# Shelter 4: Structural Assessment – Indonesia, Java

## 1.1 Introduction and Purpose

Arup was commissioned to carry out a structural review to assess and validate nine selected shelter designs for the IFRC. This document summarises the information gathered and the key outcomes of the verification of the structural performance of Shelter 4, built by the Netherlands Red Cross in Indonesia. This assessment is based on the input documents listed in Appendix A.

**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: Minimum 1 year and up to 5 years

Construction team: 3 – 4 people

Number built: 430

Approximate material cost per shelter: 260CHF

Approximate programme cost per shelter: 330CHF

**Shelter Description**

The rectangular bamboo frame structure measures 6 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 of bamboo joists and panelling, and the floor void has been filled with rubble confined by a low masonry wall all round. The structure is braced with bamboo members and lateral loads are resisted by braced frames on all sides 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.

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 un-pegging the frame from the foundations and the materials can be reused as a part of permanent housing reconstruction.



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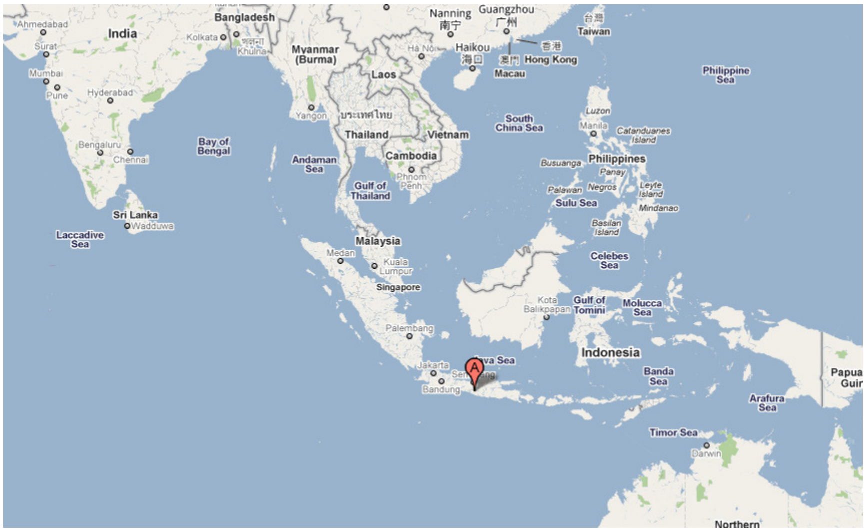
## 1.2 Location and Geo-hazards

### 1.2.1 Location of Shelter

The shelters are located in the Yogyakarta region of Java, Indonesia. It has been assumed that the shelters were built on flat sites rather than in mountainous regions, possibly in coastal locations.




### 1.2.2 Hazards

A summary of the natural hazards faced in Yogyakarta, Java, are given below[1]:

- HIGH Earthquake. A map from the Indonesian earthquake design code[2] shows that the shelters are situated in an area with a Peak Ground Acceleration (PGA) of 0.15g for an earthquake return period of 500 years[3].
- LOW wind. The area is not prone to tropical storms or cyclones. The wind loading on the shelter has been determined using national standards, see Section 1.8.3.
- HIGH Flood Risk. High rainfall in the rainy season and high run-off may lead to flooding.
- There is a risk of soil liquefaction since there is a history of this during previous earthquakes. The risk of landslides and mudflows is high in mountainous areas. Landslides are caused by earthquakes and high rainfall so will depend on the exact location of the shelters.
- Other hazards that cannot be designed against include tsunami and volcanoes. There is precedence for tsunamis and there are volcanoes to the north of Yogyakarta.
- Tropical, humid climate with temperatures generally between 20 – 30 $^{o}$C, reaching 35 $^{o}$C. South of the equator Yogyakarta has two seasons: rainy and dry monsoon. The rainy season lasts from September to April, with an average yearly rainfall of nearly 2m.

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[1] See Appendix A, Reference 1, for maps giving general hazard information for all of Indonesia, not just specifically Aceh.
[2] See Section 1.7 for code reference.
[3] A 475 year return period has generally been used with the code so this value is conservative.



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## 1.3 Geometry

The geometry was determined using the photos, diagrams and bill of quantities provided. See Appendix A for a list of source information. Figure 1.1 shows sketches of the shelter geometry, and Figure 1.2 shows a 3D image of the shelter.

