Note on the assessment:

The following is an excerpt from the Book Transitional Shelters: 8 Designs, IFRC, 2012, available from www.sheltercasestudies.org. Inclusion of this design is for information purposes and does not necessarily imply best practice. Designs are site specific.

Assessments were conducted against hazard data for each location by structural engineers using Uniform Building Code (UBC) 1997, National Building Codes and international seismic codes. Below is a summary of the approach used.

Risk to life or risk of structure being damaged

The performance of the shelter was assessed based on whether or not the shelter is safe for habitation. As a structure may deform significantly under extreme hazard loading without posing a high risk to life, the shelter was also assessed on the risk of it failing or being damaged.

For lightweight shelters, the risk that falling parts of the building would severely injure people is reduced.

Classification of hazards

For the purposes of this assessment, the earthquake, wind and flood hazards in each location have been classified as **HIGH**, **MEDIUM** or **LOW**. These simplified categories are based on hazard criteria in various codes and standards as applicable to lightweight, low rise buildings, and statistical assumptions about the likelihood of hazard occurring.

A fuller description is of the methods used is available in Section A of Transitional Shelters: 8 Designs, IFRC, 2012.

Classification of performance

The performance of each shelter has been categorised using a **GREEN**, **AMBER**, or **RED** scheme. This classification is for the risk of the structure failing or being damaged, and not the risk of people being injured.

Classification used in Section B for the performance of structures	
Classification	Meaning of classification
GREEN:	Structure performs adequately under hazard loads
AMBER:	Structure is expected to deflect and be damaged under hazard loads
RED:	Structure is expected to fail under hazard loads

Performance analysis summaries

Each shelter review in Section B has a table titled ‘performance analysis’. This table provides an overall summary of the robustness of the shelter. The table assesses the performance of the shelter with respect to the hazards at the given location.

Performance analysis (example)	
Hazard	**Performance**
Earthquake LOW	AMBER:
Wind MEDIUM	RED:
Flood HIGH	GREEN:

See Classification of Performance

See Classification of Hazards

Structure is expected to deflect and be damaged under earthquake loads.

Structure is expected to fail under wind loads.

B.1 Indonesia, West Java (2009) - Bamboo frame

Summary information

Disaster: Earthquake, September 2009

Materials: Bamboo (Dendroclamus Asper and Gigantochloa Apus) frame and bamboo matting walls with concrete foundations and terracotta roof tiles.

Material source: locally procured

Time to build: 3 – 4 days

Anticipated lifespan: 1 – 5 years

Construction team: 3 – 4 people

Number built: 430

Approximate material cost per shelter: 260CHF

Approximate project cost per shelter: 330CHF

Shelter description

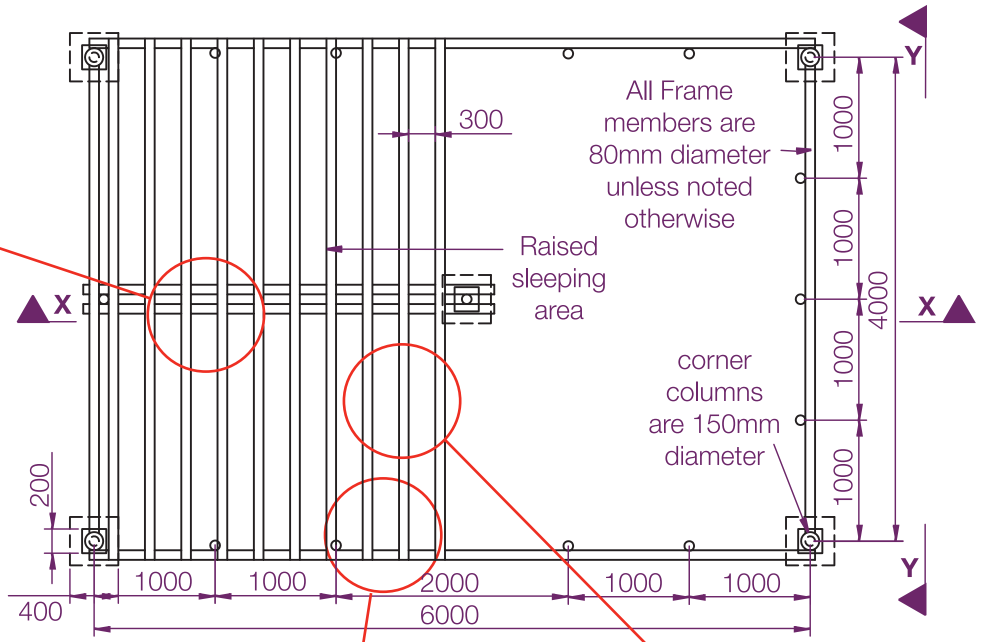
The rectangular bamboo frame structure measures 6m x 4m on plan and has a hipped roof of terracotta tiles laid on bamboo matting and laths. The frame has woven bamboo matting walls, a door at the front and two windows on each side. The back section has a raised floor which forms a sleeping area constructed from bamboo joists and panelling. The floor void has been filled with rubble confined by a low masonry wall all round. The structure is braced with bamboo members on all sides which provides stability with an additional roof truss in the centre. The shelter is supported by five bucket foundations with a length of bamboo cast in to connect to the four main columns. The frame connections are pinned using bamboo pegs and then secured with rope. The roofing and flooring are fixed with nails.

