

Transitional shelters

Eight designs

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Transitional shelters – Eight designs

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Transitional Shelters

Eight designs

Strategy 2020 voices the collective determination of the IFRC to move forward in tackling the major challenges that confront humanity in the next decade. Informed by the needs and vulnerabilities of the diverse communities with whom we work, as well as the basic rights and freedoms to which all are entitled, this strategy seeks to benefit all who look to Red Cross Red Crescent to help to build a more humane, dignified, and peaceful world.

Over the next ten years, the collective focus of the IFRC will be on achieving the following strategic aims:

- 1. Save lives, protect livelihoods, and strengthen recovery from disasters and crises**
- 2. Enable healthy and safe living**
- 3. Promote social inclusion and a culture of non-violence and peace**

Foreword

Acknowledgements

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This book was the output of the Transitional Shelter Task Group of the Red Cross and Red Crescent. It is based on the projects and contributions from the following national societies:

- American Red Cross
- Australian Red Cross
- Bangladesh Red Crescent
- Belgium Red Cross
- British Red Cross
- Canadian Red Cross
- Finish Red Cross
- French Red Cross
- Haitian Red Cross
- Italian Red Cross
- Myanmar Red Cross
- Netherlands Red Cross
- Palang Merah Indonesia
- Pakistani Red Crescent
- Peru Red Cross
- Spanish Red Cross
- Swedish Red Cross
- Swiss Red Cross
- Vietnam Red Cross

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1 How to use this book

This book contains reviews by structural engineers of transitional shelter designs that have been built in significant numbers. It is intended that this information will support the early stages of shelter programmes and inform transitional shelter decision making.

The shelters in this book **should not be used without being adapted to the context**. Inclusion of shelter designs does not mean that they have been endorsed by IFRC.

Shelter is more than a design. Designs should be developed as part of the implementation of a shelter strategy.

Acceptable risk

As transitional shelters are a balance of factors, including safety, lifespan, timeliness and cost (see section [A.1 Deciding to build transitional shelters](#)), they are seldom perfect from a structural perspective (see analyses in [Sections B.1 - B.8](#)). However, designs that are not perfect structurally can be appropriate technical responses given the constraints of a situation.

Shelter practitioners must make informed decisions based on what is an **acceptable level of risk**. Critically, shelters must not increase the threat to the lives of those living within them.

1.1 What is in this book?

This book contains the findings of technical reviews of eight transitional shelter designs. It is divided into sections:

- **Section A** discusses transitional shelter design briefs, includes a programming checklist and explains how the shelters in this book were reviewed.
- **Section B** contains summary findings of the technical reviews for the eight shelters.
- **Section C** contains design details for foundations, walls and roofs.
- **Annexes** contain details of materials, a template design brief, conversion tables, a glossary, and references.

1.2 What is not in the book

This book **is not a guideline on transitional shelter programming**. However, [A.3 Checklist for transitional shelter projects](#) provides an overview of key programmatic issues. Broader issues surrounding shelter projects such as community mobilisation, land and WASH components of shelter programmes are not included in this book.

The book references external guidance wherever possible, and does not focus on other aspects of the shelter programmes from which the designs came.

This book does not discuss shelter project processes. It focuses only on shelter design and specification issues

1.3 Audience

This book is targeted at people within the Red Cross and Red Crescent movement working in the emergency and early recovery phases after a natural disaster. The primary audience is shelter delegates. It is also intended to inform those planning and managing shelter programmes. It is assumed that readers have a strong understanding of the need for participation and experience in ensuring the close involvement of disaster affected people.

1.4 Criteria for selection of designs

The following criteria were used to select the shelter designs in [Section B](#) of this book.

- The project had already been successfully implemented.
 - Significant numbers of the shelters have been built and were not pilot designs.
 - Each shelter took a maximum of three weeks of construction on site.
 - Each shelter was able to last the entire transitional period until durable solutions were possible.
 - Accurate technical information was available.
 - The shelters were appropriate for the people for whom they were built. They also illustrated flexibility of use, encouraged efficiency of design, and could withstand local hazards. They used materials which could be incorporated into longer term recovery shelter options.
-

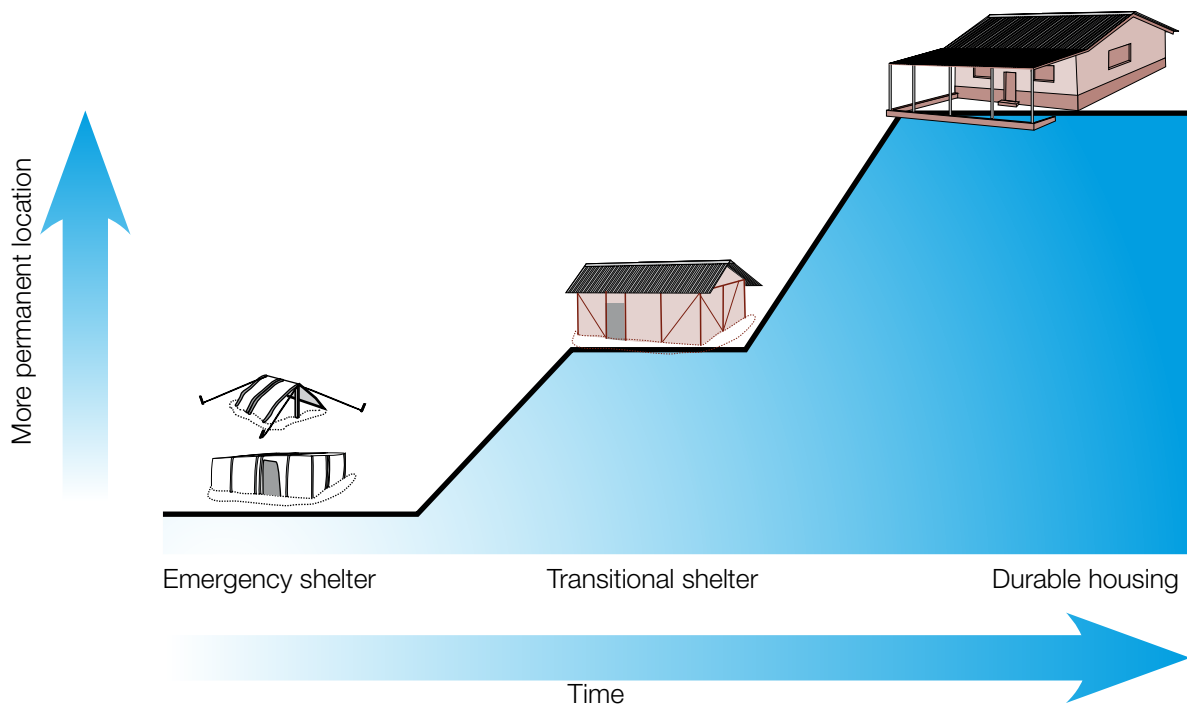
2 What is a transitional shelter?

In this book, we define transitional shelters as:

“Rapid, post disaster household shelters made from materials that can be upgraded or re-used in more permanent structures, or that can be relocated from temporary sites to permanent locations. They are designed to facilitate the transition by affected populations to more durable shelter.

Transitional shelters respond to the fact that post disaster shelter is often undertaken by the affected population themselves, and that this resourcefulness and self-management should be supported.”

This definition is adapted from: Sphere Shelter and Settlement Standard 1: Strategic Planning, Guidance note 6 (📖₁₆ Sphere Project, Sphere)



Transitional shelters can support disaster affected people between the emergency and the time when they are able to rebuild longer term housing. If well designed, the materials from the transitional shelters can be re-used for housing.

In this book we focus on transitional shelters as structures and products. Transitional shelters should be part of an ongoing sheltering process which is discussed in documents such as 📖₁₆ Sphere Project, Sphere, and 📖₁₅ Sheltercentre, UN, DfID, Shelter after Disaster.

For more on emergency shelter please refer to: 📖₁₂ IFRC, The IFRC Shelter Kit and Annex I.2 Template Design Brief.

Section A

Context and Design

This section puts transitional shelter design in context and focuses on the design brief for a transitional shelter (A.2). The process that is used in this book for checking the structures of a transitional shelters is summarised in A.4. Programmatic issues in transitional shelter projects are briefly addressed in a checklist in A.3, but are not the main emphasis of this book.

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A.1 Deciding to build transitional shelters

A.1.1 Are transitional shelters the answer?

Following a disaster, affected people often begin repairing their houses or permanently re-building. In some cases however, building transitional shelters is a required step to support shelter recovery following a disaster.

There might be many ways of supporting affected people find suitable shelter. Building transitional shelters might be one of them. Examples of many different types of shelter projects can be found in ([17](#), UNHABITAT, IFRC, Shelter Projects 2009)

Good assessments ([7](#), IFRC, Guidelines for Assessment in Emergencies) are required for all shelter projects. Issues such as land availability, access to water, and livelihoods must be assessed.

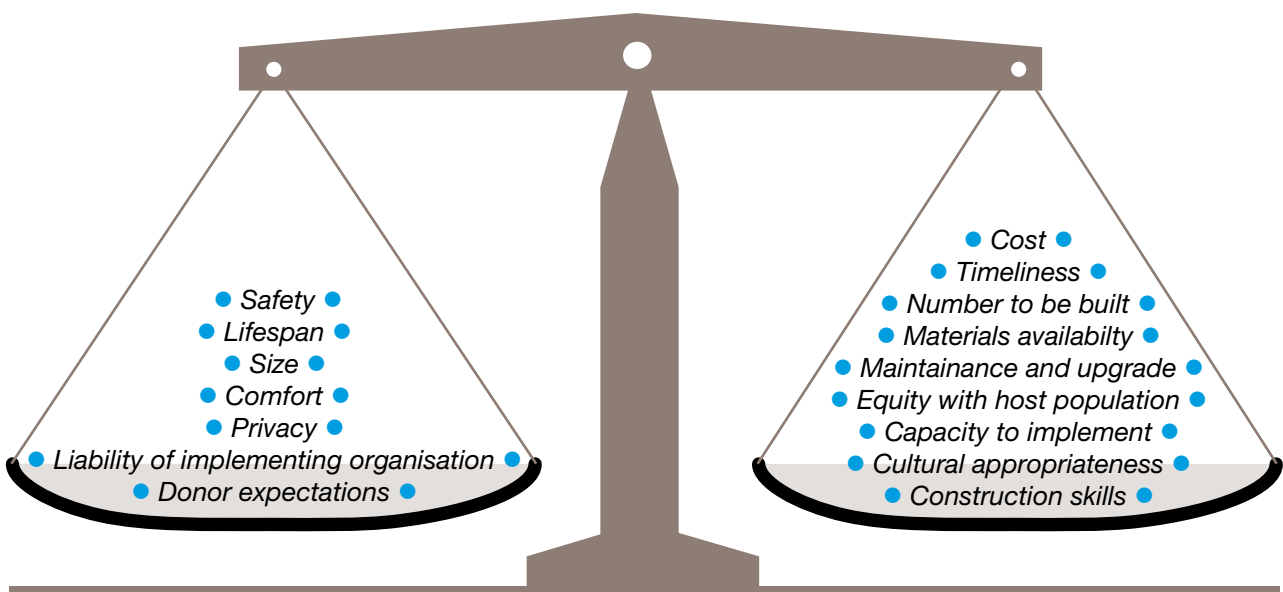
Have you thought of which other types of intervention might be appropriate?

"We built 200 beautiful shelters, but 500,000 people lost their homes.. We supported 0.2% of those in need of shelter. There was no money left to support durable reconstruction"

A.1.2 Transition to what?

Transitional shelters are intended to provide shelter between an emergency and the time when durable housing is completed. However, organisations often do not have the resources to build durable shelters after a transitional shelter response.

Before beginning a transitional shelter programme, ensure that there is a strategy in place. The strategy should consider all settlement options ([15](#), Sheltercentre, UN, DfID, Shelter after Disaster) such as those who are staying with host families. It should also include provision to support people to find durable housing.



A successful transitional shelter design must balance many factors. Design solutions are often specific to the context, and as a result no single design is suitable for all responses.

A.2 Designing a shelter

A.2.1 Appropriateness

If a shelter design is appropriate, it reflects the needs, local culture, vulnerability and capacities of the affected community and the resources available.

As every context is different, so shelter designs must be adapted to each location, response and project. What might be a good solution in one location may not work in another. However, one of the key features of transitional shelters is that they can be relocated, they can be upgraded and that the materials can be re-used.

Section B includes a diversity of shelter designs from comparatively high technology imported steel frames (B.7, B.8 and B.9) to simpler structures using local materials (B.2).

“Before the earthquake, my house was made of sticks with an iron roof. It was too lightweight to be damaged by the earthquake. My wealthier neighbour’s house was made of cement block. My neighbours have now received a Transitional shelter that cost \$3000. I have received nothing.”
Is this response appropriate?

A.2.2 Developing a transitional shelter design brief

What is a design brief?

As soon as the decision to start a transitional shelter project has been made, the first step is to develop a design brief. A design brief is a document that defines the performance of the shelter. The design brief allows shelter designs to be verified against key criteria such as safety and cost. A transitional shelter design brief must balance the ideal building from a structural perspective with constraints such as limited time and budgets.

See [Annex I.2](#) for a template for a design brief.

Participation, consultation and coordination

The design brief should be developed through consultation with the people affected by the disaster. The design brief should also be developed in consultation with the government, the shelter cluster or any other coordination mechanism that might be in place, and reference existing building codes and standards.

Coordination is required to improve consistency between organisations and between sectors of response within organisations. For example, transitional shelters should not be built without drainage, so coordination is required with WASH (Water Sanitation and Hygiene Promotion) activities.

Who builds?

The shelter owners will have different skills and time pressures to build than a contractor or a supporting organisation will. As a result, the shelter design brief will have to take into account who is building the shelter.

A.2.3 Relocation, re-use and maintenance

Transitional shelters should be designed so that they can be relocated, or the materials from which they are built can be re-used. This allows them to be built rapidly before land ownership is finalised, and also allows funding from emergency and transitional phases of response to serve affected people for the longer term.

Once construction is complete, consider what longer term support will be required to maintain the shelters and support the people living in them. This support might include toolkits, trainings on maintenance or safer construction. It might also include lighting, solid waste management, livelihoods, or other support.

“Because I could move my shelter, I was able to build it even though land ownership was still in dispute”

A.2.4 Hazards, risks and safety

Transitional shelters designs must not increase the vulnerability of occupants to natural hazards such as earthquakes, storms or disease.

Location and hazards

Although choice of land (A.2.11 Land, sites and services) is often limited, the location of a transitional shelter is often more important than its design (see C.1 Hazards and design details). Poorly located transitional shelters can increase the risks faced by occupants, while well located transitional shelters can reduce exposure to hazards such as fires, tidal surges or landslides.

Transitional shelters cannot be designed to withstand tsunamis, landslides, volcanos, or very serious flooding. Instead they must be built on safe sites.

Shelters must not increase risk of death or injury

Transitional shelters must be designed so that if they do fail in a future disaster they are less likely to kill or injure the people living in them (A.4 Checking the structures of transitional shelters). As an example, organisations often build timber framed structures following an earthquake. This is because lighter weight timber structures are less likely to cause fatalities than collapsing masonry structures in future earthquakes. However, lightweight structures can be more vulnerable to strong winds.

It is to be expected that people occupying shelters will make upgrades and alterations as time passes. Ongoing guidance and monitoring is required to ensure that these alterations do not compromise the original structure.

Defining acceptable risk

When designing for hazards, decide what kind of event is likely to occur within the lifespan of the shelter. If a one in 500 year event struck, you would most likely be dealing with another major disaster and might not reasonably expect transitional shelters to survive when the majority of the remaining housing stock also collapsed. However, if the area floods or has high winds annually, then try to account for this in the design. (See also A.4.3 Classification of Hazards)

*It is not realistic to expect a transitional shelter to withstand a weather event or an earthquake of the scale that caused houses to collapse in the first place.
BUT - We MUST design and build the shelters not to risk lives if they fail*

If the structural engineering standards are set too high, there is a real risk that the transitional shelter project will be costly and slow to implement (see A.2.6 Life span). As a result, families will risk remaining in inadequate shelter, and become exposed to new risks such as oncoming rainy season or disease. There is also a risk that the shelters will be too late and no longer meet the needs.

Design to promote best practice

Simple hazard resistant details can be part of the design and can encourage learning. For example, in an earthquake zone, build doors of lightweight transitional shelters away from the corners. This will promote good practice for when families later move towards heavier construction.

A.2.5 Timeliness and construction speed

When planning to build shelters, talk to logisticians about the practical aspects of transport, storage and procurement of materials. This discussion should include an analysis of which materials can be procured in local markets and which need to be imported.

Review the supply of skilled labour. Even if a single shelter takes a few man-days to build, building a significant number of shelters will usually take many months.

We should have spoken with the logisticians when we were designing the shelters. Now we are late...

The more complex a design is, the more training and resources will be required to build it. This can lead to delays. Many times transitional shelters have been completed after families have rebuilt their own houses.

A.2.6 Life span

Transitional shelters must be durable enough to last the entire transitional period from emergency until reconstruction.

The design brief should specify the number of months that the shelter is intended to last, given the conditions at the locations in which they will be built. When agreeing the design life of the shelter, remember that if a shelter must last for a long time it may be more expensive and slower to build.

Where possible, materials should be reusable and upgradeable, even if families are relocated to different sites. For example using more durable qualities of timber and bamboo will allow them to be reused in the permanent house.

The specification of a shelter should include detail on the quality of materials required, so that the intended design life of the shelter can be achieved. Materials and design should allow for easy maintenance and upgrade.

If too long a lifetime is specified, the shelter risks being too expensive and too slow to build.

If the designs are not properly checked, the shelters might not last long enough

A.2.7 Size and shape

The amount of covered living space that a shelter must provide is a critical determinant of the shelter design, logistics requirements, and cost. Organisations need to agree lower and upper bounds to reduce conflict between project sites.

A minimum of 18m² covered living space is often agreed. This is based on a family size of five and 3.5m² per person, quoted from Sphere indicators ([Sphere Project](#), [Sphere](#)). However, providing 3.5m² per person does not imply that Sphere has been met, nor does Sphere demand that this amount of space must be provided in all circumstances.

*Sphere says a lot more than what the size of a shelter should be...
READ IT CAREFULLY!!*

Example: Locally agreed standards: Earthquake response in Haiti 2010:

The space in urban centres was extremely limited. Building larger shelters would have forced people to move. This would have forced people to relocate away from their claim to land as larger plots would be required.

It was agreed that a transitional shelter kit for use with small groupings of shelters in urban areas should provide a minimum of 14m² per family. The provision of such small shelters could be considered as there was:

- A plan to mitigate against the impacts of crowded living conditions on inhabitants. This plan would include support with sanitation, drainage and hygiene promotion, access to livelihoods, health and child care.
- A plan to increase the covered shelter area to 3.5m² per inhabitant in an agreed timeframe.

When agreeing the covered living space, also pay attention that the space does not have so little headroom as to be unusable. Be aware that “covered living space” also includes external living areas such as verandas.

A.2.8 Privacy, security and cultural appropriateness

Shelter designs, layouts and orientations differ between countries, and even with people of different ethnicities in the same country. As a result, transitional shelter designs, their layout and their orientation must be adapted to the local culture.

In general, the design brief should aim to encourage flexibility in design such as allowing occupants to add internal divisions for privacy. Remember to consider where activities such as cooking and cleaning take place and what allowances you can make for this in the design.

In many contexts, additional features such as lockable doors may be required to provide the most basic security.

Shelters are often built by the affected population themselves. Support this resourcefulness and self-management.

Even a thin plastic sheet can help protect occupants and their belongings.

A.2.9 Ventilation and thermal comfort

The weather varies significantly between disaster locations and with seasons. For large scale disasters the weather can vary significantly across the disaster affected area.

People from different cultures will find different buildings comfortable, and be accustomed to different temperatures or humidities. Design details such as verandahs, and high ceilings can make shelters cooler in hot weather, whilst taking care to reduce air gaps, or including a lobby area can help to keep shelters warmer in cold weather.

Transitional shelter designs should provide protection from the anticipated extremes of weather, or they should be designed so that they can be upgraded with a simple winterisation kit.

Aim to design shelters to the climate and traditions

A.2.10 Environment

A large scale transitional shelter construction project requires large volumes of materials. Consider the environmental impacts of materials being used for shelters, and look at ways to mitigate them. For example 5000 transitional shelters will require more than 2500m³ of timber. Procuring the timber locally might negatively impact upon the local environment, but importing the timber, or using steel may only offset the impacts to another location.

A.2.11 Land, sites and services

Land ownership

Transitional shelters are often used as an interim solution until more formal land access can be established. As a result they may end up being built on marginal land, whether at displacement sites or where people lived before.

In some cases it may be necessary to sign agreements with the authorities to guarantee a minimum period of use. Wherever possible, funds should be set aside for follow up support in identifying land.

See [19 UNHABITAT, Land and Natural Disasters](#) for more on land issues.

Access to Services and livelihoods

Do not forget water and livelihoods! Shelter projects will ultimately fail if people cannot find water or a means to live at the locations where their shelters are built.

I have an excellent shelter, but there is no water so I cannot live here...

A.2.12 Cost / budgets

The money available per household for each disaster varies, and is often a critical determinant of shelter cost and ensuing design. As a result, there are significant variations in costs of shelters between responses. To illustrate this, the materials costs of the shelters in this book vary from 225 CHF to over 4500 CHF per shelter.

When judging the cost per shelter, compare the cost of each shelter with the disposable income of affectees and host population. Support given to families in building transitional shelter is usually many times that provided to them in livelihoods programming.

Some risks of a transitional shelter being at too high or too low a standard and cost	
Too high	Too low
Programmes risk being slow, and the shelters being delivered too late for the transitional phase of a response.	Shelters may risk collapse and inhabitants risk injury.
Number of shelters that you can afford to build is small, limiting the number of people that the project can support.	Shelters may be refused by affectees.
Shelters risk being to a higher standard than for households who will not receive a shelter. This can lead to divisions in society and increased dependance for future disasters.	The quality of materials is low and not sufficiently durable to be reused in a permanent house.
	The design life of the shelters will be too short.

A.3 Checklist for transitional shelter projects

Be aware that the situation will change quite rapidly after a disaster as people help themselves, and markets and roads reopen. To deal with changing contexts:

- ↘ Transitional shelters should be designed to be upgradable, and components should be repairable.
- ↘ Transitional shelter projects must be adjusted continually according to ongoing monitoring and evaluation.

Remember that for transitional shelters to be useful, an informed decision to distribute them must be taken as quickly as possible.

A.3.1 Assessment

Needs

- ↘ Do the affected people need support with transitional shelter construction?
- ↘ Would other types of support such as tool kits, vouchers, cash distribution, or supporting markets meet shelter needs more effectively?
- ↘ Who will the shelters be for? Will there be social impacts of providing shelters free of charge to a selected population but ignoring others?
- ↘ What coping mechanisms do people have?
- ↘ Have people been consulted as to what materials they most require?
- ↘ Are there any vulnerable individuals or groups within the community? Do transitional shelters meet their needs?
- ↘ How do the transitional shelters compare to how people were living before?
- ↘ What resources do people have and what can they salvage from their old homes?
- ↘ What is the cost in comparison to shelters used by the non-affected population and the affected population?

Organisational capacity

- ↘ Does your organisation have the capacity to properly assess the needs of the most vulnerable affectees?
- ↘ Does your organisation have the capacity to adequately and promptly implement the transitional shelter construction project, considering your limitations?
- ↘ What additional staffing and training will be needed to implement the programme?
- ↘ Does your organisation have the funds to build sufficient transitional shelters to make a significant impact?

Community capacity

- ↘ Who will build the shelters?
- ↘ Are local carpenters and masons available?
- ↘ What is the level of participation of the affected communities?
- ↘ Do all affected people have the skills to build the shelters?
- ↘ Do all of the affected people have the skills and resources to maintain the shelters?
- ↘ What support will be available to those who are not able to build their shelters?
- ↘ Is there a construction season? Are there times of year when people do not build as a result of weather or other livelihoods activities?

Strategy and coordination:

- ↘ Do transitional shelters fit in with the activities of the government, coordination mechanisms, and other organisations?
- ↘ Do transitional shelters fit in with your organisation's other sectors (such as livelihoods, water and sanitation)?
- ↘ Would it be more effective use of resources to move straight into recovery?
- ↘ Is funding going to be made available in the future for permanent housing?

Skills and staffing

- ↘ Do you have a team in place to implement or monitor the project?
- ↘ Are there other organisations that you could form partnerships with?

Land and settlement

- ↘ Do the majority of the affected people have access to land on which to build?
 - Is the land safe?
 - Is the ownership of the land agreed?
 - Is the ownership of the shelters agreed?
 - How long will people be able to remain on the land?
- ↘ Are basic services such as water available at the shelter sites?

See also
the checklist
in the shelter
and settlement
chapter of
Sphere...

Materials and alternatives

- ↘ Which materials do people already have available, or can they salvage? (Many disasters will knock houses over but will not lead to all of the materials being lost)
- ↘ Will the transitional shelter be suitable to integrate with the existing construction culture so that people can repair and maintain them?
- ↘ Where will the materials come from, and will people be able to maintain them?
- ↘ Is the design adapted to the available sizes of the materials?

Hazards

- ↘ Can people build safely with sufficient support?
- ↘ Are the transitional shelters appropriate for the climatic conditions?
- ↘ Are proposed shelter locations safe? (Often the only available land is vacant because it is hazardous.)

Logistics and distribution

- ↘ Have you consulted with the logistics and procurement team concerning the best options and sources for procurement?
- ↘ Is local transport and warehousing available?
- ↘ Have you consulted with the logistics and procurement team concerning availability of materials, specifications and the time it takes to deliver?
- ↘ Have you consulted with the logistics team how distributions of materials will take place?

Time

- ↘ How long will the shelters actually take to build (including materials transportation)?
- ↘ How long are the shelters expected to last?
- ↘ Will transitional shelters be built soon enough for them to be useful?

A.3.2 Project planning and implementation

- ↘ Have you formed a project Plan of Action?
- ↘ What are the plans for procurement, construction and project management?
- ↘ Is there a **design brief** (See I.2 [Template Design Brief](#))?
- ↘ What training and technical support will you be offering to project staff and to disaster-affected people?
- ↘ Have you budgeted for logistics and staffing costs?

Monitoring and evaluation

- ↘ Who will be conducting ongoing monitoring of the distribution and effectiveness of the transitional shelters?
- ↘ Who will evaluate and monitor the project?
- ↘ How will you monitor the project?
- ↘ How will you evaluate the project?
- ↘ Will you be conducting a survey to monitor satisfaction among those who receive the shelters?
- ↘ Based on monitoring and ongoing assessments, are you prepared to adapt your plan?
- ↘ How will you monitor the impacts of transitional shelter on permanent housing?

A.4 Checking the structures of transitional shelters

A.4.1 Process

This section discusses how the structural aspects of transitional shelters in [Section B](#) of this book were checked. To check the shelters a three stage process was used. This is illustrated below:

- **INPUTS:** Information on the shelter was gathered. This included information on the broader context including the purpose of the shelter and where it was built. This determined the hazards and loads it would be exposed to and which building codes and standards are relevant. The shelter was then defined in terms of its geometry, stability system, member sizes and materials. When information was not available, assumptions were made.
- **CHECK:** The performance of the main elements of the structure was checked against relevant codes and standards ([A.4.2 Approach to codes and standards](#)).
- **OUTPUTS:** Annotated drawings of the as-built shelter, an associated bill of quantities, a summary of structural performance and recommendations for improvements were produced as final outputs.

