



Handbook on Good Building Design and Construction Central Jawa

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June 2006

Purpose of the Handbook

This Handbook is made to provide simple information to house owners, to house designers and builders, and building monitors to teach principles of good design and good construction in a natural hazard prone area. Thoroughly studied, they will also guide on whether to repair or rebuild damaged houses. The descriptions are followed by a code of minimum standards for construction of houses in Central Jawa.

After the detailing of a facet of good design or construction, since many concepts are not easy to describe, the Handbook contains pictures to facilitate understanding. The photographs mainly have been taken of construction practices in Yogyakarta and Jawa Tengah in places affected by the earthquake of 27 May 2006. Areas in Central Jawa are earthquake and volcano prone, and are also subject to flooding due to sudden downpours of rain. The principles of this book are designed to minimize vulnerability to these natural hazards.

In an area that is prone to earthquakes, not only principles of design are important, but also principles of construction, since the best designed house, which has been well covered and painted, may hide serious structural defects in the construction. These defects may lead to serious injury and death, and loss of property when the forces of nature strike the house.

Let us develop a culture of safety in all our buildings, not just doing the minimum and the cheapest, but building houses that will safeguard families and assets in times of emergency.

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Please also refer to Pedoman Teknis, Rumah dan Bangunan Gedung Tahan Gempa, Departemen Pekerjaan Umum, June 2006

Design Principles

1. Foundations

- The ground under the building has to bear the weight of a house. If it is a weak soil, the foundations must be made stronger. If the house has more than one floor the foundation must also be made stronger. Foundations are best when continuous under the house.
- Is the building built on sand, rock, clay?
- Soil for a good foundation that can carry the weight of a house must be well drained so that it is dry and not waterlogged.



Example of bad foundations. The houses are being built in a swampy, flood prone area. Soon after they were built the houses were flooded when there was heavy rain and water entered the houses. These foundations in permanently wet soil will also be weak when an earthquake shakes the ground.

Design Principles



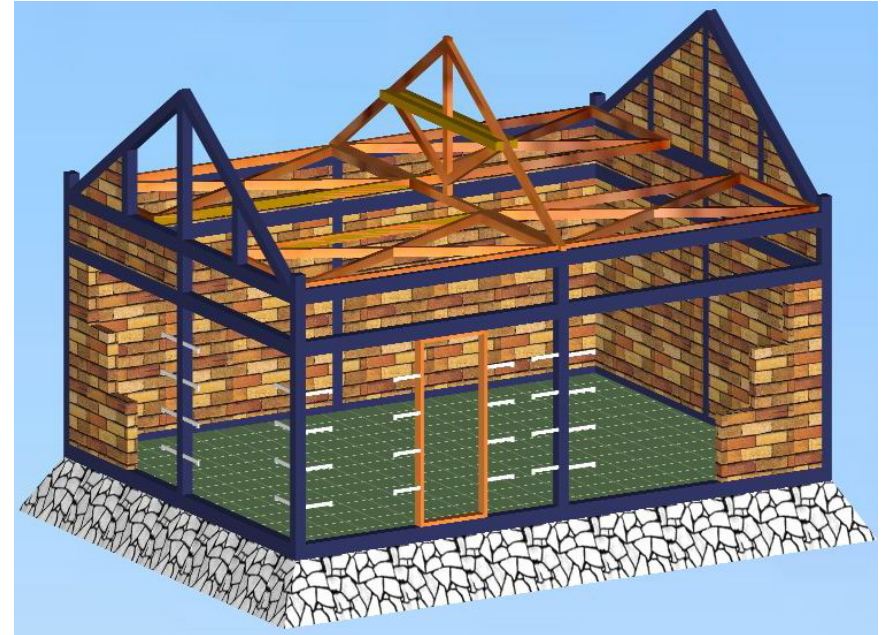
Example of a building with no solid foundation under its columns, and no connection between columns and foundation. The columns were placed on the ground and bricked around, which gave some support for the vertical load, but there was no foundation underneath them, and when they overturned due to a lateral load from an earthquake, the building collapsed. The columns needed to be strongly connected to an adequate foundation.

2. The building needs a coherent structure

- A regular structure
- An integrated structural ring beam around tops of doors and windows connected to columns
- An integrated structural ring beam around top of walls connected to columns
- **Triangular gable end walls must be structurally supported**



This regularly structured building was surrounded by many buildings which collapsed and were totally destroyed by the earthquake due to the proximity of an active fault. Notice the structure of columns and floors which are all joined to each other in a regular format. Overhanging parts of the building are all well supported by columns. This building survived without structural weakness.



