Temporary Shelter for Refugees

by

Anna Pepper (CTH)

Fourth Year Undergraduate in Group D, 2003/2004

merit

I hereby declare that, except where specifically indicated, the work submitted herein is my own original work.

Signed: ______________ Date: 26/05/2004

Temporary Shelter for Refugees - Technical Abstract

Anna Pepper (CTH)

This project is carried out in conjunction with *shelterproject*, a not-for-profit organisation aiming to consolidate expertise in responding to the shelter needs of populations affected by conflict and natural disaster.

The project has two parts. The first is to develop a set of common performance specifications for a family emergency shelter. The development of standards is important as the shelter sector does not have the same guidelines and standards in place that other humanitarian aid sectors such as water and sanitation have. The second stage is to work towards developing a family shelter that fits the specifications developed.

Performance Specifications

No overall set of performance specifications has been developed for a family shelter. Certain criteria can be gathered from the UNHCR guidelines and the Sphere Project guidelines, however both guidelines cover all aspects of refugee welfare and do not cover in detail the performance of a shelter. As a result of this most of the specifications developed were based on field experience of *shelterproject* and NGOs.

The three main areas in which criteria were developed are:

1. Physical criteria - This ensures that the physical comfort of the user is maintained. This includes areas such as thermal comfort, fresh air, health and personal safety.
2. Logistical criteria - This covers the factors that can affect the duration and efficiency of transporting a shelter to the field.
3. Social criteria - This includes issues such as privacy, cultural and political sensitivities and material reuse on return home.

The criteria were developed into a set of specifications which were discussed at the *shelterproject* peer review in April 2004 and it is hoped that following further work on the specifications by *shelterporject* they will be incorporated in a guidance manual published by UN/OCHA.

Family Emergency Shelter Design

The design brief for the shelter was that is should fit the specifications developed above, that it should be a 'kit' shelter suitable for distribution overseas and that it should be for a family of 5-6.

Consideration of standard shelter types, leisure and military tents and also commercial tents (such as polytunnels) alongside common areas of shelter failure led to the generation of a number of different concepts for a family shelter. Each of these concepts was evaluated in terms of weight for a given material, head room, likelihood of ponding and abrasion of the covering. The evaluation combined with some 2-D calculations considering global behaviour of the shelters suggested that a hoop shaped shelter was the most sensible option to develop further.

shelterproject and Oxfam had previously developed a hoop shelter (smaller than that being considered) using MDPE hoops. Agricultural polytunnels are also constructed in a similar manner and so both were relevant sources of information and experience.

The dimensions of the shelter were determined by ensuring the headroom and area per person values given in the specification were met. The final dimensions were 4.4x3.6m forming a tunnel from 3 hoops, with a ridge pole and side bracing members. Additional area is to be provided at each end of the tunnel through the use of vestibules.

Plastic upper bound analysis determined the required plastic moment for each of the hoops and this combined with material manufacturing, section shape and joint possibilities led to a range of options. To find the best combination a solution space defined by the key specifications of weight, cost and the ability to provide the required strength for the required shelter size was created.

From the solution space the most viable option was steel circular hollow section of two diameters, with the hoops having a larger diameter than ridge and bracing members. The hoops were constructed from four sections in order for them to be rolled and to fit the specification for packed length. The joints were all fabricated from sheet steel using hand tools.

Following the construction of a prototype shelter, simple displacement tests were carried out, measuring the displacement in lateral and longitudinal directions when a force was applied. The results were compared to an Oasys model of the shelter and were consistently higher but of the same gradient. The shape of deformation observed and predicted by Oasys was very similar.

An evaluation of the shelter frame developed against the specifications indicated that the majority of specifications were met. The main area where the shelter was outside the specification was cost and this is likely to reduce if the shelter is manufactured on a larger scale.

shelterproject are continuing to work on the prototype with the aim of making it into a 'kit' shelter that can be used in the field.

Contents

1 Introduction

This project is carried out in conjunction with *shelterproject*, a not-for-profit organisation that aims to consolidate expertise in responding to settlement and shelter needs of populations affected by conflict and natural disasters. *Shelterproject* are currently involved in research in many areas of the shelter sector and the work carried out on this project is directly related to these research areas.

To understand the context of the shelter sector it is not necessary to consider in detail the workings of the humanitarian relief world, but it is important to appreciate that shelter, like any other sector such as water and sanitation, is part of the overall response to an emergency, and that in any emergency the overriding purpose is to save lives.

In disasters where there are many displaced people the United Nations High Commissioner for Refugees (UNHCR) often takes a leading role. As a result, a set of guidelines detailing minimum standards of response has been developed. The Sphere Project, which aims to consolidate intentions of many aid agencies, has also developed a set of guidelines. When minimum standards of response are discussed these are the sets of guidelines referred to. The following section clarifies the role of shelter and the need for standardisation.

1.1 Why is shelter important?

At the beginning of 2003 there were over 20,500,000 people of concern to the United Nations High Commissioner for Refugees (UNHCR)[4]. These people had been forced to leave their home as a result of terrorism, war, drought, famine or other natural disaster.

Many of these people will stay with family and friends, stay in reconstructed and repaired buildings or be given a host family. Shelter is always the last option when all others have been considered; however for a significant number of people this is all there is. The following quote from Sphere Project Guidelines[3] show that shelter is at its most basic a means to survival.

> "Shelter is a critical determinant for survival in the initial stages of a disaster. Beyond survival, shelter is necessary to provide security and personal safety, protection from the climate and enhanced resistance to ill health and disease. It is also important for human dignity and to sustain family and community life as far as possible in difficult circumstances."

1.2 Why standardise?

A vast number of tents are deployed by aid agencies and non-governmental organisations (NGOs), for example the United Nations agency UNHCR purchased 100,000 tents in preparedness for the conflict in Iraq.

This illustrates the scale on which agencies can work. In an ideal situation a standard level of provision is offered whatever the scale, however this is not always the case. There can be great variation in the provision offered to people with the same needs, and sometimes the tents available do not meet the guidelines covering minimum standards for shelters published by UNHCR and Sphere. The following extract [12] shows that shelter provision is variable in the field.

> "The diversity of shelter provision for many people at Maslack camp in similar circumstances represents an uneven and unsatisfactory deployment of resources. Partly attributable to the different arrival times of IDP's to the same camp, it is primarily the result of highly variable specifications and solutions for the same population. While some agencies were constructing earthquake-resistant houses, others provided tents."

The following comments from a *shelterproject* report comparing tent specifications [13] show the consequences of diverse shelter provision.

> "There is a danger that the variation in tent specifications will lead to
>
> 1. Distributing markedly different tents to people with the same needs
> 2. Distributing inappropriate tents leading to higher costs and human suffering"

2 Project Aims

Having discussed the importance of shelter in an emergency situation, and the need for standardisation, the context and motivation for the project have been set. In consultation with *shelterproject* the following aims for the project were developed.

- **Develop performance specifications and design criteria for a family emergency shelter that meets minimum humanitarian guidelines**
- **Work towards a family shelter design that meets these specifications and criteria and is suitable for field deployment**

The first aim will form part of *shelterproject's* ongoing work in attempting to bring about agreement and development of standards similar to those already in place in humanitarian aid sectors such as water and sanitation. Developing a shelter that meets the specifications is within a more specific context, as it is unrealistic to expect a single design to be adopted by the entire sector. The development of a shelter design will build on previous research carried out by *shelterproject*. The specifications will be addressed first, and the information gathered from this will be input into design ideas for a shelter.

3 Design Criteria and Performance Specifications

There has been some research carried out on certain aspects of shelters resulting in standards, such as the minimum recommended floor area per person published in the UNHCR guidelines and the Sphere Project guidelines. However no overall set of performance specifications or standards has been developed specifically for a family shelter. Certain aspects of the criteria for a shelter can be gathered from guidelines, e.g. recommended floor area, but much of the criteria discussed below is the result of field experience of *shelterproject.* The criteria have been divided into three main areas - social, logistical and physical.