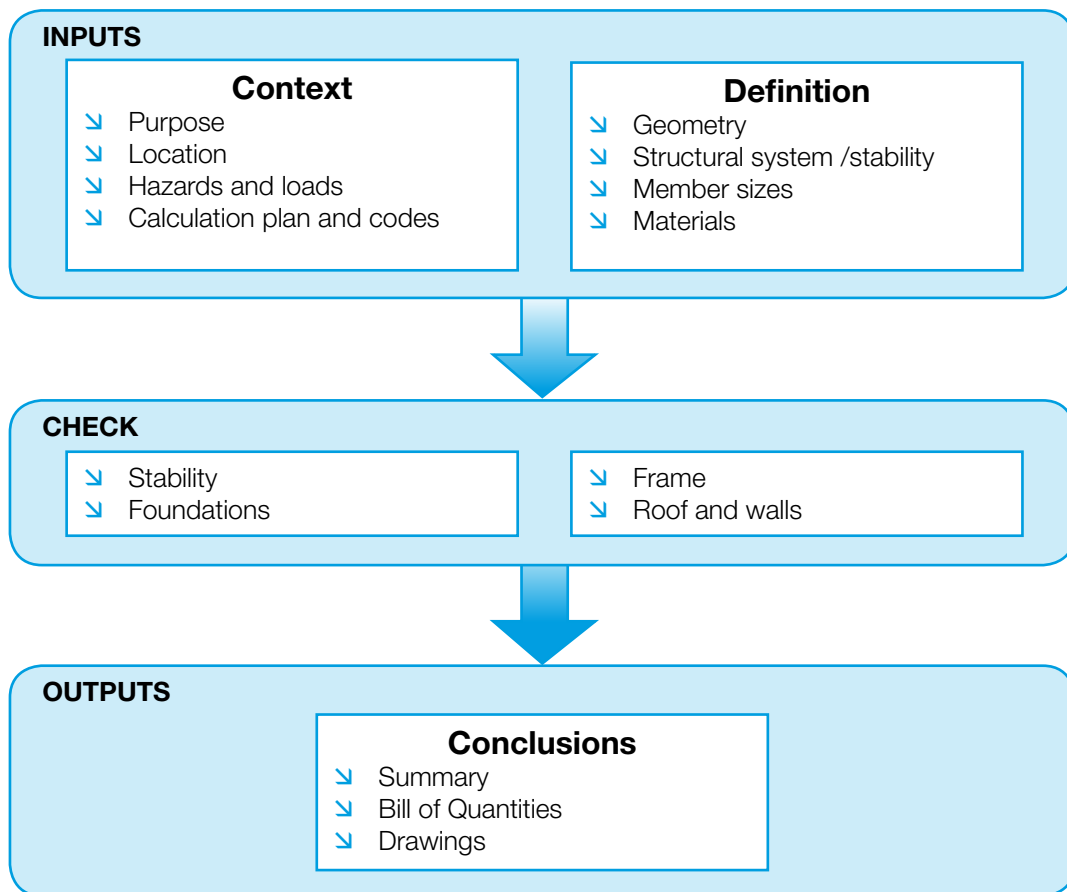


Illustration of the process by which shelters were checked

A.4.2 Approach to codes and standards

Codes used

The [International Building Code \(IBC\) 2009](#) has been used as a reference for the design checks on the transitional shelters. It is globally recognised and provides a good basis for calculating extreme loading cases such as earthquakes or strong winds. Other building codes ([Uniform Building Code \(UBC\) 1997](#) and [National Building Codes & Standards](#)) have been referenced when they are available or appropriate.

Risk to life or risk of structure being damaged

The performance of each shelter in [section B](#) was assessed 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, each shelter was also assessed on the risk of it failing or being damaged ([A.4.4 Classification of performance](#)).

Because most transitional shelters are lightweight, the risk that falling parts of the building would severely injure people is reduced. However, if a shelter is damaged, it will often need to be repaired or rebuilt.

Applicability of building codes to transitional shelter

For the shelter reviews in this book, design criteria have been developed based on the codes and standards discussed above. These criteria take into account the intended lifespans of the shelters.

Building codes are typically developed for permanent structures. They are not directly applicable to transitional shelters nor to post disaster situations. To be 'code compliant' every element of a structure must be checked against, and comply with, the criteria set out in the code. As a result, the structures in this book have been checked in the context of code requirements. Key assumptions and reasoning for interpreting the standards are stated in the "assumptions" sections for each shelter review ([see Section B](#)).

Shelter upgrades and improvements

Possible upgrades and alterations to improve structural performance are marked on the shelter construction drawings in [Section B](#). Further generic improvements to foundations, walls and roof are summarised in [Section C](#). Such recommendations will not necessarily make the transitional shelter 'code compliant', but they are straightforward measures for improving the performance of the structure.

Connections and workmanship

In addition to the overall design, the performance of a shelter is dependent on the quality of workmanship and connections between elements. These aspects are not covered in this book but are important considerations in delivering a transitional shelter programme.

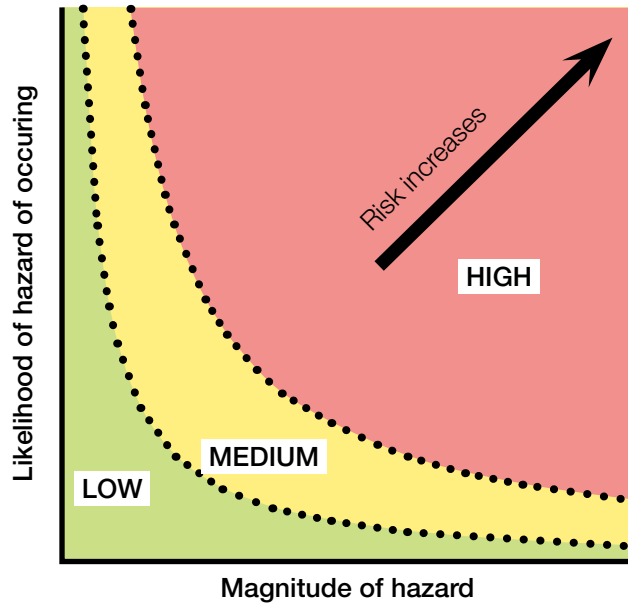
Soil type

For all calculations, a stiff soil type ([Soil Profile Type/Site Class D as defined in Uniform Building Code \(UBC\) 1997 – Volume 2 Table 16-J](#) or '[ASCE/SEI 7-10 – Minimum Design Loads for Buildings and Other Structures](#)', [Table 20.3-1](#)) has been assumed. However, in earthquake prone locations where liquefaction of the soil can occur, specific measures may be required.

A.4.3 Classification of hazards

Magnitude, likelihood and risk

For the purposes of this book, 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.



The risk is a combination of the likelihood of the hazard occurring and the magnitude of the hazard. Note that an event with a high likelihood can still be a low risk if the expected magnitude is low.

Earthquake

The classification of earthquake risk used in this book is based on the seismic design categories defined in [ASCE/SEI 7-10](#). Design for earthquake loads is derived from the Peak Ground Acceleration (PGA. [See Annex 1.4.1 Full Glossary](#)) for a 475 year return period. The PGA is then modified to reflect the soil and building type.


Wind

The classification of wind risk used in this book is based on [Uniform Building Code \(UBC\) 1997](#). This is expressed as wind speeds which is a parameter that can be used directly in design. These are related to the Saffir Simpson hurricane scale in the table below, which is approximate and for comparison only.

Flood

The classification of flood risk is based on knowledge of historical flood data and local weather effects, and is highly dependent on the local site conditions. Flood damage can be caused by both flash floods and standing water. Each type of flooding has a different impact on structures.

Hazard classification used in Section B for earthquake, wind and flood				
	Earthquake	Wind (approximate)		Flood
Hazard	Seismic Design Category *	Basic Wind Speed ** (km/hr)	Saffir/Simpson Hurricane Category	Risk of flooding
LOW	B	Less than 113	< 1	Low risk of flooding
MEDIUM	C	113 to 160	1-2	Medium risk of flooding
HIGH	D	Over 160	3-5	High risk of flooding

* This is based on  ASCE/SEI 7-10, Table 11.6-1 assuming Risk Category I (Table 1.5-1 representing a low risk to human life in the event of failure) and based on the modified PGA.

** The sustained 3 second gust speed at a height of 10m in flat open terrain for a 50 year return period (as defined in the  Uniform Building Code (UBC) 1997, Section 1616.


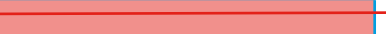
A.4.4 Classification of performance

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. It is not based on the risk of the structure injuring people if it does fail.


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

A.4.5 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 (A.4.4 Classification of Performance) of the shelter with respect to the hazards (A.4.3 Classification of Hazards) at the given location.


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

See A.4.4
Classification
of
Performance



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

See A.4.3
Classification
of Hazards



Structure is expected to fail under wind loads.

Section B

Analysis of the transitional shelters

This section provides the summaries of structural analyses that have been conducted on eight transitional shelters. The analyses are based on the process outlined in section A.4. For each shelter, basic summary information and a bill of quantities is provided. Drawings are annotated with potential design improvements and details that should be checked or monitored. For each shelter design, a performance analysis table is included. This compares the performance of the structure with the hazards where the shelter was built. Finally notes on potential upgrades are provided.

Contents

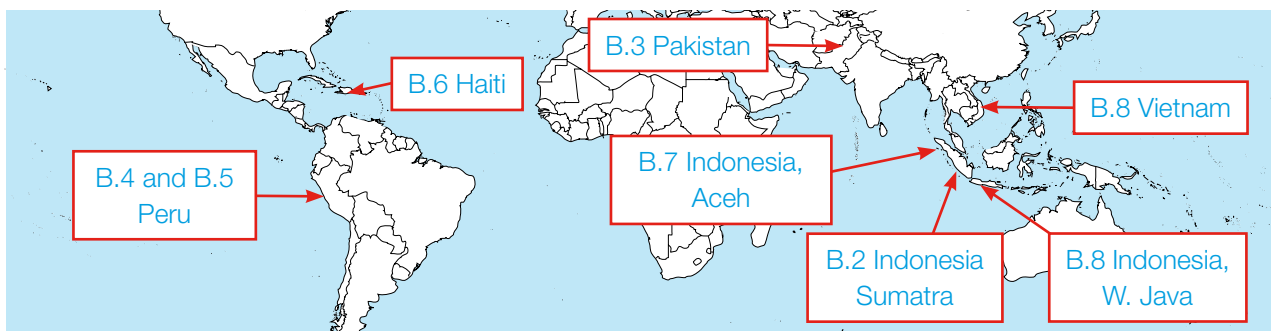
B	Overview of designs	25
B.1	Indonesia, West Java (2007) - Bamboo frame	27
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B.3	Pakistan (2010) - Timber frame	39
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B Overview of designs

Eight different transitional shelter designs are summarised and technically reviewed in the following pages. The designs have all been built in significant numbers by members of the Red Cross and Red Crescent movement following disasters. Criteria for inclusion can be found in [Introduction 1.4, Criteria for selection of designs](#)

The process by which the shelters were analysed can be found in [Section A.4, Checking the structures of transitional shelters](#).

It is intended that the drawings and bills of quantities in this section are used to inform the design process. However, they should not be used as standard designs, and they must not be used without local adaptation.



Bamboo frame



B.1 Indonesia, West Java

Transitional shelter design is a balance of factors, including safety, lifespan, timeliness and cost. As a result, the shelters are seldom perfect from a structural perspective. However, designs that are not structurally perfect may well be excellent technical responses given the constraints of a situation.

Timber frame



B.2 Indonesia, Sumatra, Padang (2009)



B.3 Pakistan (2010)



B.4 and B.5 Peru (2007)

Steel frame



B.6 Haiti (2010)



B.7 Indonesia, Aceh (2005)



B.8 Vietnam (2004)

B.1 Indonesia, West Java (2007) - 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

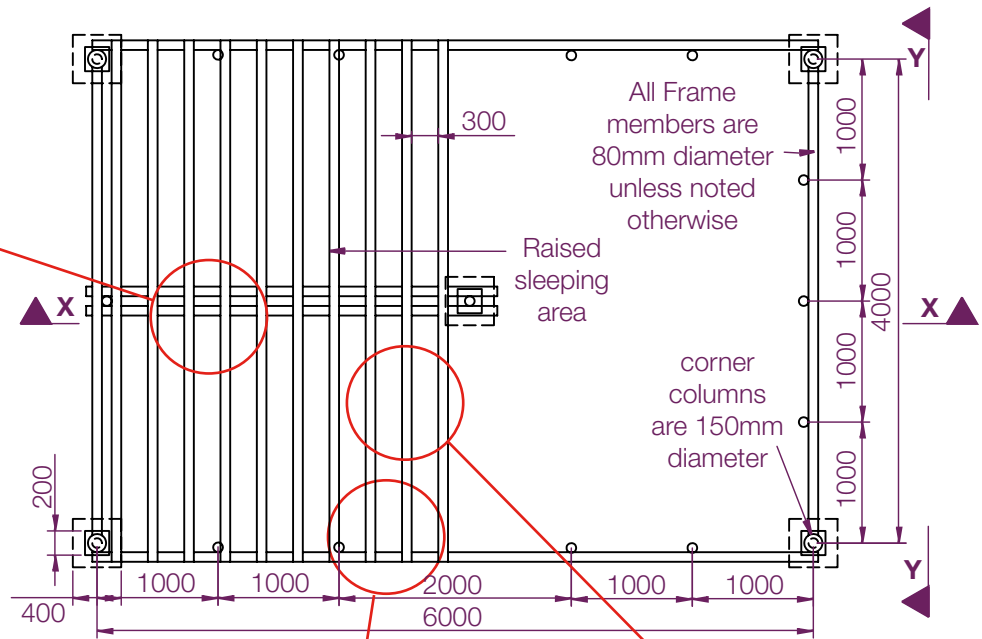
The rectangular bamboo frame structure measures 6m x 4m on plan and has a hipped roof of terracotta tiles laid on bamboo matting and laths. The frame has woven bamboo matting walls, a door at the front and two windows on each side. The back section has a raised floor which forms a sleeping area constructed 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 earthquake 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

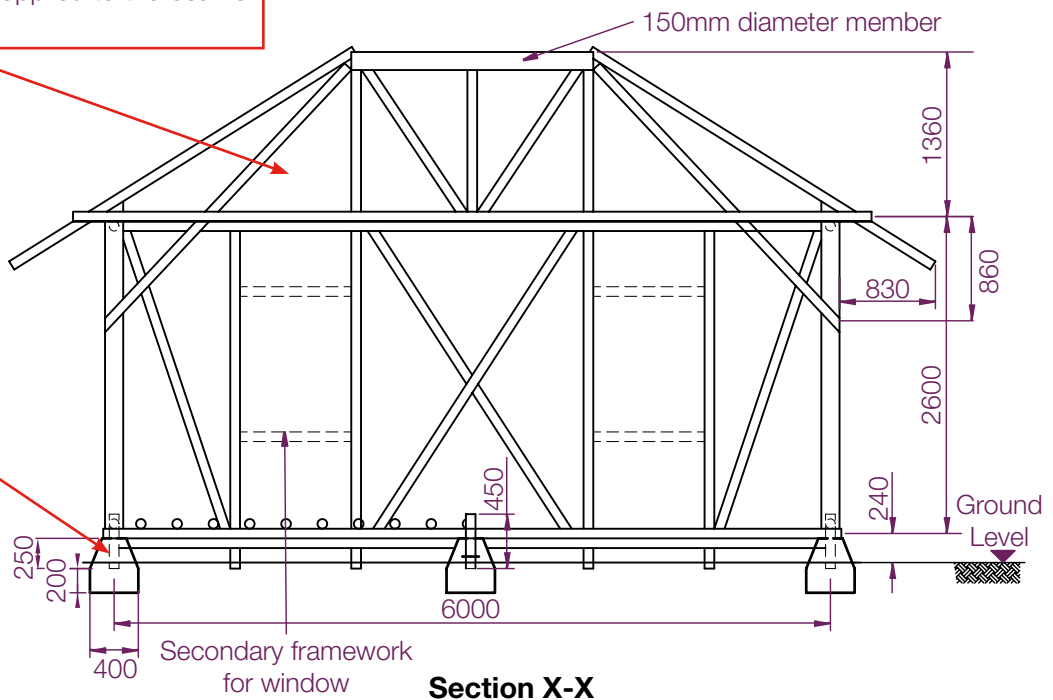
CHECK: The roof space must not be used for storage unless the members, connections and foundations are checked for the increased forces.

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.

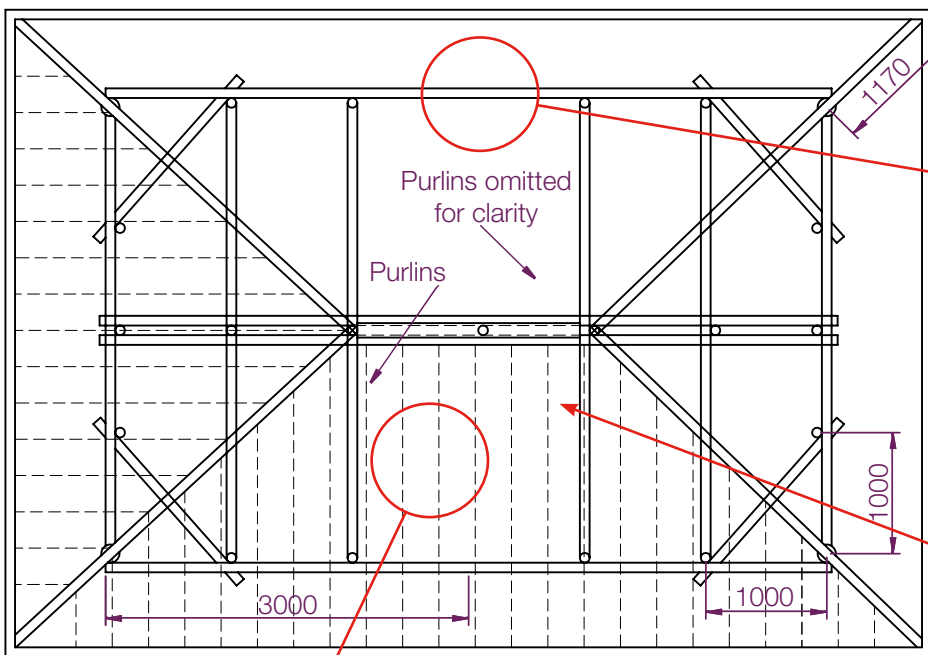
CHANGE: Strengthen beams at the base of the walls that frame the floor. This can be done by using two bamboo sections adequately connected so that the load is shared between them.

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: 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

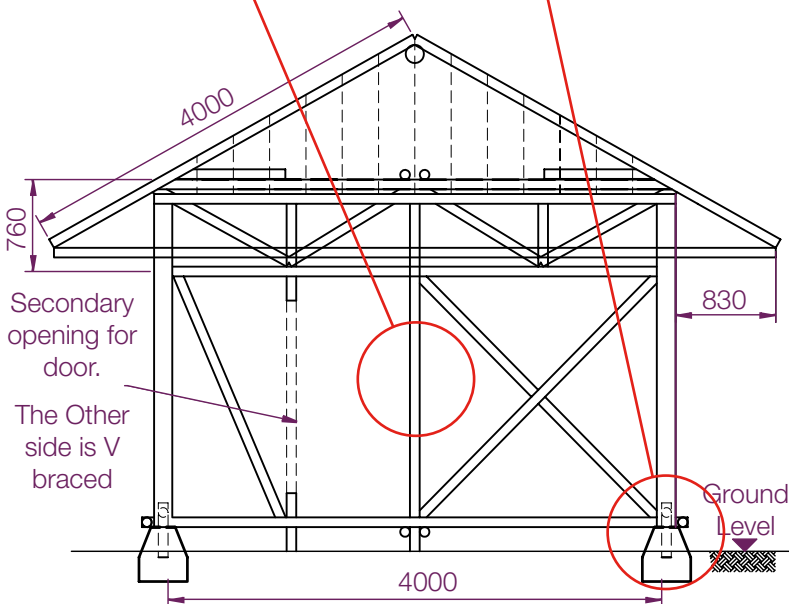
CHANGE: Add an additional column or strengthen eaves beams that support the roof to take gravity, wind and seismic loads. This could be done by using a larger section. The connections of the beams to the columns should also be strengthened in accordance with the new section sizes.

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.



Section Y-Y

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.



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/m³ and the elastic modulus is 17,000N/mm² 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 quantities

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	

B.2 Indonesia, Sumatra, Padang (2009) - Timber frame



Summary information

Disaster: Earthquake, 2009

Materials: Timber frame, palm fibre roof, concrete bucket foundations and palm matting wall panels

Materials source: Local

Time to build: 2 days

Anticipated lifespan: 6-12 months (residents expected it to last more than 24 months)

Construction team: 5 people

Number built: 7000

Materials cost per shelter: Approximately 350 CHF (2009)

Project cost per shelter: Approximately 500 CHF (2009)

Shelter description

The shelter is a timber framed structure with palm roofing and walls. It measures 4.5m x 4m on plan and is 3.35m tall to the ridge beam and 2.4m to the eaves. It has a pitched roof of 23.6 degrees.

There is no bracing, but some stability is provided by three portal frames tied together by horizontal members at ground, eaves and ridge level. Each portal frame is made up of two or three columns and a roof truss with rafters and corner bracing members. The corner bracing in the frames provides lateral stiffness. Secondary non-structural members include: floor joists, roof joists spanning between rafters and transoms to support palm matting wall panels. The shelter has a suspended floor. This is assumed to be coconut wood boarding spanning between the floor joists. The columns are embedded into concrete bucket foundations that sit directly on the ground.

Shelter performance summary

The shelter is constructed from locally sourced materials that are familiar to the occupants and do not require specialist tools or equipment for assembly. It can therefore be quickly constructed after a disaster and is relatively simple to maintain and adapt over time, depending on the needs of the occupants. This shelter offers a good short term design solution that is appropriate in areas vulnerable to high seismic and wind loading. The minor addition of bracing would improve its performance significantly and reduce deflections. However, if the shelter is upgraded, for instance by replacing the matting with roof sheeting or ply, then the roof trusses, frame and foundations will need to be strengthened, and the timber should have been treated.

Plans and comments

CHECK: The design and detailing of all connections is critical to the stability of the structure. It should be checked for local load cases.

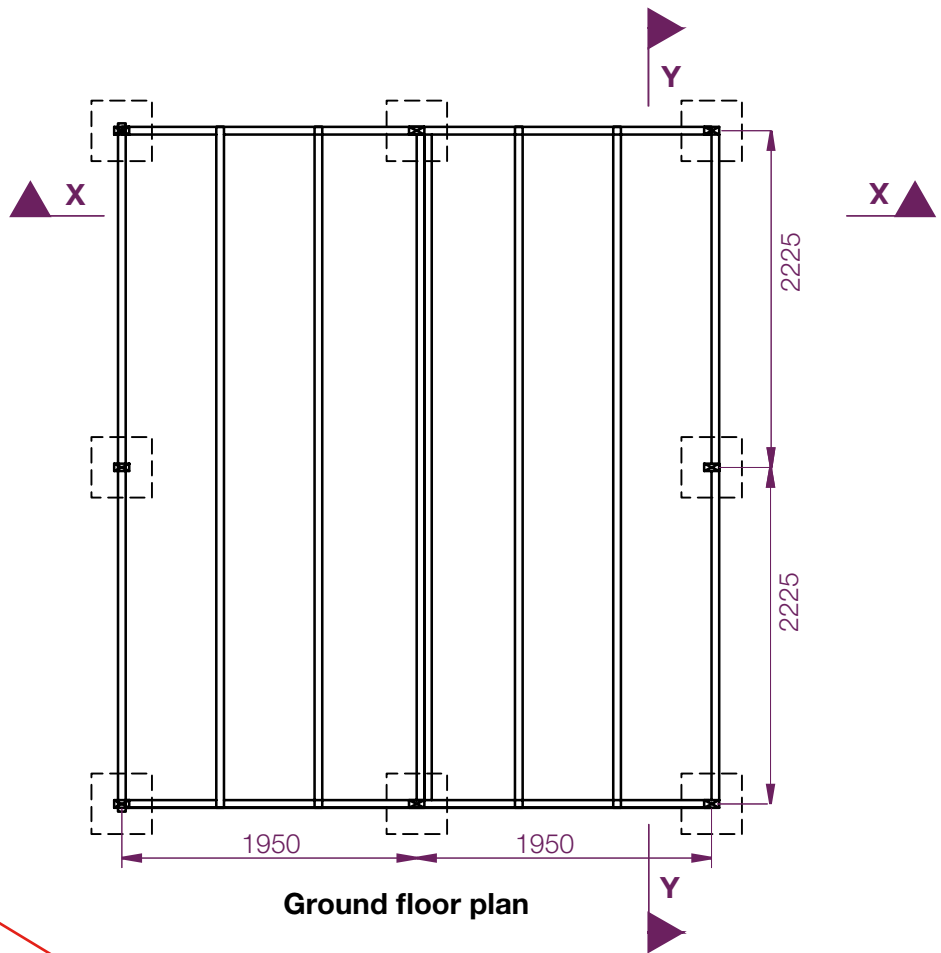
CHECK: The palm matting and thatch has been assumed to be sacrificial or permeable under wind loading. Where walls and roof are upgraded care should be taken to modify the structure to resist the additional wind or seismic loads.

CHECK: If roof or walls are upgraded the roof needs to be strengthened by adding an extra truss and increasing the size of purlins, rafters and the eaves beams.

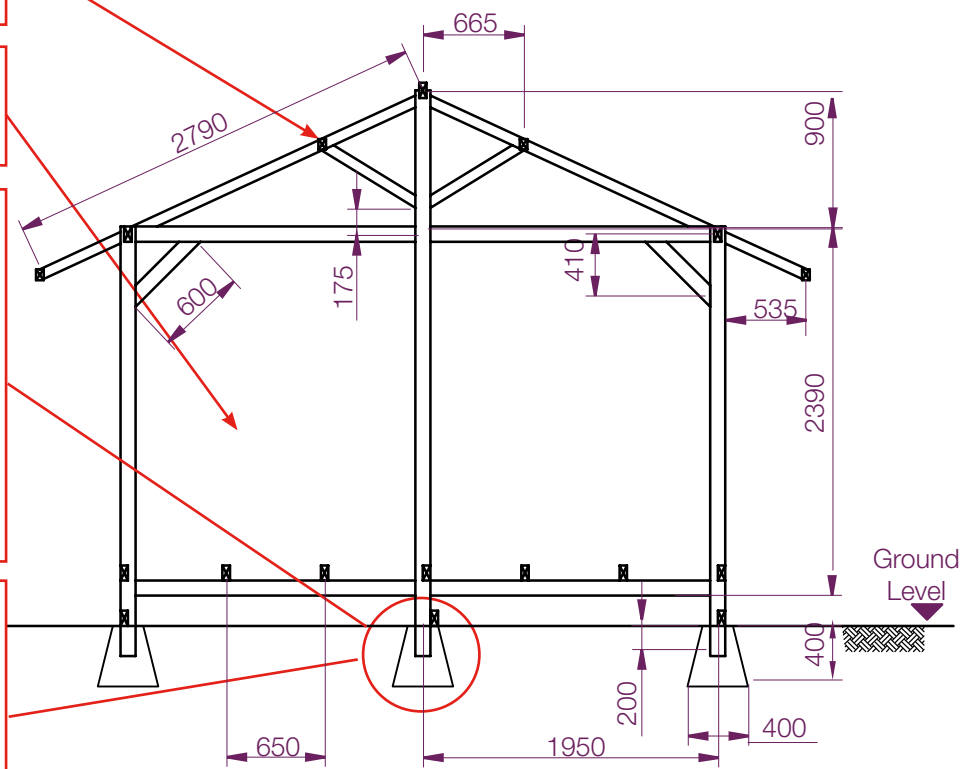
CHANGE: Add diagonal in-plane bracing to walls to improve lateral stability.

CHANGE: Columns should be properly tied to the foundations to prevent uplift of the structure. If the shelter is upgraded, use embedded base plate foundations or screw in ground anchors (Section C.1) to resist seismic loads and wind loads.

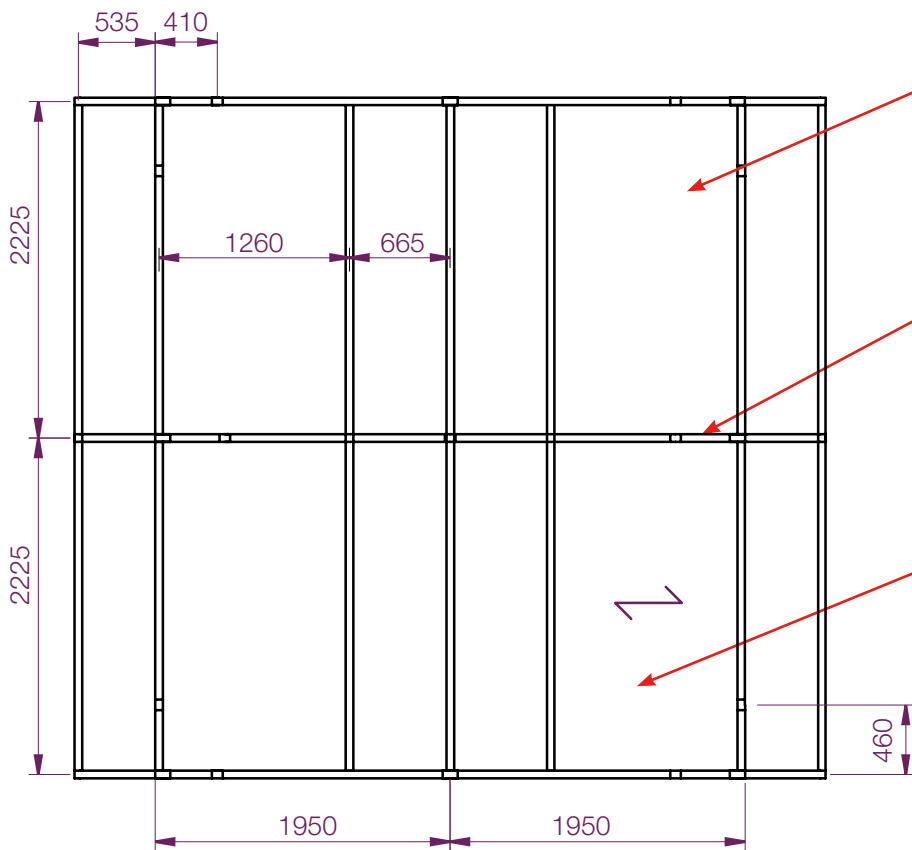
CHECK: In areas known to have high local wind pressures care must be taken to provide adequate foundations and member sizes to account for this.



