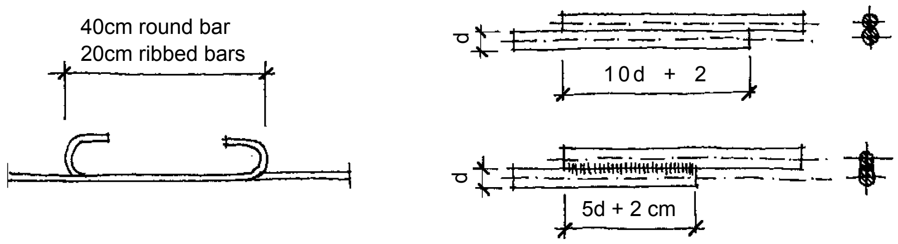
Continuous post with double beams
and joists with shank dowels

Paired (double) post timber post-framed structural systems are very elastic (ductile) and therefore very resistant to earthquake.

Post-frame construction in reinforced concrete is a fixed joint system - different from a timber frame which is elastic - it only has high resistance to earthquake if correctly detailed.



Because the length of steel reinforcing rod is limited, end to end connections can be made by overlapping hooked ends, or welded.



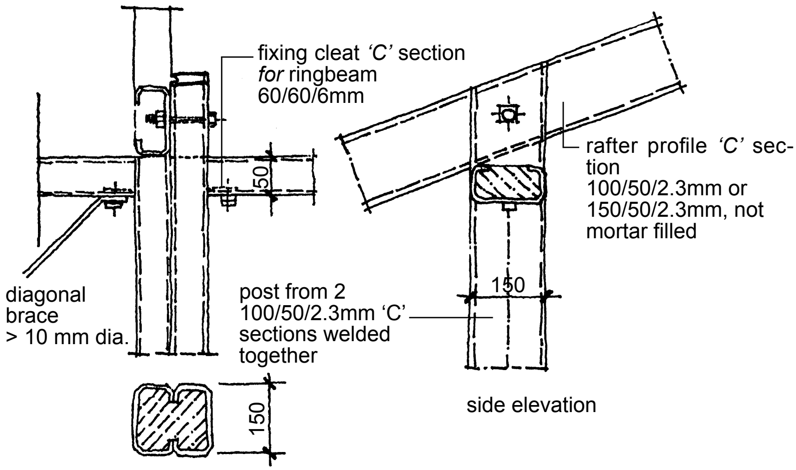
The usual connection for steel reinforcing bar is to provide overlaps, 20 cm on ribbed bars, > 40 cm on round steel bar.

For welded connections: welded one side *weld length* should be >10d + 2cm (12 cm on 10 mm Ø bars), welded two sides *weld length* should be >5d + 2cm (7 cm on 10 mm Ø bars)

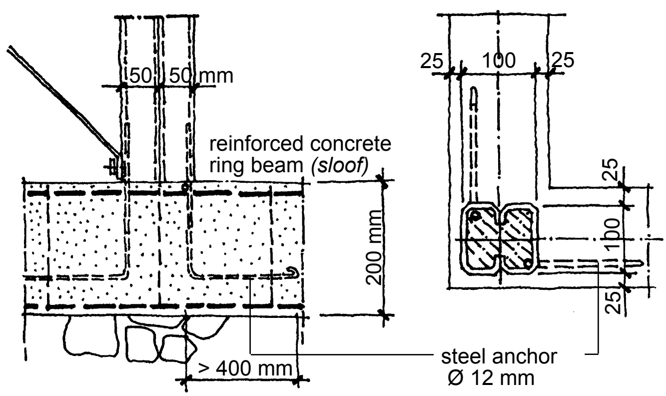
Steel framed systems using C sections

‘C’ section steel framed construction performs diferently to reinforced concrete framed construction in the face of fire. Without sufficient covering provided by concrete, steel is quickly heated and quickly collapses. To avoid this problem, the frame can be covered with fire resistant material, or if the shape of the section allows, filled with cement mortar. Because these sections are easily cut and joined (welded), rust problems are easily solved.

These systems combine the ‘stiffness’ of small extruded shapes, with the elacticity of braced post-framed structures and have considerable capacity to withstand earthquakes.



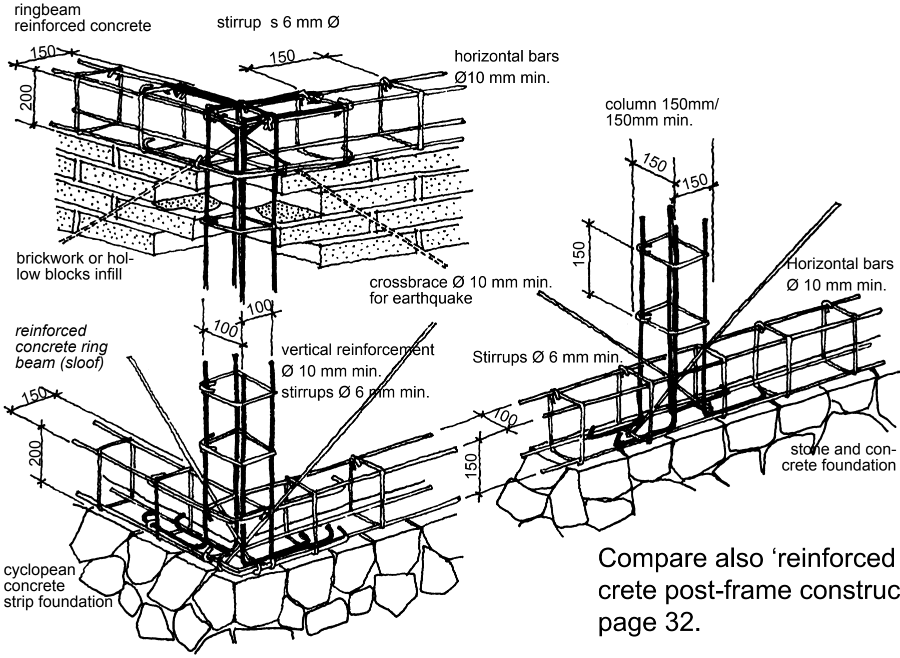
Cross Section : mortar filled post



Elevation of post

Plan: corner post

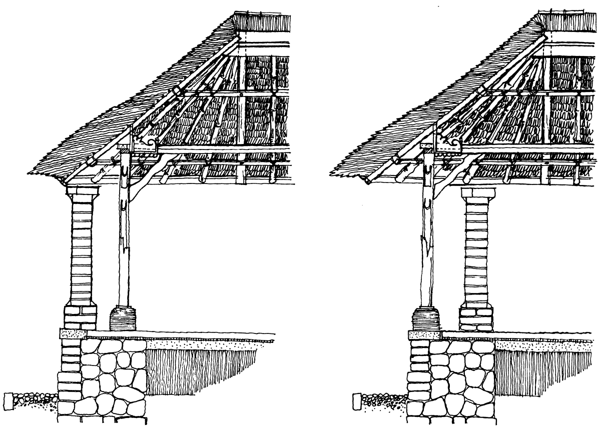
Shear walls, masonry with integral columns



Compare also ‘reinforced concrete post-frame construction’ page 32.

Loadbearing posts with separate, non loadbearing walls

Buildings can also make use of separate systems, walls to define spaces and provide privacy and security, and loadbearing elements which carry roof loads. Structurally this is a better solution compared to the most common Indonesian system which is a combination of ‘massive’ masonry and structural concrete framework.