This illustrates good structural design principles for a reinforced concrete structure and brick wall building. A complete structural frame around the building is tied in to the foundation, the walls and the roof structure. Doors and windows have a beam over them to carry the weight of the wall above and to strengthen the columns. The top of the walls is also tied together with the columns, by a second reinforced concrete ring beam, and end walls are strengthened.



Good Structure. This is a well structured house that follows the above design principles. The houses on both sides of it collapsed. Notice the good regular structure framing the building, and that the structure on both floors is the same.



This is an example of bad practice. The columns are very poor, made in many stages with gaps in concrete in between so that the reinforcing will rust. The columns are also too small because the bricks were laid first, the columns were made to fit within the thickness of a brick, and there was not enough room for properly covering the column reinforcement. There is no ring beam over the window, which has a wooden frame that has been placed in the wall after most of the window opening was made, making it very weak to a lateral force from a hazard impact. If the wood of the window frame deteriorates, the wall will begin to crack and then may collapse.



An example of a well built but poorly structured house. In an earthquake, despite the fact that this is a new building, the walls have already begun to crack diagonally from the corners of doors and windows, and a crack can be seen close to the corner of the house, going from top to bottom. This building has no real structure to resist lateral forces on the walls, and no ring beam above doors and windows and at the top of the walls to tie the house together.



Not good structure. Another example of a reasonably designed house which has too little attention given to a structure to brace the walls against lateral forces. There is no structure holding the walls together. No strengthening is provided around openings in the walls, and they cracked when the forces of nature struck it. There will be progressive deterioration which will be hard to repair. There is also no ring beam along the top of the walls to prevent them from moving apart in an earthquake, and the tile roof falling in.

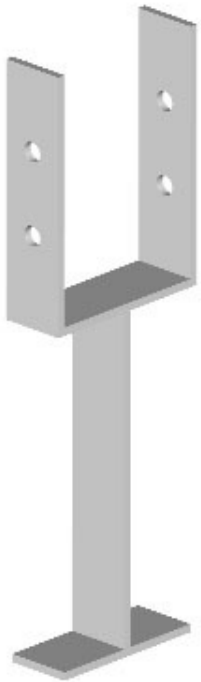


Good practice. Reinforced concrete column inserted to strengthen the triangular gable end wall so that it will not fall when a lateral force strikes the building. The reinforcing steel must be cast into the concrete ring beam at the top of the walls. All end walls of this nature need reinforcement to strengthen them, or they are liable to fall when the building is subjected to a major lateral force.



All external features need to be adequately supported and tied into the main structure. The lack of cross bracing and the lack of ties between this awning and the main house has led to failure of all the columns and serious potential to collapse.

Connection of wood frame building to concrete frame/brick stub walls.

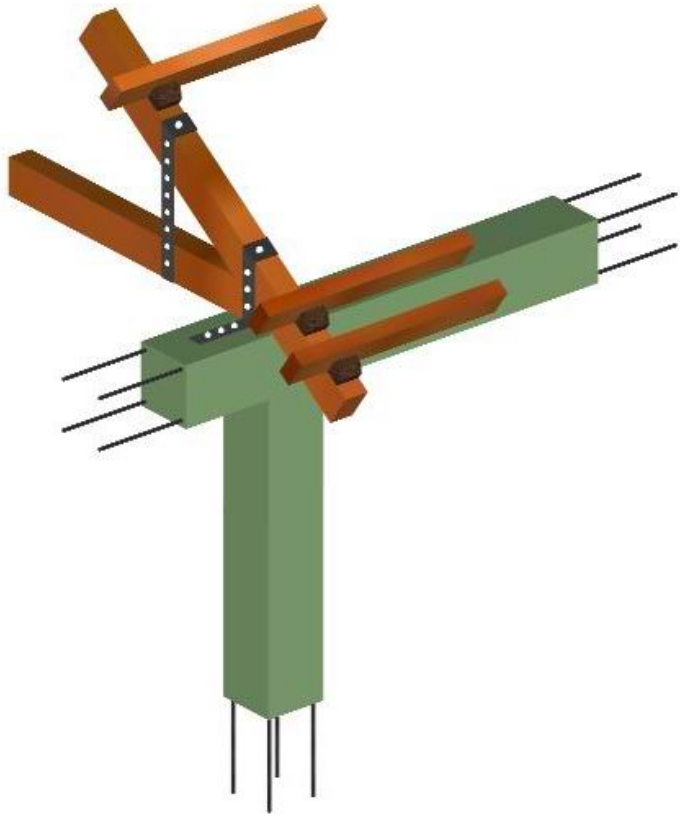


It is essential that a wood frame structure building, or a wood frame mounted on a concrete frame/brick stub wall must be fully anchored together. A bracket, as shown above left, made of non-corrodable metal, must be cast into the bearing structure or foundation to provide a structural connection for the whole wall through to the foundation. Each wood column must be bolted to the bracket as shown, and the bracket must be fully secured into the concrete as shown on the right.