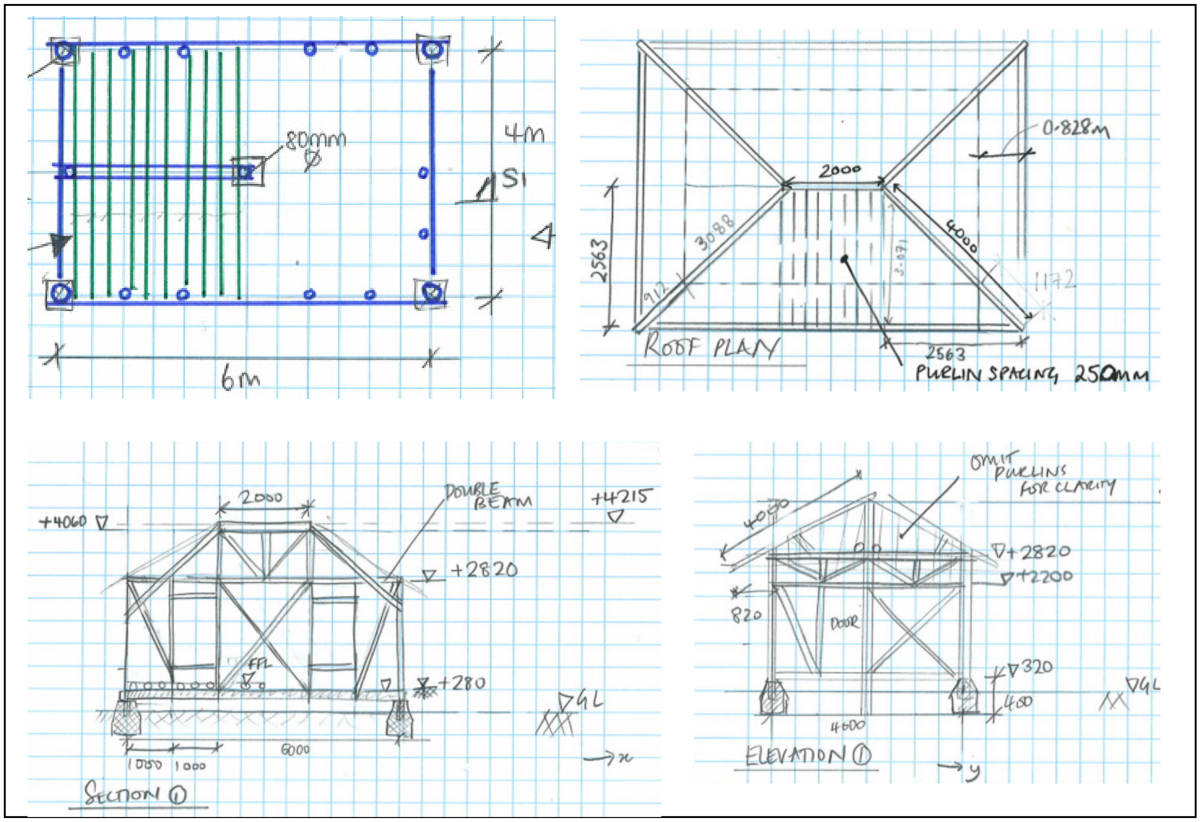


**Figure 1.1 – Sketches of Shelter Geometry**

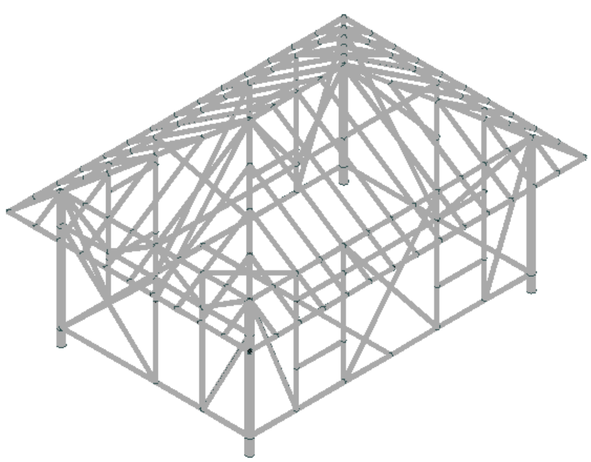

**Figure 1.2 – 3D Drawing of Shelter**



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**Geometrical Assumptions:**

- All main member connections are fixed with bamboo pins and rope, and are assumed to be pinned for analysis.
- It has been assumed that the foundation dimension are as shown in Figure 1.3 and consists of a solid concrete bucket with an 80mm diameter stub cast in with two plain 10mm diameter 200mm long iron bars. This stub is then connected to the columns using bamboo pins.