Ground floor plan



Section X-X



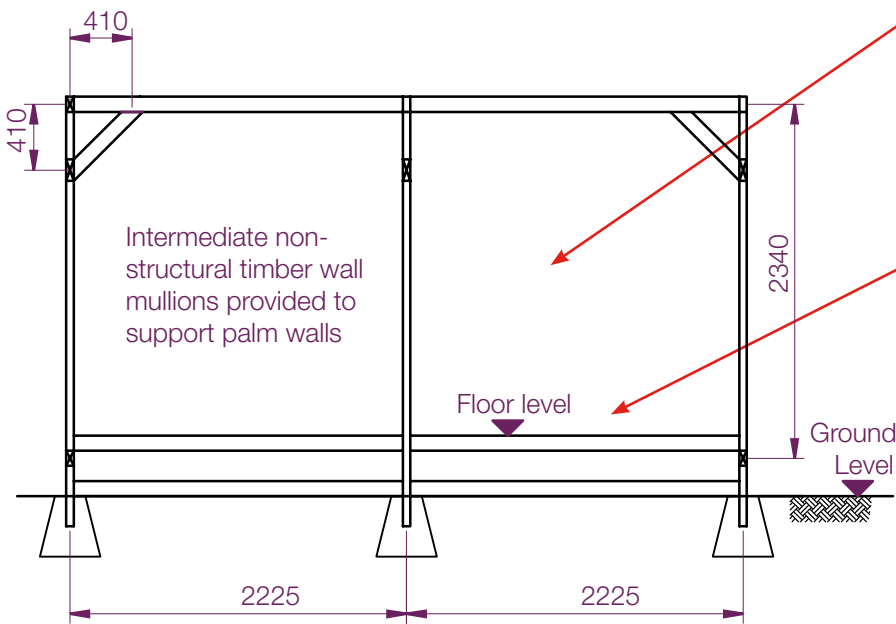
Roof Level Plan

CHANGE: Add bracing in the plane of the roof. Alternatively, use properly nailed roof sheets (see Section C.3) so that the roof acts as a diaphragm.

CHECK: If the weight of the roofing material is increased, the roof member sizes must be re-considered.

CHECK: The roof can be upgraded using corrugated iron sheeting: with a maximum span of 1.5m (Sheet 1, Annex I.1). If the roof is upgraded, then cross bracing will be required in the roof.

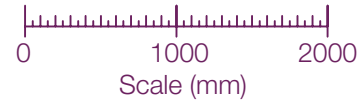
CHECK: Walls can be upgraded using 1/2" thick structural grade plywood (plywood 1 annex I.1.3). We have assumed that vertical framing is spaced at 600mm, and that the plywood is nailed with maximum 150mm spacing. If the wall is upgraded, then vertical framing members must be spaced closer together (24 members total rather than 16).



Section Y-Y

CHECK: Do not upgrade walls using masonry or cement blocks since heavy materials will perform poorly in an earthquake.

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



Durability and lifespan

The timber is untreated but is raised from the ground and so will resist termite attack.

The palm roof and walls will require replacement if damaged by the wind or if the expected life of the structure is exceeded. The shelter is intended to be demountable but the short lifespan of the untreated materials (with possible exception of the doors) mean that it is unlikely that they will be reused.

Performance analysis*

Performance under gravity loads is satisfactory. However the walls require bracing to provide lateral stability and columns must be tied to foundations.

Hazard	Performance
Earthquake HIGH	AMBER: Damage is expected as the structure has little resistance to lateral loads. However, it is very lightweight, relatively flexible and attracts low seismic loads. Overall it will pose a low risk to the lives of the occupants.
Wind LOW	GREEN: Assuming that the walls and roof are permeable to strong winds, the frame will not be damaged. If less permeable materials are added to the walls or roof, the frame should be braced, tied down to the foundations and strengthened.
Flood HIGH	GREEN: Specific checks against standing water have not been made in this analysis. However the raised floor helps to prevent flood damage.

*See section A.4.5 Performance analysis summaries

Notes on upgrades:

If the palm matting or thatch is replaced with less permeable materials (for example roof sheets) the shelter will experience greater wind loads. Maintenance and replacement of the matting walls is required to extend the life beyond six months.

Upgrading the roof with corrugated iron sheeting would result in higher uplift wind loads. As a result, roof members would need to be strengthened and the spacing between them would need to be decreased. Foundations would also need to be upgraded to prevent uplift and sliding of the shelter, and the structure would need to be tied to the foundations.

Upgrading the walls with plywood would mean that the structure is no longer permeable to wind. Additional wall members would be required, the size of the header beam would need to be increased, and further bracing would be required in the roof and the walls to resist the increased wind loads. The foundations would also need to be upgraded to prevent sliding and to prevent uplift.

Upgrading the walls with masonry or other very heavy materials is not recommended. It would attract high seismic loads causing the structure to perform poorly in an earthquake. Collapse of a heavy roof or unreinforced masonry walls poses a serious risk to the lives of the occupants.

Assumptions:

- ↘ The structure has been checked for a roofing material weight of 0.2kN/m². The maximum allowable floor live load is 0.9kN/m² which is appropriate for lightweight shelter design.
- ↘ The palm matting and thatch has been assumed to be sacrificial or permeable under wind loading. If the walls and roof are upgraded, care is required to modify the structure to resist wind or seismic loads.
- ↘ A stiff soil type (see Site Class D, [International Building Code \(IBC\) 2009](#)) has been assumed in analysis of the structure. Softer soil, or soil of variable quality may adversely affect the performance of the shallow foundations. 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. However, such damage is unlikely to pose a risk to the lives of the occupants due to the lightweight nature of the structure.
- ↘ The design and detailing of all connections is critical to the stability of the structure and should be checked for local load cases. It has been assumed that all connections can transmit member forces.

Bill of quantities

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	Material Specification See annex I.1	Quantity	Total	Unit	Comments
Structure -Foundations					
Portland Cement	Concrete	0.053	0.053	m ³	2 x 42.5kg bags
Sand/Gravel	Concrete	0.267	0.267	m ³	
Main Structure					
Floor Beams 5 x 10cm (L=4.00m)	Timber 1	2	8	m	
Truss Beams 5 x 10cm (L=4.00m)	Timber 1	3	12	m	
Floor Ties 5 x 10cm (L=4.50m)	Timber 1	3	13.5	m	
Ridge Beam 5 x 10cm (L=4.50m)	Timber 1	1	4.5	m	
Eaves Beams 5 x 10cm (L=4.50m)	Timber 1	2	9	m	
Floor Joists 5 x 10cm (L=4.50m)	Timber 1	7	31.5	m	
Columns 5 x 10cm (L=2.75m)	Timber 1	6	16.5	m	
Columns 5 x 10cm (L=3.65m)	Timber 1	2	7.3	m	
Wall Mullions 5 x 7cm (L=2.20m)	Timber 1	16	35.2	m	
Portal Brace 5 x 10cm (L=0.65m)	Timber 1	10	6.5	m	
Truss Brace 5 x 7cm (L=0.80m)	Timber 1	6	4.8	m	
Truss Brace 5 x 7cm (L=0.95m)	Timber 1	1	0.95	m	
Rafter 5 x 7cm (L=2.80m)	Timber 1	6	16.8	m	
Roof Joist 5 x 7cm (L=2.25m)	Timber 1	8	18	m	
Covering -Wall					
Palm mat walling 1 x 2m			40	m ²	
Covering -Roof					
Coconut leaf roofing			25.1	m ²	
Plastic Sheet 4 x 6m	Plastic	1	24	m ²	
Covering -Floor					
Floor Boards – 2.5cm thick	Timber 1		18	m ²	
Fixings					
Nails – 8d	Nails		3	kg	
Bolts – 10 -12mm	Bolts	18	18	pieces	
Hinges		8	8	pieces	
Tools required					
Concrete formwork bucket		8	8	pieces	
Hammer		1	1	piece	
Saw		1	1	piece	
Shovel		1	1	piece	
Pick axe		1	1	piece	
Spanner		1	1	piece	

B.3 Pakistan (2010) - Timber frame



Summary information

Location: Pakistan – Khyber Pakhtunkhwa and Gilgit-Baltistan (Northern Areas)

Disaster: Flood, July 2010

Materials: Timber frame, corrugated steel sheet roofing and plastic sheeting (bricks and roof insulation locally sourced by homeowners)

Material source: Timber: local. Roof sheeting: internationally and locally procured

Time to build: 1 day

Anticipated lifespan: 24 months

Construction team: 4 people

Number built: 10,000

Approximate material cost per shelter: 500CHF

Shelter description

The shelter consists of 7 triangular frames, connected by a ridge pole. The ridge pole is supported by two 2.74m high vertical columns at each end. The shelter is 4.3m x 5.7m on plan. It has a low (0.9m) brick wall constructed inside the frame to provide protection against flood damage and retain warmth. The roof is pitched at 44 degrees and is made of corrugated steel sheeting. The sheeting is nailed to purlins that span between the frames. The roof sheeting is laid on top of locally available insulating material and plastic sheeting. The foundation of the shelter is provided by burying the rafters and columns approximately 0.3m in to the ground on top of stone footings. Guy ropes over the roof sheeting have been used to help prevent uplift under wind loads.

Shelter performance summary

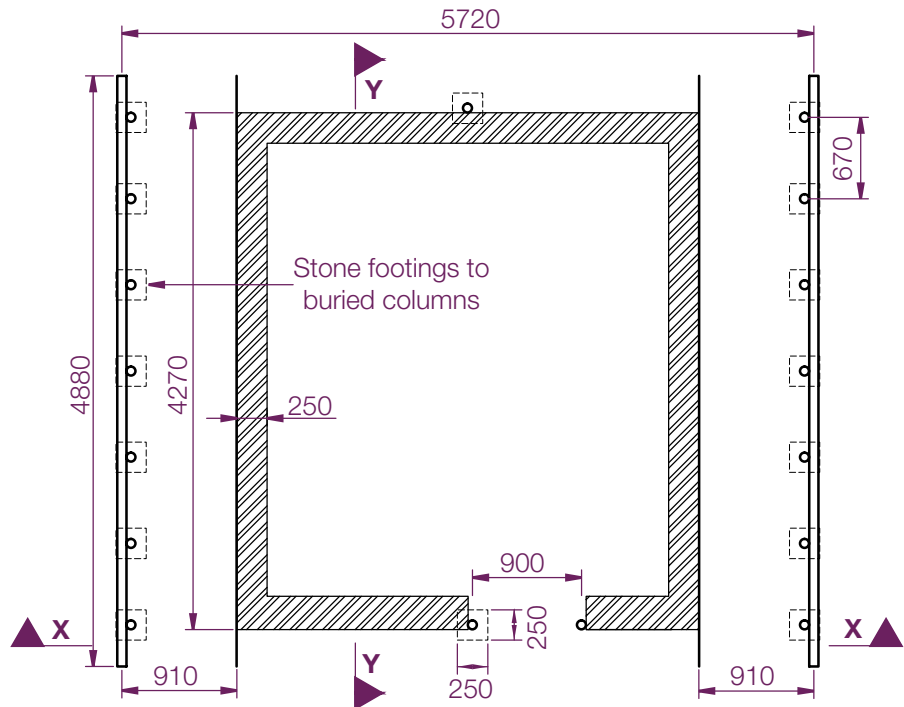
This shelter presents a simple, low-cost transitional shelter option that is quickly constructed and appropriate for cold climates. The addition of A-bracing in the triangular frame and more robust foundations would significantly increase the performance of this shelter under seismic and wind loading and would be strongly recommended. The shelter uses locally sourced materials that are familiar to the occupants and do not require specialist tools or equipment for assembly. The framing materials can be substituted, for example bamboo or cut timber can be used as an alternative to the timber poles detailed here. This shelter has been provided as 'kit' which does not include the low level wall which can be provided by the occupants. Alternatives to brick include concrete blocks, unfired earth bricks and timber.

Plans and comments

CHECK: In areas known to have higher local wind pressures, adequate foundations and member sizes must be provided to account for this.

CHANGE: Treat timber members to prevent rot and insect degradation.

CHECK: Can also be constructed using bamboo members. In this case the appropriate number of members, sizes and fixing details should be designed accordingly.



Ground floor plan

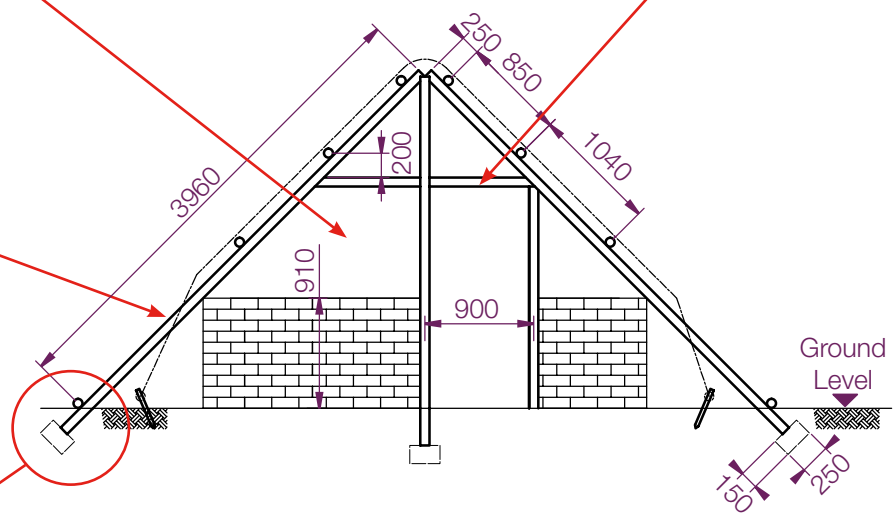
CHECK: Check that the soil type for the shelter location is stiff, otherwise design foundations accordingly.

CHECK: Plastic wall sheeting should be connected back to the timber studs using 8d nails at 50mm centres on all sides.

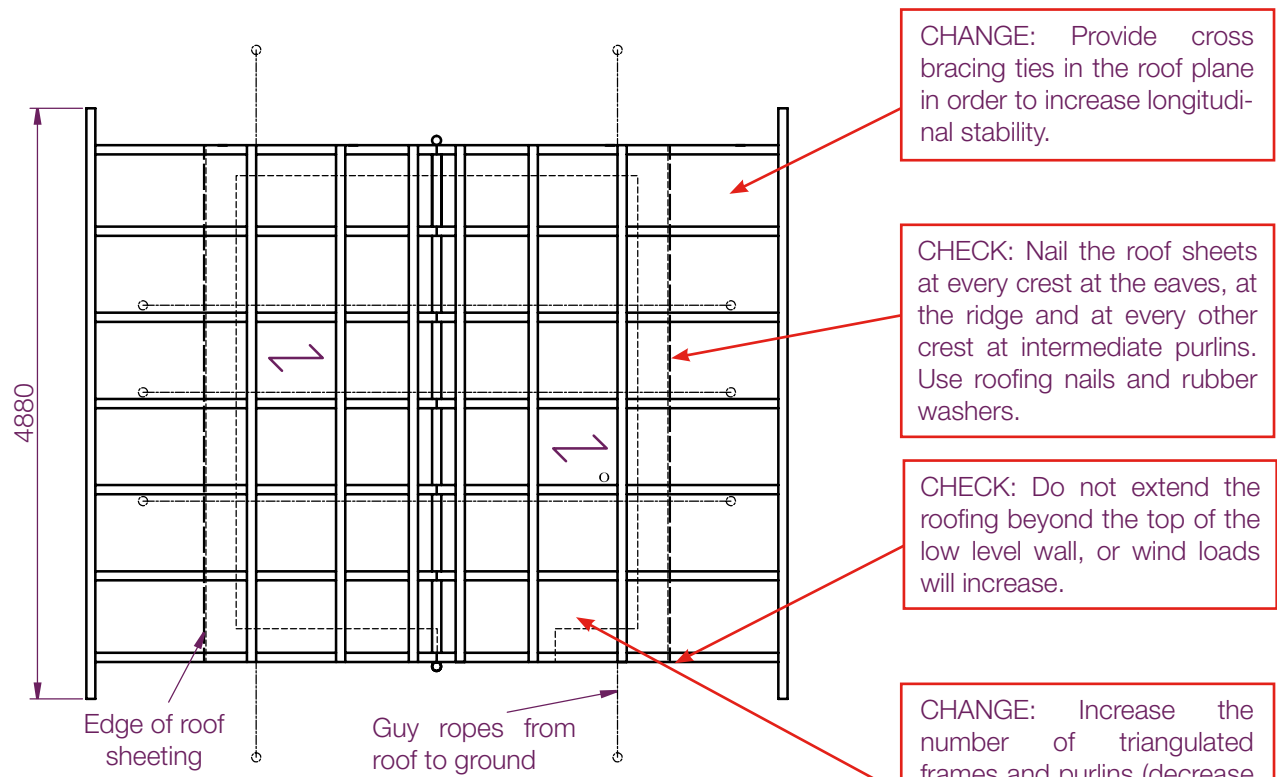
CHANGE: Add purlins just below top of wall to support the edge of the roof sheet and transfer wind and snow loads back to the main frame. The roof sheet should be nailed to this purlin at every crest using nails and rubber washers.

CHANGE: Use an alternative foundation solution to provide uplift and sliding resistance against wind and seismic loads. (See [concrete pad foundations and ground anchors in section C.1](#))

CHANGE: Add timber A-bracing member to all triangulated frames to withstand wind and snow loads (7 total).



Section X-X



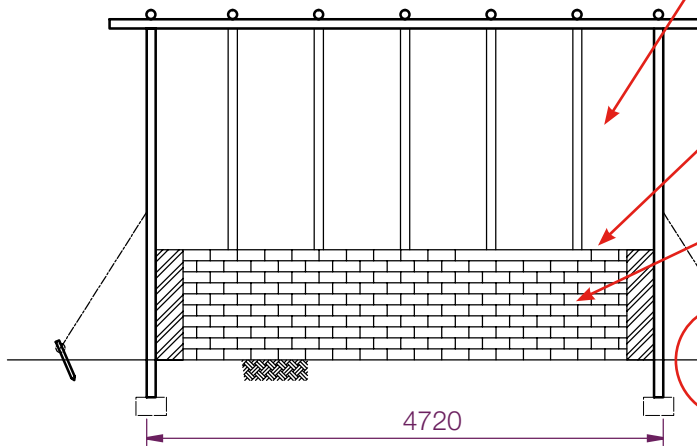
Roof Level Plan

CHANGE: Provide cross bracing ties in the roof plane in order to increase longitudinal stability.

CHECK: Nail the roof sheets at every crest at the eaves, at the ridge and at every other crest at intermediate purlins. Use roofing nails and rubber washers.

CHECK: Do not extend the roofing beyond the top of the low level wall, or wind loads will increase.

CHANGE: Increase the number of triangulated frames and purlins (decrease the spacing) according to design for expected snow drift loads.



Section Y-Y

CHECK: Do not raise the masonry above 0.9m as it will increase the risk to life and will increase the seismic forces on the structure.

CHECK: The walls will not resist seismic loads and may collapse in an Earthquake event.

CHECK: Use guy ropes to help prevent uplift of the shelter. To ensure good performance under wind loads alternative foundation solutions should also be provided.



Durability and lifespan

It is expected that the materials in this shelter kit will eventually be used for rebuilding permanent housing, and it is designed to be easily dismantlable with reusable materials.

The timber is not treated so will rot where buried in moist ground, but acacia timber does have natural resistance to termite attack. Treatment would be recommended where timbers will be re-used in permanent homes.

Performance analysis*

The performance of the frame under gravity and seismic loads is satisfactory. In-plane bracing and A-frame bracing in the roof would improve the stability of the shelter. For extreme snow loads additional purlins and rafter frames are required to support the roof sheeting and reduce the stresses in the members in addition to the inclusion of A-frame bracing.

Hazard	Performance
Earthquake HIGH	AMBER: An alternative foundation solution is required to resist uplift and sliding forces. The masonry walls perform poorly under seismic loads but are low. The shelter frame is however lightweight and flexible, therefore posing a low safety risk in the case of damage.
Wind LOW	RED: The shelter does not perform adequately under wind loads. A-Bracing in the triangular frames and an additional purlin at the eaves must be provided to ensure the rafters and purlins can withstand the wind pressures. In plane bracing in the roof and anchor foundations are also required to resist uplift and sliding.
Flood HIGH	AMBER: High rainfall leads to high run-off and mud flows from high ground. Brick walls laid using cement mortar provide flood protection along with the use of sandbags. No specific checks have been carried out to verify the performance of the wall in this case.

* See section A.4.5 Performance analysis summaries

Notes on upgrades:

Alternative wall materials such as nailed plywood sheeting or timber boarding can be used if the recommendations for wind pressure and snow resistance are taken into account. The roof should not be extended to ground level unless rafter sizes are increased to take the resulting higher snow loads.

Masonry should be kept to low levels only. Upgrading the shelter with very heavy materials to a high level or on the roof is not recommended as they will attract high seismic loads causing the structure to perform poorly in an earthquake. Collapse of a heavy roof or unreinforced masonry walls poses a serious risk to life.

Assumptions:

- The front and back of the structure will be clad with plywood or plastic. It is assumed that the cladding is fastened sufficiently well to transfer wind loads back to the frame.
- Plastic sheeting is not pulled taut between purlins and rafters; the corrugated roof sheeting transmits wind and snow forces directly to the timber frame. It has been assumed that fibrous matting will be used as insulation. If heavier straw coverings are to be used, the structure should be checked accordingly.
- The corrugated sheeting stops just beyond the masonry wall and does not extend outwards to the ground.
- The columns and rafters are assumed to be embedded by 0.3m into the soil.
- The brick wall is not connected to the frame, but where wind pressures act outwards, it will impose a horizontal force on the rafters at the top of the wall. The wall has been assumed to be free standing and made with the best available mortar quality.
- Joints are fixed with nails but are strong enough to transmit forces between members. The detailing of all connections is critical to the stability of the structure and should be checked for individual cases.
- 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 life.
- Existing foundations are formed by poles bearing down onto a stone footing at least 200 x 200mm x 100mm thick.

Bill of quantities

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					
Stone Bases 200 x 200 x 100 (thick)	-	16	16	Pieces	
Guy rope stakes 75mm dia. (L = 1m)	Timber 3	10	10	m	
Main Structure					
Vertical columns 75 dia. (L=3.05m)	Timber 3	2	6.1	m	
Inclined rafters 75 dia. (L=4.27m)	Timber 3	14	60	m	
Ridge beam 75 dia. (L=4.27m)	Timber 3	1	4.3	m	
Floor footing beams 75 dia. (L=4.88m)	Timber 3	2	9.8	m	
Secondary Structure					
Roof Purlins 75 dia. (L=4.27m)	Timber 3	6	26	m	
Covering – Wall, Roof and Floor					
Roof Sheeting 1.85m x 0.75m	Sheet 1	24	33	m ²	
Insulation Material	-	-	27	m ²	
Plastic Sheeting 4m X 6m	Plastic	3	72	m ²	
Masonry 215 x 102 x 65 clay bricks	-	2100	3	m ³	Material provided by homeowner
Fixings					
Galvanised Nails – 10d	Nails	1	1	kg	Exact number determined by fixing guidance
Galvanised Nails – 20d	Nails	1	1	kg	
Galvanised steel washers – 1.5" diameter	-	100	100	pieces	
Round rubber washers – 1.5" diameter	-	100	100	pieces	
Polyethylene rope – 12mm diameter	-	-	50	m	For guy ropes
Rope – 9.4mm diameter	-	-	100	m	Exact use unknown
Tools Required					
Hammer	-	1	1	piece	
Hand saw	-	1	1	piece	
Shovel	-	1	1	piece	
Pick axe	-	1	1	piece	
5m tape measure	-	1	1	piece	

B.4 Peru (2007) - Timber frame



Summary information

Disaster: Earthquake 2007

Materials: Bolaina (Bolayna) Timber frame with timber cladding and corrugated metal sheet roofing

Material source: All materials sourced locally and produced in local fabrication workshops

Time to build: 1 day (4 people -)

Anticipated lifespan: 24 months +

Construction team: 4 people with 1 engineer and 1 project manager to supervise

Number built: 2020

Approximate material cost per shelter: Unknown

Approximate project cost per shelter: 560CHF

Shelter description

The shelter has a Bolaina (Bolayna) timber braced frame, measuring 3m x 6m on plan with a single pitched roof at four degrees. The shelter is clad with tongue and groove solid timber board walls and a corrugated fibre cement sheet roof. It is 2.4m high and stands on a new or existing concrete floor slab. In instances where a new slab has been used, wire ties wrapped around nails have been cast into the slab and attached to the frame at all column locations to resist uplift. Where existing slabs have been used the shelter has been staked to posts installed outside the slab. The shelter is constructed as 6 panels which are then nailed together using connecting wooden members, connecting plates and plastic strapping. A central roof edge beam is attached to the panels and are purlins nailed on top of this to support the roof.

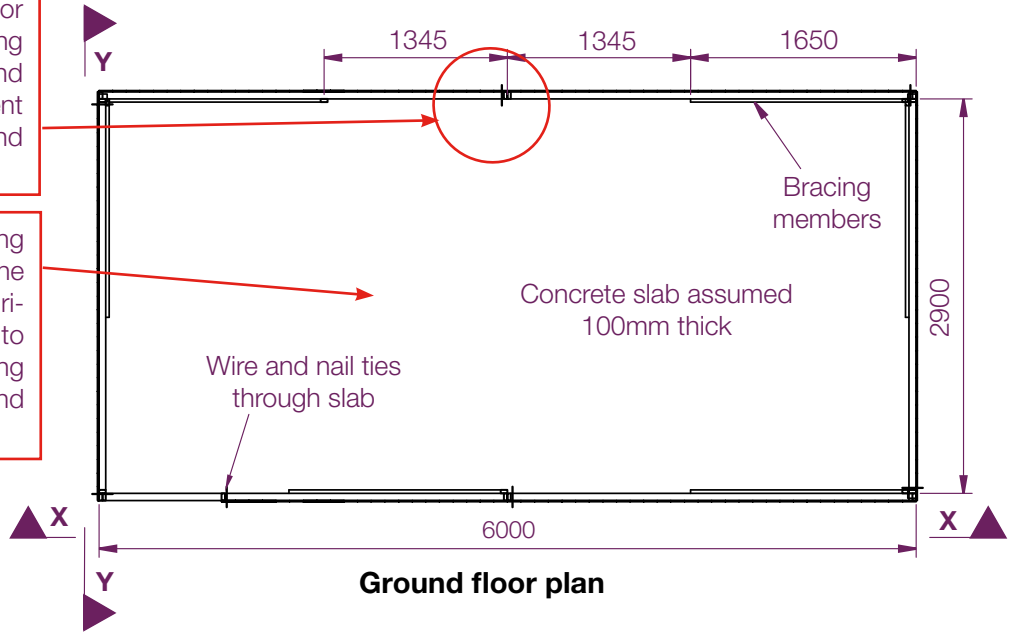
Shelter performance summary

This very lightweight, simple box-shelter offers a good design solution in areas vulnerable to seismic loading but does not perform well under wind loads. It uses locally sourced materials, and does not require specialist tools or equipment for assembly. Constructing it in panels has advantages in terms of speed of construction and quality control. However, member sizes need to be increased and the foundation fixing improved in order to provide a sound structure under gravity and seismic loads. More significant improvements are required to resist high wind loads which may not be practical, for instance large foundations. It is not suitable for upgrading into permanent housing in the long term. The timber should be treated to increase its durability and usefulness to the occupant in the event it is reused. If left untreated it will be more susceptible to rot and insects.