Design Principles

3. Joining walls to roof structure

- **Column reinforcement should protrude from the top of concrete columns and be bent around roof trusses for structural strength, or roof trusses should be strapped with metal ties to the wall structure.**



An illustration of binding roof trusses to building structure. Roof trusses should be constructed over columns, and for a concrete column the reinforcement should protrude at the top and be bent over roof trusses to join the roof structure with the wall structure. Metal straps can be used for this role, particularly where the building structure is made of wood.



An example of column steel reinforcement bent over roof truss to tie house structure to the roof structure. This is an essential detail in areas subject to earthquake and to winds, to maintain house integrity when a natural hazard strikes the structure. The ring beam at the top of the wall has not yet been constructed on this house.

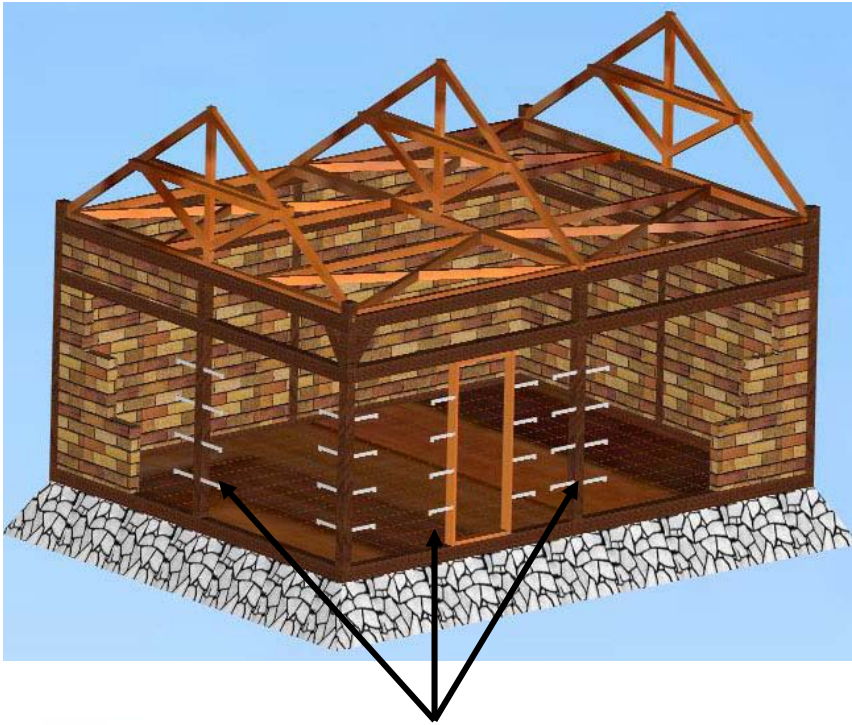
Design principles



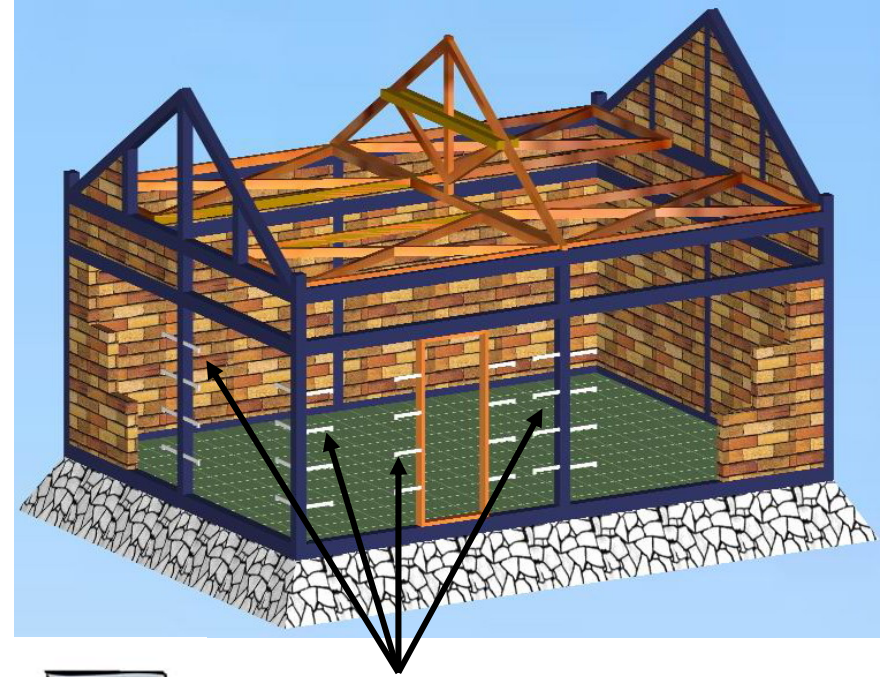
Example of incorrect practice. The roof structure is good, but no connection is made between roof trusses and the building structure. The roof is just standing on the top of the house walls and is subject to moving with high winds or other forces of nature.