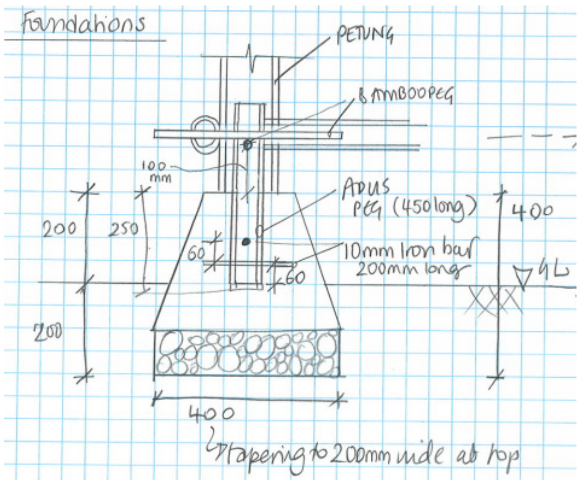


**Figure 1.3 – Foundation Detail**

- The roof is made up from purlins spaced at 250mm, supported by the main rafters and ridge beam with an eaves beam connecting them at the edge. A woven bamboo mat covers the purlins and on top of this bamboo laths (4 split from each bamboo segment) have been nailed at every purlin. The terracotta roof tiles are then placed on this with nominal fixings.



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## 1.4 Structural System

- Vertical loads are transferred from the roof purlins back to the rafters, eaves beam and ridge beam which then carry the load back to the four large corner columns supported by the concrete bucket foundations which bear directly on to the soil.
- In the transverse direction, stability is provided by the braced wall frames on either side. These contain both single braces and cross braces that take tension and compression forces (see Figure 1.4).
- In the longitudinal direction, stability is provided by braced wall frames on either side which contain both single braces and cross braces that take tension and compression forces (see Figure 1.4). Some of the wind loads are also attracted by the central roof truss which carry these forces back to the floor level beams in bending.
- In plane bracing at the ceiling level at the corners of the roof means that the roof acts as a moment frame to resist racking on plan.
- Resistance to uplift is provided by the weight of the building and the foundation, and resistance to shear by friction between the foundation and the soil.

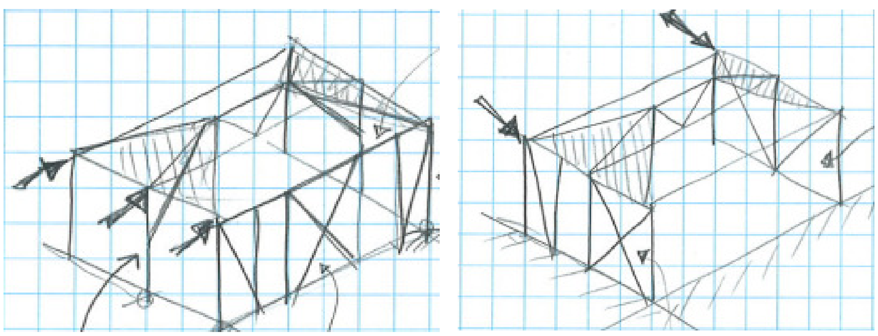

**Figure 1.4 – Frame Lateral Stability System**

## 1.5 Member Sizes

The table below shows the key timber frame member sizes that have been assumed for the structural assessment. The diameter of the members was scaled from the information provided[1] and the corresponding thickness calculated from the internal diameter using the equation d=0.82D (see Figure 1.5)[2]. The lengths given are based on information from the drawings and Bill of Quantities referenced in Appendix A.

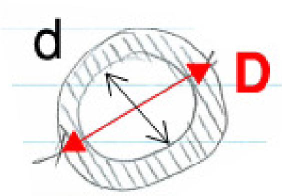


**Figure 1.5 – Bamboo Cross Section**

[1] See foundation detail to scale in Appendix A, Reference 3.
[2] See Appendix A, Reference 9, Page 64.



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The table does not include secondary bamboo framing to form doors or other non-structural elements. The full list of elements is given in the updated Bill of Quantities in Appendix B.