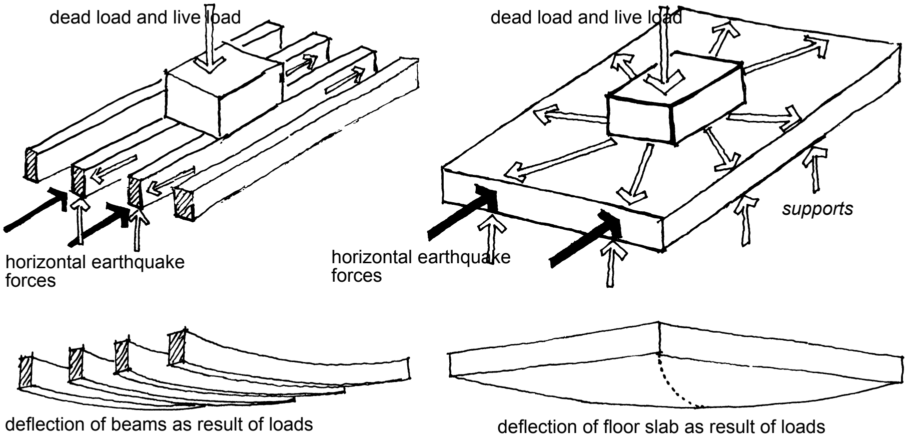
Note. Solutions with columns carrying roof loads, and walls defining spaces, are traditional and can still be seen, for example, in Bali. On the left the structure of a community building, on the right the construction of a sacred building

The advantages of this form are that the framed structure is relatively light and the walls that define spaces are not high (2.0 m high will provide enough privacy). There are no gable walls. In the event of an earthquake, collapse will be less dangerous.

Floor slabs (multistory buildings)

Floor slabs are horizontal space-dividing structures in a multistory building.[14] They have two functions, receiving and distributing loads and dividing space.

The nature of a buildings structure (the wall and column arrangement), its ability to resist horizontal forces (earthquake, wind) and its loadbearing capacity influences the choice of floor slab system.

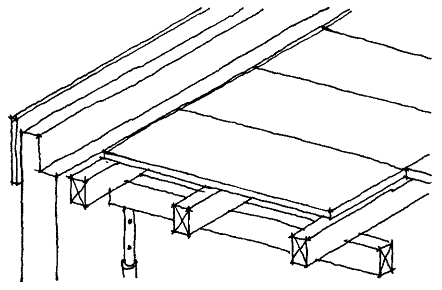


Loads (live and deadloads) that exceed the capacity of the floor structure can lead to deflection/buckling of beams. The structure may be unable to cope with additional horizontal loading, (eg; earthquake) leading to failure and collapse.

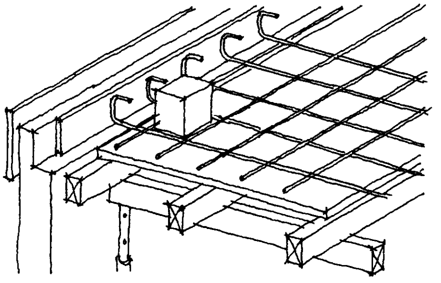
Horizontal concrete floor slab reinforcement can be either uni-directional (one way principal steel bars) or two-way (two way principal steel bars). The reinforcement must be designed to suit the direction from which the load will arrive. Earthquake resistant reinforced concrete floor slabs should be least 12 cm thick

14 Ronner, Heinz. *Kontext 74 – Decke.* 2nd edition. Zurich: ETH, 1986 p. 13-16, 33

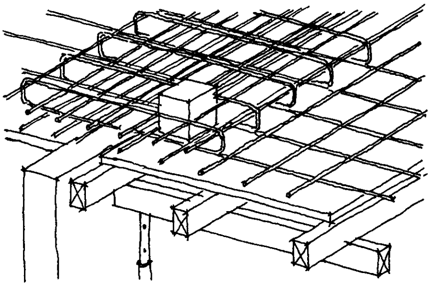
Reinforced concrete floor slab construction[15]



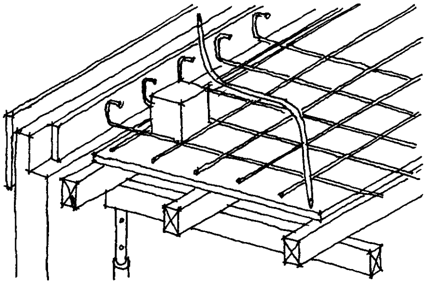
Formwork: timber beams and joists with plywood sheets



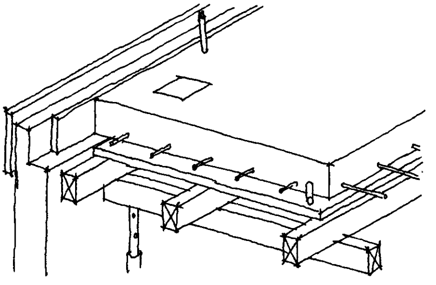
Place the principal steel reinforcement 2 cm above the formwork



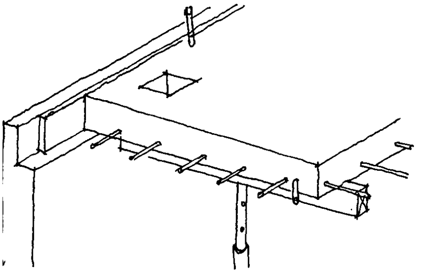
Support points with negative moment peak *need* additional top reinforcement in the floor slab.



Before the concrete is poured, all blockouts have to be placed including conduits/pipework.



The concrete slab should be poured in one go. The curing concrete needs to be kept moist for 2 weeks.



After 3 weeks the concrete formwork may be removed but the floor must be supported for 2 more weeks.

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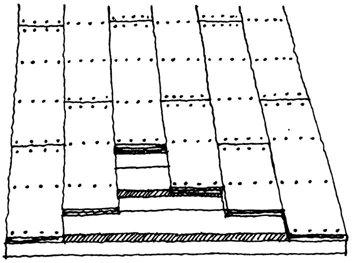
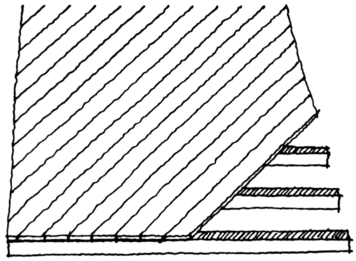
15 illustration of concrete floor slab construction based on: Ronner, H. *op.cit.* p.28-29; also regulation and treatment of reinforced concrete: NI-2. *Peraturan beton bertulang di Indonesia.* 5th edition. Bandung 1977; and Frick/Koesmartadi. *op.cit*. p. 100-107

Timber beams and joists with floorboards *are a lightweight form of construction. Lightweight floors are advantageous for elevated positions in a building, despite their poor sound-insulation characteristics.*

To increase earthquake resistance, use plywood >18 mm.thick min. or timber boards >20mm. thick, fixed on the diagonal. While still a simple loadbearing beam structure, functionally it becomes a slab which can resist and distribute horizontal forces. To span 3 m, use timber beams (hardwood) at 50 cm centres with the following dimensions. 40 mm/180 mm, 50 mm/160 mm, or 60 mm/150 mm .



Sub-floor made of plywood sheets



Sub-floor made of diagonal timber boards

Roof

Observations show that horizontal forces are larger in taller buildings and where the building's upper part is heavier; with lower centres of gravity buildings are more stable and more able to withstand earthquake.