Shelter performance summary

This vernacular style of construction uses locally available materials with the intention that they can be reused in the construction of permanent housing. It is a low-cost, rapidly constructed design, but requires some relatively minor alterations to improve its structural performance under normal gravity loads, as well as earth-quake and wind loads. Bamboo is a good material in earthquake areas as it is flexible and is unlikely to fail. However the lightweight bamboo frame is not compatible with the roofing material which is heavy. Unless the tiles are securely fastened to the structure they will pose a risk of collapse. In non-seismic areas, the design is an appropriate solution, but an alternative, lightweight roofing material is recommended in seismic areas. It is essential that the bamboo is treated to prevent decay.

Plans and comments

CHANGE: Increase the number of floor beams supporting the sleeping area and increase the number of supports or strengthen them to support the floor joists loads on the floor.



Ground floor plan

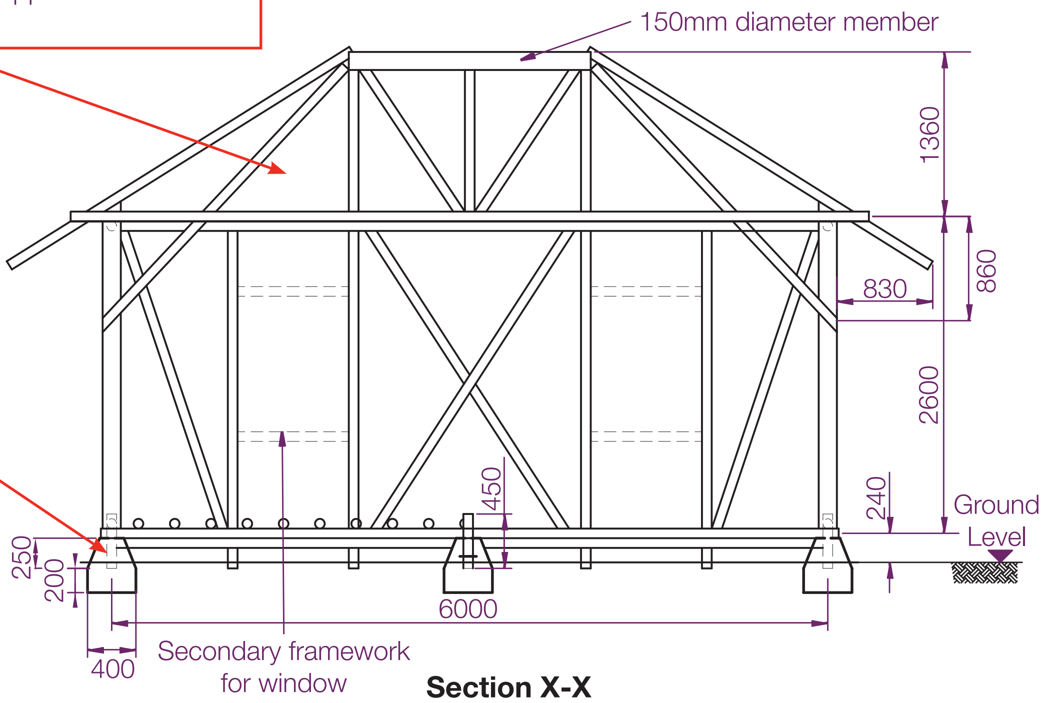
CHECK: The roof space must not be used for storage unless the members, connections and foundations are checked for the increased forces.

CHANGE: Strengthen beams at the base of the walls that frame the floor. This can be done by using two bamboo sections adequately connected so that the load is shared between them.