3.1 Physical criteria

The quote below taken from Sphere Project Guidelines defines the primary purpose of a shelter and indicates the criteria involved in ensuring the physical comfort of the user.

> 'The design of the shelter is acceptable to the affected population and provides sufficient thermal comfort, fresh air and protection from the climate to ensure their dignity, health, safety and well-being.'

Usable area: It is important that each person has adequate space for both health and general comfort. This includes ensuring there is enough room to stand upright in some areas of the shelter.

Ventilation: Adequate ventilation should be provided to ensure that there is a supply of fresh air and that unwanted smells and moisture are removed. There are particular health implications if ventilation is not provided, such as respiratory problems.

Winterisation: To ensure the shelter provides adequate protection from the climate it should be capable of winterisation when necessary.

Durability: Although the shelter is a temporary solution it may be used for as long as two years and it should provide the same protection throughout the duration of use.

Fire safety: The purpose of the shelter is to protect from the environment but the shelter should cause no danger either. Hence flammable materials or those likely to produce toxic combustion products should be avoided. Consideration of fire safety should also include a recommended time to evacuate the shelter.

Structural integrity: The frame of the shelter should be all that is required for shelter stability. This minimises the need for guy ropes creating external hazards and removes the need for the outer to be stressed, ensuring that failure does not occur if the outer is damaged.

3.2 Logistics related criteria

Transporting a shelter from place of manufacture to the field is ideally carried out as quickly as possible; these criteria are factors that can affect the duration and efficiency of this process.

Weight: This should be kept as low as is sensible and possible.

Volume: This should also be kept as low as possible.

Packed length: This is to ensure that the packed shelter can fit into a standard pallet for ease of transportation, particularly on land in a 4x4 vehicle.

Cost (double skin): This should also be minimised, as often there will be a specific sum of money and the more tents that can be purchased for the given sum the better.

Storage: If the shelter is manufactured at a time when it is not required it must be capable of being stored in a warehouse for a period of time and must not decay or perish during that time.

3.3 Social criteria

An emergency shelter is a temporary solution when all other possibilities have been exhausted; the opportunity for development and support of livelihoods should always be a priority and these criteria represent this.

Adaptability: Component parts should be kept to a minimum and be interchangeable as far as is possible. It should be possible for components to be replicated by local manufacturers using local materials. Repairs should be possible with non-specialist skills and equipment.

Development support: The materials used in the construction of the shelter should be suitable for use in reconstruction or modification upon return home or suitable for resale.

3.4 Performance specifications

The design criteria discussed above were developed into a set of specifications. These were then presented at the *shelterproject* peer review held in Brussels in October 2003, where the UN and other aid agencies were represented. Following the circulation of a revised specification and a further peer review held in Geneva in April 2004 a specification has been developed to incorporate suggestions made by ECHO, SHA, JICA, UN/OCHA, CHF, ICRC, and MSF-Belgium. The revised specification incorporating these points is shown below, with those still under discussion included in an additional table.

Category 1	**physical specification**
Usable area	$3.5m^2$ per person, meeting UNHCR and Sphere standards, requiring: • $21m^2$ for a shelter classed for a family of 6 • $17.5m^2$ for a shelter classed for a family of 5
Internal volume	33% of total floor area should have 1.8m minimum head height
Ventilation	Adaptable by users according to climatic demands, reducible to control heat loss, but not sealable in order to prevent suffocation and reduce the incidence of communicable diseases resulting from air pollution.
Operating climate	• -25^oC to $+45^oC$ Must be capable of component changes for use in hot or cold climates
Lifetime	Must be capable of 18 months continuous usage
Fire safety	2 minutes escape time following the beginning of a fire, achieved through: • Risk of fire and flame spread must be minimised • Materials producing toxic fumes must not be used
Structural integrity	• The structure must stand following the failure of the covering or a fixing, i.e. it should incorporate a certain level of redundancy • Must not fail in peak wind speeds of up to 100km/h
Vector control	Measures should be taken to minimise vector presence
Colour	Reflection/heat absorption must be considered as well as internal lighting.
Safety	Materials used must be non toxic

Category 2	**logistical specification**
Total weight	40-60 kg
Packed volume	$0.3 - 0.5m^3$
Packed length	1.5-2m
Maximum cost	• \$100 (single skin) • \$150 (double skin, not including costs for an insulated liner)
Storage	5 years minimum without degradation

Category 3	**social specification**
Adaptability	• Component count should be kept to a minimum • Components should be interchangeable as far as is possible • Components should be available or replicable locally • Repairs should be possible with non-specialist skills and equipment
Privacy	• It should be possible to sub-divide the internal volume into at least two spaces and a divider should be provided
Development support	• Materials used should be suitable for later re-use, upgrading, modification or reconstruction on return
Colour	• Cultural and political sensitivities should be taken into account • Must admit adequate light for reading
Environmental impact	• Should be manufactured and can be disposed of without negative environmental impacts

Additional Specifications

Flooring	• There should be no space between floor and wall through which water, dirt etc can get in • A ground sheet should be included that the tent can be placed on
Resistance to water	• Outer skin water resistance/waterproofing should be specified
Construction	• Simple assembly instructions should be included with the shelter

Further work is being carried out on the specifications by the *shelterproject* team with the hope of including it in a guidance manual published by UN/OCHA.

4 Family Emergency Shelter

The idea of shelter in the form of a tent is not a new idea as the quote below shows [11]

> '... the most typical low-technology donor product is clearly the tent, and for thousands of years it has probably been the basic form of emergency shelter.'

It is therefore important to note that the intention is not to reinvent 'the tent' but to use all the available information to select the most appropriate form. The chosen form is then to be developed into a useful shelter in the light of the key criteria such as simplicity, weight and cost that meet the specification discussed in the section above.

4.1 Design brief

In addition to the common specification given in the previous section the shelter that is to be developed as part of this project will:

- Use UNHCR/MSF specification PVC sheeting in 4m widths
- Be for a family of 5 - 6 putting the area in the $17.5 - 21m^2$ range
- Aim to be a 'kit' tent

A 'kit' form tent is supported by the example given below. However this does not mean that any consideration of the reuse of materials and the possibility of local repairs should be excluded when considering material choices.

> 'As an example in Eritrea even most wood and steel has to be imported by sea. The only pipe manufacture is low quality PVC pipe. Some factories maintain small stockpiles of reinforcement bar. The nearest site with mass availability is probably Nairobi, with no direct land access.' [6]

The UNHCR/MSF sheeting has been tested and has shown great versatility in the field. It also has increased durability compared to canvas in terms of rotting. USAID/OFDA also support the use of plastic sheeting [5] suggesting it has a lifetime of over one year in normal field conditions and has many uses such as repairing walls, covering a roof in a new building in addition to use for a personal temporary shelter. These are largely the reasons behind specifying this covering.

4.2 Shelter overview

A shelter that has been used since the 1800's is the canvas ridge tent, shown in figure 1(a). It is still seen today by some as the defacto emergency relief tent. It relies on guy ropes for stability and can degrade quite quickly depending on the type of canvas used. It also offers limited headroom and if guy ropes are not kept tight the sides can sag and severely reduce the living space.