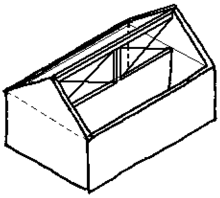
Lightweight roof construction can be designed to withstand normal external influences, such as temperature, weather, humidity, wind and earthquake loads, conflagration, and flying ash.

The main materials for lightweight roof construction are timber, bamboo, and steel sections; roof cladding materials include pantiles, interlocking clay tiles, shingles, galvanized corrugated metal sheet, and fibre cement tiles or corrugated sheet. The construction system and the cladding will influence the minimum roof pitch.

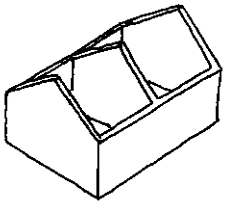
In this manual only timber framed and steel framed constructions for gabled roofs will be discussed.

A raftered timber roof construction is better because it has no supporting timber framework. Because it is light and simple, it is also economical.

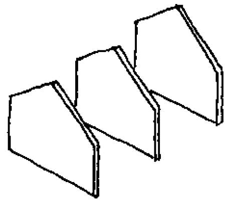
Gabled roofs can be used on ‘massive’ structures or ‘shear wall’ structures, with a ridge beam.



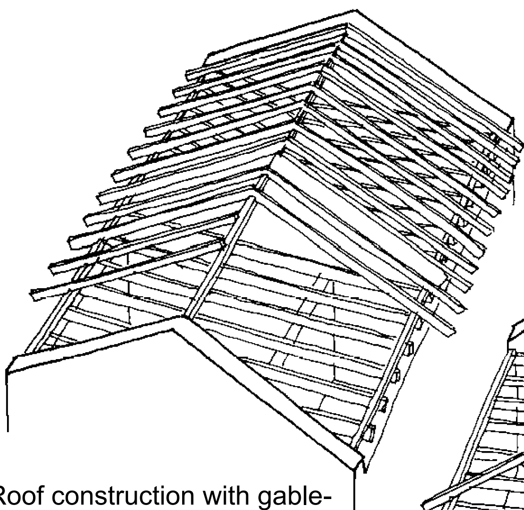
‘massive’ building structure, with a ridge wall and a framed ridge support



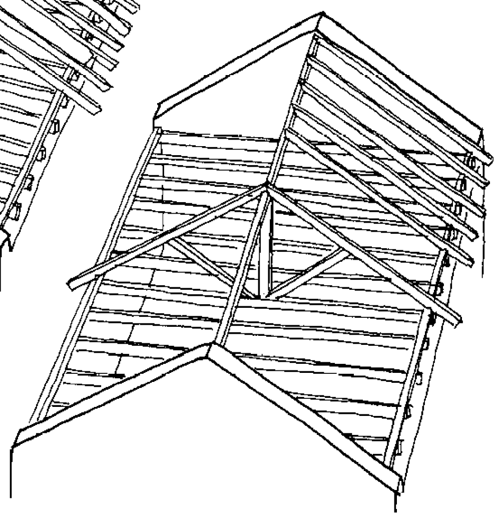
‘massive’ building structure with gables requires a ridge beam.



‘shear wall’ structure with gables requires a ridge beam



Roof construction with gable-wall, an economical timber roof structure

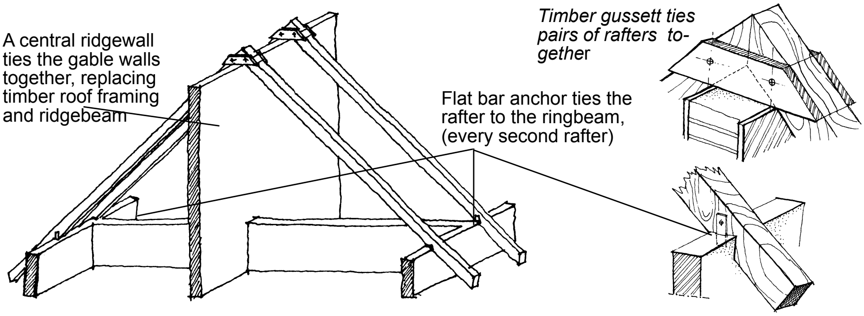


Typical timber roof construction

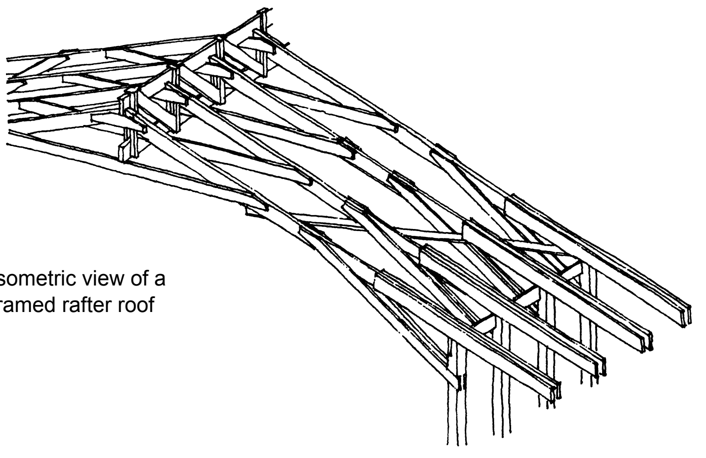
Timber dimensions for a gabled roof, spans 3.00 m are:[16]

- purlin 80mm/140 mm,
- rafter 40mm/120mm, spacing < 600 mm,
- battens 20 mm/30 mm (for light roof covering, not to be walked on), battens 30 mm/50 mm (for concrete tiles, for roof maintenance traffic to be walked on).

Raftered roof construction can be very simple (without purlins or strutting). The rafters bear directly on the reinforced-concrete ridgebeam, with a steel anchor fastening every second rafter. At the ridge, the ends of every pair of rafters are tied with a timber gussett (see illustration)