| Members | Size (mm) | Length (m) | Bamboo Type |
|---|---|---|---|
| **PRIMARY** | | | - |
| Columns | 150 x 13.5 thick | 2.66 | Giant |
| Ridge Beam | 150 x 13.5 thick | 2.6 | Giant |
| Roof bottom chord | 80 x 7.2 thick | 6.08 | Black |
| Roof truss bracing | 81 x 7.2 thick | 1.8 | Black |
| Truss diagonals | 82 x 7.2 thick | 3.5 | Black |
| Wall bracing | 83 x 7.2 thick | 3.5 | Black |
| Roof diaphragm bracing | 84 x 7.2 thick | 1.65 | Black |
| Rafters | 85 x 7.2 thick | 4 | Black |
| Eaves Beams | 86 x 7.2 thick | 6.08 or 4.0 | Black |
| Wall footer beams | 87 x 7.2 thick | 6.08 or 4.0 | Black |
| **SECONDARY** | | | |
| Floor beams | 87 x 7.2 thick | 3 | Black |
| Floor Joists | 87 x 7.2 thick | 4.08 | Black |
| Purlins | 87 x 7.2 thick | 3.5 | Black |
| Wall transoms | 88 x 7.2 thick | 2.86 | Black |
| Roof edge beam | 89 x 7.2 thick | 5.13 or 7.13 | Black |
| Ventilation bracing | 90 x 7.2 thick | 1.3 | Black |
| Ceiling Beams | 90 x 7.2 thick | 3.84 | Black |

## 1.6 Materials

The bamboo for the frame, matting, laths and ropes was sourced locally and the terracotta tiles reclaimed from existing damaged housing. It has been assumed that the frame is made from treated bamboo lengths, cut and pre-drilled with the required holes for fixing. The connections are assumed to be bamboo pegs and rope, with the exception of the nailed laths on the floor and roof.



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### 1.6.1 Bamboo

The frame, bamboo matting, cladding and floor and roof laths are all made from bamboo. The larger sections including the main columns are made from Giant Bamboo, also known locally as Bambu Petung (*Dendrocalamus Asper*) and the cladding materials and other smaller members from Tropical Black Bamboo, also known locally as Bambu Apus (*Gigantochola Apus*)[1].

Bamboo is essentially a grass and is fast growing (up to 25m over 6 months), flexible, renewable and light in weight for its strength. It must be harvested once mature (3-5 years) and at the right time to ensure that it has good structural properties. It has a lower durability than timber and is very susceptible to insect attack and rot. It should therefore be thoroughly dried and preferably chemically treated. For a more detailed description of harvesting and treating methods refer to 'Humanitarian Bamboo – A manual on the humanitarian use of Bamboo in Indonesia', www.humanitarianbamboo.org[2].

The harvested bamboo lengths are called culms and consist of a hollow tube with stiffening plates or nodes spaced at intervals as shown in Figure 1.6[3]. The culms are denser and stronger towards the outside and have a silica coating on the outside. The alkali conditions in concrete may destroy the pectin in the bamboo so it should therefore be protected using bitumen (which will also increase the bond) before being cast into foundations. Bamboo is versatile and can be split into four sections to form laths that can be used for floors and roofs (see Figure 1.7). Thinner strips can also be made and woven into bamboo matting which is used for wall coverings.

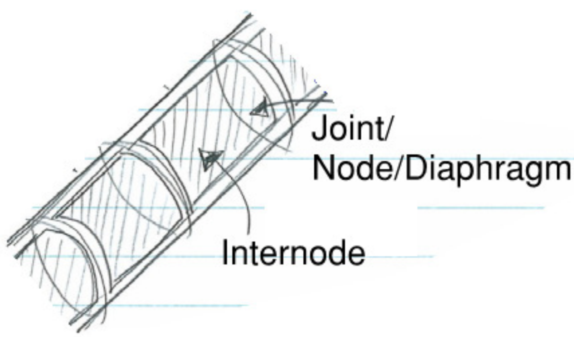


**Figure 1.6 – Structure of Bamboo**

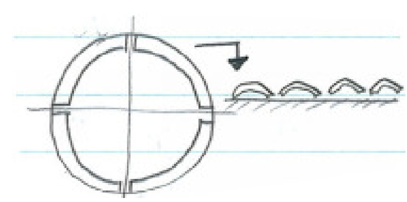

**Figure 1.7 – Bamboo laths**

Bamboo culms are tapered from root to tip and the node spacing, wall thickness and their physical properties also vary over the length. The bottom section should be used for structural members and the properties are averaged over the length for design. The variable properties of bamboo make standardisation difficult and assumptions have been made as summarised below.

Bamboo has a high tension and compression strength parallel to the grain, and in compression its' strength is enhanced by the stiffening of the nodes. In comparison to timber bamboo is more flexible but also fails in a more brittle manner. This is due to the weakness of sections in shear and the low strength of bamboo in tension perpendicular to the grain which is induced by bending and leads to splitting/crushing failure. Ductility and plastic behaviour therefore cannot be relied upon in design and elastic analysis must be used. Allowable stress design is carried out in a similar manner to timber, but the allowable stresses used for bamboo are significantly factored down (by a factor of

[1] See Appendix A, Reference 7, for a description of these bamboo species.
[2] See Appendix A, Reference 6.
[3] See Appendix A, Reference 5 for a full description of the physical properties of bamboo.