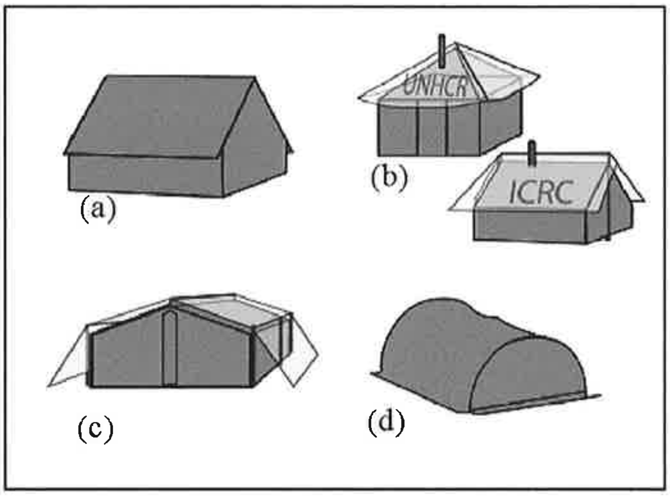


Figure 1: Shelter types [1]

Another tent commonly used is the centre pole tent, shown in figure 1(b), it is a high walled canvas square with a steel centre pole and bamboo side poles. It offers a good amount of headroom and can be fitted with an insulated liner, however it is very heavy and also relies on guy ropes for stability. Larger centre pole tents with two poles are also available but they are not generally used to shelter families.

Frame tents, such as figure 1(c), are not particularly common in the field as they are bulky and expensive. If they are used they are generally for housing larger groups of people rather than families, however the most common use is probably as military tents where the specification and budget are at a much higher level and weight is not such a crucial issue.

A new generation of tents is emerging that use a hoop frame, as shown in figure 1(d). A particular tent developed by *shelterproject* and Oxfam uses MDPE water pipe hoops and UNHCR plastic sheeting. The hoop shape gives increased internal volume for a given floor area and no external guy ropes are needed. The hoop has the advantage that it is possible to put many hoop shelters back to back to form a larger shelter, i.e. modularity.

There are a number of tents available that are not for the express purpose of emergency survival. These are similar in style to the tents discussed above, but often use expensive materials such as carbon fibre to make them lightweight. Another less obvious example is the agricultural polytunnel that uses steel hoops and stressed plastic sheeting to form a covered tunnel. These polytunnels are similar in form to the emerging hoop tunnels discussed above.

4.3 Failures

Shelters that are currently used are often subject to problems and some of the common ones are listed below. They suggest that in general high stress and wear should be avoided and consideration should be given to the paths along which wind and rain will travel around the shelter.

- Poles breaking
- Canvas rotting
- UV degradation of materials
- Ponding
- Wind damage
- Abrasion and wear of covering
- Guy rope fixings
- Fastening failure

(a) Damaged (b) Damaged joints (c) Damaged bamboo poles (d) Damaged end spikes for steel poles

Figure 2: Damaged tents in camp management compound, Maslack, Heart [1]

4.4 Concept ideas

Having considered the shelters discussed in the previous section, some general shelter forms were sketched and then evaluated against the specification developed in section 3 and the key failure areas considered in 4.3. Particular points considered at this stage in the evaluation were the issues of wear and ponding and the provision of floor area and headroom.

Figure 3 below is a summary of this process. It can be seen from the figure that the most likely possibilities are a frame tent or a hoop as they both have the possibility of few or no guy ropes, which eliminates the reliance on tent pegs to provide stability; it also removes some key areas of high stress. In addition they both can offer a certain level of headroom for a given floor area and so are more efficient in terms of habitable volume.

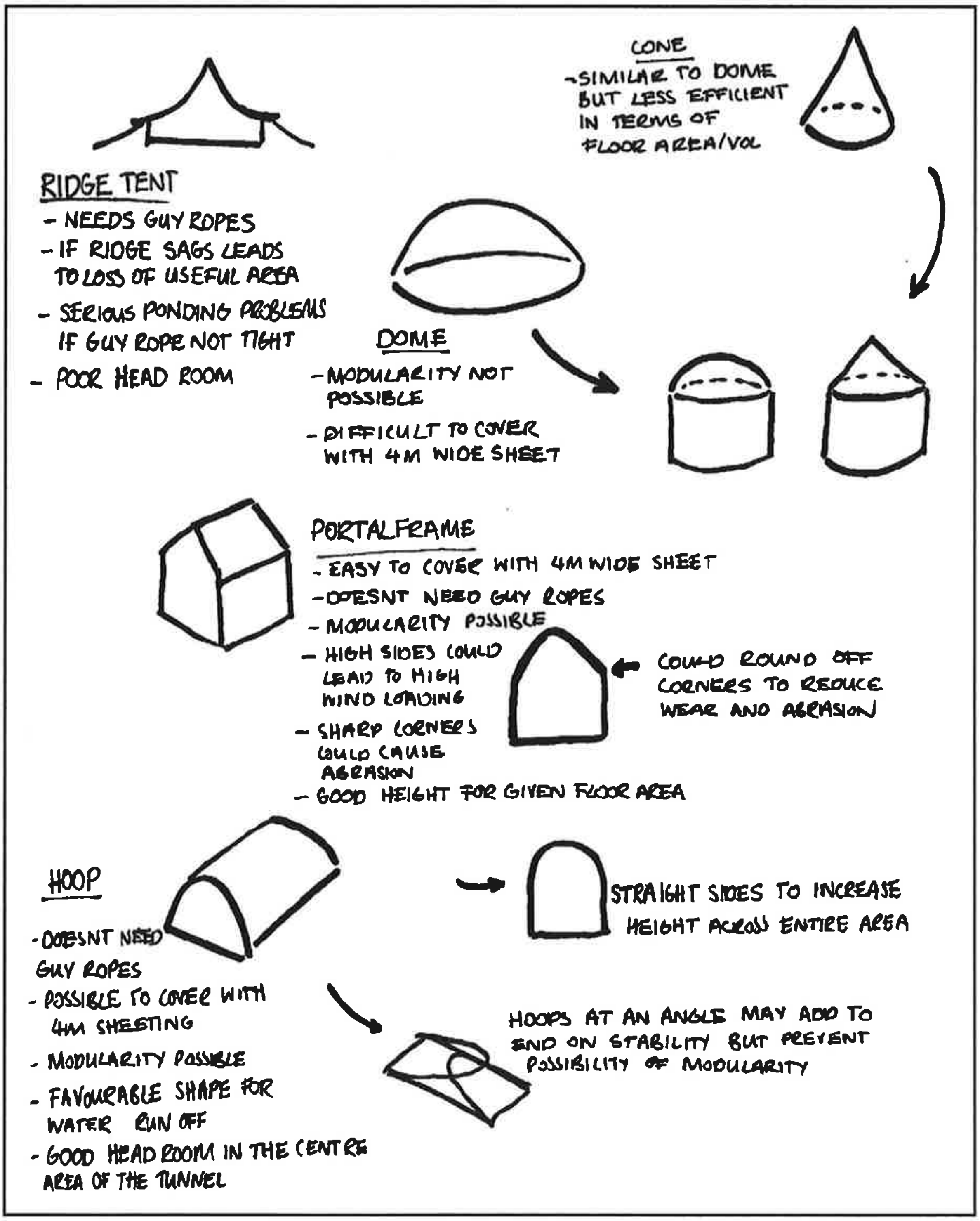


Figure 3: Concept Shapes

4.5 Frame versus hoop

As a result of the concept generation and evaluation a frame shelter and a hoop shelter were both identified as possibilities. They were then developed further giving consideration to the actual floor plan, the internal volume, possible material choices and the resulting joints needed. Consideration was also given to the way in which the shelter could be covered with plastic sheeting efficiently. The merit of a porch was also considered as this greatly increased the floor area and provided a space that could be opened up for use during the day for childcare, storage of cooking equipment or simply sitting.

Simple 2-d calculations were carried out to look at the global behaviour of each shelter form, and consideration was given to the weight each form would have for a given material. These results combined with the consideration of wear and abrasion on sharp points suggested that the hoop was the better design to develop further. This decision was also backed by the practical experience of erecting a basic hoop tent and a square centre pole tent (which would be similar in size and bulkiness to a frame tent) with the hoop tent being much easier and quicker to put up. The basic form and dimensions for each of the shelters is shown in figure 4 and a summary of salient points is shown in table 1.