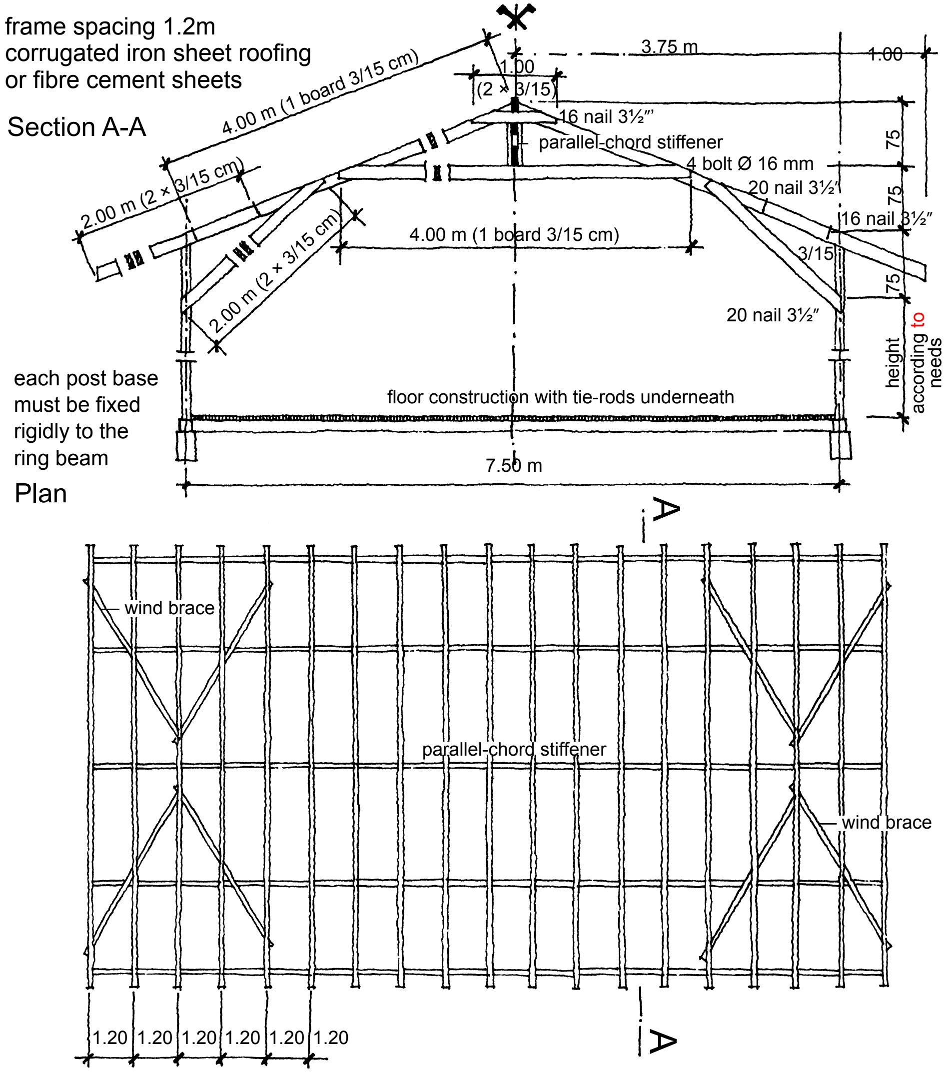
Another form of light timber framed rafter construction uses separate timber sections assembled into a structural frame. (see illustration below).



Isometric view of a framed rafter roof

16 see: Frick, Heinz/Moediartianto. *Ilmu konstruksi bangunan kayu.* Yogyakarta: Kanisius, 2004. p. 75, 94

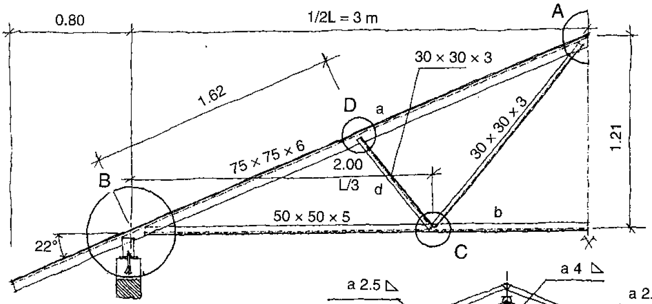
This framed raftered roof construction uses nailed and bolted timber sections. It is a light construction and can span up to 7.50 m. This construction suits meeting rooms, small industries, and warehouses. The posts must have fixed foundation supports. Facing pairs of posts must be joined with tie rods (e.g. round reinforcing bars ∅ 8 mm) to stabilize the single span two-winged frames.



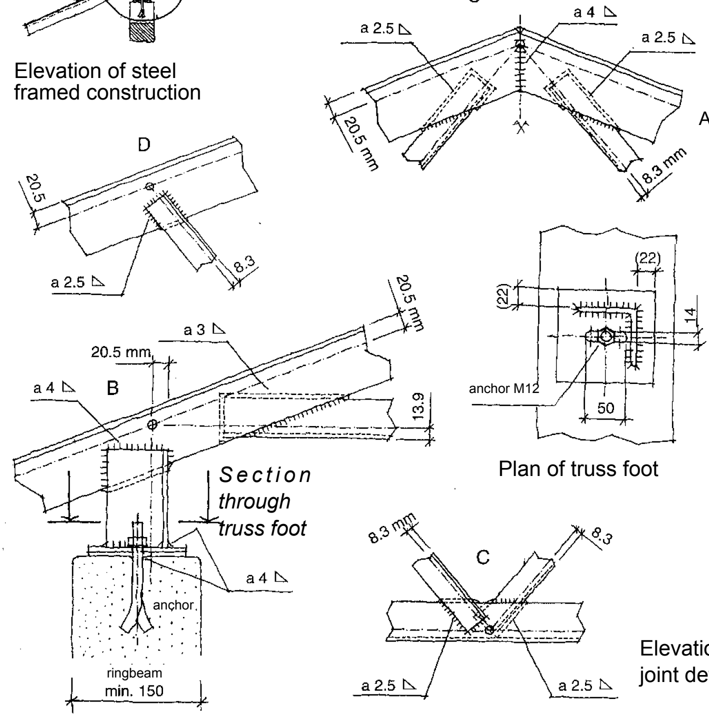
Plan of framed raftered roof above, using 30 mm x 150 mm timber,including location of wind braces

Steel frame construction is usually used when long timber beams are difficult to get or very expensive. Steel construction has the advantages of lightness and strength, enabling it to resist earthquake, but the disadvantage of not being fireproof. When exposed to fire untreated steel structures collapse quickly.

A simple steel roof construction, Polenceau bar frame spans 6.00 m, frame spacing 2.50 m. This roof has minimum slope of 19deg (e.g. for concrete tiles) up to a maximum of 30deg. (eg. for interlocking clay roofing tiles) with total weight 1.0 kN/m². [17]



Elevation of steel framed construction



Section through truss foot

Plan of truss foot

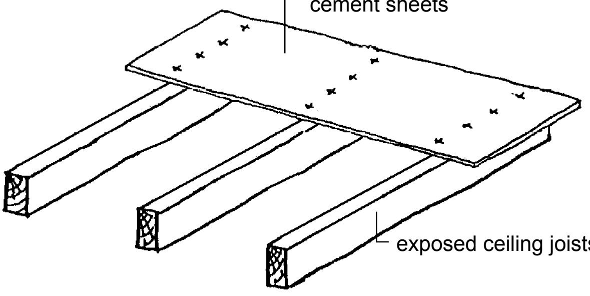
Elevation of steel truss joint detail A-D

17 SKAT (ed.), *Roof Truss Guide*. St.Gallen: SKAT, 1998 p. 67-68

Ceilings

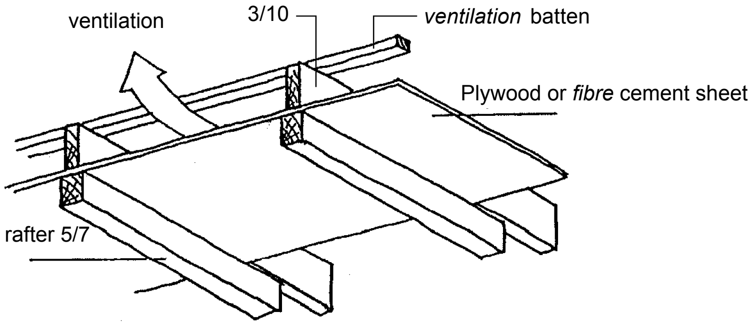
A ceiling is usually an esthetic improvement *(covering the timber roof construction)*, and the soffit of concrete slabs etc) or is required for technical reasons (fire prevention, acoustic performance, to cover electrical and mechanical installations). To withstand earthquakes the ceiling should be fixed on top of *its* supporting framework, to prevent roof tiles and any equipment in the ceiling space falling onto occupants of the space below.