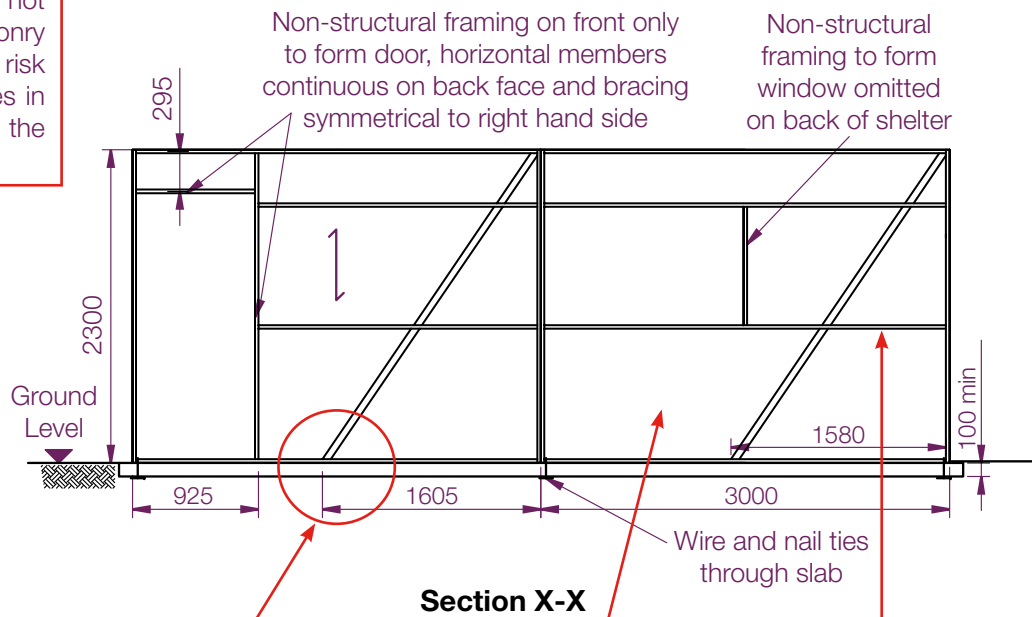
Plans and comments

CHANGE: Increase column sizes or decrease spacing according to local wind pressures to prevent bending failure and excessive deflection.

CHECK: If an existing slab is used for the base, design appropriate anchor system to resist uplift and sliding forces under wind and seismic loads.



CHECK: Do not upgrade using masonry due to increased risk to life and increases in seismic forces on the structure.



CHANGE: Treat timber members to prevent rot and insect degradation.

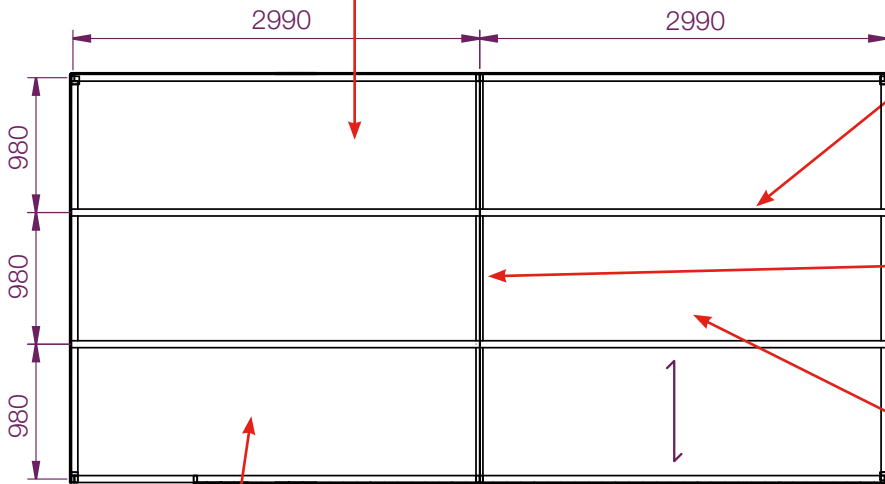
CHANGE: Increase size of timber bracing members to take compression forces and move braces to meet at column base instead of floor beam.

CHECK: Fix timber wall planks to transoms using 6d nails at a maximum spacing of 150mm.

CHANGE: Increase the dimension of the nailed face of timber members to 50mm to avoid splitting when nailed.

CHECK: The fibre cement roof sheeting is heavier than alternative roofing materials such as corrugated steel sheeting. This increases the risk to life in the event of an earthquake or strong wind.

CHANGE: Decrease purlin spacing and use timber with a bigger section and depth



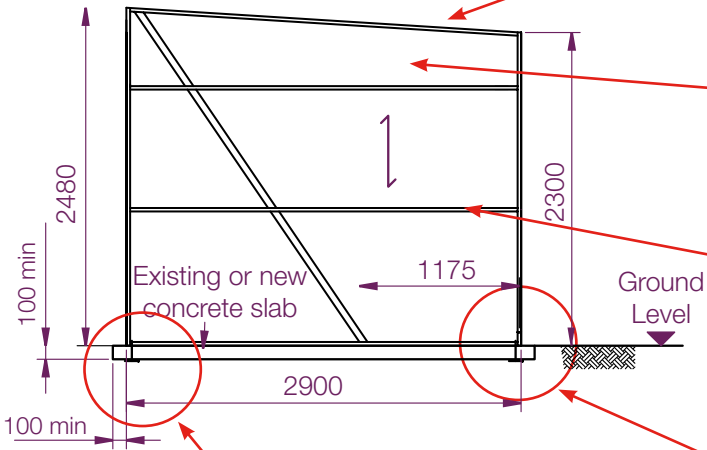
CHANGE: Increase the size of the central roof and eaves beams to take dead and wind loads.

CHANGE: Use crossed double wire ties as bracing in roof plane to provide stability under lateral loads.

Roof Level Plan

CHECK: Fix roof sheeting using two 8d nails per roof sheet panel in 2mm oversize holes with washers, placed through the crown. Use a 70mm overlap and a seal between sheets for total weatherproofing.

CHANGE: Increase roof pitch to over 5 degrees to allow rain water run-off, and prevent deterioration of the roof.



CHECK: Increase timber plank thickness from 9.4mm to 12.5mm minimum to provide an adequate weather covering, or add plywood sheathing.

CHANGE: Space wall transoms at a maximum distance of 400mm to prevent excessive deflection and failure of the timber plank walls under wind loads and improve lateral stability.

Section Y-Y

CHANGE: Use an alternative foundation solution to provide uplift and sliding resistance (see C.2, concrete pad or screw in ground anchor) against wind and seismic loads, or use three double wire ties per column when casting a new slab (28 in total).

CHECK: The soil type for the shelter location should be stiff, otherwise design foundations accordingly.

CHECK: Design member connections for local hazard conditions by connecting members using wall plates and additional wood strips, and securing roof against uplift using plastic strapping



Durability and lifespan

The shelters were intended to be upgraded, and for the materials to be reused.

Since the timber is untreated, the durability is poor and the members are susceptible to damp and rot.

Performance analysis*

The performance of the shelter under gravity loads is inadequate. The roof should be strengthened by decreasing the purlin spacing and using larger roof and eaves beams. Further modifications are required to strengthen the building under seismic and wind loads.

Hazard	Performance
Earthquake HIGH	AMBER: The performance of the shelter under seismic loads is inadequate. The roof should be strengthened and the size of the bracing in the plane of the wall must be increased and be connected to the base of the column. The shelter must be better tied to the foundations to prevent sliding. The resistance of the shelter to lateral loads is low so damage is expected. However, as the shelter is relatively lightweight and flexible it poses a low risk to life.
Wind MEDIUM	RED: The structure has insufficient resistance to wind loads. It must be more securely tied down to prevent uplift and sliding, in addition to the strengthening of the roof and wall bracing. In-plane wire cross bracing is required in the roof, the spacing of the wall transoms must be decreased and the columns strengthened to resist lateral wind pressures.
Flood MEDIUM	RED: The shelter does not incorporate any flood protection strategies and the connection of the shelter to the slab may be insufficient to hold the shelter during a flood.

* See section A.4.5 Performance analysis summaries

Notes on upgrades:

The shelter is most commonly upgraded by adding an internal partition. Wooden panel partitions improve the lateral stiffness. In many cases the shelter was insulated with polythene or plastic to retain heat in cold weather. If additional insulation is added, then further strengthening may be required.

The shelters were built with materials which were intended to be reused. However, since the timber is untreated, the durability is poor and the members not suitable for reuse in permanent housing.

In some cases modules have been joined together to form larger structures. In this case the internal walls must be retained, otherwise the shelter will become unstable. Nailed plywood walls would provide a more durable and stiff solution than the timber planking.

Upgrading the shelter with masonry or using heavy materials on the roof is not recommended. They will attract higher seismic loads, and collapse of a heavier roof or unreinforced masonry walls poses a serious risk to life.

Assumptions:

- Fibre cement roof sheeting is a relatively heavy sheet (see sheet 3 in annex I.1.3).
- Timber wall panneling is sufficiently fastened and of sufficient strength to transfer wind loads back to the frame without damage to the cladding.
- The connections between the six frame panels are of sufficient strength to transfer forces between frames and use the recommended plastic tape strapping and timber wall plates. Columns have been assumed not to act compositely, but adequately nailed connections are recommended.
- The primary roof beams and purlins are supported off the wall panels, and not from secondary supports.
- All connections are nailed with two nails and are assumed to act as pinned connections.
- It has been assumed that the shelter has been fixed to a newly cast 100mm thick minimum concrete slab using a double wire tie at each of the column locations (seven in total). Each wire tie consists of a single 6d nail with a double AWG 16 wire twisted around to leave the two free ends above the concrete. It has been assumed that the slab has one layer of square A142 mesh (see Annex I.1.2) reinforcement half way down.
- Fixings between members have been made using nails, but are of sufficient strength to transmit forces.
- A stiff soil type has been assumed.

Bill of quantities

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	4	4	bags	42.5kg/bag
Sand	Concrete		.34	m ³	Estimate
Gravel	Concrete		.68	m ³	Estimate
Wire mesh Reinforcement		18	18.0	m ²	
Nails – 6d	Nails	7	7	Pieces	
Wire (16 AWG)	Wire	6	6.0	m	Estimate
Main Structure					
Columns – 25 x 50 (L=2.5m)	Timber 4	13	32.5	m	
Roof Beam – 25 x 50 (L=3m)	Timber 4	2	6.0	m	
Eaves Beams – 25 x 50 (L=2.9m)	Timber 4	2	5.8	m	
Eaves Beams – 25 x 50 (L=3.0m)	Timber 4	4	12.0	m	
Floor Beams– 25 x 50 (L=2.9m)	Timber 4	2	5.8	m	
Floor Beams – 25 x 50 (L=3.0m)	Timber 4	4	12.0	m	
Bracing – 25 x 50 (L=3.0m)	Timber 4	6	18.0	m	
Secondary Structure					
Purlins – 25 x 50 (L=3.0m)	Timber 4	4	12.0	m	
Wall Transoms – 25 x 50 (L=3.0m)	Timber 4	6	18.0	m	
Wall Transoms – 25 x 50 (L=2.9m)	Timber 4	4	11.6	m	
Wall Transoms – 25 x 50 (L=2.05m)	Timber 4	2	4.1	m	
Door & window framing – 25 x 50 (L=1.0m)	Timber 4	2	2.0	m	
Covering – Wall and Roof					
Fibre cement roof sheeting (1 x 3m sheet, 6.25 thick)	Sheet 3	6	6	Pieces	
Timber tongue & groove planks. 87.5 x 9.4 (L=2.48m)	Timber 4	68	169	m	
Timber tongue & groove planks. 87.5 x 9.4 (L=2.30m)	Timber 4	43	98.9	m	
Timber tongue & groove planks. 87.5 x 9.4 (L=0.42m)	Timber 4	10	4.2	m	
Timber tongue & groove planks. 87.5 x 9.4 (L=0.32m)	Timber 4	16	5.1	m	
Timber tongue & groove planks. 87.5 x 9.4 (L=1.01m)	Timber 4	16	16.2	m	
Timber tongue & groove planks. 87.5 x 9.4 (L=2.48 decreasing to 2.30m)	Timber 4	70	70	Pieces	

Fixings					
Nails – 8d roofing nails with protecting cap/washer	Nails		0.5	kg	
Nails – 6d	Nails		1.6	kg	
Plastic Tape (10 x 150)		8	8	Pieces	For joints
Steel hinge 2.5"		7	7	Pieces	
Screws	Screws	3	3	Pieces	
Wood strips – 30 x 60 (L=3m)	Timber 4	2	6	m	
Wall plates – 60 x 60 x 9.4 thick	Timber 4	-	7.5	m	Corner plate reinforcement
Tools Required					
Hammer	-	1	1	Pieces	

B.5 Peru (2007) - Timber Frame



Summary information

Location: Peru, Ica Province

Disaster: Earthquake 2007

Materials: Eucalyptus wood poles, bamboo matting, plastic sheeting, wire and nails, concrete slab

Material source: Mats and wood locally available, plastic sheeting imported, staples and staple guns imported.

Time to build: 2 days

Anticipated lifespan: 12 months minimum

Construction team: 4 people

Number built: 3000

Approximate material cost per shelter: 225CHF (2007)

Programme cost per shelter: 340CHF (2007)

Shelter description

The structure is a rigid box consisting of braced frames in both directions. The braced frames provide lateral stability. The eucalyptus timber frame has a flat roof and is covered with stapled plastic sheeting and nailed palm matting on all faces. The shelter is 2m high and 3m x 6m on plan. The bracing consists of crossed twisted wires. The 75mm diameter columns are connected horizontally with 50mm diameter horizontal members. The foundation and floor consists of an unreinforced concrete slab with cast in wire ties. The connections between members are made using bent nails.

Shelter performance summary

This very lightweight braced box shelter provides an effective temporary solution that can be easily disassembled and the materials re-used. It uses local materials and simple construction techniques, so can be built quickly. The very minor improvements that are recommended in this analysis would improve the performance and overall robustness of the shelter under normal gravity and seismic loads. However, significant modifications would be needed to improve its performance under wind loading.

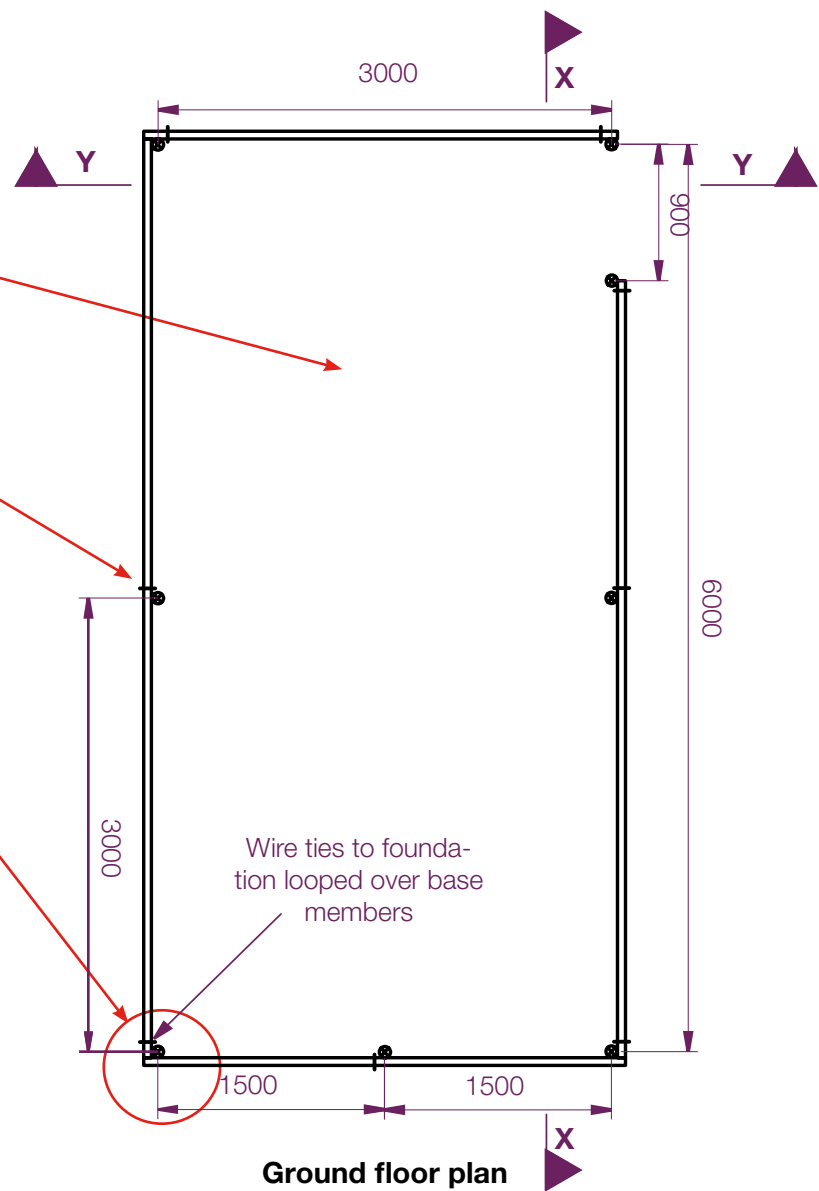
Plans and comments

CHECK: See Annex I.1 for the correct concrete mix for the slab. A layer of mesh reinforcement to increase tie pull out resistance is required.

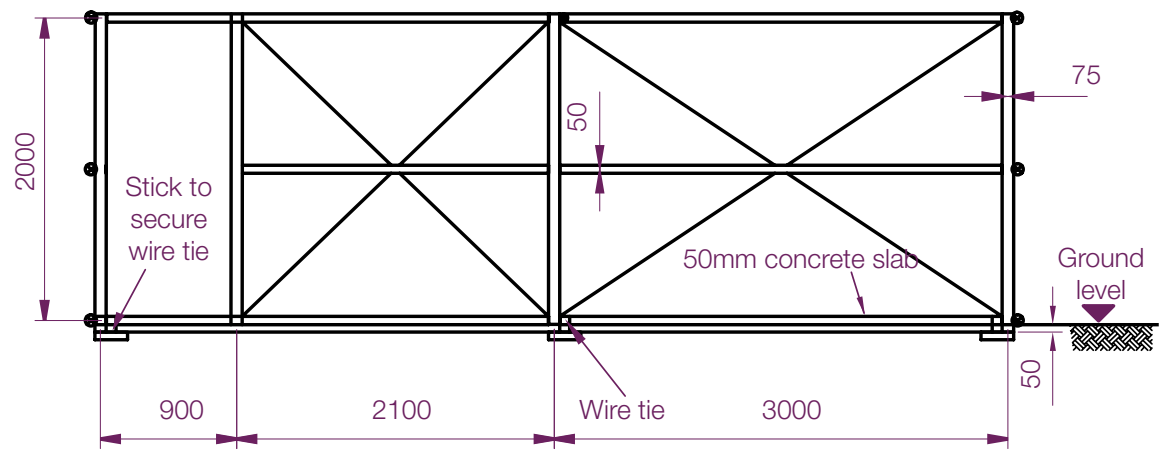
CHANGE: Use 8 columns to decrease the roof member spacing.

CHANGE: Two double wire ties are required per column, cast into the foundation and tied to the structure to prevent uplift under wind loads.

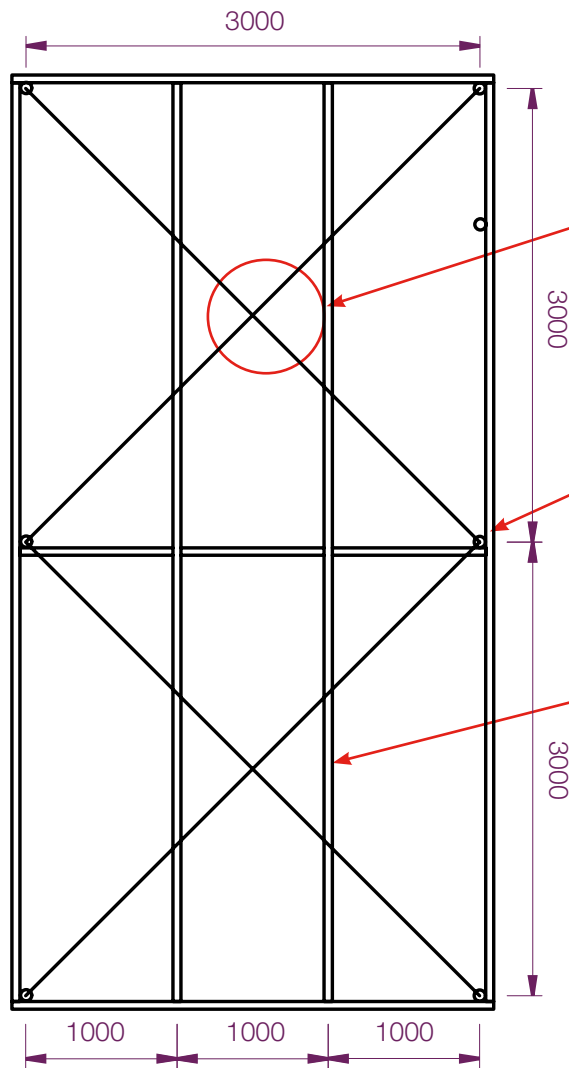
CHECK: The design and detailing of all connections is critical to the stability of the structure and should be checked.



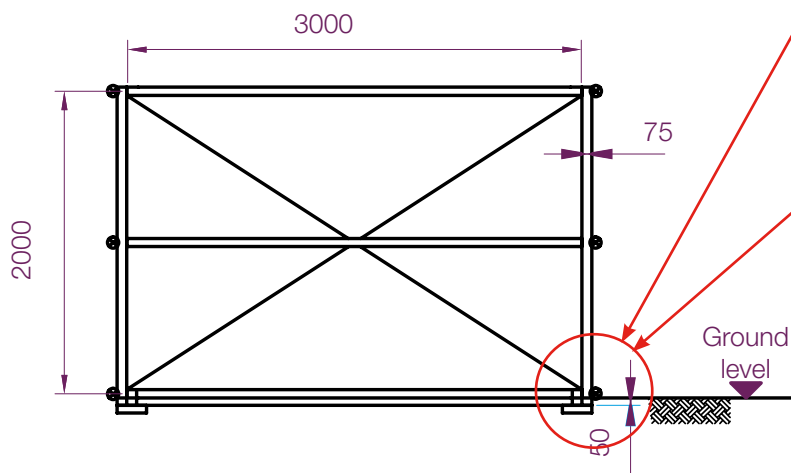
Ground floor plan



Section X-X



Roof Level Plan



Section Y-Y

CHANGE: Increase bracing to 10 strands of wire on end faces and roof to provide adequate resistance to wind pressures.

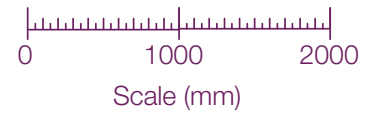
CHECK: All member sizes, particularly central columns and bracing, should be increased in accordance with design to local wind pressures.

CHECK: If the roofing is upgraded with a heavier material the roof member sizes must be increased accordingly.

CHANGE: Modify foundations to concrete bucket or embedded base plate foundations (see Section C.2) to prevent problems with uplift / sliding under wind loads. For example the columns could be securely tied into embedded concrete pockets.

CHECK: In areas known to have high local wind pressures adequate foundations and member sizes must be provided.

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



Durability and lifespan

The shelter is demountable and could be easily moved from its foundation by cutting the wire ties.

The matting traps dirt and mould and is prone to breakage where stapled, the plastic sheeting may fail due to wear and tear and the timber is untreated. The shelter is not upgradable, but straw mats and frame could be reused. The timber frame can be reused, but the slab cannot, and a new foundation will be required if the shelter is moved.

Performance analysis*

The performance of the shelter under gravity and seismic loads alone is satisfactory. Under wind loads, modifications are required to strengthen the shelter.

Hazard	Performance
Earthquake HIGH	AMBER: Medium risk of failure. The shelter attracts low seismic loads and its performance is adequate. The resistance of the shelter to lateral loads is low so damage is expected. However since it is lightweight and relatively flexible it poses a low risk to the lives of the occupants when damaged.
Wind MEDIUM	RED: High risk of failure. The structure has insufficient resistance to wind loads. The structure must be more securely tied down to prevent uplift and the foundation size increased to prevent sliding. More bracing must be added in the walls and roof to provide sufficient lateral stability. Additional columns and roof members are also required.
Flood MEDIUM	RED: High risk of failure. The flood risk increases during El Nino period every 10-15 years. The shelter does not incorporate any flood protection strategies so in the case of flooding the damage would be great.

* See section A.4.5 Performance analysis summaries

Notes on upgrades:

Upgrading the roof with materials of a similar weight, for example lightweight metal sheets would not change the structural performance of the shelter. In order to upgrade the roof or walls with heavier and more substantial materials, such as plywood, the frame member sizes would need to be increased, connections strengthened and foundations upgraded to take the increased gravity and seismic loads.

Upgrading the shelter with masonry or other very heavy materials is not recommended as they attract high seismic loads causing the structure to perform poorly in an earthquake. Collapse of a heavy roof or unreinforced masonry walls poses a serious risk to the lives of the occupants.

Assumptions:

- A stiff soil type (see Site Class D, [International Building Code \(IBC\) 2009](#)) has been assumed in analysis of the structure. Softer soil, or soil of variable quality may adversely affect the performance of the existing shallow foundations. 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 pose a lives of the occupants.
- It is assumed that under wind pressures the plastic sheeting will not tear. This will transfer wind forces to the structure. This requires a maximum distance between staples of approximately 150mm on all edges.
- The foundations consist of 8 ties with 10mm * 10mm * 100mm sticks embedded below the 50mm thick concrete slab. The slab has wire mesh reinforcement at 25mm depth and there are 4 wires providing resistance per tie point.
- The roof members are slender and can only support a minimal dead load. It is assumed that there are no additional roof loads such as volcanic ash, sand or snow.
- All connections are sufficient to transfer the required forces between members.
- The plastic sheeting is assumed to be 'hand-taut' (not machine fixed) and will not flap in the wind.

Bill of quantities

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	Material Specification See annex I.1	Quantity	Total	Unit	Comments
Structure - Foundations					
Portland cement	Concrete	2	2	bags	42.5kg/bag
Sand/Gravel	Concrete	1	1	m ³	Estimate only
Wire mesh reinforcement		18	18	m ²	
Main Structure					
Main columns (2m x 75mm dia.)	Timber 2	8	14.0	m	
Window column (1.6m x 75mm dia.)	Timber 2	1	1.6	m	
Beams (6m x 50mm dia.)	Timber 2	6	36.0	m	
Beams (5.1m x 50mm dia.)	Timber 2	2	10.2	m	
Beams (3m x 50mm dia.)	Timber 2	8	24.0	m	
Structure - Door					
Verticals (2m x 50mm dia.)	Timber 2	2	4.0	m	
Horizontals (0.9m x 50mm dia.)	Timber 2	3	2.7	m	
Covering – Wall and Roof					
Plastic sheet (4m x 6m)	Plastic		54	m ²	
Bamboo mats (2m x 3m)	-		54	m ²	
Fixings					
Galvanised AWG16 wire	Wire	130	130	m	Used in double lengths
Nails – 10d	Nails		3	kg	
Nails – 8d	Nails		2	kg	
Nails – 4d	Nails		1	kg	
Staples – 22/25	Staples	2000	2	box	
Hinge – 62.5mm steel		3	3	piece	
Knocker – 50mm steel		1	1	piece	
Padlock		1	1	piece	
Tools Required					
Hand saw		1	1	piece	
Shovel		1	1	piece	
Hammer		1	1	piece	
Pliers		1	1	piece	
Clippers		1	1	piece	
Wheel barrow		1	1	piece	
Industrial stapler		2	2	piece	
5m tape measure		1	1	piece	
7m plastic level pipe		1	1	piece	

B.6 Haiti (2010) - Steel Frame



Photo: Beatriz Garlaschi for Spanish Red Cross



Summary information

Disaster: Earthquake 2010

Materials: Galvanised steel frame, timber studs, plastic sheeting walls, corrugated steel roof sheeting, concrete foundations, bolts, screws and nails

Material source: Steel frame: imported from Spain, Other materials: sourced locally

Time to build: 2 days

Anticipated lifespan: 24 months

Construction team: Unknown

Number built: 5100

Approximate material cost per shelter: 1700 CHF

Approximate programme cost per shelter: 4300 CHF

Shelter description

The shelter consists of a galvanised rectangular steel frame with an 8.5 degree mono-pitch roof and a suspended floor. The height to the eaves is 2.55m and 3m to the ridge and there is no bracing. The shelter is 3 x 6 m on plan and has 6 columns spaced on a 3m grid, fixed to 800x800x400mm rectangular reinforced concrete foundations using a 300x300x6mm base plate and four ordinary bolts per base. The raised floor is also supported by 13 additional stub columns on 100x100x6mm base plates bearing directly on to the soil. The main structure is three primary frames with rectangular hollow section columns.