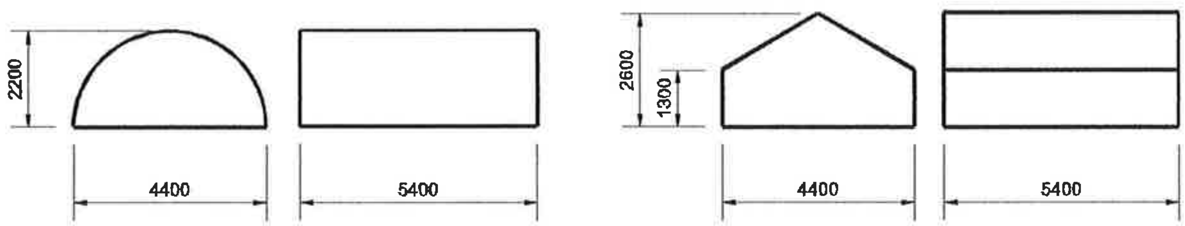


Figure 4: Shelter form and dimensions

Hoop	**Frame**
Floor area = $23.8m^2$	Floor area = $23.8m^2$
Floor area with height +1.8 m = 57%	Floor area with height +1.8 m = 61%
Max. member length = 1.73m	Max. member length = 2.56m
Max. moment for 1kN/m load = 0.36 kNm	Max. moment for 1kN/m load = 0.87 kNm

Table 1: Hoop versus Frame comparison

4.6 Previous work

Having chosen a hoop frame as the most suitable design to follow it was important to look in detail at work carried out on similar shaped shelters. This includes the MDPE Oxfam tunnel tent that *shelterproject* have been developing and also the commercial solution, polytunnels.

Commercial polytunnels have been used for many years for agricultural purposes. Looking at different manufacturers there appears to be a fairly standard use of materials with the hoops generally manufactured from galvanised steel tube with a ridgepole connecting the hoops, bracing at the end bays but no bracing in the central bays. Most used stressed polythene as a covering.

The stages discussed below show the development of the MDPE hoop shelter and the problems encountered when attempting to create larger shelters. It should be noted that it appears that the MDPE has reached its limit in the small shelter (3.6x3.6m) when a single pipe of 63mm is used.

1 The original hoop shelter

During 1999 and 2000 *shelterproject* and Oxfam GB developed the first hoop shelter. The following quote describes the shelter [2]. "This shelter system is constructed from 63mm MDPE water pipe, scaffolding tube, tent poles, some rope and plastic sheeting. It is designed to be mass-produced with a very short lead-time. It can be packed into a manageable size for transportation."

2 A 6m wide hoop shelter

An attempt was made by Babister in 2001 to create a 6m wide shelter. Many problems occurred as the extract shows [8]:
"The size of the shelter has the disadvantage of being made with an odd number of pipe section so that no ridge-pole is present. This appears to be critical to preventing water ponding."
"The structure failed because the MDPE pipes in a semicircular configuration of this size were not strong enough. The purlins bent from the bottom causing the whole structure to deform."

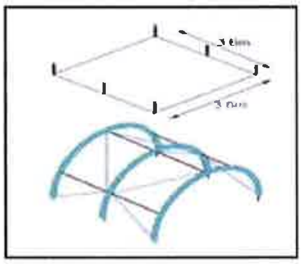


Figure 5: Oxfam MDPE Hoop shelter [1]

A second attempt was made to create a larger shelter by Guttridge in 2001-2002. Again there were a number of difficulties in achieving this and three different prototypes were created to try and solve some of the problems. The quotes below relate to each of the three prototypes [9]

1. "The failure mechanism was bending symmetrically out of the plane of the hoop." "The flexibility of the structure made it hard to tension the bracing ropes without distorting the structure. The guy ropes remained attached but some of the bracing ropes were slack due to the deformation."
2. The second prototype used three 63mm OD pipes bundled together."The second prototype failed in a similar shape to the first: the pipe arches bent along the axis of the shelter"
3. The third prototype included longitudinal rods of steel reinforcing bar. The shelter stood for 8 weeks and was considered to fulfil its purpose as a shelter.

Alternatives were considered such as resting hoops against each other but it was thought that introducing curvature in two directions would lead to folds in the sheeting, which might flap in the wind and could allow water to build up. Modifications suggested

- Sheath any steel used to avoid rubbing and rusting
- Future prototypes could incorporate a 'spanish windlass' tensioning device
- Long term creep of MDPE should be considered

5 Shelter Design

The development of the shelter design was carried out in a series of iterations starting with a plastic upper bound analysis to determine the plastic section modulus required for the hoop. Section shapes and material were then considered alongside joint options and manufacturing details.

It should be noted that although consideration is given to the covering a detailed design is not considered in this project. The design process concentrates on the frame structure.

5.1 Shelter dimensions

The dimensions of the tent were determined by ensuring that the headroom of 1.8m over 33% of floor area and $3.5m^2$ area per person required in the specifications were met in addition to ensuring the sensible use of the plastic sheeting manufactured in 4m widths.

Initially a 4 hoop tunnel was considered with two 4m widths of sheeting used along the length of the tunnel, joined in the middle. However after discussion with the team at *shelterproject* the use of vestibules was considered. A prototype tent developed by the company Reltec had made good use of vestibule areas and this, combined with the practical uses of vestibules for childcare and cooking, supported the decision to use a 3 hoop tunnel with vestibules at each end.

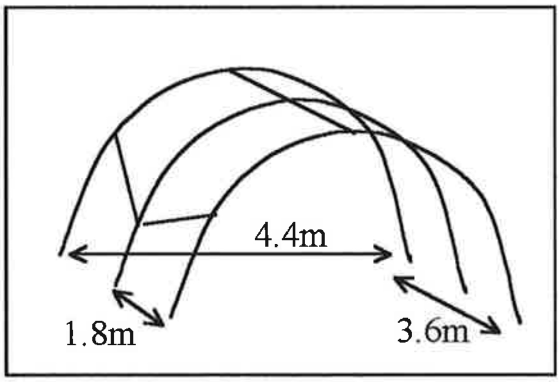


Figure 6: Shelter form and dimensions

The proposed basic 3D frame for the main tunnel area is as shown in figure 6. The shelter is 3.6m long so that there is sufficient sheeting out of the 4m width to fix round the end hoops. Orientating the sheeting in this direction will ensure that the reinforcing strips in the sheeting run across the shelter and should roughly line up with the hoops. The vestibule areas are not shown as the exact dimensions depend on the development of a vestibule design, which will not be considered in detail in this project. The position of the side bracing is also approximate at this stage in the design process.

5.2 Analysis

A global 2D analysis using virtual work was carried out to determine whether a hoop or frame structure should be developed further, with the results as shown in section 4.5 above. Following on from this, using the chosen dimensions, plastic upper bound 2D calculations were carried out to determine the plastic moment for the hoop. The expected wind loading was idealised as a lateral point load on each side of the hoop, with a positive pressure coefficient on the near side and suction on the leeward side. The area over which the pressure acts was taken to be one full bay width as this is the area the middle hoop supports and is the worst case. The velocity used was the mean wind speed the shelter should be expected to withstand. The plastic hinges were assumed to form at the point of application of the forces.

For the analysis as discussed above, with Θ defined as in figure 7 and $F = 0.5\rho C_p V^2 A$ with the values given below.