Ceiling support structure. The ceiling is usually supported by 5cm x 7cm joists spaced to suit the ceiling sheet material. A more efficient method uses 3cm x 10 cm timber ceiling joists, at the same time tieing the rafters to the ring beam.



Ceiling support construction with exposed ceiling joists (also applicable for wavelike ceilings).

A ceiling can also function as an extra waterproof layer. The size of fibre cement or plywood ceiling sheets can be matched to the rafter spacing. The sheets can be horizontal, or fixed to the underside of the rafters. When fixed under the rafters, the uppermost sheets should overlap lower sheets; in plywood the upper side should be painted or waxed. When fixed to ceiling joists the ceiling sheets can be laid edge to edge or overlapping.On top of the rafters fix ventilation boards 30mm x 60 mm or 30mm x 100 mm (see illustration next page).



Ceiling construction on top of the rafters

Plywood can be used for ceilings and can be bent to match the ceiling-profile.

Thickness of plywood	Standard size length x width	Maximum size for ceilings width	length
6 mm	2440 × 1220 mm	600 mm	1220 mm
4 mm	2130 × 915 mm	600 mm	600 mm

Plywood is not waterproof, and should be painted or waxed, particularly where it might come into direct contact with moisture. Alternatively, use a waterproof sheet material under the roof-tiles, *on top of the plywood*.

Fibre **cement sheet** as a ceiling material is used in standard sizes of 1000 x 1000 mm or 1000 x 2000 mm. Ceiling construction should be adjusted to suit the sheet size. The maximum unsupported area of *fibre* cement sheet 5 to 6 mm in thickness, should not exceed 500mm x 1000mm.

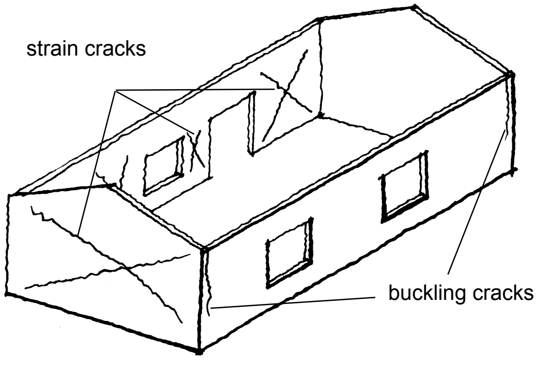
Woven bamboo *(gedeg)* in various sizes is still used as ceiling material in houses in rural areas and is a safe and strong material. Like the other ceiling sheets mentioned woven bamboo should be fixed on top of the ceiling support structure in order to prevent roof tiles falling onto occupants.

6. Renovation of houses damaged by earthquake

Earthquakes most frequently occur in developing countries, leaving many dead and major damage to simple houses. Up to 98 % of deaths are caused by the collapse of simple houses.

If we examine buildings damaged by earthquake we can observe the following:[18]

- Earthquake tremors cause strain in masonary walls, particularly at the intersections with end walls, where the turning moments are resisted. This strain leads to cracking, usually from the top to the bottom of the wall in line with the inner face of the end wall. No longer tied to the rest of the building, the end wall often collapses. This decreases the stability of the building as a whole, leading to collapse of the roof structure.
- Strain within the major walls is resolved around doors and windows,



with diagonal cracking starting from the corners of openings. If excessive movement is allowed, movement fractures occur.

Buildings which are damaged but still standing can be renovated and strengthened to withstand future earthquakes. This can be achieved as follows:

- To repair a damaged reinforced concrete column or reinforced ring beam, wrap with steel bar or flat bar reinforcement and cover with a special purpose mortar. If absent, ringbeams can be added; damaged ringbeams can be strengthened with an earthquake belt.

18 according to: Rosman, Riko. *op.cit*. p. 66-67

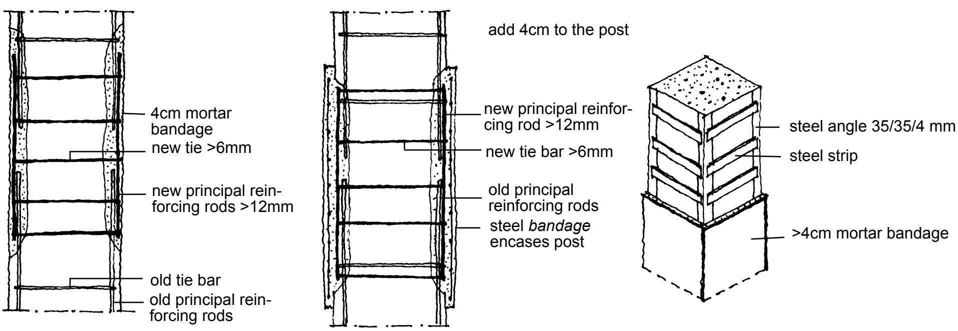
- To strengthen a damaged brickwork wall, remove the old plaster, tie steel reinforcing mesh to the face of the wall, 4 mm or 5 mm *dia*.min, 15cm x 15 cm. grid, then cement render 30 mm thick.
- To repair roof construction and gable walls, add windbraces to the roof structure, a reinforced concrete gable belt and a reinforced concrete seismic belt for the ringbeam.
- To strengthen foundations and *sloof*, separate the loadbearing structures from the space dividing walls (see figures p.34).

Reinforced columns and reinforced concrete ringbeams

Cracked columns weaken the structure of a building because air passes through the crack and (oxygen) eventually rusts the steel reinforcement. Cracked posts can be repaired as follows:

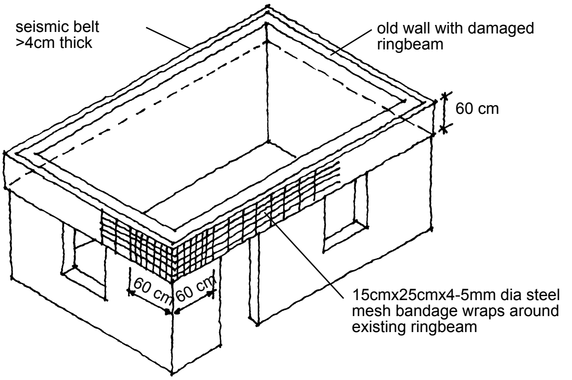
Cracks under 6 mm wide can be injected with special mortar (epoxy grouting mortar).

Wider cracks, and non-standard posts (eg: columns < 15 cm x 15 cm), with reinforcement damaged by torsion or movement, have to be chiseled open, damaged concrete and steel removed, new steel bars and concrete introduced, then wrapped with a ‘bandage’ of new steel rod or welded steel angles and strip, then rendered with special mortar.



Damage to ring beams mainly occurs when the reinforcement wasn’t well tied to the columns at the ends, or when reinforcing rod end to end connections were inadequate, leading to a stretch >40 cm.

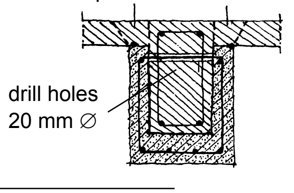
A seismic belt for a ringbeam consists of a steel reinforcing mesh bandage, 15 cm x 15 cm or 15 cm x 25 cm grid size, 4-5 mm dia.min, 60 cm wide, in cement mortar at least 4 cm thick. On the corners of the building, for a distance of 60 cm each side, the reinforcement is doubled. Cement mortar, (1 part cement, 3 parts sand) is applied, in three layers to avoid cracking or holes.[19]

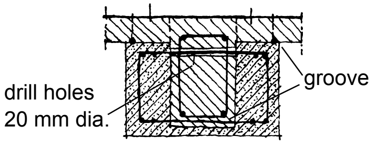


Buildings built before 1980 were often built without ringbeams. New ringbeams can be added to existing, strong walls, or the way the loads are distributed in the structure can be changed. (See foundations and ringbeams p. 48-50.)