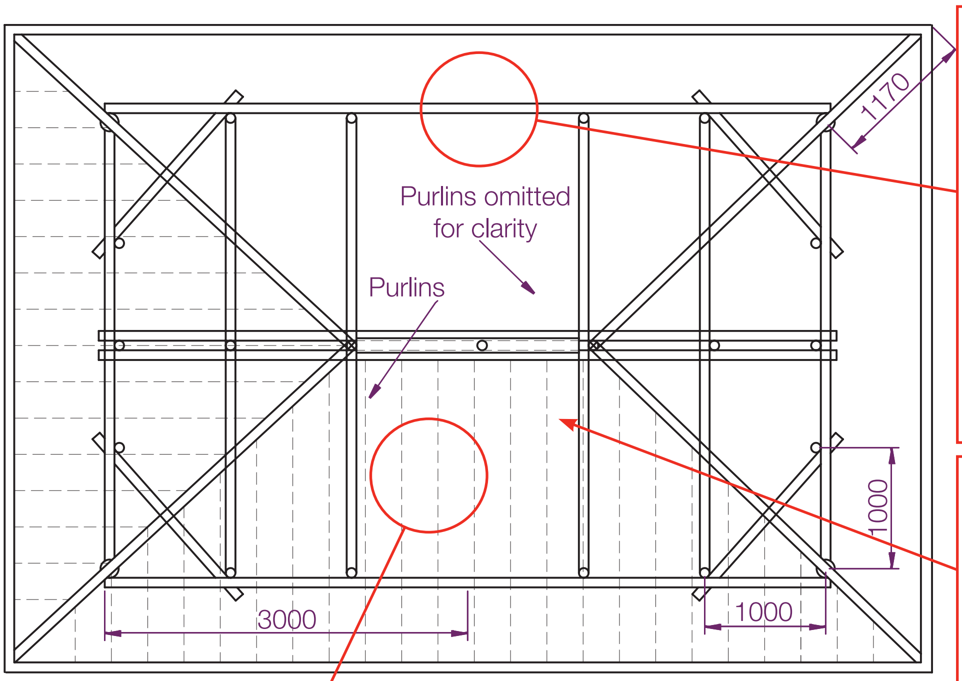
CHECK: Nail every roof and floor lath to each purlin or joist with small diameter nails. Bamboo matting can also be nailed to bamboo frames using small nails. Care must be taken when nailing to bamboo to avoid splitting.

CHECK: Bracing arrangements could be simplified to reduce the number of members and therefore the number of connections. Where possible braces should also meet at column bases to reduce the forces applied to the beams and columns.

CHECK: Protect bamboo cast into foundations using bitumen to prevent damage caused by exposure to chemicals in the concrete. Where the required lifespan is greater than one year, use an alternative material cast in to the foundation (for example steel).



Section X-X



Roof Level Plan

CHANGE: Add an additional column or strengthen eaves beams that support the roof to take gravity, wind and seismic loads. This could be done by using a larger section. The connections of the beams to the columns should also be strengthened in accordance with the new section sizes.

CHANGE: Use an alternative and lighter weight roofing material since terracotta tiles will fall in an earthquake event and pose a high risk to life. Note that if a lighter roof is used, the foundations will need to be reviewed to ensure they resist uplift.

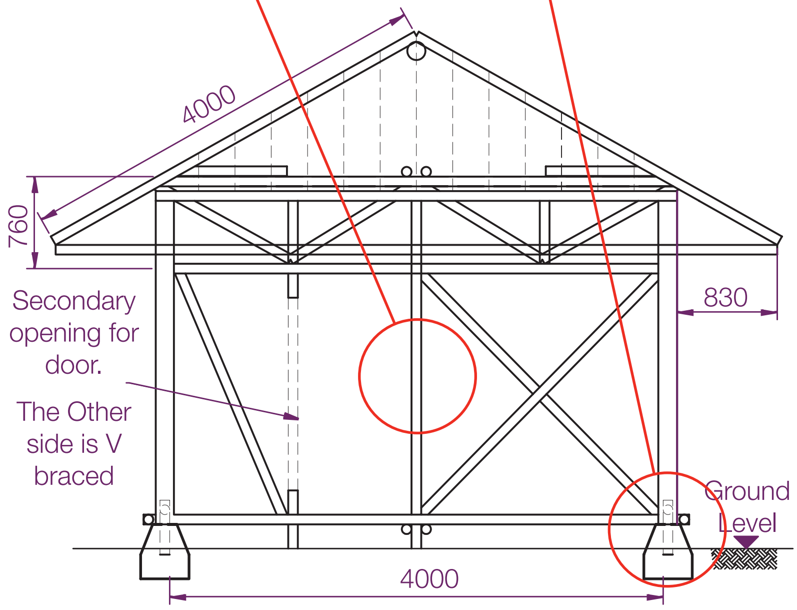
CHECK: Nail every roof and floor lath to each purlin or joist with small diameter nails. Bamboo matting can also be nailed to bamboo frames using small nails. Care must be taken when nailing to bamboo to avoid splitting.