- Cp = 1
- $V = 16.5ms^{-1}$
- R = 2.2m
- A = 3.96m^2
- F = 614N

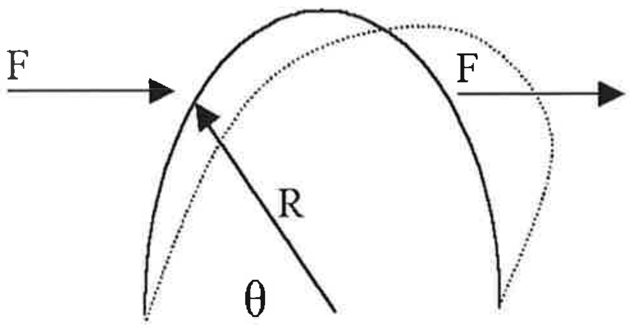


Figure 7: Application of lateral loads

The resulting work equation gives

$Mp = \frac{FR\sin 2\Theta}{2}$

For $\Theta = 45^0$ Mp = 675Nm.

In addition, a simple model was created using the software package Oasys. A single hoop was constructed from eighteen small straight beam elements. The ends of the hoop were pinned such that the hoop was free to move in plane but restrained from moving out of plane. The bending moment diagram is shown in figure 8. The maximum moment for the single hoop, subject to the same loading as shown in figure 7, from the Oasys output is Myy = 666Nm.

The Oasys analysis is a lower bound method and by finding a solution indicates that an equilibrium system that is everywhere satisfied has been found. The true solution lies between the upper and lower bound and by designing for the upper bound plastic moment which is greater than the lower bound that has shown to be safe the design should be conservative. The maximum moment did occur at the point of application of the load, which is consistent with the assumptions made in the hand calculation.

It was expected that the loading on the ridge and side bracing members would be less than the hoops and would be more accurately modelled using a uniformly distributed load to represent snow build up rather than a point load. Further upper bound calculations resulted in the required plastic moment Mp = 160Nm for the ridge and side bracing members.

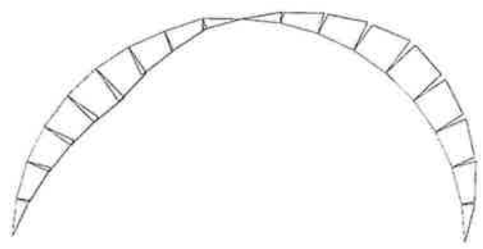


Figure 8: Oasys moment output for a single hoop

The resulting plastic moments were then used to calculate required member section sizes depending on the yield strength and the section shape of the member where $M_p = Z_p \sigma_y$

Although not fully optimised in terms of weight, steel circular hollow sections were sized as just discussed and then input into an additional Oasys model for the entire shelter. The hoops were again modelled using a number of small straight beams and the ridge and bracing members were modelled from individual beams, but a reduction in section size was incorporated due to the expected lower loading on these members. This model was also loaded as in figure 7 on the first hoop with the second and third hoop unloaded. The moment output from Oasys gave a maximum Myy = 537Nm at the point of application of the load. This is again less than the hand calculation and is also less than the moment in a single hoop. This may be due to the bracing and hoops carrying some of the load leading to a lower moment developing in the first hoop.

Deflections were also predicted using Oasys and these are discussed alongside the testing of the shelter in section 7.3.

More extensive analysis has not been carried out as:

- The shelter is not to be a high tolerance structure but rather the analysis is a basic guide to the strength and suitability of the shelter, i.e. to give a level of confidence in the structure
- It is likely that in the field it will not be possible to guarantee the quality of construction and unexpected modifications may be carried out

5.3 Materials and section shape

Considering the specification and design criteria for a shelter covered in section 3 the selection criteria for materials is as shown below:

1. Cost
2. Weight
3. Availability in the field
4. Stiffness
5. Weathering resistance
6. Environmental impact

Material indices and Ashby maps were used to make material selections, minimising weight and maximising strength; however a number of the suggestions were not suitable in terms of a 'kit' tent, particularly concrete, reinforced concrete, brick and stone. Other materials considered for a 'kit' form:

- MDPE
- PVC
- Steel
- Aluminium
- GFRP
- CFRP
- HDPE
- Wood/bamboo

Of the materials listed above MDPE, PVC and steel are the best options with regard to availability and cost, although GFRP and CFRP have weight and strength advantages. The table below shows some simple availability information for some of the materials considered above. Although the tent is to be in 'kit' form it is important to consider the likelihood of repair and replacement materials being found locally.

Material	Availability Notes
MDPE	• Africa - variable • South Africa - possibly ok • Asia, Afghanistan - not good • Karachi, China, India, Indonesia - potentially in major cities
PVC	• Generally available although quality variable
Steel	• Rebar and angle iron common • Hollow section rarer in the field, but ok in cities
Aluminium	• Not widely available and requires specialist welding equipment

Table 2: Material Availability [7]

In addition to the material considerations given above it is also important to consider the different section shapes available, as this is a particularly effective way of obtaining a member of a given strength for as little weight as possible.

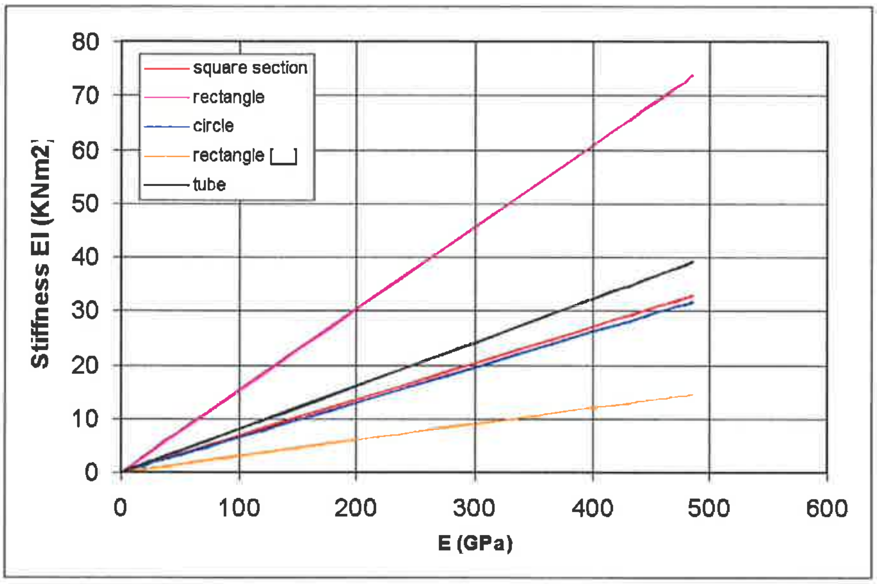


Figure 9: Graph of stiffness for different section shapes

The graph in figure 9 shows that for a given cross-sectional area a rectangle with depth greater than breadth gives the greatest stiffness and that a tube or circular hollow section also gives high stiffness. Following brief consideration of manufacturing and jointing methods, and taking into account the importance of familiarity of material, as it is likely that the shelters will be constructed and repaired by inexperienced workers, it was decided that the circular hollow section was the better choice.

5.4 Joints

In addition to the actual manufacture of the joint the abrasion of the plastic sheeting had to be considered for each of the options, as did the ease of repair with limited materials in the field and simplicity of construction. There are a number of different joints and the most feasible options are shown in figure 10.