Reinforced concrete beams

A damaged or weak beam can be repaired or strengthened by adding reinforcement and broadening its *cross section*. Dimensional changes are most effective if they include the height as well as the width. After suitable temporary propping, the damaged concrete and reinforcement must first be removed, new reinforcement tied in place, and new concrete placed from above through a trough made in the floor slab over.





19 drawing from: Earthquake hazard centre newsletter vol.1 no.2. *Seismic retrofitting*. Wellington, NZ, October 1997, p.6

New techniques use steel strips 40 mm - 80 mm wide and 3-5 mm. thick, glued with epoxy resin onto the bottom or the sides of reinforced concrete beams. This technique adds reinforcement to cope with 'shearing' forces, but is only for exposed concrete situations (without plastered or rendered finishes)

Brickwork walls

Damaged brickwork walls standing firmly can be repaired as follows:

– brickwork walls which include concrete stiffening columns, in which the brickwork is cracked but the columns are in good condition, can be repaired with diagonal bracing (see figures on p. 24). Remove the old plaster along the lines of the new bracing. Install diagonal braces in both directions (steel bars 5 mm dia, nailed to the wall, the ends tied into holes drilled into the joints between columns and ringbeams.) Rerender the wall 25mm thick.

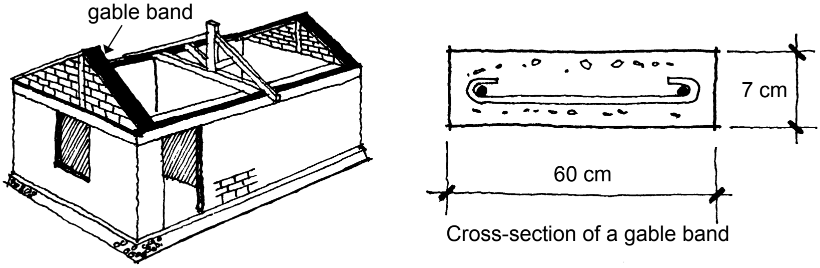
– a cracked brickwork wall without columns can be strengthened as follows: remove the old render and nail a steel reinforcing mesh (15 cm x 15 cm x 4.5 mm dia. min.) to the wall, one side only, then rerender min. 25 mm thick (see figures on p.23).

This is a complex and expensive procedure and should be compared to the technique which reuses the wall as a non-load bearing structure (see Foundations and footing beams (sloof) p. 48-50).

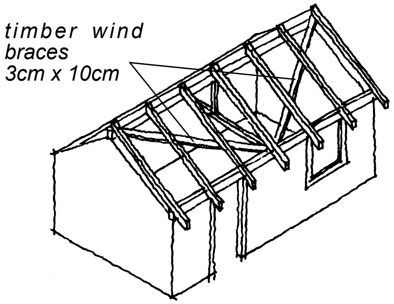
Roof construction and gable walls

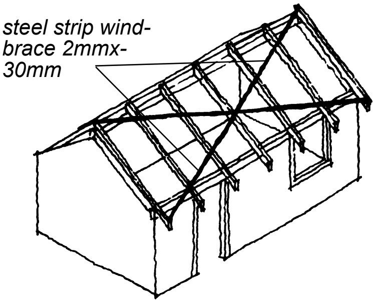
Shaking caused by earth tremors is magnified in the uppermost parts of a buildings structure. The tops of gable end walls are high above the ground and are usually damaged first. If the gable end collapses, the roof will follow, so the role of the gable end wall and its construction must be considered carefully.

- Gable walls with concrete stiffening columns can be strengthened by adding a gable 'band' (a broad reinforced concrete 'rafter' on top of the gable wall, following the line of the rafters, tied to the ringbeam on top of the longitudinal walls. A gable 'band' is usually only as thick as the rafters, allowing the battens to extend 60 cm past the gable end.[20]



- Elevated gable end walls are almost always damaged in an earthquake, so it is safer to remove the gable wall above the ring beam (if one exists) and rebuild with timber framed construction lined with boards, woven bamboo, plasterboard, or similar. Note. The roof framework must then be strengthened with wind braces. (timber or steel strips to brace the roof framework against wind and earthquake forces). Timber windbraces, min 3 cm x 10 cm, are nailed from underneath to each rafter, and run diagonally from highpoints on the ridge at the gable ends to lowpoints at the rafters ends. Alternatively, steel strip 2 mm x 30 mm can be nailed from above each rafter, crossing diagonally on each roof plane.





Foundations and footing beam (sloof)

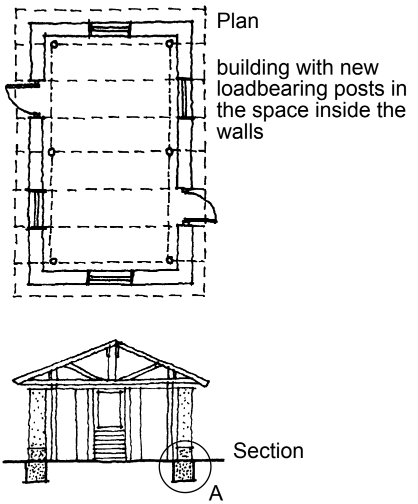
Repairs to damaged foundations are almost impossible, but are inevitable in some situations, eg, when the damaged building is part of our cul-

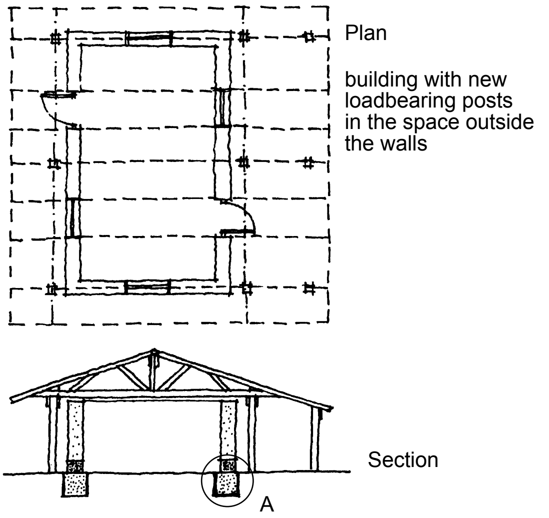
20 drawing from: Pratima Rani Bose. *Seismic protection of masonry buildings using rectangular masonry units laid in good mortar.* Included in Earthquake hazard centre newsletter vol.1 no.1 Wellington N.Z. July 1997, p.3

tural heritage. A minipile system can be used to strengthen foundations but because of the high cost and the necessity for engineering advice, this work is not explained further in this manual.

If a wall is standing, but is cracked and unable to carry any load, it can *possibly* be used as a non loadbearing wall. (see figures on p. 34). In this case, the foundation and footing beam are not strengthened, only repaired.

This technique allows the walls of old buildings to be used as space dividers only, without carrying any roof loads. Roof construction which is not damaged should firstly be taken apart. The dimensions of the old building and the condition of the old roof structure will determine whether the new loadbearing structure will be inside or outside of the old walls, as shown in the figures below.