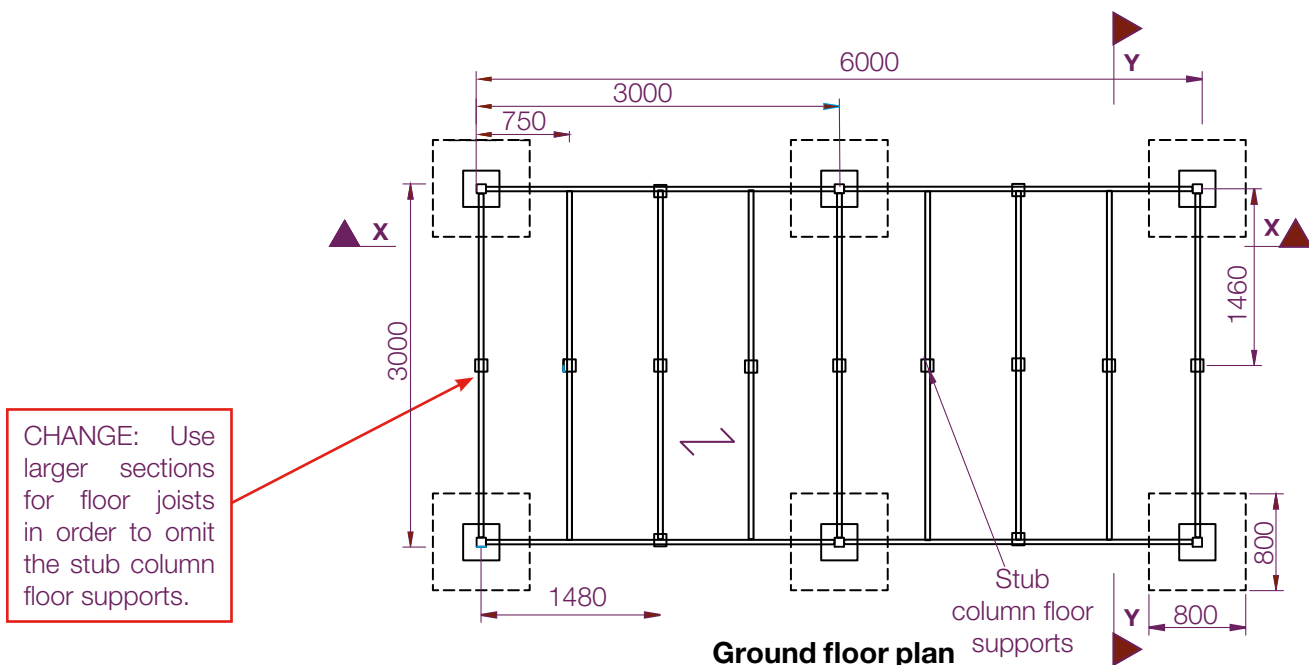
The roof cladding is corrugated steel sheeting nailed to steel secondary roof members spaced at 0.75m intervals spanning between the three primary frames. Timber studs are screwed to the steel members and the plastic wall sheeting is attached to this. Additional timber sub-framing is used to form windows and doors.

Shelter performance summary

This imported, pre-fabricated steel frame solution is relatively expensive, but quick to construct once the materials have arrived in-country. As designed, the steel frame has very limited lateral stability because there is no bracing in the walls or roof. As such, it does not perform well under seismic and wind loading*. Significant alterations are required to improve its performance include modifications to foundations, steel members and bracing in the walls and roof.

* Note: This analysis is based on higher basic wind speeds than were agreed by the shelter cluster and operational organisations in Haiti - see assumptions below (p58).

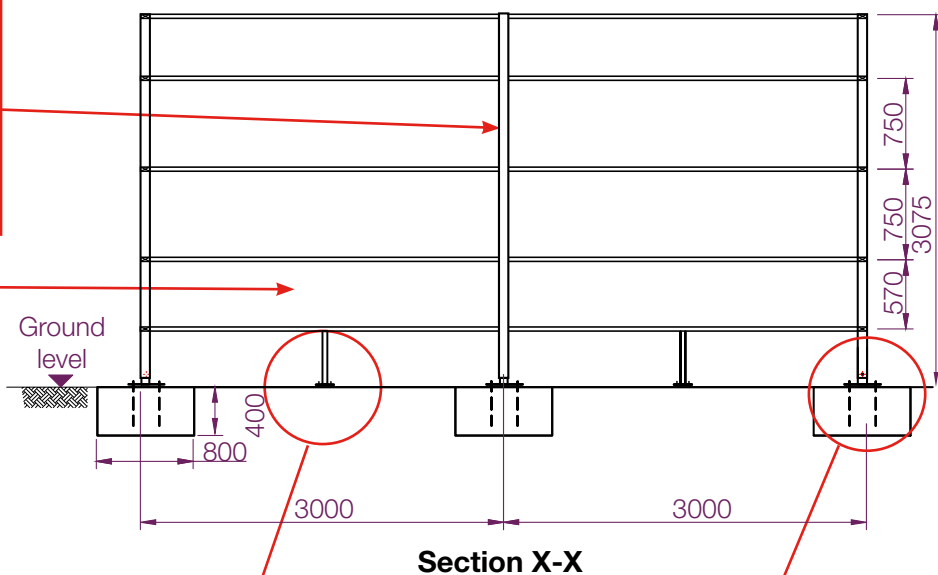
Plans and comments



CHANGE: Use larger sections for floor joists in order to omit the stub column floor supports.

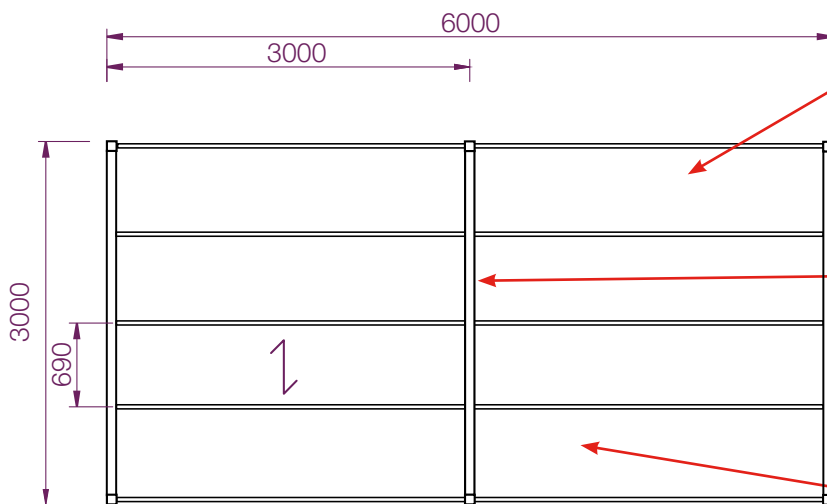
CHANGE: Decrease column spacing for out of plane loads in accordance with design to recommended wind pressures, and increase number of foundations and rafters accordingly.

CHANGE: Lateral stability can be improved by using ½" thick structural grade plywood ([plywood 1 annex I.1.3](#)), with vertical framing spaced at 600mm and the plywood with maximum 150mm nail spacing. Alternatively in plane diagonal bracing could be provided. In either case, header and primary floor beams must be strengthened ([See Section C.3](#)).



CHANGE: Add concrete pad footings ([See Section C.2](#)) underneath the stub column floor supports to distribute bearing pressures on to the soil.

CHANGE: Use an alternative foundation solution to prevent uplift and sliding under wind loads ([Embedded base plate or screw in ground anchor - see section C.2](#)). In areas known to have higher local wind pressures, design foundations and member sizes accordingly.

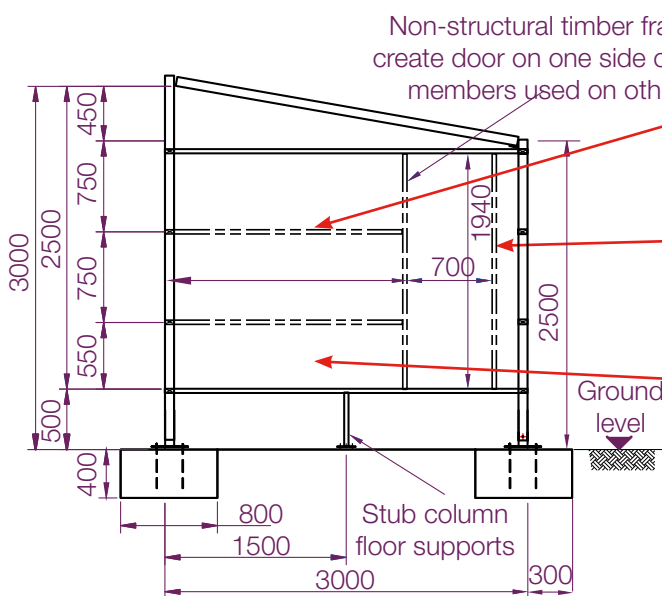


CHANGE: Provide bracing in the roof and securely fasten the roof sheet to the purlins using screws at every crest at eaves and ridge, and every other crest for rows in between (see Section C.4).

CHANGE: Strengthen roof purlins, roof beams and wall transoms to take hurricane wind pressures.

Check: Fasten roof sheet to purlins using screws spread at appropriate intervals (see Section C.4).

Roof Level Plan



CHECK: Connect plastic wall sheeting to the timber studs using 8d nails at 150mm centres all round.

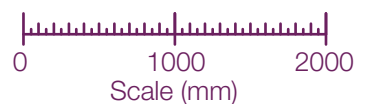
CHECK: Design timber sub-frame to take wind pressures from walls back to steel members and therefore connect adequately to the steel frame.

CHECK: Do not upgrade using masonry or cement blocks due to risk to life, and the increase in seismic force that would be attracted to the structure.

Section Y-Y

CHECK: Provide hurricane straps at connections to secure wooden elements and steel elements against hurricane wind pressures.

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



Durability and lifespan

The shelter is demountable with foundation bolts that can be cut to reuse the frame. The intention is to put two shelters side by side to form a double pitched roof structure or four together to use as communal facilities. The frame is durable and has galvanised members. The plastic sheeting will require replacement.

Performance analysis*

Performance of the frame under gravity loads alone is satisfactory. However there is no lateral stability system and it is essential to provide in plane bracing in the roof and walls (see [Section C.3](#)). Additional concrete foundations are required under stub column floor supports to take loads and prevent sagging.

Hazard	Performance
Earthquake HIGH	RED: Currently the shelter does not perform well under seismic loads. Bracing is required in the walls and roof to provide lateral stability. The structure is lightweight and relatively flexible posing a low risk to the lives of the occupants.
Wind VERY HIGH	RED: The shelter does not perform well under high wind loads. The shelter should be braced, and the foundation improved. The column spacing should be decreased and the wall supports, roof purlins and roof beams strengthened to take uplift and lateral hurricane wind pressures.
Flood HIGH	GREEN: The shelter has a raised floor to prevent flood damage but no specific checks against standing water have been made.

* See section [A.4.5 Performance analysis summaries](#)

Notes on upgrades:

The shelter may be upgraded by replacing the plastic sheeting walls with plywood or corrugated metal sheet. To provide resistance to wind pressures, this upgrade would require: In-plane bracing for the roof and walls, concrete foundations under the stub column floor supports, upgraded main foundations (to prevent uplift and sliding), decreased column spacing and strengthened wall supports, roof beams and roof purlins.

If the roof or walls are upgraded with heavier materials, member sizes should be increased and connections strengthened to take the increased gravity and seismic loads. Upgrading the shelter with masonry is not recommended, as collapse of a heavy roof or unreinforced masonry walls would pose a serious risk to life.

If shelter modules are combined to create larger structures, the bracing must remain in the internal walls.

Assumptions:

- A basic wind speed of 217 km/hr* has been assumed along with Exposure Category C ([ASCE/SEI 7-10](#)). This is extremely high and it is difficult to resist these pressures in lightweight shelters.
- With more detailed knowledge of the site planning and placement of the shelters, the design wind pressures could be reduced by: intelligent grouping to reduce the Exposure Category to B (with the edge shelters designed for stronger winds) or providing a hurricane shelters designed to withstand full hurricane loads.
- The maximum allowable floor live load is 0.9kN/m² and it has been assumed that the roof of the structure will not be subjected to loading from volcanic ash, or sand.
- A stiff soil type (see Site Class D, [International Building Code \(IBC\) 2009](#)) has been assumed. For sites where liquefaction may be a hazard, the shelters could be seriously damaged in an earthquake.
- If the plastic sheeting is nailed to the timber studs using 8d nails at 150mm intervals the columns and wall transoms will fail in bending before the plastic sheeting ruptures or tears/pulls out where it is nailed.
- During manufacture, holes have been made in steel members to connect other elements.
- Foundation base plates are 400*400*6mm thick (see [Steel 1, Annex I.1](#)) and are held down to 800*800*400mm plain concrete foundations by four M20 320mm long bolts (see [annex I.1](#)).
- It is assumed that all connections are of sufficient strength to transmit forces between members.

* Note: Although this analysis is based on wind speeds of up to 217km/hr, the shelter was designed to resist wind speeds of 140 km/hr with calculations up to 161 km/hr following the standard NBE-EA-95. Shelter cluster technical guidelines for Haiti also indicated peak wind speeds of up to 100mph (161km/hr).

Bill of quantities

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 available timber lengths and allowances for spoilage in transport and delivery. Steel section thickness does not include galvanised coating.

Item (Dimensions in mm)	Material Specification See annex I.1	Quantity	Total	Unit	Comments
Structure - Foundations					
Portland cement (42.5kg bags)	Concrete	3	3	bags	Modify quantity to reflect specification see Annex I.1
Sand	Concrete	-	0.38	m ³	
Gravel (20mm aggregate)	Concrete	-	0.38	m ³	
Reinforcement bars 10mm diameter (L=9.0m)	Rebar	4	4	bars	
Column base plate (300x300x6thk plate, 300 long 80x80x2thk column stub)	Steel 1	6	6	pieces	
Floor support base plate (100x100x6thk plate, 435 long 40x40x2 column stub)	Steel 1	13	13	pieces	
Holding down bolts (20 dia. 320 long)	Bolts	24	24	pieces	
Main Structure					
Columns (80x80x2thk, L=3m)	Steel 3	3	9	m	
Columns (80x80x2thk, L=2.55m)	Steel 3	3	7.65	m	
Floor beams (40x40x2, L=2.995m)	Steel 3	4	11.98	m	
Roof cross beams (80x80x2, L=3.0m)	Steel 3	3	9	m	
Secondary Structure					
Floor joists (40x40x2, L=2.9m)	Steel 3	9	26.1	m	
Roof purlins (40x40x2, L=2.88m)	Steel 3	10	28.8	m	
Wall transoms (40x40x2, L=3.0m)	Steel 3	14	42	m	
Window framing (32.5x100, L=0.75m)	Timber 2	8	6	m	
Door framing (32.5x100, L=1.95m)	Timber 2	2	3.9	m	
Timber studs (32.5x100, L=3.35m)	Timber 2	45	151	m	Depends upon arrangement
Plywood door (1.94m x 0.7m)	-	1	1	piece	
Covering – Wall, Roof and Floor					
Plywood flooring (21.8 thick)	Plywood 2	-	18	m ²	
Steel sheeting (0.75m x 1.83m)	Sheet 1	40	54.9	m ²	
Plastic sheeting (6m x 4m)	Plastic	3	72	m ²	
Mosquito net	-	-	9	m ²	
Fixings					
Bolts, nuts + washers (20 dia. 320 long)	Bolts	12	12	pieces	
Bolts, nuts + washers (10 dia. 100 long)	Bolts	99	99	pieces	
Brackets (35wide, 70+20legs, 2 thick)	Steel 3	70	70	pieces	
Bolts, nuts + washers (6.25 dia. 100 long)	Bolts	65	65	pieces	Use unknown
steel angles (75x75x18.75)	-	150	150	pieces	To fix timber framing
Nails (10d)	Nails	1400	9.1	kg	Exact numbers will vary, minimum spacing on drawings

Nails (8d)	Nails	1900	8.2	kg	
Nails (4d)	Nails	3800	5.4	kg	
Hinges	-	3	3	pieces	
Door latch + padlock	-	1	1	piece	
Self tapping screws	Screws	75	75	pieces	Exact numbers may vary, minimum spacing on drawings
Tools Required					
Drill	-	1	1	piece	
Hammer	-	2	2	pieces	
Screw driver	-	2	2	pieces	
Tape measure	-	1	1	piece	
Spirit level	-	1	1	piece	
Plumb bob + 50m gut	-	1	1	piece	
Sockets (to fit 6.25/10/20 dia. bolts)	-	3	3	pieces	
Spanners (to fit 6.25/10/20 dia. bolts)	-	4	4	pieces	
Knitted Gloves	-	2	2	pieces	
Spade	-	1	1	piece	
Hand saw	-	1	1	piece	
Ladders	-	2	2	pieces	

B.7 Indonesia, Aceh (2005) - Steel frame



Summary information

Disaster: Tsunami, 2004

Materials: Galvanised steel frame, steel sheet roofing, Radiata Pine/Douglas Fir or equivalent treated timber planks, steel foundation plates and anchors, door fixtures, nails, bolts and screws

Material source: Steel frames were manufactured regionally. The roof sheeting and timber imported internationally

Time to build: 1 day to construct the frame. 2 days minimum to clad the shelter

Anticipated lifespan: Minimum 5 years

Construction team: 4-5 people

Number built: 20,000

Approximate material cost per shelter: 4765CHF (2004)

Project cost per shelter: 5100CHF (2004)

Shelter description

The structure consists of a cold rolled, hot dip galvanised steel frame with a pitched roof of 24.3 degrees and a raised floor. The height is 2.8m to the eaves and 4.15m to the ridge. The platform area of the shelter is 25m² with a cantilevering balcony at opposite sides front and back and a cantilevering roof covering the balconies. There are 6 columns fixed using column base plates nailed directly into the ground. Metal roof sheets are screwed to steel purlins spanning between primary roof beams. Limited lateral stability is provided by timber plank wall cladding fixed to timber studs that are in turn screwed to the steel frame. The floor consists of timber planks spanning between steel joists.

Shelter performance summary*

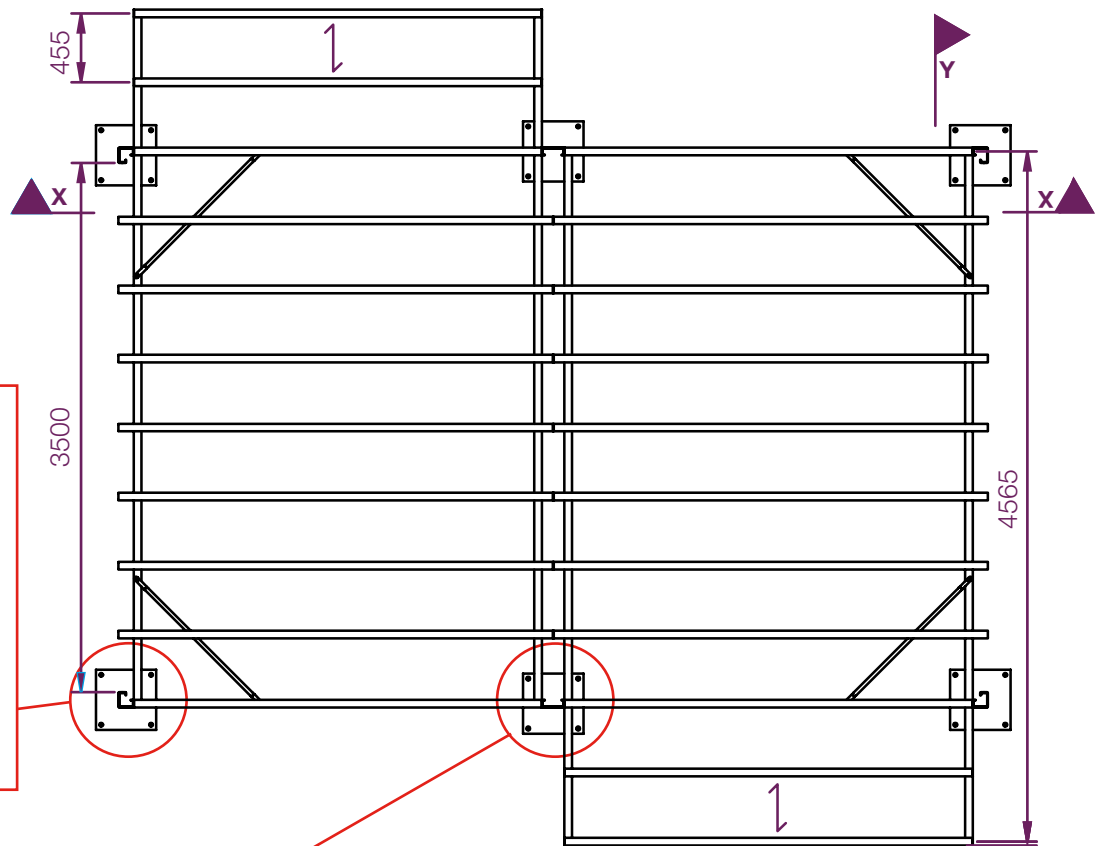
This shelter 'kit' presents a good design solution that is appropriate in areas vulnerable to high seismic loading although minor alterations are required for wind loads. Ensuring that timber planks are nailed to create a diaphragm or substituting them for plywood panels, strengthened columns and upgraded foundation details would improve its performance significantly (See Section C). It provides a transitional shelter option that is good quality, quickly scalable, and can be re-used or re-cycled. However it is comparatively expensive and there may be delays due to importation of materials. The design is similar to that of vernacular housing, with the steel replacing the traditionally used timber for the framing material.

* This shelter assessment is based on the assumption that the timber cladding was non-structural. In fact the timber planing was double nailed to form a structural system as in C.3.2 Walling option 2: shear panels.

Plans and comments

CHECK: In areas known to have high local wind pressures adequate foundations and member sizes must be provided.

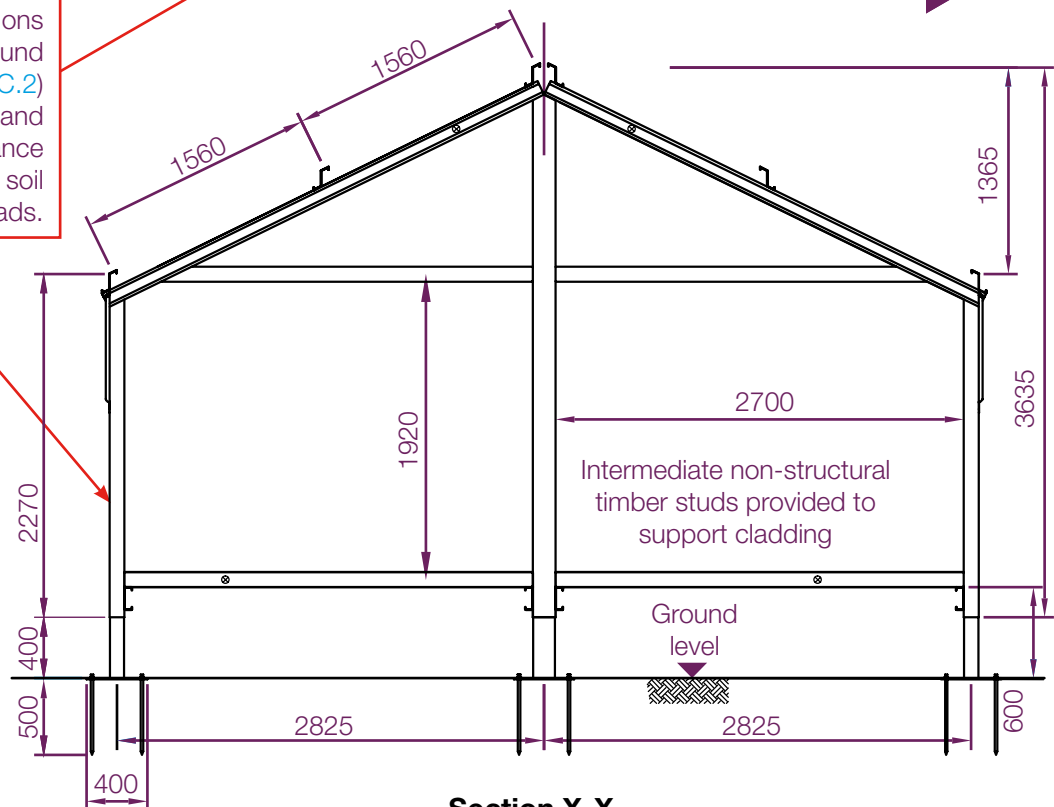
CHANGE : Modify the foundations from base plate nailed to the soil to concrete pad foundation (Section C.2) depending on soil type to prevent settlement of shelter.



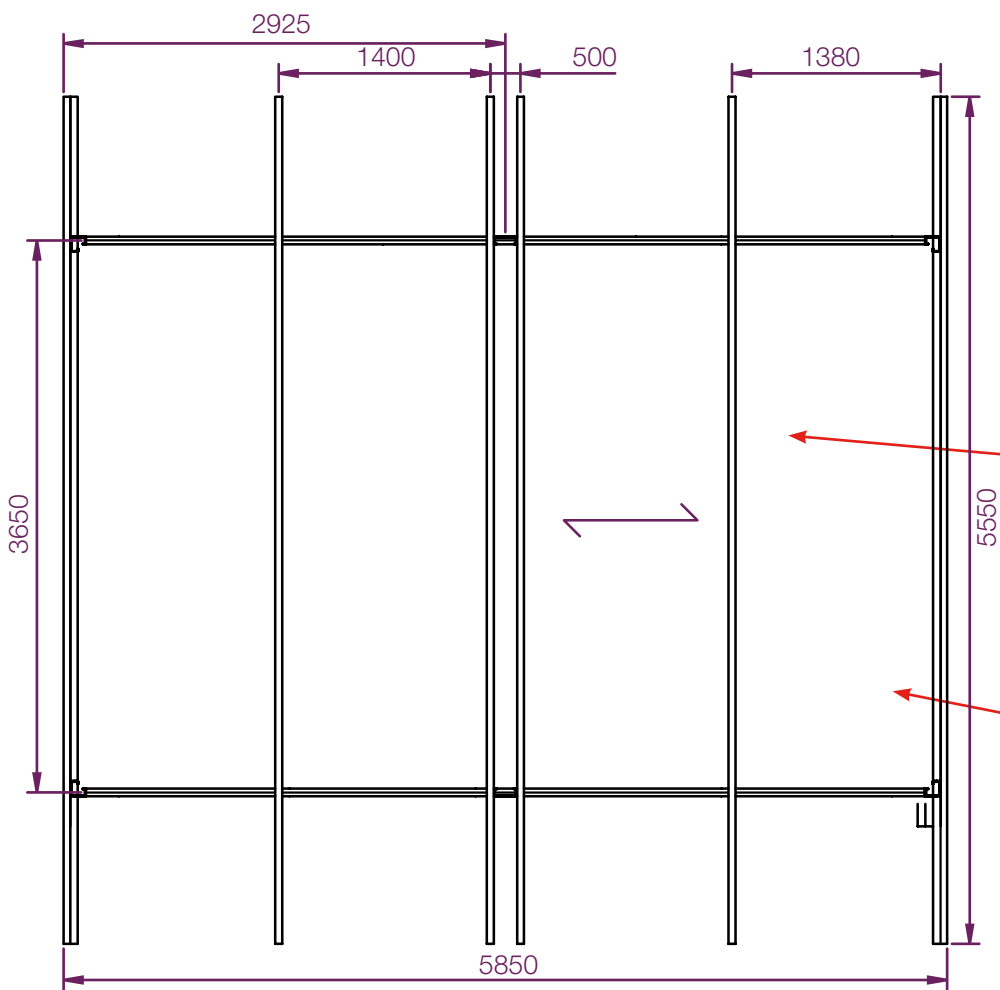
Ground floor plan

CHANGE: Use base plate or foundations or screw in ground anchor (Section C.2) to increase uplift and sliding resistance depending on soil type and wind loads.

CHANGE: All column sizes should be increased in accordance with design to local wind pressures.