4. Tying walls to building structure

- Walls must be tied into the building structure so that they do not move separately when the forces of nature impact them.
- Wall ties should be hooked into the wall structure.
- Stairs should be adequately supported.



Good practice. An illustration of a wood frame brick wall building, where metal ties are used to tie brick walls to the main wooden structure of the building. Steel wall ties are to be at 40cm spacing, and a minimum of 10mm diameter.



Good practice. An illustration for a reinforced concrete frame and brick wall building, where metal ties are used to tie walls to the main building structure. Steel wall ties are to be at 40cm spacing and a minimum of 8mm diameter, and bent at the end. They are for all openings in the walls.



A good example of wall ties cast into columns to connect the walls with the building structure. Ties are at 40cm spacing from bottom to top of the wall. However, in this illustration they lack hooks at the ends at this point in construction.



Result of no ties. This is an example of what happens when walls are not tied to columns, and also where there are no structural ring beams tying the structure together. The wall has separated and moved independently from the wall on the right, and has suffered multiple fractures due to no strengthening with ring beams.



Result of lack of ties. Another example of what happens when the walls are not tied to the columns. The wall panel on the left is moving away from the column because it has not been tied into the column.



Stairs need to be properly supported and tied to the house structure at an intermediate landing or when there is a change of direction. When this is not done, they may fail, as in this picture.

Design Principles

5. Roof Truss ties

- The joints of roof trusses need to be bolted together and tied with metal straps to provide flexibility but not collapse under the forces of nature.



This illustration shows the metal straps tying together the different elements of the roof structure at this joint in roofing, so that they will be held together when affected by extreme forces of nature.

Design principles



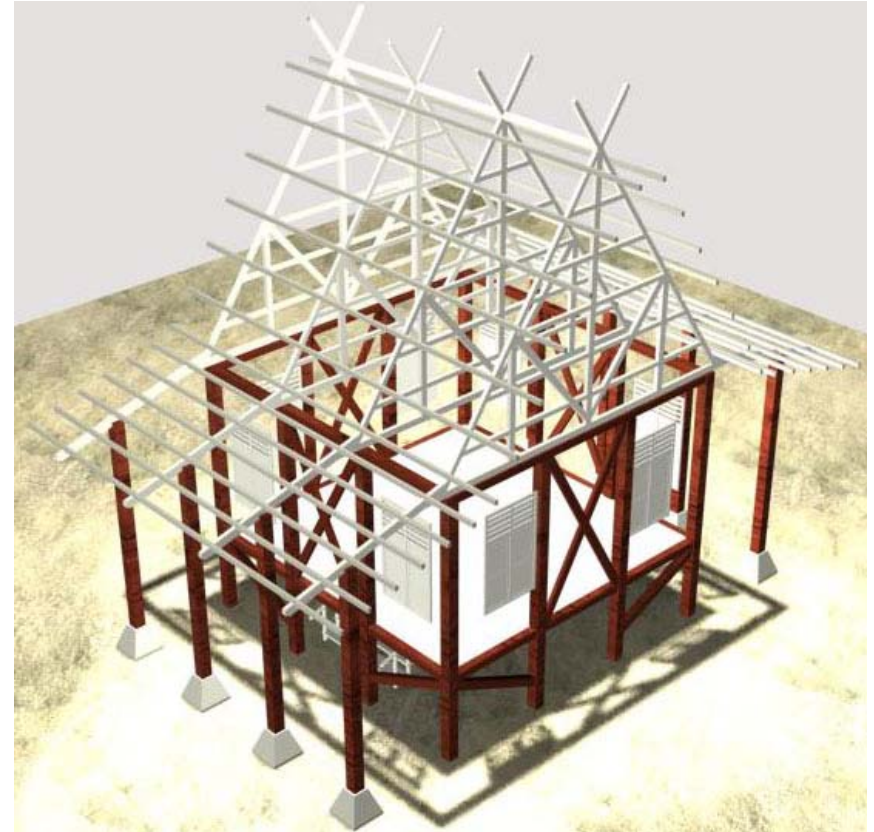
This illustration shows a strap across the joint at the apex of the roof structure. This is always good practice. Notice also that for a wooden roof structure, wooden blocks should be used for support, not a single nail and not a nail into the wood.