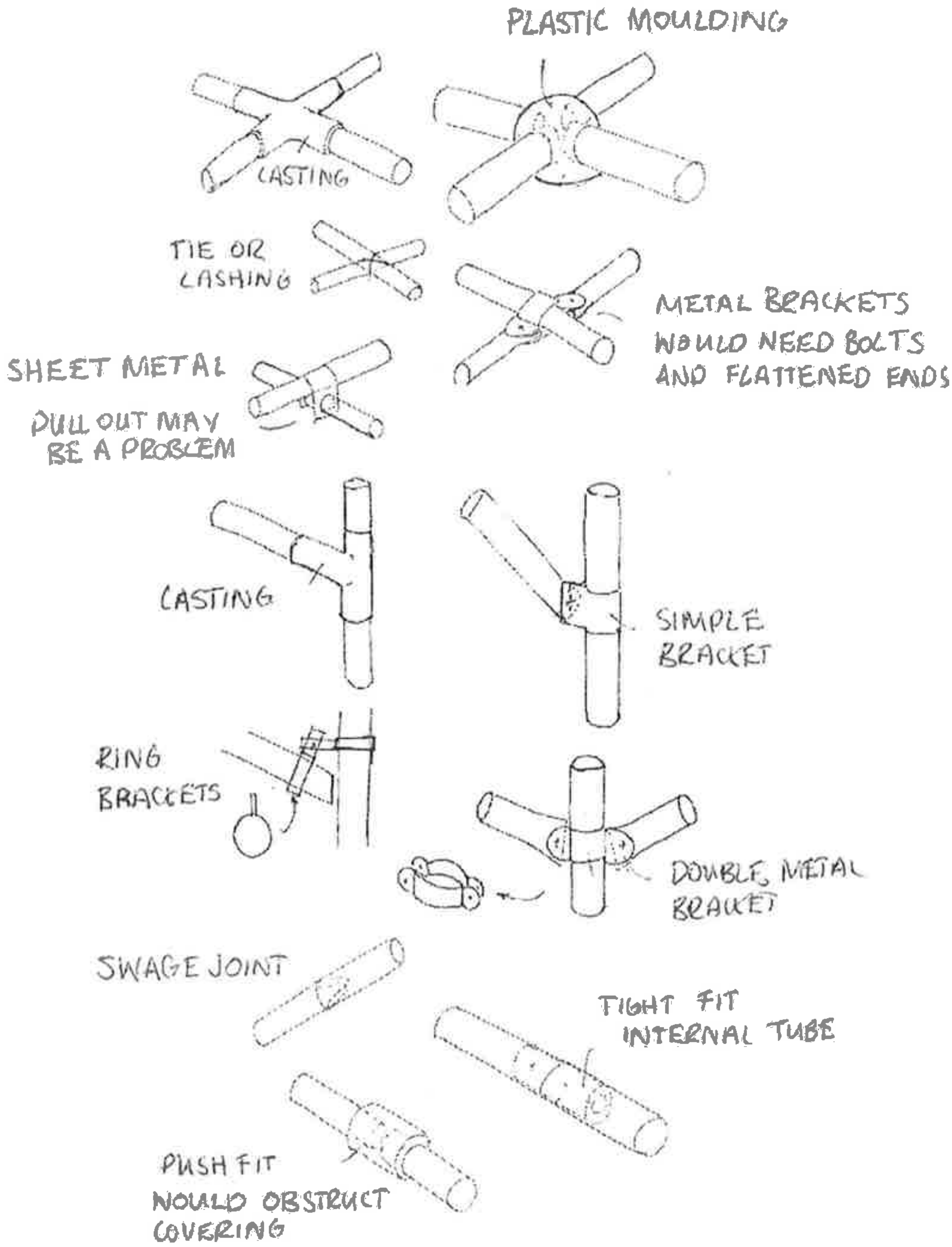


Figure 10: Joint Options

5.5 Manufacturing

The most important manufacturing issue was how to create curved members.

Investigation into various methods, including how commercial polytunnel manufacturers create hoops, led to the solution - a rolling machine. An example is shown in figure 11 [10]. Discussion with manufacturer Firsttunnels resulted in the assurance that if the 'kit' tent was to be produced on a mass scale this type of machine could carry out the necessary bending at high speed.

Thought also needed to be given to the manufacture of the actual joints especially as these were the areas where local repairs may be necessary. In general methods that could be carried out using hand tools were considered such as cutting and drilling of sheet and tubular material.

Figure 11: Rolling Machine

5.6 Solution space

A section modulus in terms of radius was calculated from the required plastic moment estimated in 5.2. Following this a spreadsheet was used to minimise the cross-sectional area by varying the diameters and wall thickness of a circular hollow section while still ensuring the required section modulus was achieved taking account of the yield strength of various materials.

Combining these calculations with the discussion of the previous sections resulted in a number of options. To find the best combination a solution space defined by the key specification criteria of weight and cost and the ability to provide the required strength for the required shelter size was created. This is illustrated in figure 12. Also listed in the solution space are key points in each of the options, including areas where important information has yet to be determined. The arrows that reach into the solution space are for options considered fully viable, those that only touch are options that have factors that may result in them not being completely suitable and those without arrows do not fit the solution space.

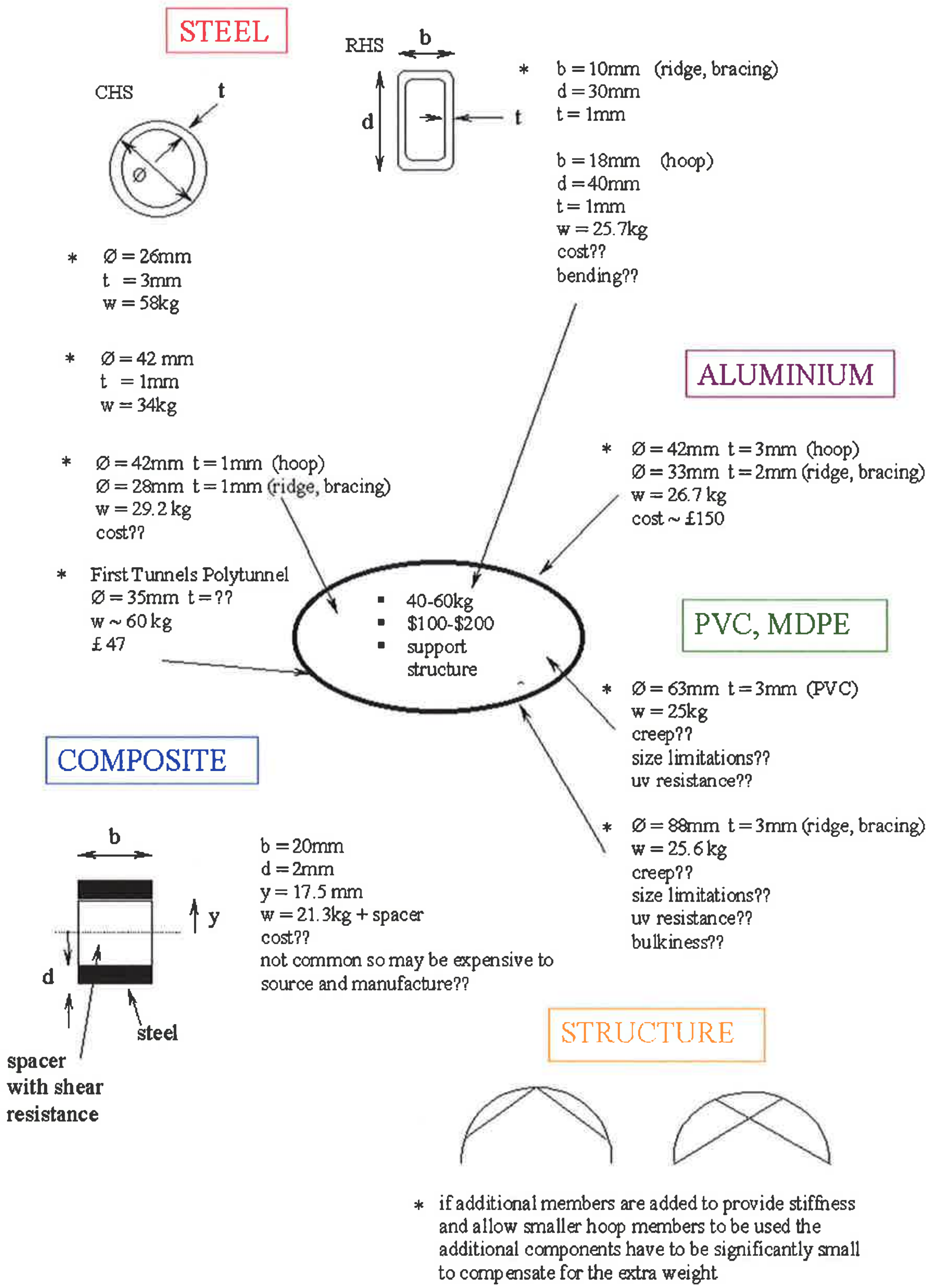


Figure 12: Solution Space

6 Prototype Development

The solution option chosen was steel circular hollow section in two different sizes, a larger diameter for the hoops and a smaller diameter for the ridge and bracing members. This choice was made as a result of many factors the most important of which are:

- Steel is widely available in the UK where the 'kit' tent is to be manufactured. This means cost will be low when manufactured on a large scale, equipment will be widely available and manufacture can be carried out at high speed.
- Steel is a relatively common material world wide and is certainly more familiar to people than a composite or polymer alternative and this is important both in terms of the people in the field constructing and repairing the shelters, and also donors who provide the funding for the purchase of shelters. Often large sums of money are involved and it is important that the donor has confidence in the shelters being purchased.
- Steel is a useful material to refugees when reconstructing buildings on their return home.

Issues that have to be considered following the choice of steel are:

- Surface finishing to ensure it does not degrade during the specified lifetime
- Ensuring the use of as many standard sizes and methods as possible to ensure material availability and increase shelter adaptability.

Having optimised sections for required plastic section modulus and low weight as discussed in section 5.6 and shown in figure 12 it was then necessary to assess the availability of these sections. This proved difficult as many metal suppliers stocked only imperial size circular hollow section. As a result the closest imperial sizes had to be used. These were

- 38.1mm diameter 1.5mm wall thickness for the hoops
- 25.4mm diameter 1.2mm wall thickness for the ridge and side bracing.

The location of the side bracing also had to be determined. This was carried out by locating one end of the bracing at the point where a plastic hinge may be likely to form on the hoop. The bracing on the middle hoop was located at a point which provided stability to the middle hoop, was at an angle such that ponding behind the bar was unlikely to occur, made only minimal infringement on the internal area of the shelter and was as short as was feasible. This resulted in the bracing being located approximately 1.65m above the ground on the outer hoops and 0.15m above the ground at the middle hoop.

6.1 Manufacturing the hoops

The metal supplier rolled the circular hollow section into hoops using equipment similar to that shown in figure 11. This required the hoops to be divided into 4 sections due to the limitations of the machine used. This was useful in meeting the 'kit' shelter packed length specification. It should be noted that in the prototype built the steel was not galvanised due to time and cost constraints of this particular project; however the metal supplier suggested that if purchasing in bulk galvanising the steel would not be outside the required cost of the shelter.

The two main joining options for the hoops as shown in figure 10 are swaging or using an internal tube. It was decided that using internal tube was the better method, as once drilled as part of the kit shelter, repairs would be possible using alternatives if bolts were lost or failed, whereas repairing damaged swaged ends may be more complex in the field.

Figure 13: An example of one of the hoop joints

The inserts into the hoops were a tight fit. To help make construction easier one end of the tube was rivetted onto a hoop member and holes were drilled in the other end for bolting on site. Figure 13 shows an example of the joint. The rivets and bolts used both had shear capacity of 2.5kN which is greater than the expected load.

6.2 Manufacturing ridge and bracing members

Simplicity was again the overriding factor in the design of the joints. Sheet metal components were chosen so that they could be easily replicated with a minimal number of tools if repairs were required in the field. The sheet metal used was 1.2mm thick steel. Again the constraints of this particular project did not allow the steel to be galvanised but this would be required if the joints are to be effective throughout the expected life of the shelter.

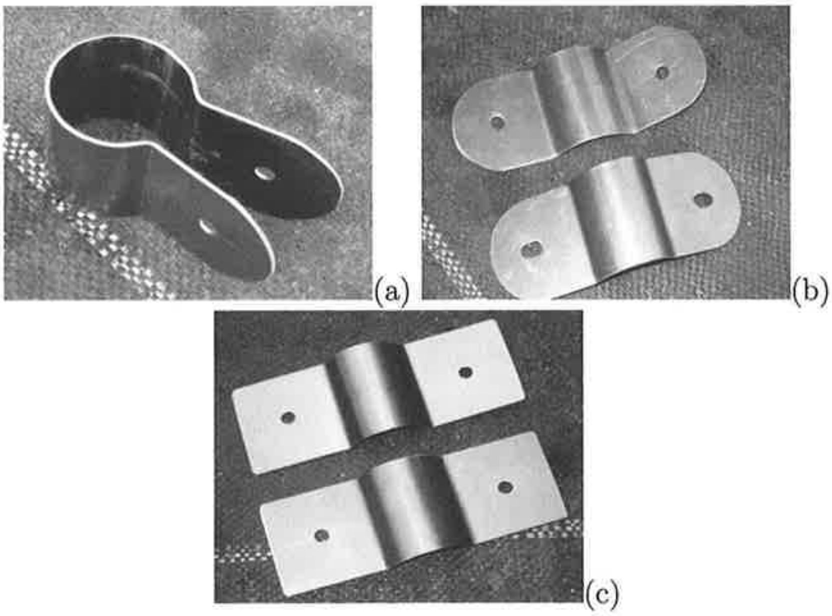


Figure 14: Bracing and ridge joints

Figure 14 shows an example of each of the three main joints. Joint (a) is used to connect bracing to the outer hoops. Joint (b) is used to connect bracing to either side of the centre hoop. Joint (c) is used to connect the ridge member to either side of the centre hoop. Joints (a) and (b) have curved ends to allow better location of the members at an angle.

For all of the joints shown above the ends of the bracing members were flattened and drilled and M6 bolts were used for connection.

The side bracing members were longer than the specification for packed length allowed and so they had to be made of two members joined. A similar method was used as for the hoops. Solid aluminium rods were inserted into the ends of the members and drilled with bolts used for connections. Tube as used in the hoops would have been preferable but due to the limited material available at the time this was not possible. Figure 15 shows an example of the joint.

Figure 15: Side bracing member joint

6.3 Restraint details

The shelter design was not connected to the ground in any way and so needed restraint to prevent uplift. *shelterproject* have provided a downward force on their MDPE shelter, as discussed in section 4.6, by burying the covering in trenches either side of the shelter and filling back up with soil. This has proved effective in the field and so the method was adopted.

A method of locating the hoops was also required and again the solution was found in previous work by *shelterproject*. Reinforcing bar is driven partially into the ground, with approximately 250mm above ground for the hoops to fit over. To minimise weight 12mm diameter reinforcing bar was used.

6.4 Construction and assembly

The construction sequence was as follows

1. Mark out the shelter area of 4.4m x 3.6m with reinforcing bar driven into the ground for each end of the three hoops
2. Build each of the three hoops
3. Place the ridge and side bracing joints on the hoops and then place the hoops on the reinforcing bar
4. Connect the ridge members
5. Connect the side bracing members
6. Put the covering over the tent

The photographs in figure 16 show examples of the construction of the shelter with the stage of construction as described above indicated.

The shelter was quite simple to put up, with two people taking approximately 1-2 hours from kit to shelter.

It should be noted that it was not possible to bury the cover into the ground due to restrictions on the site used, however this would be done in the field. This would provide restraint against uplift much more effectively than holding the cover down with lengths of timber as was used on the prototype.