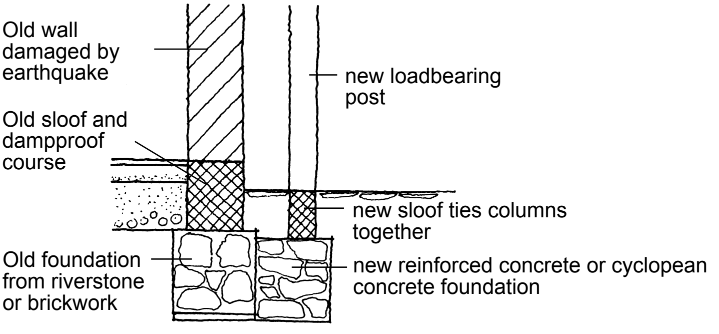


When preparing foundations for new structural posts, ensure that:

- The depth of the new foundation does not exceed the depth of the older, weaker foundations
- To avoid settlement between the old and new foundations, the new foundation should not have sand in the bottom of the excavation. Ie,

cyclopean concrete or reinforced concrete foundations should completely fill the excavation.

- A new footing beam should connect the foundations of all the new posts. Do not connect the new footing beam with the old one. The function of this new footing beam is to connect the bases of the new structural framework, so that during an earthquake the new structure will move as one.



Detail A, Foundation

7. What to do in the event of an earthquake[21]

Protection and security objectives addressing earthquake threat

Improvements in the earthquake resistance of buildings must be supported by education about appropriate and effective community and individual behaviour.

Indonesia is a region with a high potential for natural disasters such as earthquakes and volcanic eruptions. Wherever we live in Indonesia we live with disasters. However, while tied to disasters, we can use our knowledge to prevent and mitigate the risks.

Behaviour and social order

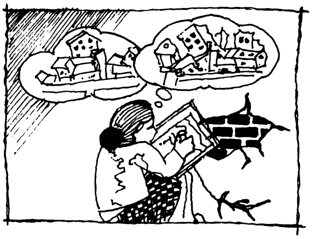
This chapter explains how individuals can protect themselves and their communities, remembering that the first moments after an earthquake are very important in reducing its impact. None the less, permanent large scale precautionary actions involving many parties are also required.

These activities can be divided into three stages; before, during and after the quake.

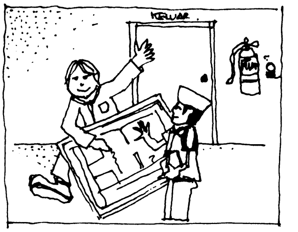
21 This chapter based on: Bachtiar, A. http://www.iagi.or.id, 20 June, 2006; and Yayasan IDEP (ed.), *Panduan umum penanggulangan bencana berbasis masyarakat.* part A: *Persiapan dan pencegahan.* Ubud: IDEP, n.d., p. A57-A59

Before an earthquake, take the following precautions.[22]

- Understand what an earthquake is and how it works.
- Make sure that the structure of your house and its setting best addresses the dangers – landslide, tsunami, etc. which might result from earthquake.
- Evaluate and maintain the buildings' structure to withstand earthquakes.

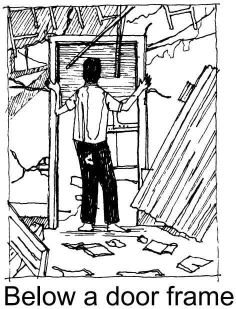


The main thing is to ensure the house and its surroundings are as safe from earthquake as possible



Know the area surrounding your home and workplace as well as possible

- Understand the environments where you live and work: take notice of the position of doors and emergency stairs, so when an earthquake happens you already know the safest places to go, how to leave the building and where to run for cover. If necessary, give each door frame the name of a member of your workgroup or family, so that everyone knows where to take cover when an earthquake happens.

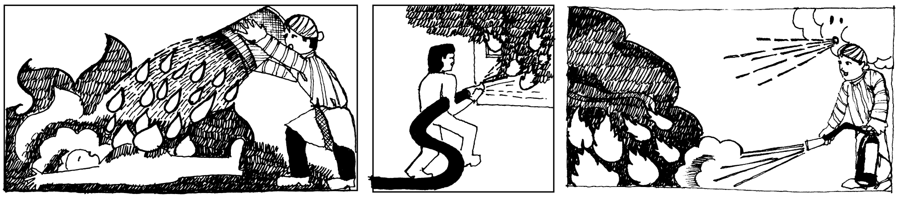


Below a door frame is the safest place inside the house for adults

Below a table is the safest place for children inside the house

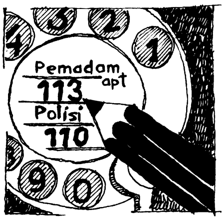
- Learn first aid.
- Learn how to use fire-fighting equipment.

22 Badan Meterologi & Geofisika. http://www.bmg.go.id/antisipasi.asp *Apa yang harus anda kerjakan sebelum, saat, dan sesudah terjadi gempa bumi*. 8 June 2006

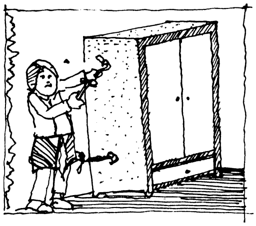


Use fire fighting equipment, buckets, hydrants, and fire extinguishers, to extinguish combustion completely.

- Take note of important telephone numbers to be called when an earthquake happens.

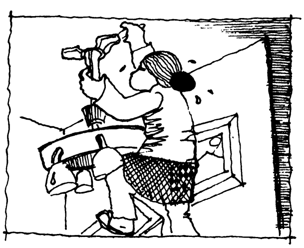


Take note of important telephone numbers

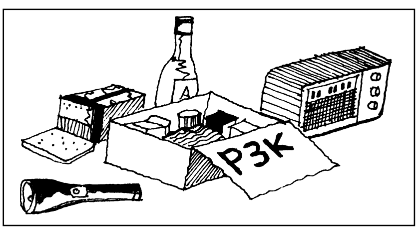


Tie heavy and tall furniture to the wall

- Consider the safety of furniture arrangements (wardrobes, cup-boards, etc.) and tie any tall furniture to the wall to prevent it moving, collapsing, or falling over.
- Move easily combustible materials to safer places to prevent the spread of fire
- Always turn off water, gas, and electricity when not in use.
- Where possible move heavier objects to lower positions.
- Regularly check any hanging objects, like lamps, fans, etc.



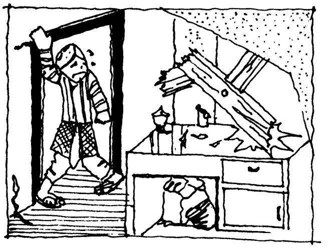
Check hanging objects



Prepare a first aid box and its contents

- Prepare a first aid box, flashlight, radio, and emergency provisions of food and water.

What to do during an earthquake:[23]



- If you are in a building, squat or lay down on the floor. Use door frames as shelter, also any other household equipment (beds, tables) strong enough to resist falling objects.
- Stay where you are taking cover and be ready to move. Wait until the tremors stop, then move.
- Stay away from glazed windows, fireplaces, stoves or other household equipment that can possibly fall. Stay inside to avoid broken glass or other building debris.
- At night, if you are in bed, do not run outside. Find a safe place under your bed or table that is strong enough, and wait until the tremors stop. Soon after it stops, check the members of your family and then find a save place.
- If you are in the middle of a crowd, find shelter. Stay calm and ask the others to be calm. If the situation is already safe, move to an open space, away from large trees or buildings. Be aware of the potential for aftershocks.
- If you are outside, find open space away from buildings, tall trees, and the electricity network. Stay away from cracks in the ground caused by earthquakes.