CHANGE: Use a deeper/ larger foundation or alternative foundation solution to provide sliding resistance under wind and seismic loads (See screw in ground anchor, Section C.2.). Check the shear capacity of the column to foundation connection.

CHECK: Use bamboo that is at least three years old and check the maturity and quality. Dry and treat bamboo sections to protect from rot and insect attack. Refer to www.humanitarianbamboo.org for guidance on harvesting, treatment, allowable node spacing and taper.

CHECK: The design and detailing of all connections is critical to the stability of the structure, especially when in tension. It may be appropriate to strengthen connections by locally filling the bamboo tubes with mortar. Wire and nails should not be used to connect the main members as this is likely to cause splitting of the bamboo. Use only small nails with care to fix wall, roof or floor coverings.

CHECK: Do not upgrade the walls using masonry due the already large seismic force attracted to the structure. Upgrading walls with masonry will risk lives.



0 1000 2000
Scale Bar

Section Y-Y

Durability and lifespan

The durability of the shelter is dependent on the quality of the bamboo used, its treatment, and the condition of the matting. The bamboo should be treated before casting into concrete and the frame members should also be treated to prevent rot and insect attack. The shelter is easily moved by unpegging the frame from the foundations and the materials can be reused as a part of permanent housing reconstruction.

Performance analysis*

The performance of the shelter is generally good. There are, however, some simple improvements that could be made to prevent failure under high loads. The roof and floor edge beams should be strengthened for all loads and the internal floor beams strengthened to take live loads only.

Hazard	Performance
Earthquake HIGH	RED: The performance of the frame under seismic loads is inadequate. The roof and floor edge beams should be strengthened to resist seismic loads and prevent collapse of the roof. Due to the heavy weight of the roof tiles the structure attracts a large seismic load. As the tiles are not fixed to the purlins, they will fall during an earthquake. This will pose a significant risk to life. An alternative foundation solution should also be used to prevent sliding in an earthquake.
Wind LOW	AMBER: To prevent collapse of the roof under wind loads the roof and floor edge beams should be strengthened. An alternative foundation should also be used to prevent sliding.
Flood HIGH	AMBER: The shelter floor is raised by 0.32m and protected by a low brick wall. No specific checks have been carried out on the frame or foundations.

* See section A.4.5 Performance analysis summaries

Notes on upgrades:

Upgrading the shelter walls with masonry or other very heavy materials to a high level is not recommended as they will attract even greater seismic loads causing the frame of the structure to perform poorly in an earthquake. The collapse of unreinforced masonry walls poses a serious risk to the lives of the occupants,

Assumptions:

- The roof is covered by a woven bamboo mat on the purlins. Bamboo laths are nailed at every purlin to fix the mats. Terracotta roof tiles are placed on the mats but will come loose in an earthquake.
- The low brick wall (and rubble filling the floor void) is not connected to the bamboo frame so will not place any forces on it.
- All main member connections are fixed with bamboo pins and rope, and are assumed to act as pinned connections. It has been assumed that all connections are of sufficient strength to transmit forces between members.
- It has been assumed that the foundations are 400 x 400 tapering to 200 x 200 concrete buckets with an 80mm diameter bamboo stub cast in. This is secured using two plain 10mm diameter 200mm long iron bars. This stub slots into the bamboo columns and is then connected using bamboo pins.
- A stiff soil type has been assumed in analysis of the structure. For sites where liquefaction may be a hazard (near river beds, coastal areas with sandy soils and high water tables), the shelters could be seriously damaged in an earthquake, but such damage is unlikely to risk the lives of the occupants.
- The average diameter of the Giant bamboo is 150mm (wall thickness 13.5mm) and the Tropical Black bamboo is 80mm (wall thickness 7.2mm). The average density is 700kg/m^3 and the elastic modulus is 17,000N/mm^2 for both species. The distance between the nodes is 300mm for Giant bamboo and 330mm for Black bamboo.
- The bamboo density, diameter, thickness, elastic modulus and node spacing has been averaged over the length of the section and the initial curve of members has been ignored. In practice it is essential to ensure that the quality of the bamboo used fits these assumptions by checking the top and bottom dimensions. It has been assumed that the bamboo is properly harvested, treated and sufficiently dried.
- The split bamboo members used for the raised floor and roof laths, and the matting used on the walls, are of sufficient strength to take the applied loads.