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7 in total, which allows for variability in material quality[1]) from the ultimate stresses. In seismic design an R value of 1 is used to account for this lack of ductile behaviour (see Section 1.8.4).

The density of the bamboo has been assumed to be 700kg/m$^3$, this is in the middle of the range recommended for bamboo[2]. From the assumed density the allowable stresses for design have been calculated using formulae based on test results[3]. These allowable stresses have then been compared to the actual stresses in the members from the applied loads.

**Summary of assumptions made in bamboo design:**

- Diameter of Giant bamboo is 150mm and Tropical Black bamboo is 80mm (average diameters since bamboo is tapered).
- Average thickness along length of Giant bamboo is 13.5mm and Black bamboo is 7.2mm
- Dry bamboo (moisture content 12% in a relative humidity of 70%)
- Average density over length for both species is 700kg/m$^3$
- Average elastic modulus over length for both species is 17,000N/mm$^2$
- Distance between nodes varies so has been averaged over the length (300mm for Giant bamboo and 330mm for Black bamboo).
- Natural curve of bamboo members and irregularity of cross section has been ignored. Curve should be minimised when cutting bamboo members.

[1] See Appendix A, Reference 10.
[2] See Appendix A, Reference 9, Page 22.
[3] See Appendix A, Reference 8, Section 3, Table 1.



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### 1.6.2 Material Assumptions

| Type | IFRC Specification | Arup Assumption | Comments |
|---|---|---|---|
| Concrete | Cement, Coral and Sand mix (1:2:3) | Compressive cube strength $f_{cu}$ = 15-20MPa (low strength concrete), see I.1 concrete specification | Specification given suggests that the quality of the concrete is low |
| Foundation reinforcement | Iron bar, 10mm diameter and 200mm long | Plain steel reinforcing bar, 10mm diameter, minimum yield strength 250N/mm$^2$, minimum cover to reinforcement 25mm | |
| Terracotta Roof Tiles | Salvaged ceramic/terracotta roof tiles | Large clay interlocking pantiles, 403 x 325mm, 9.9tiles/m$^2$, minimum head lap 47mm, installed weight 0.4kN/m$^2$ | Recommended fixings: short 8d roofing nails and clips |
| Bamboo columns and ridge beam | Bambu Petung (*Dendrocalamus Asper*) | Giant Bamboo, average properties along length: 700kg/m3 density, 300mm node spacing, Young's Modulus 17,000N/mm$^2$, dead load design allowable stresses: compression 9.1N/mm$^2$, bending 14N/mm$^2$, shear 2.1N/mm$^2$ | See Bamboo 1, I.1 and Section 1.6.1for further details |
| Bamboo frame and foundation stubs | Bambu Apus (*Gigantochola Apus*) | Tropical Black Bamboo, average properties along length: 700kg/m3 density, 330mm node spacing, Young's Modulus 17,000N/mm$^2$, dead load design allowable stresses: compression 9.1N/mm$^2$, bending 14N/mm$^2$, shear 2.1N/mm$^2$ | See Bamboo 2, I.1 and Section 1.6.1for further details |
| Bamboo laths/split bamboo | Bambu Apus (*Gigantochola Apus*) | Roofing and flooring laths made from bamboo section split into 4 pieces, bamboo density 700kg/m$^3$, weight 0.083kN/m$^2$ | Nail to every purlin or joist with small nails |
| Bamboo matting/woven bamboo | Bambu Apus (*Gigantochola Apus*) | Woven mats made from 2mm thick bamboo strips split from main piece, weight (assuming bamboo density 700kg/m$^3$) 0.028kN/mm$^2$ | Nailed to panel frames which are nailed to the main structure using small nails |
| Bamboo pegs | Bambu Apus (*Gigantochola Apus*) | 10mm diameter bamboo pegs, bamboo properties as for structural members | Made using solid sections of bamboo branch or by driving through a punch |
| Rope | Palm fibre rope to secure joints | 3mm diameter lashing made from sugar palm fibre | No properties assumed since joints not checked |
| Nails | Small nails | 4d/6d nails in 275N/mm$^2$ yield strength steel, see I.1 specification for further details | Care must be taken when nailing to bamboo members to avoid splitting |



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## 1.7 Codes, Standards and References

**General**

The IBC (International Building Code) 2009 has been used as a basis for the design checks on the shelters since it is widely accepted worldwide, particularly for extreme loading cases such as earthquakes or strong winds. Other codes have been referenced where appropriate or where the IBC was thought to be less applicable. This includes national codes where appropriate and the UBC 1997.