Section X-X

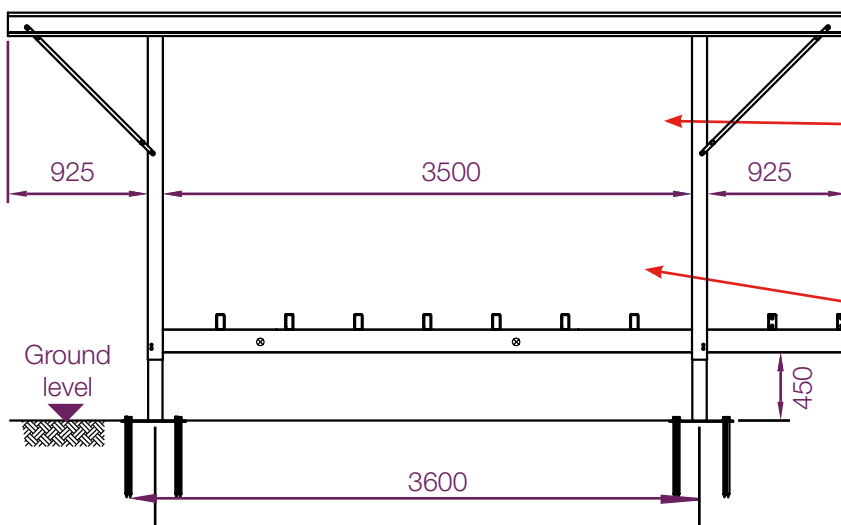


CHECK: The design and detailing of all connections is critical to the stability of the structure and should be checked for individual cases.

CHECK: Fasten roof sheet to purlins using screws spaced at appropriate intervals (Section C.4).

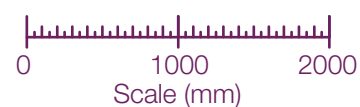
CHANGE: Provide in-plane bracing in the roof to increase lateral stability.

Roof Level Plan



CHANGE: Improve lateral stability by nailing planks to each other (Section C.3.2) upgrading the walls using 1/2" thick plywood (plywood 1 annex I.1.3) with vertical framing spaced at 600mm and the plywood with maximum 150mm on centre nail spacing (Section C.3). In this case header and primary floor beams would also require strengthening. Alternatively, walls could be braced in-plane with diagonal steel bracing.

CHECK: Do not upgrade walls using masonry or cement blocks due to risk to life and increase in seismic force attracted to the structure.



Section Y-Y

Durability and lifetime

The shelter frame, tools, timber planks and studs were delivered as a 'kit'. The timber planks and studs were delivered to site pre-cut and treated. The plywood was supplied separately. Windows and gable materials were not provided in the kit to encourage local markets. The shelter 'kit' was designed to be demountable and easy to relocate.

The durability of the shelter is good since the steel members are galvanised and the timber is treated.

Performance analysis*

The performance of the frame under gravity loads alone is adequate. The foundations must be upgraded to prevent the settlement of the column bases into the soil. Bracing is required in the walls and roof to improve the lateral stability and make the structure safe.

Hazard	Performance
Earthquake HIGH	AMBER: Medium risk of failure: Damage to the shelter is to be expected due to the low resistance to lateral loads provided by the timber cladding. Bracing or suitably nailed plywood should be used to improve the lateral stability and prevent failure in the event of an earthquake. The foundations should also be changed to prevent settlement. The structure is lightweight and relatively flexible so will pose a low risk to life if damaged.
Wind LOW	RED: High risk of failure: The shelter does not perform well under wind loads. In addition to bracing the walls and roof, an alternative foundation is required to prevent settlement, uplift and sliding under wind loads. The column size should also be increased.
Flood HIGH	GREEN: Low risk of failure: The shelter has a raised floor to prevent damage but no specific checks against standing water have been made.

* See section A.4.5 Performance analysis summaries

Notes on upgrades:

In many cases, the shelter has been upgraded by adding porches, partitions and extensions. However the main shelter structure has largely remained unaltered. In instances where the occupants were provided with permanent housing, the shelter was used as an extension, a second home, or a shop.

The performance of this shelter would be significantly improved for a relatively small cost by providing intermediate studs, nailed plywood shear walls and roof bracing.

If the shelter is adequately braced, the foundations modified and the column sizes increased, the roof or walls of the shelter can be upgraded with materials of a similar weight to those already in use. Upgrading the shelter with heavier materials will require appropriate foundation upgrades. Upgrading the shelter with masonry or other very heavy materials is not recommended as they will attract high seismic loads causing the structure to perform poorly in an earthquake. Collapse of a heavy roof or unreinforced masonry walls poses a serious risk to the lives of the occupants.

Assumptions:

- The maximum allowable floor live load is 0.9kN/m², which is appropriate for lightweight shelter design, and it has been assumed that the roof of the structure will not be subjected to loading from volcanic ash, sand or snow.
- A stiff soil type (see Site Class D, [International Building Code \(IBC\) 2009](#)) 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 in an earthquake but such damage is unlikely to risk the lives of the occupants.
- All fixings and connections are of sufficient strength to transmit forces between members.

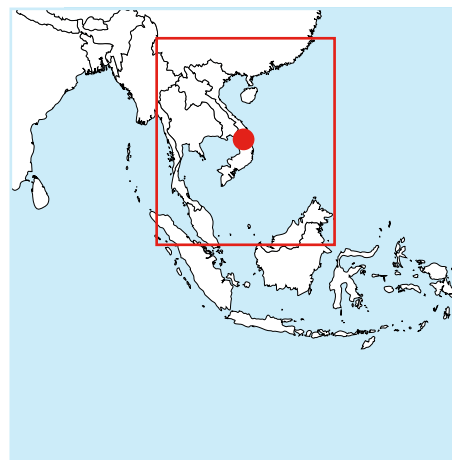
Bill of quantities

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 spoilage in transport and delivery.

Item (Dimensions in mm)	Material Specification See annex I.1	No.	Total	Unit	Comments
Structure – Foundations					
Guide post foundation 1 (400x400x8mm thick plate)	Steel 1	2	2	pieces	
Guide post foundation 2 (400x400x8mm thick plate)	Steel 1	4	4	pieces	
Anchor nails (19 dia. x 600)	Steel 1	24	24	pieces	
Main Structure					
Centre columns (150x50x1.6, L=3.79m)	Steel 2	2	7.58	m	
Corner columns (100x100x1.6, L=2.425m)	Steel 2	4	9.70	m	
Primary floor beams (150x50x1.6, L=4.613m)	Steel 2	4	18.45	m	
Roof truss beam (100x50x1.6, L=3.205m)	Steel 2	4	12.82	m	
Primary roof beams (100x50x1.6, L=2.79m)	Steel 2	4	11.16	m	
Bracing (25 dia. x 1.6thk, L=1.2m)	Steel 2	16	19.20	m	
Secondary Structure					
Floor edge joists (100x50x1.6, L=2.79m)	Steel 2	8	22.32	m	
Main floor joists (100x50x1.6, L=2.873m)	Steel 2	14	40.22	m	
Roof purlins (246x2, L=5.68m)	Steel 2	6	34.08	m	
Covering – Wall, Roof and Floor					
Roof panels (740x3440)	Sheet 2	16	40.73	m ²	
Timber wall planks (160x20, L varies)	Timber 3		44.60	m ²	Lengths by supplier
Timber studs (3.79 or 2.42m)	Timber 3	6	17.28	m	
Timber floor planks (160x20, L varies)	Timber 3		26.10	m ²	
Fixings					
Guttering (457x0.5thk, L=4.675m)		1	4.68	m	
Roof flashing (458x0.5thk, L=2.028m)		3	6.08	m	
Bolt + nut + 2 washer (M12x25)	Bolts	172	172	pieces	
Bolt + nut + 2 washer (M14x30)	Bolts	28	28	pieces	
Hex Screw (M5x19)		90	90	pieces	
Nails (8d)	Nails				Quantity as per fixings
Tools Required					
Taper Punching Tool, 3-14mm diameter		2	2	pieces	Makes holes in roof panel
Big Hammer		1	1	piece	
Carpenter Hammer		2	2	pieces	
Screw Driver		2	2	pieces	
Tape Measure, 5m		1	1	piece	
Plumb Bob + 50m gut		1	1	piece	
Water Level ~30cm		1	1	piece	

Sockets, No. 17 and 22		2	2	pieces	
Spanner, No. 17 and 22		4	4	pieces	
Knitted Gloves		2	2	pieces	
Bag		1	1	piece	
Multipurpose heavy duty spade		1	1	piece	
Hand saw, 18" length		1	1	piece	
Ladders		2	2	pieces	

B.8 Vietnam (2004) - Steel frame



Summary information

Disaster: Typhoons and floods from 1997 to the present day

Materials: Galvanised steel frame and zincalume corrugated roof sheeting

Material source: Concrete, blocks, plywood and roofing; sourced locally. Steel frame: procured nationally

Time to build: 3 days

Anticipated lifespan: 5 years

Construction team: 6 people

Number built: 215

Approximate material cost per shelter: Unkown

Approximate project cost per shelter: 1500 CHF

Shelter description

The shelter is a galvanised lightweight steel frame with plywood walls and a corrugated steel sheet roof. It has a covered area of 3.6 x 8.4m on plan including a living area of 3.6 x 7.2m. The roof has a pitch of 16.5 degrees. The height of the roof varies from 3.2m at the eaves to 4.6m at the ridge. There are two doors, one at the side and one at the front, and a cantilevered canopy projecting 1.3m beyond the door to form a porch. There are twelve columns, six of which have screw in ground anchor foundations, connected in pairs by a braced truss to form a moment frame. The stability system is formed by these three moment frames tied together by two further moment frames on each edge of the building. There is steel tie bracing underneath the roof sheeting. The shelter has a 100mm thick concrete slab base cast over the screw anchor foundations and floor tie beams. There is a low, non-structural, 0.5m, brickwork wall providing a degree of flood protection.

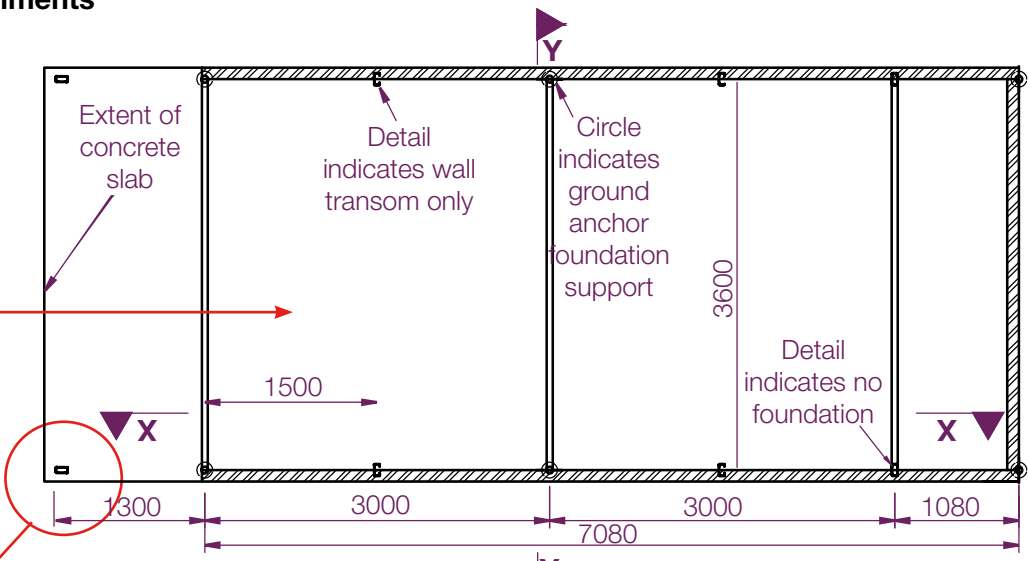
Shelter performance summary*

This shelter is an adequate design for low seismic areas but does not perform well under wind loading. The framing is relatively complex and has been adapted from previous designs. It is more than a transitional shelter and is likely to become a permanent house. It is very tall which provides the opportunity to include a mezzanine level or raised floor; although the frame would have to be strengthened structurally to support these elements. The frame is made from very thin sections not typically used in construction and the stability relies on the continuity of elements as a moment frame rather than bracing. Its performance could be greatly improved by improving the foundations, the steel members and bracing the walls and roof.

* Note that on a recent project evaluation, most of these shelters were found to be still standing after seven years, and remained in good condition. They are seen by many as a permanent house.

Plans and comments

CHECK: The concrete mix for the base slab should be as per 1.1.2 and a layer of mesh reinforcement used to prevent cracking and increase strength.



Ground floor plan

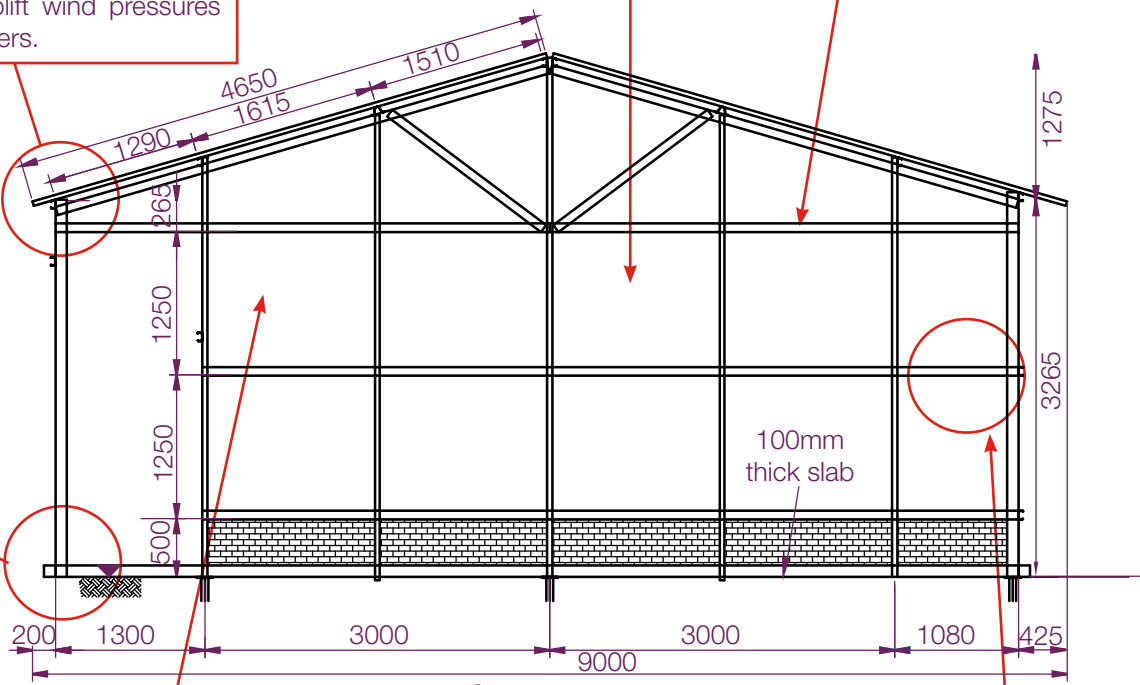
CHANGE: Strengthen column members by using a box section or by connecting thicker interlocking channel sections to improve bending capacity under seismic and wind loads.

CHANGE: Reduce height and length of porch canopy to reduce the effect of uplift wind pressures on these members.

CHECK: Plywood wall sheeting (Plywood 1, annex 1.1.3) must be nailed to intermediate timber studs spaced at a maximum of 600mm with 150mm nail spacing and 8d nails.

CHANGE: Increase size of eaves beams on all sides to take seismic and wind loads.

CHANGE: Canopy columns require screw in ground anchors (see Section C.2) as used for other columns in order to prevent uplift under the high local wind pressures.

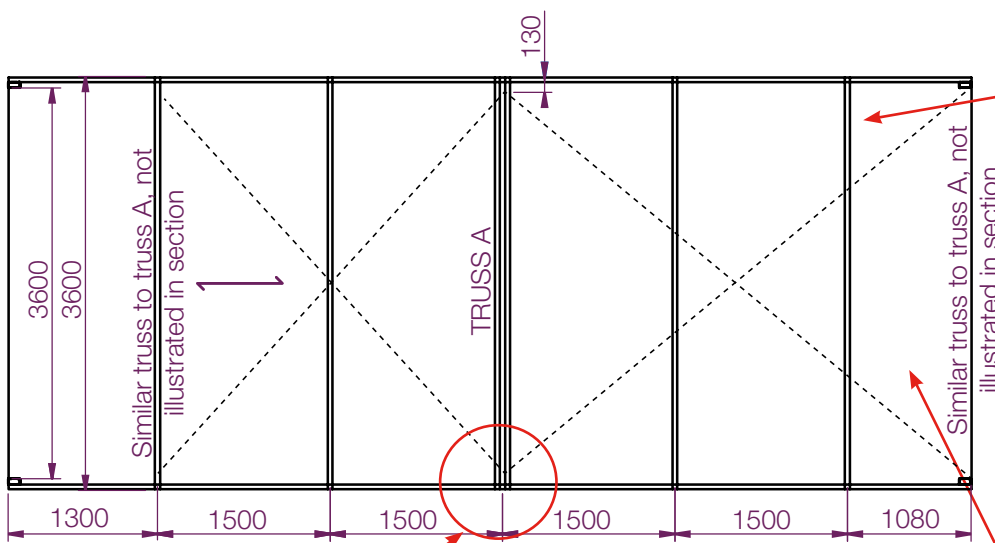


Section X-X

CHANGE: In-plane wall cross bracing or plywood shear walls required to improve the lateral stiffness of the shelter (see Section C.3).

CHECK: Brick wall will not withstand seismic loads and may collapse in an earthquake event.

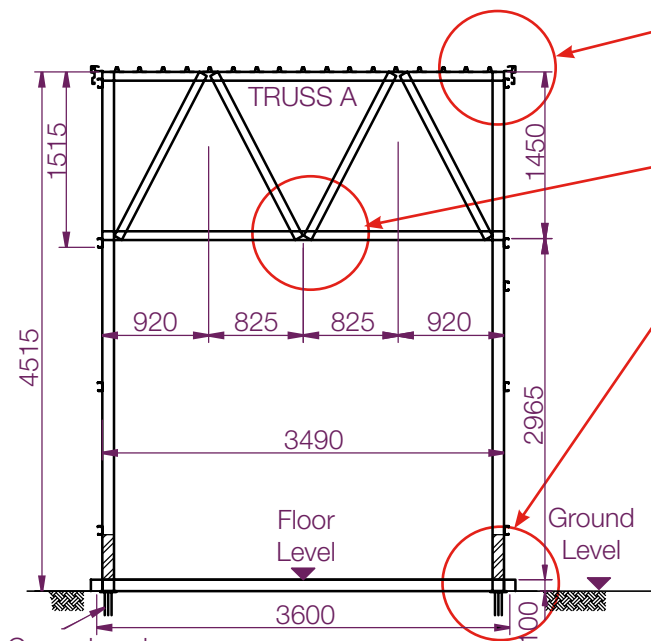
CHANGE: Decrease spacing of wall transoms and change orientation so that bending under wind loads occurs around the stiff axis.



Roof Level Plan

CHANGE: Do not offset roof bracing from columns. Bracing diameter should be increased to take forces from lateral wind loading.

CHECK: Roof sheeting should be 0.5mm thick and should span 3m with an intermediate purlin at the centre. Sheeting should be fixed using nails with washers at each crest at the eaves and ridge, and at every other corrugation crest on purlins in between.



Section Y-Y

CHANGE: Column heights can be reduced since no attic or mezzanine level is provided in the shelter. This would reduce the wall areas and therefore the wind loads on the shelter.

CHANGE: Strengthen rafters, bracing and truss chords to take lateral wind loads, for example by using thicker sections.

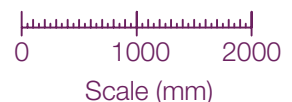
CHANGE: Use a screw in Ground Anchor foundation (See Section C.2) as indicated but with stabiliser plates to increase the shear capacity.

CHANGE: Increase thickness of all steel members to standard section sizes in order to increase the durability of the structure.

CHECK: The design and detailing of all connections is critical to the stability of the structure and should be checked for individual cases.

CHECK: In areas known to have high local wind pressures adequate foundations and member sizes must be provided to account for this.

CHECK: A stiff soil type has been assumed in analysis of the structure. Rock or softer soils may not be suitable for screw in ground anchors so an alternative foundation solutions may be required.



Durability and lifespan

In many cases the shelters have been upgraded and extended using salvaged and recycled materials. The shelters were designed to be demountable and reusable in other locations.

As the cold formed steel sections are extremely thin, they are susceptible to corrosion, especially in salty environments, and the durability of the shelter is therefore poor.

Performance analysis*

Performance under gravity loads is satisfactory. Bracing or plywood shear walls must be provided in order to increase the lateral stiffness of the structure.

Hazard	Performance
Earthquake LOW	AMBER: The performance of the shelter under seismic loads is satisfactory. Damage is expected as the structure is flexible and has a low stiffness under lateral loads. Some steel members require strengthening to ensure the frame will not fail in the event of an earthquake. However, it is lightweight and attracts very low seismic loads so will pose a low risk to life.
Wind MEDIUM	RED: The shelter attracts high wind loads because of its height. The frame is un-braced and relies on the continuity between the steel members and the cladding for stability. As a result, it is unlikely to perform well under wind loads. The foundations require strengthening to improve the shear capacity, and the spacing of the purlins and wall transoms should be decreased and the size and thickness of all members increased.
Flood HIGH	GREEN: Specific checks against standing water have not been made, however the provision of the 0.5m high brick wall helps to prevent flood damage.

* See section A.4.5 Performance analysis summaries

Notes on upgrades:

Upgrading the roof or walls with materials of a similar weight would not change the structural performance of the shelter providing all cladding materials are adequately fixed to prevent damage under wind loads.

Upgrading the roof or walls with heavier materials, would mean that member sizes would need to be increased and the connections and foundation capacities checked under the increased gravity and seismic loads.

Upgrading the shelter with masonry or other very heavy materials above the current wall level is not recommended as they will attract high seismic loads causing the structure to perform poorly in an earthquake. Collapse of a heavy roof or unreinforced masonry walls poses a serious risk to life.

Assumptions:

- The bottoms of the columns that are not connected to the screw anchors are provided with limited restraint since they are cast in to the 100mm thick concrete floor slab. This slab is assumed to be reinforced with mesh only.
- The low brickwork wall is not connected to the structural steel frame so does not place any loads on it.
- All connections between members have been assumed to be pinned and fixed with two screws. Throughout it has been assumed that all connections are of sufficient strength to transmit forces between members.
- The columns are bolted to base plates and the screw in ground anchors have a stiffened 140mm diameter plate welded to the top of them. These plates are bolted together using four 30mm long, M12 bolts in slotted holes. The column bases, screw foundation connections and floor ties have then been cast into a 100mm thick slab that forms the floor of the shelter and from which the 0.5m high wall is supported. The column bases have been assumed to be pinned and the slab is assumed to be resting on the ground.
- The screw in ground anchor foundations are similar to those illustrated in [Section C.2](#) (1200mm long, 60mm diameter, 3mm thick steel tube with a 400mm diameter, 3mm thick, 150 pitch helical screw plate at the base).
- The shelter walls are made from plywood sheets nailed to timber studs. These studs are screwed to the frame or an equivalent system that transmits wind loads back to the frame without being damaged.

Bill of quantities

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	Material Specification See annex I.1	Quantity	Total	Unit	Comments
Structure – Foundations					
Screw Ground Anchors	See Section C.2	6	6	Pieces	See assumptions
Portland Cement	Concrete	15kg	15	Bags	42.5kg/bag, estimate only for 3.5m ³ concrete
Sand	Concrete		1.3	m ³	Estimate
Gravel	Concrete		2.55	m ³	Estimate
Wire Mesh Reinforcement			32.5	m ²	
Primary Structure					
Columns 2No. 100x50x0.75 Channels Interlocking to form box (L=3.3m)	Steel 4	4x2	26.4	m	
Columns 2No. 100x50x0.75 Channels Interlocking to form box (L=4.5m)	Steel 4	2x2	18.1	m	
Columns 2No. 100x50x0.75 Channels Interlocking to form box (L=3.7m)	Steel 4	4x2	29.2	m	
Rafters 75x40x0.75 Channel (L=4.5m)	Steel 4	4	18	m	
Transverse Beams 75x40x0.75 Channel (L=3.5m)	Steel 4	4	14	m	
Longitudinal Beams 75x40x0.75 Channel (L=4.3m)	Steel 4	2	8.6	m	
Longitudinal Beams 75x40x0.75 Channel (L=4.1m)	Steel 4	2	8.2	m	
Truss Bracing 75x40x0.75 Channel (L=1.65m)	Steel 4	8	13.2	m	
Truss Bracing 75x40x0.75 Channel (L=1.93m)	Steel 4	3	5.8	m	
Wall Bracing 75x40x0.75 Channel (L=1.7m)	Steel 4	4	6.8	m	
Secondary Structure					
Floor Ties 100x50x0.75 Channel (L=3.5m)	Steel 4	3	10.5	m	
Cable Bracing – 4mm dia. (L=5.3m or 4.5m) + Turn Buckle	Steel 4	4	19.6	m	
Wall columns 75x40x0.75 Channel (L=3.65m)	Steel 4	2	7.3	m	
Wall Transoms 75x40x0.75 Channel (L=3.0m)	Steel 4	6	18.2	m	
Wall Transoms 75x40x0.75 Channel (L=4.1m)	Steel 4	2	8.2	m	

Door Framing 75x40x0.75 Channel (L=2.3m)	Steel 4	2	4.6	m	
Purlins 75x35x0.75 Channel, 12mm lip (L=3.6m)	Steel 4	6	21.6	m	
Purlins 103x61x1.0 thk. (L=3.6m)	Steel 4	2	7.2	m	
Covering – Wall and Roof					
Plywood – 12.5mm thick	Plywood 1		90	m ²	
Roof Sheeting – 0.5mm thick (4.65x2m)	Sheet 2	4	34	m ²	
Ridge Capping 578x0.45mm thk. (L=3.8m)	Sheet 2	1	3.8	m	
Flashing 289 x 0.4mm thk (L=4.9m)	Sheet 2	4	19.6	m	
Timber studs	Timber 2				As required for walls
Fixings					
Bolts – M12x30	Bolts	35	35	Pieces	
Self tapping screws 10-24x22	Screws	200	200	Pieces	Roofing
Self tapping screws 15-15x20	Screws	80	80	Pieces	Flashing
Self tapping screws 12-14x20	Screws	500	500	Pieces	Frame
Cleat 100x50x1.9mm thick	Steel 1	4	4	Pieces	
Foundation Cleat 150x80x4mm thk	Steel 1	6	6	Pieces	
Nails – 8d	Nails				As required for walls
Fixing Strap	Steel 1		76	Pieces	For roof
Tools Required					
Drill		1	1	Pieces	
Hammer		2	2	Pieces	
Big Hammer		1	1	Pieces	
Screw Driver		3	3	Pieces	
Tape Measure, 5m		1	1	Pieces	
Spirit Level		1	1	Pieces	
Plumb bob + line		1	1	Pieces	
Spade		1	1	Pieces	
Hand saw		1	1	Pieces	
Ladders		2	2	Pieces	

Section C

Typical Design Details

This section includes some foundation details, wall systems as used in transitional shelters, and the principles required in tying roofing down.

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C.1 Hazards and design details

A transitional shelter's ability to resist a hazard is a combination of where it has been located and its design. For lightweight shelters, some risks, such as tidal surges, landslides and volcanos cannot be reduced by design, and choosing safe locations is the only way to reduce the risks.