6. Cross bracing of walls and roof.

- In order to resist lateral forces, walls and roof structure need cross bracing at all levels, particularly if it is a wooden structure.
- The larger the span of the roof, the more bracing is needed, particularly if the roofing is made of heavy clay tiles.
- This is a major principle in the construction of traditional houses.



Good roof cross bracing practice. Notice the cross bracing across the center of this roof structure, which has held the roof intact even when the rest of the building was seriously damaged. For a roof of this size there should have been more cross braces for greater safety.



Example of a cross bracing system for the walls and also for the columns under the house for a wooden house structure. The cross bracing system provides strength against lateral forces so that the building does not collapse sideways but is held together.

7. Drainage Principles

- A high rainfall area requires a drainage plan for roof water to a common drain. Levels of the drainage system need to be included on plans so that rain water flows away and does not form puddles that breed insects around houses.
- Drains should be covered or bridged where necessary to allow access over the top for people and vehicles.
- Drains should have a V form at the bottom to reduce accumulation of water if levels are incorrect.

8. House elevation

- The house floor should be elevated above the surrounding ground level, and extra height is needed in vulnerable situations such as locations close to the sea, or close to a floodable waterway.

Construction and Materials Principles

The design of a building may incorporate all the good design principles, and yet the way it is constructed may lead to its failure when the forces of nature are applied to it. This section deals with good construction methods, and principles for choosing good materials for construction.

1. Foundations

- Foundations must be dug down to solid ground.
- Only broken rock should be used in foundations, not unbroken rounded river stone or rounded seashore stone. River stone can be used if broken.
- Sufficient mortar is needed to join stones used in the foundation into one solid foundation that will not subside unequally.
- Reinforcement is needed to connect the bases of column reinforcing steel in the foundations.



A good foundation, well laid, cemented and joined together, made of broken stone. But there is no column steel fixed in the foundation. The building built on this good foundation will not be anchored to it.



Good material for foundations—broken rock which is of a hard rock unlikely to break easily. This material is of a harder rock, of sufficiently large size that rocks will not slip between each other. If it is properly laid and properly cemented, it will make a good foundation.



This foundation is weak, since it has too many rounded stones that are not properly laid, and are not adequately bonded together with cement. The result is often that the floor and walls will crack as the foundations settle or move unequally.

Rounded river or beach rocks do not make good foundations unless they are broken, because they are liable to slip between each other. They need to be broken to avoid slipping, and they need to be carefully cemented between each other.



Good concrete foundations. The foundations of these houses have been well laid using sufficient cement to bind the rocks together, and the steel for the columns has been tied together within the foundation.

Construction and Materials Principles

2. Sand and Gravel

- Coral sand should never be used in any construction.
- Coarse sand should be sieved to remove stones, fine particles and dust.
- With volcanic sand only coarse volcanic sand should be used, not fine powder.
- If the sand comes from a dirty or sea water source, it must be washed.



Bad example of concrete using coral sand. Example of the disintegration of concrete due to the use of coral sand. This concrete is returning to powder. The only action possible at this point is to dig it out and to start again, wasting time, money and resources.



Example of good quality sand. This sand is all of about the same coarse texture and does not have stones in it or a lot of dust. Sand can be tested by lifting up a handful and letting it fall back to the ground. If a significant portion of it blows away instead of falling straight down, it has too much dust and needs to be sieved.



Example of poorly graded sand. This sand has not been separated from the stones, so it is already a sand/gravel mixture. If gravel is now added to this mixture, it will not be suitable for making concrete because there will be too little fine material in it to bind the stones together.



Bad practice. Debris should not be allowed to be mixed with any of the ingredients for making concrete. Such debris seriously weakens the strength of concrete. This sand will need to be cleaned before it is used for mixing into concrete. All plastic, leaves, grass, roots, and other debris must be removed before using sand or gravel for making concrete. Harmful debris particularly enters the concrete when it is mixed by hand on the ground.