**Other references used for this shelter:**

- Standards referred to by IBC 2009 including: ASCE 7-10 (2010) for loading
- UBC 1997 Volume 2 for preliminary wind calculations and parts of seismic calculations
- Indonesian National Codes including:
    - o 'Pedoman perencanaan pembebanan untuk rumah dan gedung' (Imposition of planning guidelines for homes and buildings) SKBI-1.3.53.1987, Jakarta, Oktober 1987 the predecessor of 'Tata cara Perencanaan pembebanan Untuk rumah dan gedung' (Planning procedures for loading for houses and buildings) SNI-03-1727-1989.
    - o 'Standar Nasional Indonesia - Tata Cara Perencanaan Ketahanan Gempa untuk Bangunan Gedung'(Planning Procedures for Building Earthquake Resistance) SNI-03-1726-2003', Bandung, Juli 2003

## 1.8 Loads

### 1.8.1 Dead Loads

- Self-weight of structural materials applied in accordance with the densities specified in Section 1.6.1.

### 1.8.2 Live Loads

- For IBC compliancy a live load of 1.92kN/m$^2$ on the ground floor and 0.96kN/m$^2$ on the roof should be applied[1]. In this case however, no live load is assumed on the roof since there will be no maintenance access or snow load. The live load allowance for the ground floor has been reduced to 0.9kN/m$^2$ since this represents a more realistic loading situation for transitional shelters..

[1] 'International Building Code 2009' – Table 1607.1.



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### 1.8.3 Wind Loads

The wind loads have been calculated using the method given in the Indonesian design code[1]. This specifies a minimum standard pressure to be used in coastal locations for normal height construction modified by a pressure coefficient depending on the building type. The values in the following table were used.

| | |
|---|---|
| Wind pressure for areas up to 5km from the coast – 2.1.3.2 (2) | p = 0.4kPa |
| Wind coefficients assuming a closed building, a building with an opening on one side or a canopy – 2.1.3.3, Figure 1 (1), (2) & (3)[2] | Varies for each case on each surface |

The pressure coefficients from the Indonesian code were adapted using the British Standard for Wind Loading[3] since this covers the pressure coefficients for hipped roof specifically in greater detail. Values were chosen that were consistent with the Indonesian Code.

Modifying the wind pressure by the pressure coefficients gives a maximum lateral force on the structure of 7.8kN in the transverse direction. The resulting factored pressure on the windward face of the structure used to classify the wind hazard level was found to be 0.58kPa.

Local knowledge of higher wind speeds must be taken into account by using higher design pressures for specific shelter locations where necessary.

[1] Refer to Section 1.7.
[2] See Section 1.9.1 for an explanation of the use of these three different cases.
[3] BS6399-2: 1997, Figure 21 and Table 11.



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## 1.8.4 Seismic Loads

Seismic Loading has been considered in accordance with the IBC[1] using a short period design acceleration based on the UBC methodology. Stiff soil has been assumed (soil category D or Site Class D). The design response acceleration was determined using the PGA detailed in Section 1.2.2.

| | |
|---|---|
| Assume Site Soil Category D[2] (20.3-1) and use PGA (Z) in UBC Table 16-Q | $C_a = 0.22g$ |
| Assume structure response in 0.5-1.5s period (UBC 16-3) to get $S_{DS}$ | $S_{DS} = 2.5C_a = 0.55g$ |
| Assume Risk Category II[3] (Table 1.5-1) in Table 11.6-1 | Seismic Design Category D |
| Importance factor assuming Risk Category II – Table 1.5-2 | $I_e = 1.0$ |
| Assume no codified seismic lateral system – Table 12.2-1[4] | R = 1.0 |

The equivalent lateral force procedure has been used to calculate horizontal loads for design. The resulting base shear is 15.0kN which is greater than the resulting lateral wind force. This is unusual for a transitional shelter and is due to the large weight of the roof.

[1] 'ASCE 7-10 – Minimum Design Loads for Buildings and Other Structures', Chapters 11&12.
[2] In locations where liquefaction is a risk the Site Soil Category should be changed accordingly for seismic design.
[3] A higher risk category has been assumed rather than Risk Category I used for previous shelters. This is because the roofing is very heavy in comparison and therefore poses more of a risk to the life safety of the occupants in the event of an earthquake. This does not however affect the magnitude of the seismic load the shelter is designed for.
[4] Bamboo braced frames are not code specified laterally resisting systems although the performance of the frame under lateral loads is reasonably good. Bamboo also fails in a brittle manner so plasticity cannot be relied upon for seismic design.