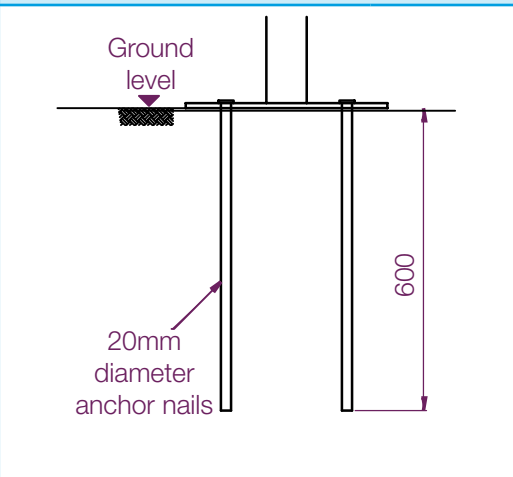
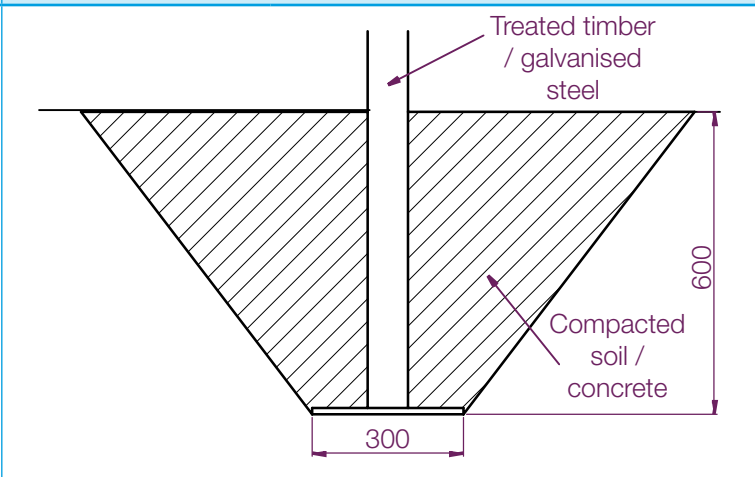
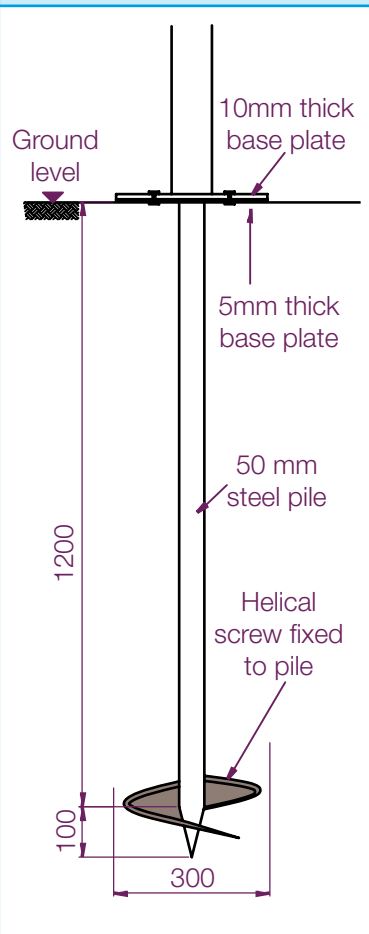
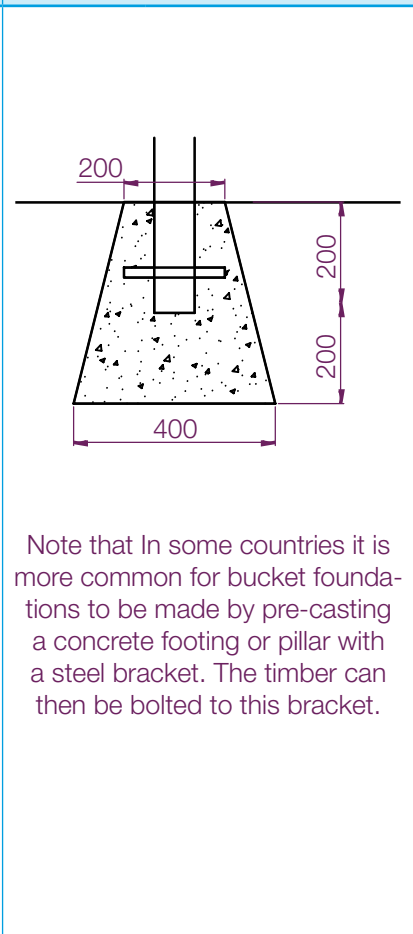
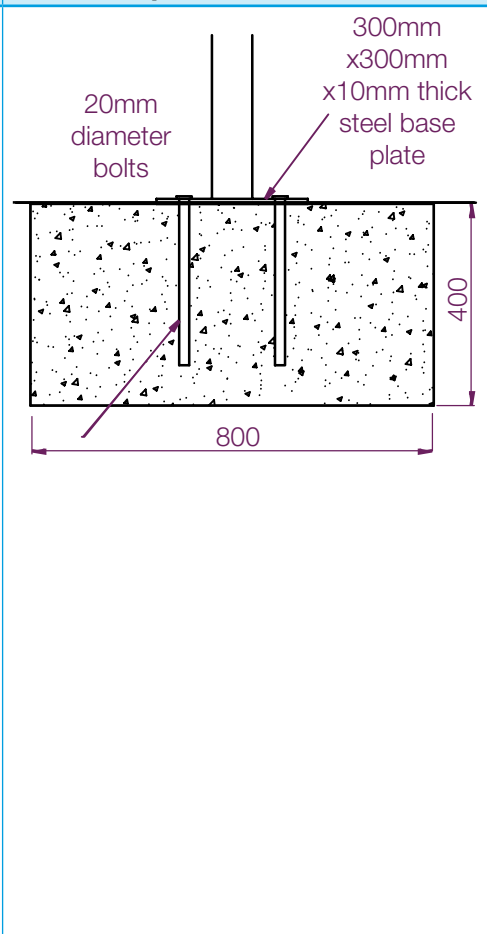
The table below, summarises how various hazards can be mitigated through choice of location and through improved design.

Hazards	Mitigating actions		
	Site Selection and Planning	Shelter Design	Construction
Windstorm / Hurricane	<ul style="list-style-type: none"> Locate away from areas exposed to strong winds. 	<ul style="list-style-type: none"> Use appropriate building shapes, materials and detailing (e.g. building orientation and roof pitch to minimise wind load). 	<ul style="list-style-type: none"> Ensure good quality of construction and workmanship.
Flood	<ul style="list-style-type: none"> Locate away from flood plains and locations with high water tables. Provide adequate drainage systems. 	<ul style="list-style-type: none"> Raise houses above ground level. Reinforce ceiling for storage in mezzanine level. 	
Earthquake	<ul style="list-style-type: none"> Locate away from fault lines. Locate away from areas where liquefaction occurs (such as near river beds, coastal areas with sandy soils and high water tables). 	<ul style="list-style-type: none"> Use appropriate building shapes, materials and detailing (e.g. strengthen ring beams at corners). 	<ul style="list-style-type: none"> Ensure good quality of construction and workmanship.
Tidal surge/ Tsunami	<ul style="list-style-type: none"> Locate away from areas vulnerable to tsunamis or storm surges. Provide clear evacuation routes, and establish clear warning systems and evacuation plans. 	<ul style="list-style-type: none"> Transitional shelters cannot be designed to withstand tidal surges or tsunamis. 	
Landslide	<ul style="list-style-type: none"> Locate away from areas vulnerable to landslides (e.g. on or at the bottom of steep slopes). Provide slope stabilising systems (e.g. retaining walls, vegetation, adequate drainage). 	<ul style="list-style-type: none"> Transitional shelters cannot be designed to withstand landslides. 	
Volcano	<ul style="list-style-type: none"> Locate away from areas vulnerable to volcanoes (e.g. away from lava flows, smoke, ash and explosions). 	<ul style="list-style-type: none"> Transitional shelters cannot be designed to withstand volcanic eruptions. 	
Fire	<ul style="list-style-type: none"> Plan settlements with fire breaks. Leave gaps between shelters to provide fire breaks. 	<ul style="list-style-type: none"> Use appropriate building materials and detailing (e.g. use fire retardant materials). 	

C.2 Foundations

These five sketches show examples of foundations that are suitable for transitional shelters. The exact choice will depend upon the specific ground conditions, the size of the likely hazard, the cost, local construction styles and local material availability.

The foundations drawn here have been selected for their ease of installation and cost effectiveness. Some of them can be reused.

Base plate nailed to soil	Embedded base plate	
		
Screw in Ground Anchor	Concrete bucket foundation	Concrete pad foundation
	 <p data-bbox="531 1624 946 1814">Note that In some countries it is more common for bucket foundations to be made by pre-casting a concrete footing or pillar with a steel bracket. The timber can then be bolted to this bracket.</p>	

C.3 Walls

The sketches below show some stability systems for walling that are appropriate to transitional shelter buildings. Some form of stability system is essential in each direction to ensure that buildings stand up in wind and earthquakes.

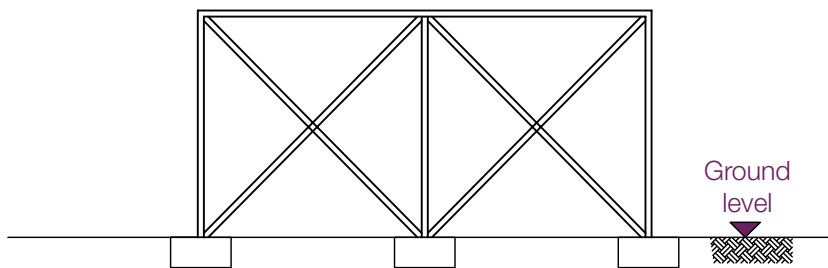
The three basic wall stability systems are:

- ↘ bracing* (C.2.1)
- ↘ shear walls (C.2.2)
- ↘ moment frame (C.2.3)

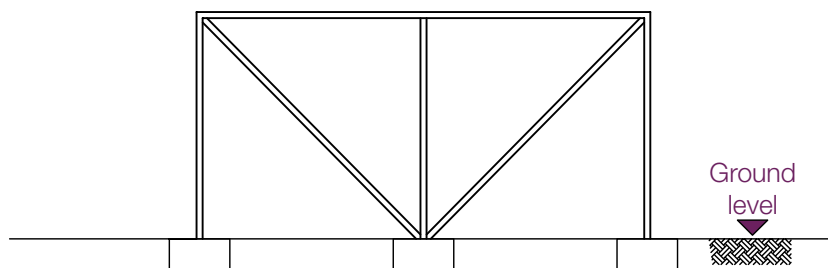
Different types of each are shown here to illustrate the basic configurations available. These configurations assume that simple connections between members can be made. However, it is good practice to use at least two nails in timber joints to give them some rigidity.

The type of stability system used in a structure will depend on the size of the likely hazard, cost, traditional styles and the local availability of materials. Note that depending on the option chosen and the size of the hazard, the deflections and deformation of the building may still be large.

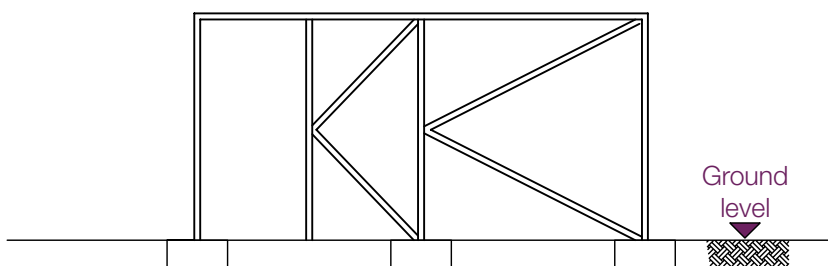
C.3.1 Walling option 1 Bracing types



Cross Bracing: Can be wire, steel, timber or bamboo (in tension only)



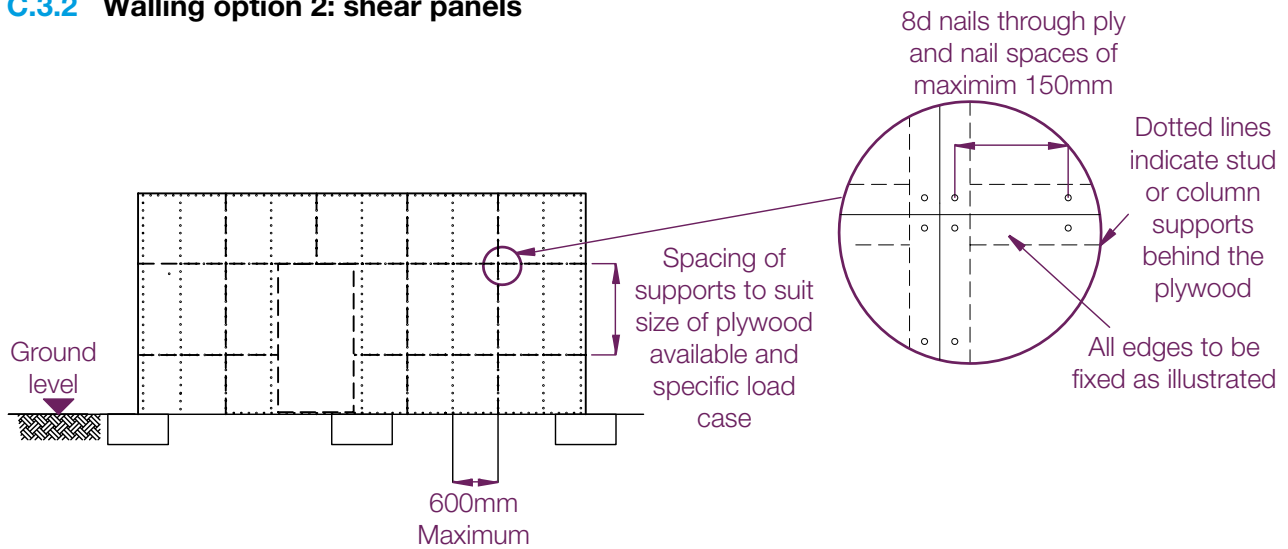
V Bracing: Can be wire, steel, timber or bamboo



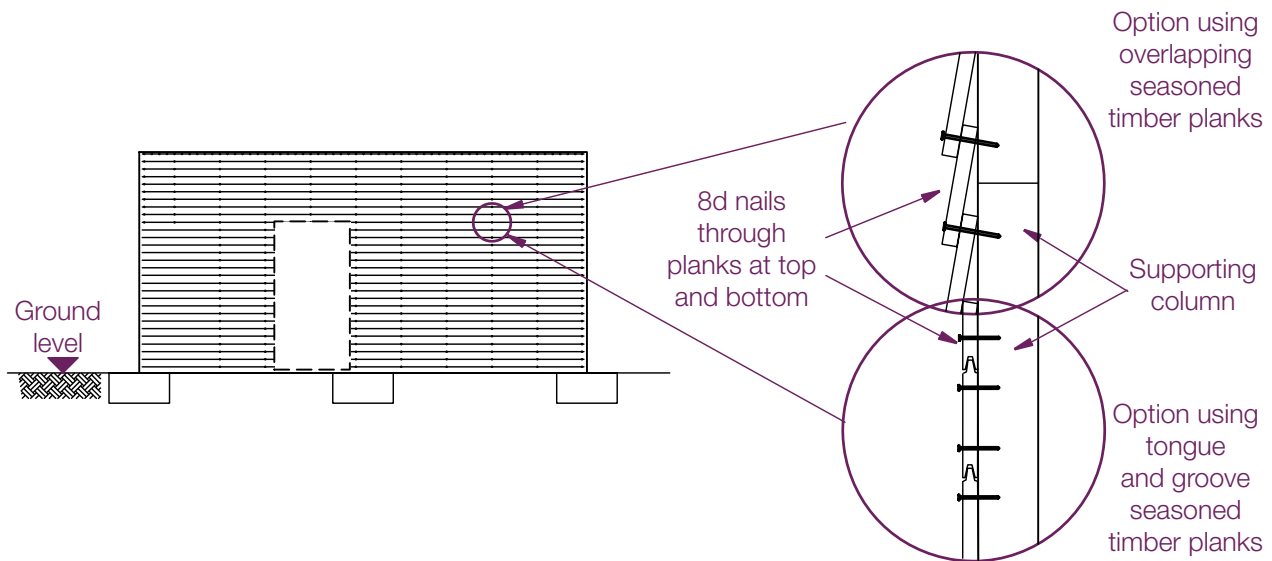
K Bracing: Can be steel, timber or bamboo (that adequately resists buckling)

*Note that all bracing connections should be able to take tension as well as compression

C.3.2 Walling option 2: shear panels

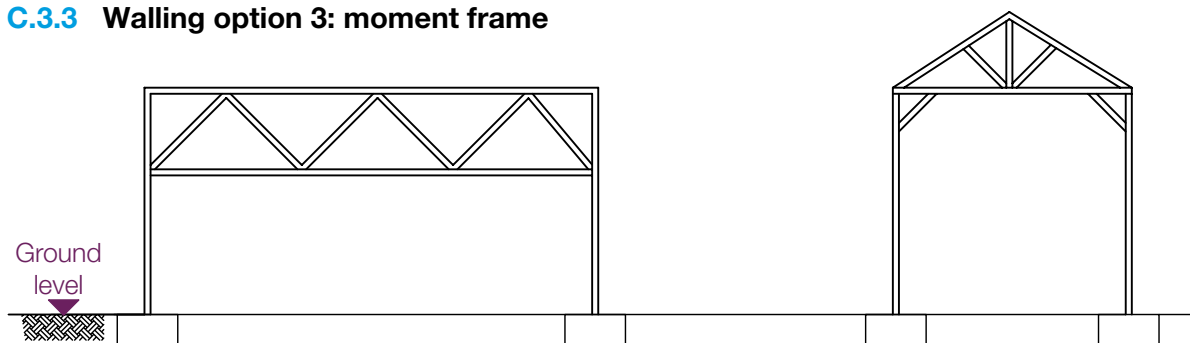


Plywood shear walls: Studs spaced at 600mm centres and doubled around openings. Structural members should be designed for specific load cases. Use ½" thick structural grade plywood ([plywood 1 annex I.1.3](#)).



Panels of Nailed Planks: Planks should overlap sufficiently and be nailed to each other at suitable centres. Note that for timber to be used structurally in this way, it must be seasoned to prevent it from splitting.

C.3.3 Walling option 3: moment frame



Moment frame: Timber or steel members with moment connections or trusses.

C.4 Roof

The drawings below show good examples of how a roof structure can be tied together.

They drawings illustrate that all of the loads (especially wind uplift forces) should be transmitted to the foundations. This is achieved by ensuring that all elements (roof sheet / purlins / rafters / beams / columns / foundations) are tied to one another adequately.

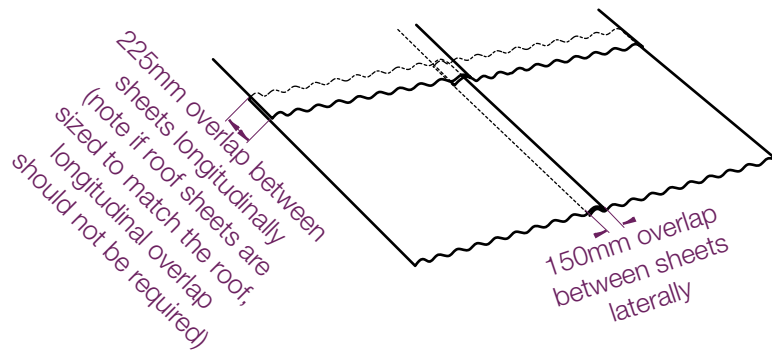
Roof sheets should overlap sufficiently to ensure that there are no leaks.

Sheeting to Purlins

Sheeting should be securely nailed to the purlins

Screw or nail through every other crest except on eaves and ridge. On the eaves and ridge sheets should be nailed on every crest

Nails should only be placed through the crest to prevent water leaking. Use twisted galvanised nails or J-hooks together with large steel washers or caps.



Purlins to Rafters

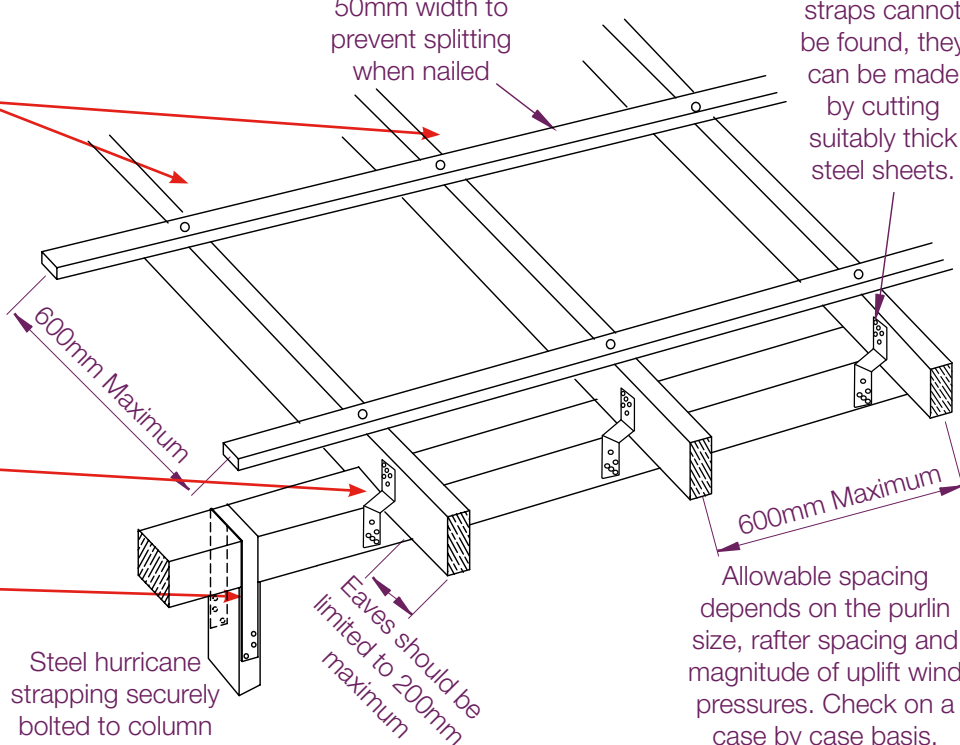
Purlins should be securely fastened to rafters

Purlins minimum 50mm width to prevent splitting when nailed

If specialised straps cannot be found, they can be made by cutting suitably thick steel sheets.

Rafters to Beams

Connection of rafters to beams may require strapping



Beams to Columns

Beams should be securely fastened to columns

Allowable spacing depends on the purlin size, rafter spacing and magnitude of uplift wind pressures. Check on a case by case basis.

Annexes

These Annexes contain materials specifications, a template for a design brief that can be used to start discussions in future disasters, basic metric to imperial conversion tables, a glossary of terms used and documents for further reading complete with annotations.

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I.1 Materials specifications

I.1.1 Introduction


The materials specifications below contain the values as used in the calculations in section B. In most cases they are not of sufficient detail to launch large scale procurements.

Please refer to [IFRC/ICRC Emergency Items Catalogue](#) for fuller guidance on specification on timber, plywood, cement, corrugated galvanised iron and plastic sheeting. The emergency relief items catalogue also contains detailed specifications for tools, nails and wire in the shelter tool kit (catalogue number KRELSHEK01).

[Humanitarian Bamboo Project](#) is a good starting place for further information on bamboo.

I.1.2 Structural materials

Material	Material Type	Specification	Required Properties
Timber 1*	Coconut Wood	High to medium density coconut wood from outside of tree or wood of similar properties	Density 400kg/m ³ , elastic modulus 7584N/mm ² , bending strength 15N/mm ²
Timber 2*	Douglas Fir – South Used as an equivalent to Eucalyptus wood in B.6 Peru and for wall cladding in B.8 indonesia, Aceh .	No. 2 Structural Grade treated timber**	Density 530 kg/m ³ , Young's Modulus 8274N/mm ² , bending strength 5.86N/mm ²
Timber 3*	Aspen or acacia/white poplar with same properties	No. 2 Structural grade treated timber**	Density 420 kg/m ³ , Young's Modulus 6895N/mm ² , bending strength 4.14N/mm ²
Timber 4*	'White Bolaina' or Douglas Fir – South	No. 2 Structural Grade treated timber or equivalent**	Density > 410 kg/m ³ , Young's Modulus 8274N/mm ² , bending strength 5.86N/mm ²
Steel 1	Minimum grade structural steel	Hot rolled galvanised steel	Yield strength 275N/mm ² , density 78.5kN/m ³
Steel 2	Cold formed galvanised steel (B.8 Indonesia, Aceh)	Cold rolled, hot dip galvanised steel, JIS G3302, ASTM A653 M-95*, minimum thickness 1.6, 2mm.	Yield strength 550N/mm ² , density 78.5kN/m ³
Steel 3	Cold formed galvanised steel (B.7 Haiti)	Cold rolled galvanised steel, JIS G3302, ASTM A653 M-95*, minimum thickness 2mm	Design yield strength 260N/mm ² , elastic modulus 210kN/mm ² , density 78.5kN/m ³
Steel 4	Cold formed galvanised steel	Cold rolled galvanised steel, JIS G3302, ASTM A653 M-95*, minimum thickness 0.75mm prior to galvanising	Yield strength 550N/mm ² , density 78.5kN/m ³
Bamboo 1****	Giant Bamboo, also known locally as Bambu Petung (Dendrocalamus Asper)	Average properties along length: 150mm diameter, 13.5mm wall thickness, 700kg/m ³ density, 300mm node spacing	Young's Modulus 17,000N/mm ² Allowable stresses for design (not including load duration factor): compression 9.1N/mm ² , bending 14N/mm ² , shear 2.1N/mm ²

Bamboo 2***	Tropical Black Bamboo, also known locally as Bambu Apus (Gigantochola Apus)	Average properties along length: 80mm diameter, 7.2mm wall thickness, 700kg/m ³ density, 330mm node spacing	Young's Modulus 17,000N/mm ² Allowable stresses for design (not including load duration factor): compression 9.1N/mm ² , bending 14N/mm ² , shear 2.1N/mm ²
Concrete	Concrete	Portland cement, sand and 20mm aggregate in mix ratio 1:3:6 by volume	Concrete assumed to be of the best available quality but with a minimum compressive cube strength, fcu, of 15-20MPa at 28 days
Steel reinforcing bar	Steel reinforcing bar	12mm diameter profiled reinforcement 	Mild steel properties assumed: minimum yield strength 250N/mm ² . Minimum cover to reinforcement 25mm.
Wire mesh	A142 Mesh	200mm x200mm wire spacings. 6mm diameter wire	

* See also [UNOCHA / IFRC / CARE International, Timber](#).

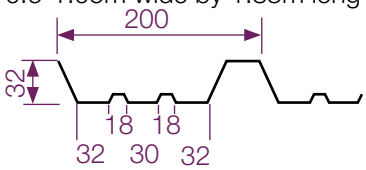
** This book uses the grading systems in NDS - see [National Building Codes & Standards](#).

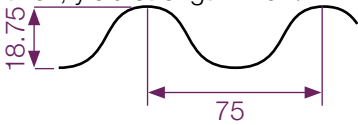
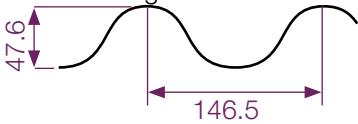
*** See [International Standards for Materials, Products, Systems and Services](#).

**** See also [Humanitarian Bamboo Project](#).

1.1.3 Cladding materials

Please also refer to [IFRC/ICRC Emergency Items Catalogue](#) for further guidance on the specification on corrugated iron.

Material	Material Type	Specification	Required Fixings
Plywood 1	Plywood for walls	½" thick structural grade, 24/16 span rated, 4 ply, density 550kg/m ³	Framing must be spaced at 600mm and a maximum nail spacing of 150mm used assuming 8d nails
Plywood 2	Plywood for floors	Plywood for floor to be 7/8" thick structural grade, 54/32 span rated, density 550kg/m ³	Plywood to be fixed using 8d nails spaced at 150mm centres
Sheet 1	Galvanised aluminium/ zinc coated corrugated steel sheeting	0.45mm thick, 75mm spacing between corrugations 18.75mm trough height. Standard sizes range from 0.6-1.05m wide by 1.83m long  Profile of the sheeting with dimensions in mm	Sheeting should be fixed using twisted galvanised 8d roofing nails (56.25mm long) with a typical spacing of 300mm on centre Along eaves and roof ridge it is recommended to nail every other corrugation – nails should be through crown

Sheet 2	Galvanised aluminium/ zinc coated steel sheets	Lightweight steel sheet, 0.5mm thick, yield strength 275N/mm ²  Profile of the sheeting with dimensions in mm	Nail using 8d nails – one or two per corrugation (through crown) depending on purlin spacing and wind pressures
Sheet 3	Fibre cement corrugated roof sheeting	High strength fibre cement sheet with polypropylene reinforcement strips, 6.7mm thick, 1086x3050mm sheets with 70mm overlap, 0.17kN/m ² installed weight  Profile of the sheeting with dimensions in mm	Two fixings per sheet in 2mm oversize holes with 8d nails & washers. 1300mm maximum purlin spacing. Seal required between sheets for total weatherproofing.
Plastic	Plastic sheeting (4m x 6m)	IFRC standard Polyethylene sheet with braided core (HDPE/LDPE)	Assume that sheeting is stapled or nailed at appropriate intervals in accordance with framing and wind pressures
Tiles	Clay interlocking tiles	Large clay interlocking pantiles: 403 x 325mm, 9.9tiles/m ² , minimum head lap 47mm, installed weight 0.4kN/m ²	Recommended fixings use short 8d roofing nails and clips from battens laid on top of rafters

I.1.4 Fixings

The specifications here are those used for the calculations in this book. Please refer to [IFRC/ICRC Emergency Items Catalogue](#) for further guidance on the specification of nails and wire.

Material	Material Type	Specification	Required Properties
Nails	Round steel wire nails	10d (~3.7mm dia. 75mm long) 6d (~2.8mm dia. 50mm long) 8d (~3.3mm dia. 62.5mm long) 4d (~2.5mm dia. 37.5mm long)	Minimum yield strength 275N/mm ² . For dimensions refer to Table L4, NDS for Wood Construction 2005.
Staples	Steel staples	22/25 staples assumed (~0.64mm thick)	Minimum yield strength 275N/mm ²
Wire	Steel wire	American Wire Gauge 16 - 1.3mm diameter	Minimum yield strength 275N/mm ²
Bolts	Steel bolts	Diameter as specified per shelter (M6, M10, M12, M14, M20 etc.)	Minimum yield strength 275N/mm ²
Screws	Steel screws	Diameter and length as specified per shelter	Minimum yield strength 275N/mm ²

I.2 Template design brief

This annex contains a sample template for a design brief for a transitional shelter. It is based on the agreed standards for transitional shelters that were agreed by the Shelter Clusters in Haiti following the 2010 earthquake, and the 2009 earthquake in Padang, Sumatra, Indonesia. Where marked in [blue text](#), indicators, standards or remarks may need to be deleted if they are not relevant to the context. Where marked with [XXX](#), values need to be collectively agreed, specific to the context.