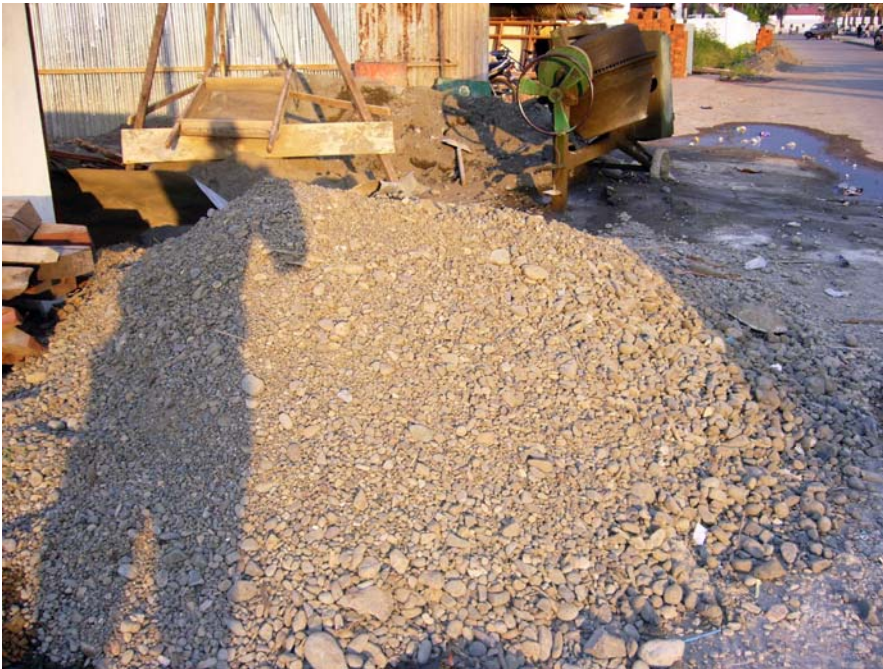
Gravel is best made of crushed rock, not of river rounded stones



Good gravel, made of crushed rock, with no larger stones. Gravel should have maximum size 20cm in order for it to fit within and around reinforcement and to strengthen concrete.

3. Mixing of concrete

- Ensure adequate cement is added.
- Mix ingredients well.
- Limit water, and use only clean water. Concrete should stand up when mixed, not flow away due to excessive water.
- Do not use any water that is salty. This destroys concrete strength.
- Use only properly selected, clean ingredients.
- If the sand contains stones, reduce the amount of gravel added.



Poorly graded gravel, with many stones too large for making good construction concrete and unable to fit around reinforcing. This mixture also has some fine sand. For house building the gravel should not have stones larger than $\frac{3}{4}$ inch (20mm).

4. Making columns

- All reinforced concrete columns should be made in one part before walls are built up. They should **not** be made in small steps as walls are built up. They should contain bars for wall ties and ring beams when constructed.
- Column reinforcement should be 4 vertical bars with hoops holding them together, spaced at approximately the same as the width of the column. Bars should be anchored in the foundation.
- End of hoop steel should be bent **135°** into the center of the column.
- Column steel must be covered with a minimum of 2cm of concrete all round.



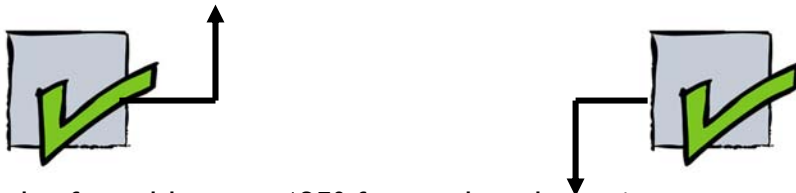
Poorly constructed column made in parts as the wall was built up around it, without wall ties between the column and the wall. The column steel is not properly covered because the steel cage was wider than the width of the bricks making up the wall. The result is that the formwork for the concrete was against the steel, and when concrete was poured, the steel was not within the column, but on its edge. The windows have been placed in the walls in a very weak way. All of this wall is weak and will be subject to collapse when under stress.



Poor concreting of column. This is a column in a collapsed house. Note the large number of large stones, the weak cement between the stones (used too much water), and that the reinforcing bars are too close to the surface of the column so that they have already begun to rust and lose strength. A plastic pipe has also been cast into the column which was too small to contain this.



Bad construction practice. These pictures illustrate bad construction of columns. On the left, steel was of inadequate diameter to bear the load and the hoops were also inadequate to bind the vertical steel and were not bent into the center of the column. They have sprung out. On the right, concrete was of poor quality and strength, with too many large stones and too much water in the mix, which also led to failure.

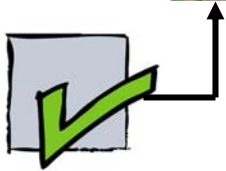


Ends of steel bent at 135° for earthquake resistance.



5. Reinforcement

- Reinforcement steel is best made of twisted deformed steel bar, or deformed bar, rather than plain round bar. Plain round bar is significantly weaker, and can pull through surrounding concrete and hence has a weaker effect.



Structural deformed steel bars



round bars



Bad practice. Bamboo cannot be used as reinforcement for concrete columns in an earthquake zone. It dries out, the concrete cannot bond to it and it lacks the strength needed to withstand major forces from nature on a building. Also, it cannot be bent at right angles to strengthen at corners or into foundations.

6. Roofing

- Roof trusses must be made with a triangular frame, placed over columns and tied to them.
- Roofing supports must be made of a block of wood rather than just a nail.
- Roofing structure wood should not be joined near the middle of a span, and not joined with a 45° cut.