Bill of quanities

The bill of quantities in the table below is for the shelter as it was built, without the design alterations suggested here. It does not take into account issues such as which lengths of timber are available and allowances for spoilage in transport and delivery.

Item (Dimensions in mm)	Material Specification See annex I.1	Quantity	Total	Unit	Comments
Structure -Foundations					
Portland Cement	Concrete	2	2	Bags	42.5kg/bags
Sand	Concrete	-	0.16	m^3	Estimate only
Gravel	Concrete	-	0.32	m^3	Estimate only
Iron bars – 200 x 10mm diameter	Steel 1	10	2	m	
Bamboo stubs – 80 x 7.2 thick (L=0.45m)	Bamboo 2	5	2.25	m	
Main Structure					
Main Columns – 150 x 13.5 thick (L=2.66m)	Bamboo 1	4	10.6	m	
Roof and Floor Beams – 80 x 7.2 thick (L=6.08m)	Bamboo 2	4	24.3	m	
Roof and Floor Beams – 80 x 7.2 thick (L=4.0m)	Bamboo 2	5	20	m	
Bracing – 80 x 7.2 thick (L=3.5m)	Bamboo 2	10	35	m	
Front Bracing – 80 x 7.2 thick (L=2.75m)	Bamboo 2	2	5.5	m	
Front Brace – 80 x 7.2 thick (L=2.15m)	Bamboo 2	1	2.15	m	
Ceiling diaphragm bracing – 80 x 7.2 thick (L=1.65m)	Bamboo 2	4	6.6	m	
Roof truss diagonals – 80 x 7.2 thick (L=3.5m)	Bamboo 2	2	7	m	
Roof truss bottom chord – 80 x 7.2 thick (L=6.08m)	Bamboo 2	2	12.16	m	
Roof truss bracing – 80 x 7.2 thick (L=1.8m)	Bamboo 2	2	3.6	m	
Roof truss verticals – 80 x 7.2 thick (L=1.3m)	Bamboo 2	3	3.9	m	
Ridge beam – 150 x 13.5 thick (L=2.6m)	Bamboo 1	1	2.6	m	
Rafters – 80 x 7.2 thick (L=4.0m)	Bamboo 2	4	16	m	
Secondary Structure					
Small Columns – 80 x 7.2 thick (L=2.86m)	Bamboo 2	10	28.6	m	
Lintel/window framing – 80 x 7.2 thick (L=1.0m)	Bamboo 2	8	8	m	
Ceiling Beams – 80 x 7.2 thick (L=3.84m)	Bamboo 2	4	15.36	m	
Purlins – 80 x 7.2 thick (L=3.5m)	Bamboo 2	55	192.5	m	
Floor Ties – 80 x 7.2 thick (L=5.85m)	Bamboo 2	2	11.7	m	
Floor Beams – 80 x 7.2 thick (L=3.0m)	Bamboo 2	2	6	m	
Floor Joists – 80 x 7.2 thick (L=4.08m)	Bamboo 2	10	40.8	m	
Front Top Bracing – 80 x 7.2 thick (L=1.3m)	Bamboo 2	4	5.2	m	

Roof edge beam – 80 x 7.2 thick (L=5.13m)	Bamboo 2	2	10.25	m	
Roof edge beam – 80 x 7.2 thick (L=7.13m)	Bamboo 2	2	14.25	m	
Collar Beam – 80 x 7.2 thick (L=0.4m)	Bamboo 2	4	1.6	m	
Roof Bracing – 80 x 7.2 thick (L=0.5m)	Bamboo 2	8	4	m	
Roof ties – 80 x 7.2 thick (L=4.08m)	Bamboo 2	2	8.16	m	
Covering – Wall and Roof					
Floor and Roof laths – 60 x 7.2 thick (L varies)	Bamboo 2		55	m^2	Maximum
Woven bamboo matting – 4 thick	Bamboo 2		95	m^2	walls and roof
Terracotta tiles	Tiles	435	44	m^2	
Fixings					
Small nails	Nails				As required
Bamboo Pegs	Bamboo 2				As required
Palm fibre rope					As required
Tools Required					
Spade		1	1	Pieces	
Drill		2	2	Pieces	