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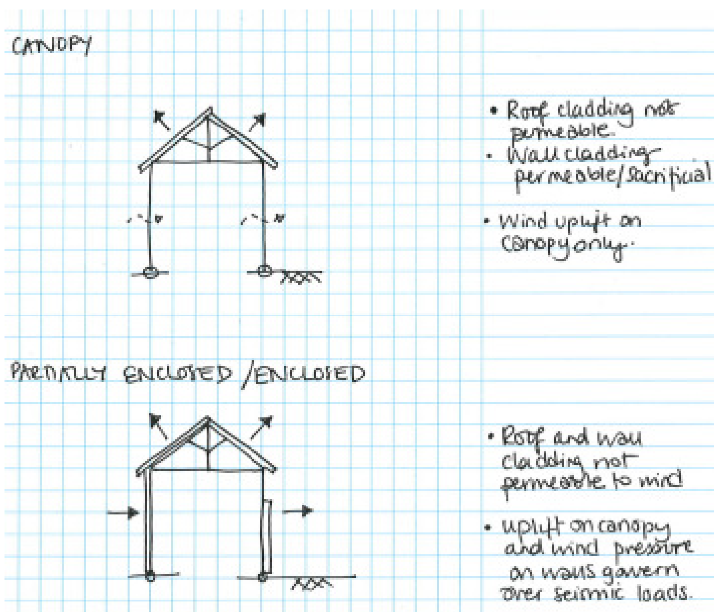
## 1.9 Calculation Plan

### 1.9.1 Design Methodology

The performance of each shelter has been assessed by checking that the structure as assumed from the information provided is safe for habitation. Relevant codes and standards have been used as the baseline for identifying appropriate performance/design criteria, but the structure has been checked against code requirements: if variations from this have been made, assumptions and reasoning for lower factors of safety and alternative standards have been justified. Logical reasoning was therefore used where necessary and upgrades suggested in order for the shelter to meet these criteria.

The shelter has been assumed to act as either enclosed or as a canopy under wind loads. Literature suggests that depending on the quality of the bamboo matting it may either act permeably[1] or as a solid medium to transfer wind loads back to the structure. To do this the matting must be adequately fixed to the frame to prevent the panels becoming damaged under wind loads. Since there are window and door openings in the shelter the uplift on the roof has been increased in the enclosed case in accordance with the Indonesian Code recommendations[2].




### 1.9.2 Structural Checks

For a summary of the checks performed to assess the building, refer to Appendix C.

[1] See Appendix A, Reference 9.
[2] See code references in Section 1.7.



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# 2 Results of Structural Assessment

## 2.1 General Key Findings

I. The foundation solution performs adequately in bearing and uplift under all combinations of dead, live, wind and seismic loads. Under wind and seismic loads the sliding resistance of the foundations must be increased by increasing the size of the concrete blocks or using an alternative foundation solution.

II. The performance of the shelter under all loads is generally good. However, under dead and live loads the floor beams in the sleeping area and floor edge beams should be strengthened or their spacing decreased to prevent failure and excessive deflection. The roof edge beams should also be strengthened to take the large dead loads from the heavy roof tiles. These beams could be easily strengthened by using double members, adequately connected to facilitate load sharing.

III. The floor and roof edge beams require strengthening to a level where they can resist seismic and wind loads. Under seismic loads the roof tiles are likely to detach and fall posing a significant risk to the life safety of the occupants.

# 3 Conclusions and Recommendations

## 3.1 Assumptions

- The roof covering consists of a woven bamboo mat covering the purlins and on top of this bamboo laths nailed at every purlin but with spaces between. The terracotta roof tiles are then placed on this with minimal fixings so they will come loose in an earthquake.
- The low brick wall (and rubble filling the floor void) is not connected to the bamboo frame so do 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, 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 if soil liquefies in an earthquake but such damage is unlikely to pose a life safety risk to 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



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checking the top and bottom dimensions. It has been assumed that the bamboo is properly harvested, treated and sufficiently dried.

## 3.2 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. Conclusions

| **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 | The performance of the frame under seismic loads is inadequate. The roof and floor edge beams must 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. The limited fixity of the tiles to the purlins means theywill fall during an earthquake which will pose a significant risk to the life of the occupants. An alternative foundation solution must also be used to prevent sliding in an earthquake. |
| Wind – LOW | To prevent collapse of the roof under wind loads the roof and floor edge beams must be strengthened. An alternative foundation solution must also be used to prevent sliding. |
| Flood – HIGH | 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. |

**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 an unreinforced masonry walls poses a serious risk to the life safety of the occupants.