Not good practice. Roof trusses are near but not over the columns, and column steel is not long enough and not bent over roof structure to connect between roof structure and column structure. This is a weak building method.

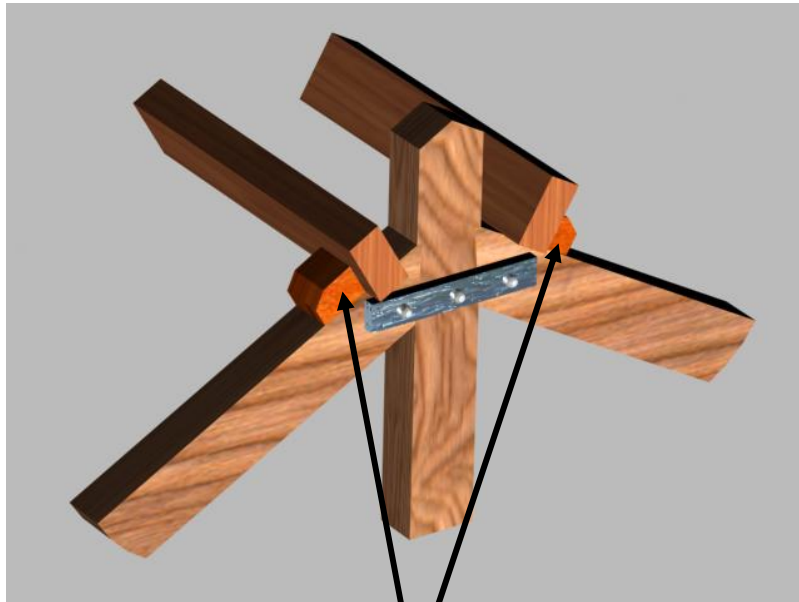


Illustration of wood blocks for securing roof structure. Do not use a single nail, which is a weak support, and may corrode and cease its function quickly in the Nias climate. Nails through the wood structure itself also are a weak support.

7. Tying wall to structure

- Wall ties to connect walls with the building's structure are to be at regular intervals of 40cm and extend from the bottom to the top of the wall.
- Wall ties must be cast into reinforced concrete columns, along with reinforcement for ring beams.
- Wall ties must be bent at the end to hook into the wall material.



A good example of wall ties inserted into columns before they were made, so that walls will be well tied in to the structural columns. They lack hooks at their ends at this point in the construction.

Construction and Materials Principles

8. Wells and septic tanks

- A well should not be located closer than 30 meters to the nearest septic tank. If they are located closer, liquid from the septic tank may contaminate the well, which may bring disease to the users of that well.
- It is best to have a common water supply from a tested clean source rather than individual wells.
- In urban areas, a common sewage system is recommended, and not hard to install.
- In rural areas rain water from the roof should be collected in covered tanks to provide a source of good household water.

Code of Minimum Standards for House Construction

1. Foundations

- a. Foundations must be designed specifically for the house in its location, according to:
 - The size of the house, number of floors, weight of construction materials
 - The foundation ground
 - The height of the water table
 - The possibility of liquefaction
- b. Each house must have a ground water and roof water drainage plan.
- c. Foundations are to be made of crushed rock laid on solid ground, well cemented, with a sloof of reinforced concrete laid on it that has connections for the house structure cast into it, brackets for wood structure, reinforcement for concrete structure.
- d. Rounded river or sea stones are not to be used unbroken for foundations.

2. House Elevation

- a. The house floor must be elevated above the surrounding area, with special consideration for possible area flooding, either by ground water or by tsunami.
- b. The possibility of landslides must also be considered.

3. Building Materials

- a. *Sand.* Must be coarse, clean, and without stones. It should not contain dust. It must never be coral sand, and if it is from the sea shore it must be thoroughly washed first and contain no shell or coral fragments.

b. *Gravel.* Must contain broken stones, not plain rounded river stones. The maximum stone size for house construction concrete is 2cm.

c. *Water.* Must be clean and free of salt and algae.

d. *Concrete.* No vegetable matter is to be mixed into concrete, no grass or wood.

It must be well mixed.

Use a minimum of water. It must be stiff. If the mixture flows like water, it has too much water.

It must be vibrated or tamped with a round rod to ensure proper filling of the form and proper cover to all reinforcing.

e. *Reinforcing steel.* Deformed steel or twisted deformed steel is best for structural use.

4. Structural Columns

- a. Must be vertical, and must be constructed before wall construction, and made in one part.
- b. Must be integrally connected to the foundation.
- c. If made of reinforced concrete, must contain 4 bars, one at each corner, of minimum size 12mm and minimum spacing 12cm.
- d. Vertical steel must have hoops around the outside, of a minimum size of 8mm.
- e. Column hoop steel must be covered with a minimum of 2cm of concrete all round.
- f. Hoops must be spaced at no further apart than the width of the column.
- g. To avoid a stone rich mixture at the bottom of the column, the first mixture should contain a higher proportion of cement and sand, and less stones.