Organisations may wish to add more programmatic issues to this technical brief such as targeting, support for the most vulnerable recipients, and technical messaging.

Performance standards and indicators for transitional shelters		
Indicators	Standard	Remarks
Key data		
Life span (see A.2.6)	<ul style="list-style-type: none"> ↘ Materials and shelter construction to allow for more than XXX months use. ↘ Materials should allow for easy maintenance and upgrade 	
Cost (see A.2.12)	<ul style="list-style-type: none"> ↘ XXX USD including transport and labour, excluding taxes and project management costs. (For one storey transitional shelter, assuming additional input of material and labour from home owners) 	<ul style="list-style-type: none"> ↘ Consider supplying only some of the materials when existing timbers / roofing materials remain. ↘ Cost may be adjusted upwards by XX% due to; market fluctuations, extra shipping costs for goods outside of the region, etc.
Covered living space (see A.2.7)	<ul style="list-style-type: none"> ↘ Provide a target of XXXm² floor space with XXXm² as a maximum ↘ In exceptional cases, a minimum of XXX m² may be considered for instances where no other space is available, and with a clear justification 	<ul style="list-style-type: none"> ↘ Assuming average of XXX persons per family "Life span" ↘ See sphere
Head height (see A.2.7)	<ul style="list-style-type: none"> ↘ A minimum of XXXm from the ground to the eaves 	<ul style="list-style-type: none"> ↘ Slight variation may arise depending on material used.
Hazard resistant construction (see A.2.4)		
Rains and Floods	<ul style="list-style-type: none"> ↘ The roof should protect the interior and walling materials from rain ↘ Foundations have sufficient strength and height to withstand flooding of site. 	<ul style="list-style-type: none"> ↘ At the same time, ensure that any roof overhang is not so large as to increase the hazard from strong winds
Wind and storms	<ul style="list-style-type: none"> ↘ Foundations must secure the shelter to the ground in strong winds. ↘ The roof must be fixed securely to be resistant to storms and must be designed with adequate strength for proposed roofing material. ↘ Structures should be designed so that timbers and the joints take the loads rather than the fixings ↘ Where appropriate: Metal strapping is strongly advised to protect against hurricane and earthquake. 	<ul style="list-style-type: none"> ↘ A pitch of 30^o-45^o for 2-pitched roofs is optimum for resistance against strong winds. ↘ A design wind speed of XXX km/h is suggested. ↘ Wide roof spans are to be avoided as they weaken the structure
Earthquake	<ul style="list-style-type: none"> ↘ Seismic resistance techniques must be incorporated into shelter form, locations of doors and windows, foundations, bracing and ring beam connections 	

Design principles		
Suitable for relocation	<ul style="list-style-type: none"> ↘ Shelters can be relocated by the occupants ↘ Where possible, materials are to be reusable 	<ul style="list-style-type: none"> ↘ The shelters may later be used as kitchens, verandas, or shops.
Hazard resistant Learning (see A.2.4)	<ul style="list-style-type: none"> ↘ Shelters should provide practical learning examples of principles of good construction (e.g. openings such as doors should be away from the corners of the structure) 	<ul style="list-style-type: none"> ↘ To promote good earthquake, hurricane and flood resistance practice.
Ventilation and thermal comfort (see A.2.9)	<ul style="list-style-type: none"> ↘ Hot climates only: <ul style="list-style-type: none"> ↘ Where possible, promote openings on XXX sides of the shelter to allow for cross ventilation ↘ Allow for adequate ventilation and design to minimise internal temperatures. ↘ Cold climates: <ul style="list-style-type: none"> ↘ Design the shelter to minimise cold air infiltration and maximise internal temperatures. ↘ Ensure that there is ventilation to prevent health hazards due to fumes from cooking fuel. 	<ul style="list-style-type: none"> ↘ Openings shouldn't affect structural integrity of the shelter.
Privacy (see A.2.8)	<ul style="list-style-type: none"> ↘ The design should allow families to add at least one internal division for privacy ↘ The shelter should provide a flexible space. 	<ul style="list-style-type: none"> ↘ Hot climates: Internal divisions should not go as high as the roof as this will reduce ventilation.
Culturally appropriate (see A.2.8)	<ul style="list-style-type: none"> ↘ Shelter layouts, materials and construction techniques to be used are familiar or easy to understand by the beneficiaries. 	
Access	<ul style="list-style-type: none"> ↘ Shelters should take into account access by disabled people, wherever possible 	
Site and services (see A.2.11)		
Tenure	<ul style="list-style-type: none"> ↘ Legal aspects of the site or plot should be resolved. ↘ A minimum time frame for any transitional agreement is XXX months but it is preferred to have an agreement of XXX years or longer (linked to life span) 	<ul style="list-style-type: none"> ↘ Take into account different forms of tenure security, including ownership, tenancy and other arrangements
Location	<ul style="list-style-type: none"> ↘ In principle, the location of the shelter should support the choice made by the shelter owners themselves. Wherever possible, shelter should be constructed at, or near to the existing homestead, without inhibiting permanent housing reconstruction ↘ Shelters should not be built next to dangerous buildings or structures, on land liable to flood, on land at risk of landslide, or in locations that expose the occupants to other hazards. ↘ Shelters should be built in locations that help occupants to maintain access to livelihoods. 	<ul style="list-style-type: none"> ↘ Except when an existing damaged house is deemed unsafe.
Plot preparation	<ul style="list-style-type: none"> ↘ Sites need to be cleared of any physical dangers 	<ul style="list-style-type: none"> ↘ Refer to any agreements on rubble removal that may exist
Water & Sanitation	<ul style="list-style-type: none"> ↘ Adequate water supply and sanitation facilities should be provided. ↘ Construction must be coordinated with WASH. ↘ Adequate site drainage is provided to minimise the risk of flooding. Individual Shelters must be connected to site drainage solution. 	

I.3 Conversion tables

The data on this page is all rounded to 4 significant figures. Penny sizes are rounded to the nearest mm.

I.3.1 Length

Imperial	1 inch (in.)	1 feet (ft.) = 12 in.	1 yard (yd.) = 3 ft. = 36 in.	1 mile = 1760 yd.
	↓	↓	↓	↓
Metric	25.4 mm = 2.54 cm	304.8 mm	0.9144 m	1.609 km

For equivalence tables in timber sizing see [UNOCHA / IFRC / CARE International, Timber](#)

I.3.2 Area

Imperial	1 square feet (sq. ft.)	1 square yard (yd ²) = 9 sq. ft.	1 acre
	↓	↓	↓
Metric	0.0929 m ²	0.8361 m ²	4046.9 m ²

1 perch = 30.25 square yards 1 acre = 4,840 square yards 1 hectare = 10 000m²

I.3.3 Volume

Imperial	1 cubic feet (ft ³)	1 cubic yard (yd ³)
	↓	↓
Metric	28.32 litres = 0.02832 m ³	0.7646 m ³

1 US liquid gallon = 3.785 litres 1 US dry gallon = 4.405 litres 1 imperial (UK) gallon = 4.546 litres

I.3.4 Weight

Imperial	1 pound (lb)	Ton (UK, long ton)	Ton (US, net ton, short ton)
	↓	↓	↓
Metric	0.4536 Kg	1.1016 MT = 1016 Kg	0.9072 MT = 907.2 Kg

Note that there are several different imperial systems of weights. We quote the British imperial ton as in the Weights and Measures Act of 1824, and the United States customary system. Additional useful conversions are:

1 lb = 16 Ounces (Oz.)

1 stone = 14 pounds (lb.)

1 hundredweight (cwt.) - UK = 112 lb.

1 hundredweight (cwt.) - US = 100 lb.

I.3.5 Nails - "penny sizes"

Imperial	Penny size	2d	3d	4d	6d	8d	10d	16d	20d	40d	50d	60d	100d
	Inches	1	1 ¼	1 ½	2	2 ½	3	3 ½	4	5	5 ½	6	10
		↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Metric	Nearest length (mm)	25	32	38	51	64	76	89	102	127	140	152	254

I.4 Glossary

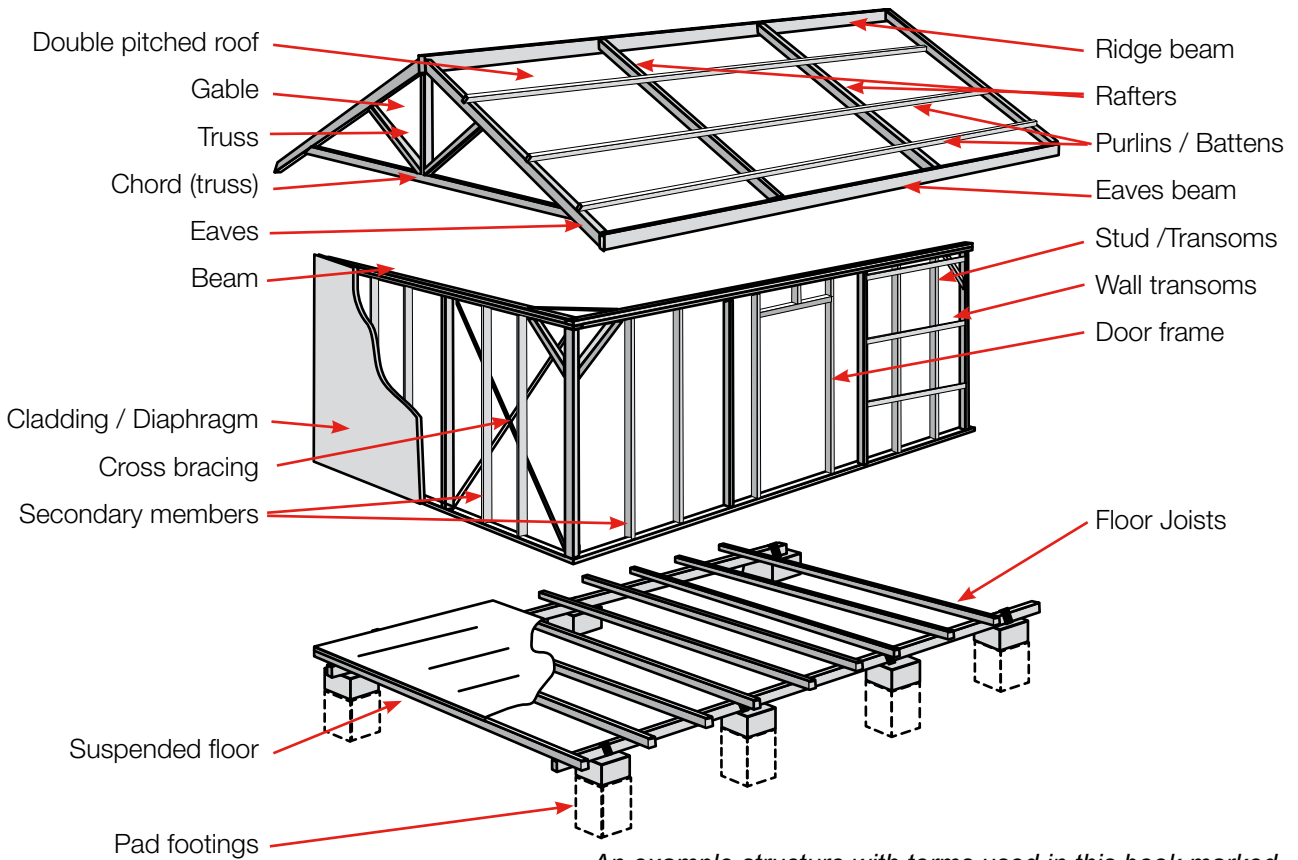
I.4.1 Full glossary

The definitions in this glossary relate to how they are used in this book. They are intended to make the technical language used in this book more understandable by the reader. Please note that we also provide a pictorial glossary in section I.4.2 [Pictorial glossary](#)

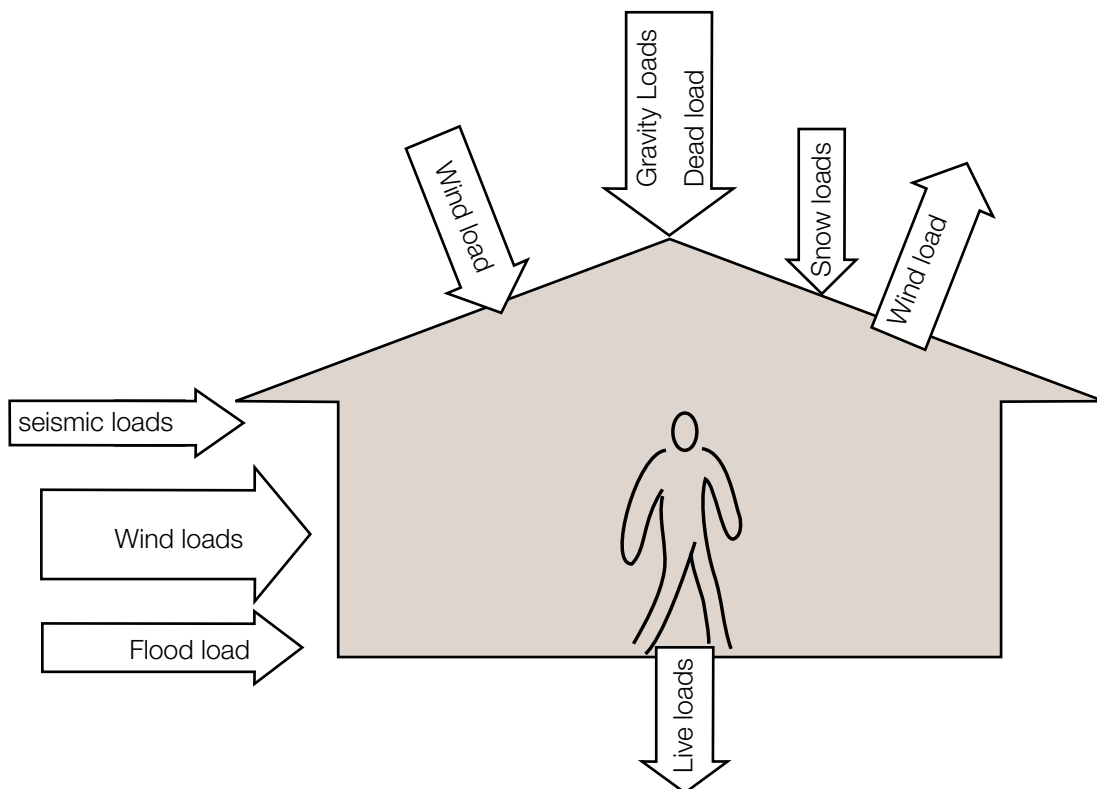
Term	Definition for the purposes of this book.
Anchor foundations	A foundation that uses a buried object to provide resistance to being pulled out.
Bill of quantities (BOQ)	A bill of quantities (BOQ), lists the materials, and quantities required to build a structure. The BOQs in this book are the minimum required.
Bracing and braced frames	Bracing is a structural member that stiffens a frame. Bracing a frame is often achieved by adding diagonal members.
Bucket foundations	A foundation consisting of concrete cast in a “bucket“ to anchor the columns to the ground.
Beam	A horizontal structural element, supported at either end. It carries vertical or horizontal loads.
Cantilever	A structure such as a beam that is supported at one end only.
Chord (truss)	The lower part (normally horizontal) of a truss that resists compression or tension.
Cladding	A covering material placed over the outside of a structure on the roof or the walls.
Cold formed steel	Steel that is rolled or bent into shape without heating.
Cross bracing	Two diagonal braces that form a cross shape. They usually take only tensile forces.
Diaphragm	A structural system used to transfer loads to the frame. Usually used to resist lateral loads such as earthquakes and winds. Commonly achieved by nailing flat sheets of plywood or timber to a frame.
Dead load	The loads upon a structure due to the weight of the materials from which the structure is built.
Double pitched roof	A roof with two sloping surfaces and a central ridge.
Eaves	An overhang at the lower edge of a roof that extends past the wall.
Eaves beam	A beam to support the lower edge of a roof.
fcu	A measure of the cube strength of concrete with units N/mm ² .
Flash flood	Fast moving flood water that can cause damage to structures and foundations.
Gable	The end wall between the edges of a double pitched sloping roof. It is usually triangular.
Ground Anchor	See anchor foundations.
Gravity loads	Forces which are applied to a structure resulting from its own weight under gravity.
Header	A horizontal structural member placed between two beams, studs or joists that supports their weight.
Hot dip galvanised	Steel that has been treated by dipping in a tank of molten zinc. This coats the sheet with a thin layer of zinc carbonate which protects the steel from corrosion.
In-plane bracing	Bracing (see definition above) in the same geometric plane as the other structural elements.
Joists	A horizontal member that supports a floor, a roof or a ceiling.
Liquefaction	When soil starts to behave like a liquid in an earthquake. This is most common near river beds, in coastal areas with sandy soils and in locations with high water tables.
Lateral loads	Horizontal loads upon a structure - such as those due to wind on a side wall.

Laths	Thin strips of wood that support tiles or other cladding. They are usually nailed in rows to framing.
Live load	The loads upon a structure due to occupants.
Loads (structural)	Forces which are applied to a structure.
Member	A part of a structure such as a beam or a column.
Mezzanine	A partial floor between main floors of a building.
Mono pitch roof	A roof with one sloping surface.
Moment frame	A frame in which bending of the beams and columns (as opposed to bracing members) provides the resistance to lateral forces.
Pad footings	A foundation that spreads the load out from a column to the ground.
Pilaster	A thickening of a foundation wall to spread the load
Pinned connection	Joint between structural members that allows rotation.
Plumb bob	A weight that is suspended from a string. It is used to ensure that structures are vertical whilst they are being built.
Helical screw plate	Screw plates at the end of a tubular ground anchor. The pitch is the distance between blades of the screw thread measured along the length of the screw.
PGA	Peak ground acceleration. An engineering term that is used to indicate the maximum acceleration experienced by the ground shaking during an earthquake.
Porch	A covered entrance typically at the front of the building.
Portal frame	See moment frame.
Portland cement	A very common form of cement. When mixed with sand, gravel and water it makes concrete.
Purlin	Roofing member to which the roof covering is attached. Purlins are supported by the rafters.
Rafters	Main structural roofing beam. On a sloped roof they run from the ridge to the eaves.
Return period	The period of time (in years) in which it is likely for a particular magnitude event to be exceeded, on a long term average.
Sacrificial cladding	Cladding that can be removed (or blown away) from a shelter without damaging the structure. Removing the cladding will reduce the wind loads on the structure and ensure its survival.
Screw foundation	See ground anchor.
Secondary members	Members that do not contribute to the stability of the structure.
Seismic loads	Loads on a building caused by an earthquake.
Slab	A rectangular concrete base to the building.
Standing water	Water that remains in place following a flood. This can damage structures in ways such as causing mud bricks to dissolve or timbers to swell.
(Timber) Studs	A wall framework containing upright posts to support cladding materials.
Suspended floor	Floor that does not touch the ground. It is supported by the frame.
Tie beam	A beam that connects two other structural elements preventing them from separating.
Truss	A rigid structure consisting of elements that lie in the same plane, commonly used in roofing. The truss is often in the form of a combination of triangles.
Uplift	Upward forces on a structure.
Wind loads	Loads due to wind.
Wall transoms	Horizontal members similar to studs that support cladding.
Zincalume	An alloy of zinc and aluminium used to galvanise iron sheet. Such sheets can last longer than those with pure zinc coatings.

I.4.2 Pictorial glossary



An example structure with terms used in this book marked



An illustration of the different types of load that can be experienced by a transitional shelter.

I.5 Further reading

 ASCE/SEI 7-10

(See also International building Code 2009)

Minimum Design Loads for Buildings and Other Structures,

Table 20.3-1 - soil profiles

Table 11.6-1 - assuming Risk Category I (Table 1.5-1 representing a low risk to human life in the event of failure) and based on the modified PGA.

 Humanitarian Bamboo Project

Website containing guidance and information on the sourcing and use of bamboo for use in humanitarian responses.

<http://www.humanitarianbamboo.org>

 IASC, Shelter Centre, Selecting NFIs for Shelter

2008.

Provides information, case studies and guidance on how to choose the best items to distribute to those affected by natural disaster or conflict

www.shelterlibrary.org

 International Building Code (IBC) 2009


ICC (International Codes Council), February 2009

The IBC superseded the UBC in 2000 and is updated every three years. It is primarily used in the United States although it is also a relevant guide in other geographies. It provides requirements for structural safety, fire-safety, and life-safety provisions that cover a range of aspects including roofs, seismic engineering, innovative construction technology, and occupancy classifications. It contains a large number of references to published standards that need to be consulted for its application. These include:

-2010 ASCE/SEI 7-10 – Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers

-2005 National Design Specification for Wood Construction, American Wood Council

 International Standards for Materials, Products, Systems and Services


International standards are maintained by standards organisations and are commonly used in the specification on materials. Often they will specify testing regimes that the materials need to pass in order to meet the standard. The standards and standards organisations referred to in this book and in  IFRC/ICRC Emergency Items Catalogue are:

- *ASTM A653: Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process. ASTM standards are maintained by ASTM International ASTM International, formerly known as the American Society for Testing and Materials (<http://www.astm.org/>).*
 - *JIS G3302: JIS G3302 relates to the quality of zinc coated steel sheet. Japanese Industrial Standards are maintained by the Japanese Industrial Association. (<http://www.jsa.or.jp>)*
 - *ISO standards: Maintained by the International Organisation for Standardisation (<http://www.iso.org>)*
 - *BS standards: Maintained by the British Standards Organisation (<http://www.bsigroup.com/>)*
-

 IFRC/ICRC Emergency Items Catalogue

Detailed specifications of all items commonly used by IFRC and ICRC

<http://procurement.ifrc.org/catalogue/>

 IFRC, Guidelines for Assessment in Emergencies

2008.

Practical information and guidance on how to conduct assessments in emergencies

From: <http://www.ifrc.org>

 ICRC/IFRC Guidelines for Cash Transfer Programming

2007

Provides information on when and how to distribute cash in disaster response

From <http://www.ifrc.org>

 ⁹ IFRC Logistics Standards Online

IFRC logistics procedures, forms and manuals

<https://fednet.ifrc.org/logisticsstandards/home.asp>

 ¹⁰ IFRC Owner Driven Housing Reconstruction Guidelines (ODHR)

2010

Guidance on the planning and implementation of assisted self help reconstruction projects.

 ¹¹ IFRC, Oxfam GB, Plastic Sheeting,

A guide to the use and specification of plastic sheeting in humanitarian relief, 2007 An illustrated booklet on when and how to use plastic sheeting most effectively in emergencies

www.plastic-sheeting.org

 ¹² IFRC, The IFRC Shelter Kit

2010

A guide on the IFRC shelter kit and how to use it.

 ¹³ National Building Codes & Standards

Building codes establish a set of rules that specify the minimum acceptable level of safety for constructed objects such as buildings and other structures (bridges, roads etc). The development and enforcement of building codes varies between countries. A number of national country codes and standards have been referred to for the review of these shelters, these include:

- *Indonesia: '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.*
 - *Indonesia: 'Standar Nasional Indonesia - Tata Cara Perencanaan Ketahanan Gempa untuk Bangunan Gedung' (Planning Procedures for Building Earthquake Resistance) SNI-03-1726-2003', Bandung, Juli 2003*
 - *NDS: National Design Specification for Wood Construction. This includes the timber grading system that is referred to in this book. <http://www.awc.org/standards/nds.html>*
 - *Peru: 'National Building Code, Technical Standard of Building E.030, Earthquake Resistant Design', Lima 02/04/03*
 - *Peru: 'Proyecto de Norma Tecnica de Edificacion, E.020 Cargas', December 2004*
 - *Pakistan: Building Code of Pakistan – Seismic Provisions 2007 (BCP SP-2007), Government of Islamic Republic of Pakistan Ministry of Housing and Works, Islamabad, 2007)*
 - *Vietnam: 'TCVN 2737:1995 Vietnamese Standards Loads and Actions – Design Code', 1995*
-

 ¹⁴ Uniform Building Code (UBC) 1997

International Conference of Building Officials : '1997 Uniform Building Code – Volume 2',

This code was the predecessor of the IBC. It was first published in 1927 to promote public safety and provide standardized requirements for safe construction, primarily in the United States. It was revised every 3 years until the final publication in 1997. In some instances it offers an alternative approach to calculating risk to the IBC, for example for seismic design, that can be used if there is limited data available.

 ¹⁵ Sheltercentre, UN, DfID, Shelter after Disaster

Strategies for transitional settlement and reconstruction, 2010

A book containing information and guidance on how to agree strategies for reconstruction after natural disasters. Contains description of the types of shelter programmes that organisations can implement.

www.shelterlibrary.org

 ¹⁶ Sphere Project, Sphere

Humanitarian charter and minimum standards in humanitarian response, 2011

Contains consensus standards agreed among major humanitarian organisations for key sectors including shelter and settlement. It also contains as actions, indicators and guidance notes as to whether standards have been achieved.

www.sphereproject.org

 ¹⁷ UNHABITAT, IFRC, Shelter Projects 2009

Case studies of shelter projects implemented between 1945 and 2009. Includes many different types of response

<http://www.disasterassessment.org/section.asp?id=45>

 ¹⁸ UNHABITAT, IFRC, UNHCR, Shelter Projects 2008

More case studies. See also UNHABITAT, IFRC, Shelter Projects 2009

<http://www.disasterassessment.org/section.asp?id=38>

 ¹⁹ UNHABITAT, Land and Natural Disasters

Guidance for Practitioners, 2010

A book containing guidance on land issues following natural disasters.

http://www.disasterassessment.org/documents/Land_and_Natural_Disasters_Guidance4Practitioners.pdf

 ²⁰ UNOCHA, Tents

A Guide to the Use and Logistics of Tents in Humanitarian Relief, 2004

A booklet describing when and how to use tents as well how to support those living in them to best adapt them to meet their needs

www.shelterlibrary.org

 ²¹ UNOCHA / IFRC / CARE International, Timber

Timber as a Construction Material in Humanitarian Operations, 2009,

An illustrated booklet on how to source and use timber for the construction of basic structures.

www.humanitarian timber.org

Note: All staff and volunteers within the Red Cross and Red Crescent Movement can access additional documents from the IFRC shelter department website on fednet:

<https://fednet.ifrc.org/en/resources-and-services/disasters/shelter/>

The Fundamental Principles of the International Red Cross and Red Crescent Movement

Humanity The International Red Cross and Red Crescent Movement, born of a desire to bring assistance without discrimination to the wounded on the battlefield, endeavours, in its international and national capacity, to prevent and alleviate human suffering wherever it may be found. Its purpose is to protect life and health and to ensure respect for the human being. It promotes mutual understanding, friendship, cooperation and lasting peace amongst all peoples.

Impartiality It makes no discrimination as to nationality, race, religious beliefs, class or political opinions. It endeavours to relieve the suffering of individuals, being guided solely by their needs, and to give priority to the most urgent cases of distress.

Neutrality In order to enjoy the confidence of all, the Movement may not take sides in hostilities or engage at any time in controversies of a political, racial, religious or ideological nature.

Independence The Movement is independent. The National Societies, while auxiliaries in the humanitarian services of their governments and subject to the laws of their respective countries, must always maintain their autonomy so that they may be able at all times to act in accordance with the principles of the Movement.

Voluntary service It is a voluntary relief movement not prompted in any manner by desire for gain.

Unity There can be only one Red Cross or Red Crescent Society in any one country. It must be open to all. It must carry on its humanitarian work throughout its territory.

Universality The International Red Cross and Red Crescent Movement, in which all societies have equal status and share equal responsibilities and duties in helping each other, is worldwide.

**For more information on this IFRC publication,
please contact:**

**International Federation of
Red Cross and Red Crescent Societies**

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This book contains reviews by structural engineers of transitional shelter designs that have been built in significant numbers. Although the designs should not be used without being adapted to the context, it is intended that the information in this book will support the early stages of shelter programmes and inform transitional shelter decision making.

This book is targeted at people within the Red Cross and Red Crescent movement working in the emergency and early recovery phases after a natural disaster. The primary audience is shelter delegates. It is also intended to inform those planning and managing shelter programmes.

It is assumed that readers have a strong understanding of the need for participation and in ensuring the close involvement of disaster affected people.