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**Watch-its for drawings: ‘Change or Check’**

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

B. CHANGE: Strengthen beams at the base of the walls that frame the floor to take imposed, seismic and wind loads. This can be done by using two bamboo sections adequately connected so that the load is shared between them.

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

D. CHANGE: Use a deeper/larger foundation or alternative foundation solution to provide sliding resistance under wind and seismic loads (Type 5, C.1) and check the shear capacity of the column to foundation connection.

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

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

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

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

I. CHECK: The design and detailing of all connections is critical to the stability of the structure and should be checked for individual cases, 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. Small nails only may be used with care to fix wall, roof or floor coverings.

J. CHECK: Do not upgrade the walls using masonry due to risk to life safety and increase in the already large seismic force attracted to the structure.

K. 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.

L. CHECK: Check the soil type for shelter location is stiff, otherwise design foundations accordingly.

M. 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 moments applied to the beams and columns.



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# Appendix A – Source Information


1. 'Natural Hazards in Aceh', Yasir Khokher and Ziggy Lubkowski, ARUP, November 2009.
2. 'Transitional shelter Task Group Summary information Transitional shelter data sheet – Indonesia', Version 3, JA & CT, 27-09-2010.
3. 'Construction Handbook – Step By Step Tutorial', Vicky "C.J." Lee.
4. 'PMI-IFRC Emergency Shelter Fact Sheet', PMI and other relevant photos (Transitional bamboo shelter Yogya 01-03) as supplied by the IFRC, 2011.
5. 'Bamboo Shelters in Colombia", David Trujillo, IStructE, 2007.
6. 'Humanitarian Bamboo – A manual on the humanitarian use of Bamboo in Indonesia', Draft 2, www.humanitarianbamboo.org, Dave Hodgkin, 2009.
7. 'Bamboo Rediscovered', Victor Cusak, 1997.
8. 'Building with Bamboo', 2nd Edition, J.A. Janssen, 2000.
9. "Designing and Building with Bamboo'. J.J.A. Janssen, Technical Report 20, 2000.
10. "Bamboo in Building Structures", Technical University of Eindhoven, Netherlands, J.A. Janssen, 1981.





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# Appendix B – Bill of Quantities

The table of quantities is for the materials required to build the shelter. It does not take into account issues such as available bamboo lengths and allowances for spoilage in transport and delivery.

| Item (Dimensions in mm) | Material Spec. | No. | 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 | 2.0 | 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 | 20.0 | m | |
| Bracing – 80 x 7.2 thick (L=3.5m) | Bamboo 2 | 10 | 35.0 | 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 | 7.0 | 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 | 16.0 | 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 | 6.0 | 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 |



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| | | | | | |
|---|---|---|---|---|---|
| Bamboo Pegs | Bamboo 2 | - | - | - | As required |
| Palm fibre rope | - | - | - | - | As required |
| **Tools Required** | | | | | |
| Spade | - | 1 | 1 | Pieces | |
| Drill | - | 2 | 2 | Pieces | |



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# Appendix C

**Calculation Plan**

1) Loading

The seismic and wind loading has been calculated using data from the Indonesian Design Codes referenced in Section 1.7, along with methodology from the IBC 2009 and BS6399-2:1997[1].

The bamboo members have been checked using allowable stress design (ASD) to IBC 2009. The loads described in Section 1.8 have therefore been combined using the un-factored load cases described in the IBC (International Building Code) 2009, Section 1605.3.1 for Allowable Stress Design (ASD). The bamboo members have been checked using allowable stresses calculated from the density (see Section 1.6.1 for further details and references).

2) Stability

   a. Overturning forces on foundations due to lateral seismic and wind loads

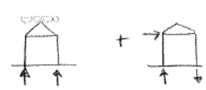
   b. Transverse Stability – key members: columns, primary beams and bracing

   c. Longitudinal Stability – key members: columns, primary beams and bracing

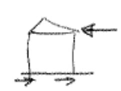
3) Foundations have been checked for the following cases accounting for the effects of overturning:

   a. Bearing pressure (dead loads + overturning)

   b. Uplift (wind uplift + overturning)



   c. Base Shear (worst case from wind/seismic)



4) Primary Members

Check members for a combination of vertical and lateral loads, including: columns, roof and eaves beams, roof truss, floor beams and bracing.

5) Secondary Members

Check members for a combination of vertical and lateral loads, including: roof purlins, floor joists, wall transoms/secondary columns, roof tiles, flooring and wall cladding.

6) Fixings – assumed to be strong enough to transmit all member forces. Connections have been assumed to be pinned for analysis, including at column bases.

[1] See Section 1.8.3.



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