5. Building Structure

- a. The building must have a regular structure.

- b. The structure must be strongly connected from foundation through walls to the roof trusses.
- c. For a reinforced concrete structured house, an integrated ring beam around the top of doors and windows must connect between and into the columns.
- d. A second reinforced concrete beam must connect the top of all walls with the columns.
- e. Ends of hoop steel must be bent 135°, as shown in the Handbook
- f. Triangular end walls of houses must be structurally supported.
- g. For a wood structure, wood posts must either go to the ground, or if above stub walls, must be securely nailed to a metal bracket concreted into stub walls.

6. Tying wall material to structural columns

- a. Wall material must be tied to the building structure with metal ties.
- b. Metal wall ties are to be hooked at the end.
- c. All wall openings are to be tied to wall material.
- d. For reinforced concrete frame buildings with brick walls, ties are to be cast into columns at 40cm spacing, and are to be a minimum of 8mm diameter.

7. Joining walls and roof

- a. In a reinforced concrete structure, column reinforcement should protrude sufficiently from the top of columns to be able to be wrapped around roof trusses, and nailed to them.
- b. For wooden houses, or in the absence of sufficient protruding steel, a steel strap should tie the roof trusses securely to columns.

8. Roofing and roof truss joints

- a. All houses are to have completely framed pitched triangular roof trusses.
- b. Roof trusses are to be placed over columns and tied to them, as mentioned above.
- c. Most roof truss joints, and particularly central ones, are to be bolted, not nailed, as explained in this Handbook.
- d. Roof truss joints of 3 or more elements are to have a metal strap joining each roof component.
- e. Wood blocks are to be used for fixing purlins to roof trusses.
- f. Joints in roof structural wood are to be made with step joints, not with 45° cuts.
- g. Joints in roof structure are not to be made near the middle of a span.

9. Cross bracing of walls and roof

- a. All wooden parts of a house structure are to be cross braced, stumps, walls, and roof.
- b. Wood roof structures are to be cross braced in both directions.

10. Drainage

- a. A comprehensive drainage plan must be part of each house. This must include drainage of ground water as well as of roof water.
- b. All drains must have a constant fall towards a common drain.
- c. Drains must be covered or have bridges for access across them, where needed.
- d. The bottom of drains should have a V formation to minimise water accumulation due to improper fall or debris in the drain.

11. Well and septic tank

- a. No well is to be constructed closer than 30m from the nearest septic tank.
- b. It is strongly recommended that a common water supply from a tested clean water source be provided for a cluster of houses.
- c. For clusters of houses, and particularly in urban areas, a common sewerage system should be provided.
- d. In rural areas, rain water from the roof should be collected in covered tanks.

House Building Checklist

1. Foundations

- House built on Sand Rock Clay
- Dry foundation Wet foundation
- Well made foundation Yes No
- Broken rock, well concreted Yes No

2. House elevation

- Adequate elevation Yes No

3. Building Materials

Sand and gravel:

- Clean, coarse sand, without stones Yes No

Mixing concrete:

- Well mixed, with limited water Yes inferior

Water quality used for making concrete Good Poor

Making columns: All columns well constructed

.. before walls Yes No

Reinforcement:

- Round steel Deformed Twisted Deformed

4. Building has a regular structure Yes No

Structural ring beam above doors & windows, & at top of

walls Yes No

Triangular end walls supported Yes No

5. Tying walls to columns

Wall ties at 40cm from top to bottom Yes No

6. Joining walls to roof structure

Column reinforcement or straps between roof trusses and

walls Yes No

7. Roofing, and roof truss joints

Roof trusses over columns and tied Yes No

Joined with bolts and straps Yes No

8. Cross bracing of walls and roof

Cross braced Yes No

9. Drainage principles

Proper drainage plan Yes No

10. Well and septic tank

Well more than 50m from septic tank Yes No

Overall assessment of the building:

Our homes contain the people and things which are closest to us. Let us ensure that our buildings are constructed more safely, so that the people inside them, and their property, will be better protected in the event of a major hazard impact. Even in more minor hazard events, the effects can be cumulative. Each one of the principles in this Handbook will have an added effect in reducing the vulnerability of the house to collapse when the forces of nature impact it.

Monitoring house design and construction will enable you to correct poor practices as they happen so that your house will better protect your family and belongings in an emergency. The expense involved in building a stronger house is little compared to the added security and protection it gives to you and your family. In many major surveys the additional cost is only about 6-8% extra compared to the cost of a house which will be destroyed.