If you are outside, stay away from buildings, electricity poles, and trees

If you are in a car, get out and stay as far away from the car as possible

23 Yayasan IDEP (ed.), *op.cit.,* p. A57

- If you are driving a car, stop when it is safe, and stay inside the car. Stay away from bridges, flyovers, or tunnels. If possible move your car away from traffic. Do not stop close to tall trees, traffic lights, or electricity poles.
- If you are on a mountain, a hillside or canyon, lookout for falling rocks and landslides due to the earthquake.

In mountainous areas avoid landslides

Move away from beachside areas to avoid tsunami

- If you are on a beach, immediately go to higher ground or somewhere hundreds of meters from the beach. Large scale earthquakes can cause dangerous tsunami several minutes or even hours after an earthquake. If the waterline is seen to recede, like an exaggerated low tide, leave the beach area immediately and move to higher ground.

After an earthquake has occured, if you are inside a building, move outside in an orderly way. Don't use the emergency stairs or the lift, use the normal stairs. Furthemore, take note of the following;[24]

If you are inside a building, leave in an orderly way, useing the stairs if necessary

Check for fires, gas leaks, and electrical short circuits

- Carry out a safety check as follows: fire or potential fire, gas leakage; close the gas line if there is the smell of gas, and keep it closed until checked by a serviceman. Damage to electricity lines; switch

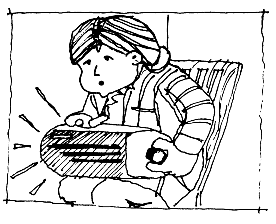
24 – Yayasan IDEP (ed.), op.sit. p. A59

off the meter, take note of any short circuits or damage to electricity cables; stay away from damaged cables even if the meter is already switched off. Check the telephone to ensure its location.

- Check yourself for injury. After helping yourself, help other people injured or trapped. Call for assistance first, and then provide first aid if possible. Do not ever try to move those with serious injuries because it can make their injuries worse.
- Protect yourself from indirect danger by wearing trousers, long sleeved shirts, strong shoes, and gloves if possible. These will protect you from injury due to broken and sharp objects.
- Help neighbors who need help. Old and handicapped people may need more help. Those with large families may also need help in an emergency.
- Clean up, and remove potentially dangerous material, including spilt drugs. Be aware of aftershocks. Most aftershocks are weaker than the initial earthquake, however they can be dangerous to buildings already weakened by the first earthquake. Stay away from buildings. Return to your house only if the authorities have advised that it is safe to do so.

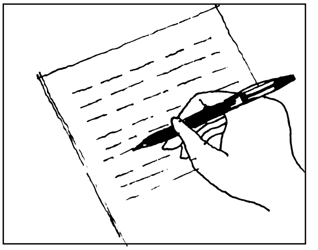
Do not enter a building after an earthquake in case of further damage from aftershocks.

- Use flashlights for lighting, not matches, candles, gas stoves, pressure lanterns or anything else which uses a naked flame.
- Stay off the home telephone. Use home telephones only in an emergency.



Listen to information from a battery-operated radio and tv

Keep the streets free for emergency vehicles



Turn on the radio to get information about damage, or volunteers' needs.

Give way to emergency vehicles.

After an earthquake, many organisations will come to the area to provide help. Accurate supporting data is needed in disaster areas. If you are asked to fill in questionnaires, give answers as honestly as possible, so that the level of damage in your area can be well recorded.

Socialization of the process.

It is essential that continuous efforts in anticipation of these disasters are socialized as soon as possible, and involve all areas of society. Formal school curriculums should include first aid and evacuation training; neighborhoods, villages, government institutions, NGO's, private sectors (including mass media) should develop strategic response capabilities and communication pathways so that these practical efforts can become responsibilities to be passed on and remembered, from generation to generation.

8. Appendix

Glossary

AC	1) abbreviation for 'air conditioning'
	2) abbreviation for 'alternating current', an electric current that reverses its direction 50 times a second at regular intervals
amplitude	the maximum extent of a vibration or oscillation measured from the position of equilibrium
batako	unburnt blocks made from trass and lime by a ram block press
conblock	unburnt hollow block made from Portland cement and sand by a ram block press
cyclopean concrete	foundation construction made of 60% concrete (1 part Portland cement : 3 part sand : 5 part gravel) and 40% rubble stones Ø < 15 cm
gable	the part of a wall (triangle shaped) that encloses the end of a gabled roof
isoseismal lines	lines on a map connecting places where an earthquake was experienced with equal strength
kolom praktis	vertical reinforced concrete column 15 x 15 cm, which is placed in between a reinforced concrete ringbeam at floor level and a ring beam at ceiling level to withstand earthquakes. The maximum spacing is 3.0 m
kuda penopang	a diagonal strengthening timber beam used in carpentry the pitch should be maximum 70° in order to distribute horizontal forces (wind or quakes)
magnitude	the quantity of strength of an earthquake (M)
massive building structure	space forming structure by which all walls are loadbearing
MMI	Modified Mercalli Intensity scale determines the quantity of strength of an earthquake in consideration to the caused building damages
P3K	(pertolongan pertama pada kecelakaan) first aid box
purlin	(peran, gording) a horizontal beam along the length of a roof, resting on a main rafter and supporting the common rafters or boards
radioactive material	emitting or relating to the emission of ionizing radia-

tion or particles in alpha, beta, or gamma rays according their radioactive decay. Radioactive material causes cancer

raftered roof — a double-pitched triangulated light and simple roof framework without purlins and posts or strutting where each pair of rafters together with a roof joist form a stable triangle

resonance — the condition in which an object or system is subjected to an oscillating force having a frequency close to its own natural frequency

ring beam — (ring balok) a reinforced concrete beam or squared timber head beam on top of the wall on each storey and below the roof framework in order to distribute the forces uniformly to the load baring structure below

seismograph — an instrument that measures and records details of earthquakes, such as force and duration

sesar — fault or faulting system, an extended break in a body of rock, marked by the relative displacement and discontinuity of strata on either side of a particular surface

settlement — subsidence of the ground or a structure built on it

shaft — a long narrow typically vertical hole that accommodates utilities, installations, and elevators in a building or provide ventilation

shear wall building structure — space forming structure by which only parallel or radial shear walls are loadbearing and all other walls are only space partitioning

skeleton building structure — a grid of loadearing columns determines the building structure. All needed walls are non-loadbearing partition walls or curtain walls

sloof — footing beam made in form of a reinforced concrete beam or squared wall plate between strip or pad foundations and the wall construction which distributes the building load uniformly to the foundation

stability — the state of being stable

structure — the arrangement of loadbearing parts and the relation between loadbearing and non-loadbearing parts regardless whether this building structure is visible or not

struktur gedung — (building structure) is the primary structure of loadbearing members of a building, such as foundation, walls, columns, floor slabs, and roof structures

tectonic plates — form the outer crust of earth, which is still in motion. Their thick-

	ness is 50-250 km
trasraam	(dampproofing course) a horizontal waterproof layer preventing raising damp which can damage the structure of walls in the long term, and impact on the health and comfort of occupants in the short term
tsunami	a long high sea wave caused by an earthquake, submarine landslide, or other disturbance
wind braces	timber boards nailed from underneath to each rafter, running diagonally from highpoints on the ridge at the gable ends to lowpoints at the rafter’s ends, or steel stripes, which are nailed from above each rafter, crossing diagonally on each roof plane

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