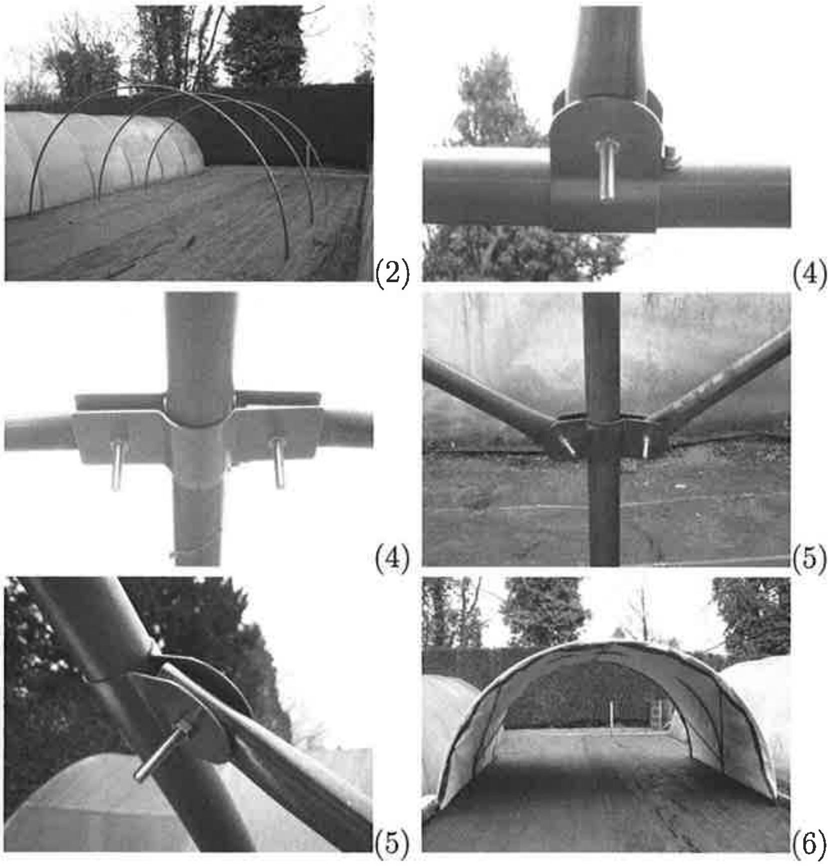


Figure 16: Construction photos

6.5 A 'kit' shelter

The design brief was for a 'kit' shelter. Figure 17 shows the frame components piled together with the longest member being the hoop segments at 1.73m.

Figure 17: The frame components

As part of the kit the specification requires simple assembly instructions that can be understood by people in any part of the world; therefore the instructions are entirely diagrammatic removing translation and language problems. An example of these instructions is shown in figure 18.

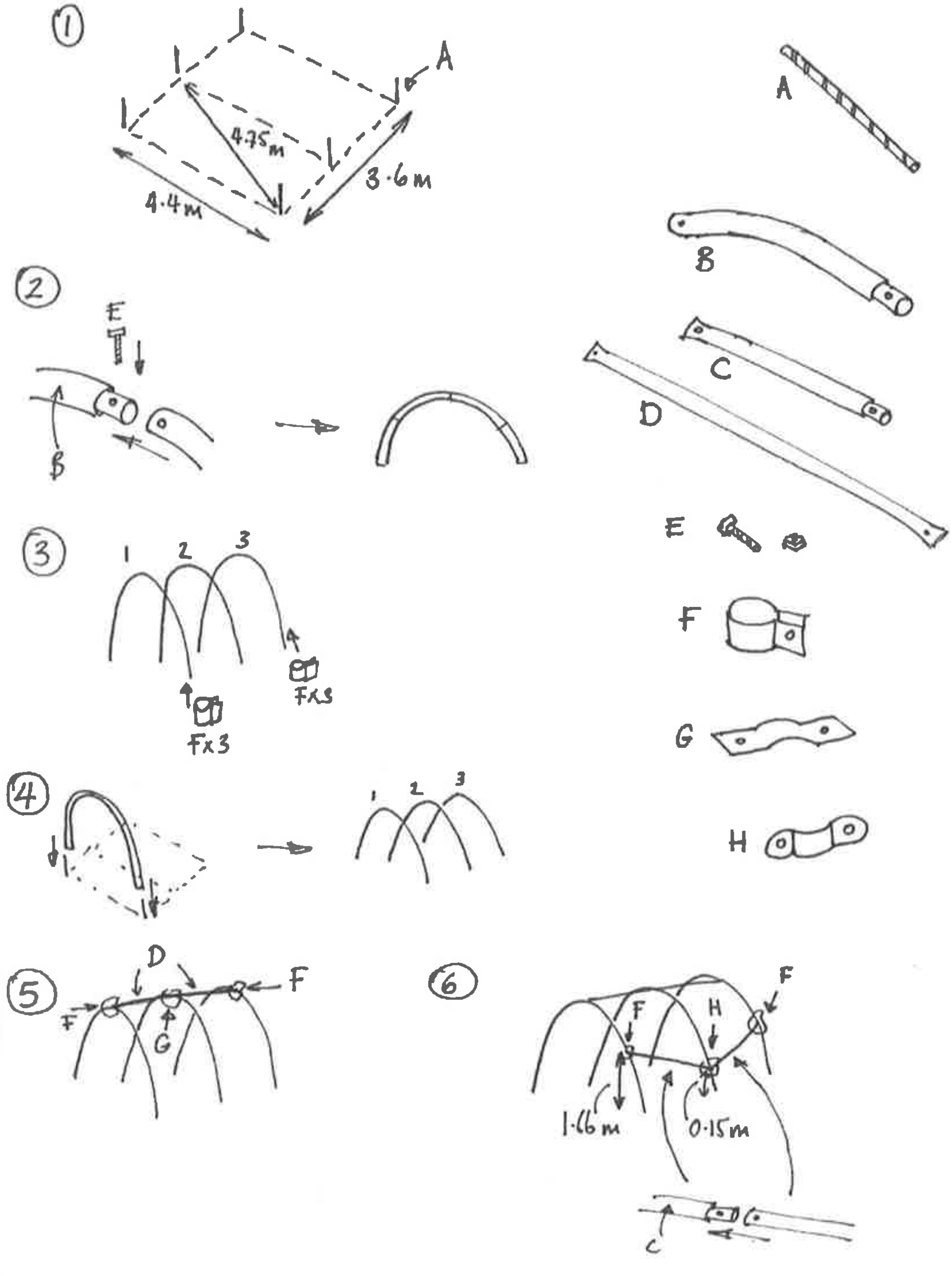


Figure 18: Assembly instructions

7 Testing

After the shelter was constructed it was left up for 4 days, during which there was heavy rain and very strong winds. The cover needed tightening and timber was used to provide restraint against uplift (as it was not possible to bury the cover) but the shelter remained standing. The cover was removed (as the wind increased) and the frame has stood for two months. At the end of this period of time some simple displacement tests were carried out.

7.1 Test plan

There are no standard structural tests for shelters against which the prototype can be compared and so a simple displacement test was devised. The two main directions in which deformation and displacement were expected were laterally, i.e. in the plane of the hoops, and longitudinally, i.e. along the length of the shelter. It was decided to measure the displacement in each of the expected directions separately forming two distinct tests.

1. A single force applied in the plane of the hoop at the point where a plastic hinge is expected to form
2. A force applied at the top of the hoop in the longitudinal direction

7.2 Test equipment

The easiest means of applying the force for both tests was to use a rope and pulley system, adding weights to a basket attached to the end of the rope. The actual set-up of the pulley was different for each of the two tests. The lateral load test was as shown in figure 19 (a) and (b). A bar was used to apply the force and the rope was arranged such that the force applied to the hoop was horizontal in the direction shown in the figure and the weights were added in the vertical direction, again as shown in the figure. The longitudinal test was simpler and was as shown in figure 19 (c) and (d).

The displacement for each test was measured using a plumb line and the distance moved from a reference point. This was carried out using a long ruler fixed securely onto a vertical stand.

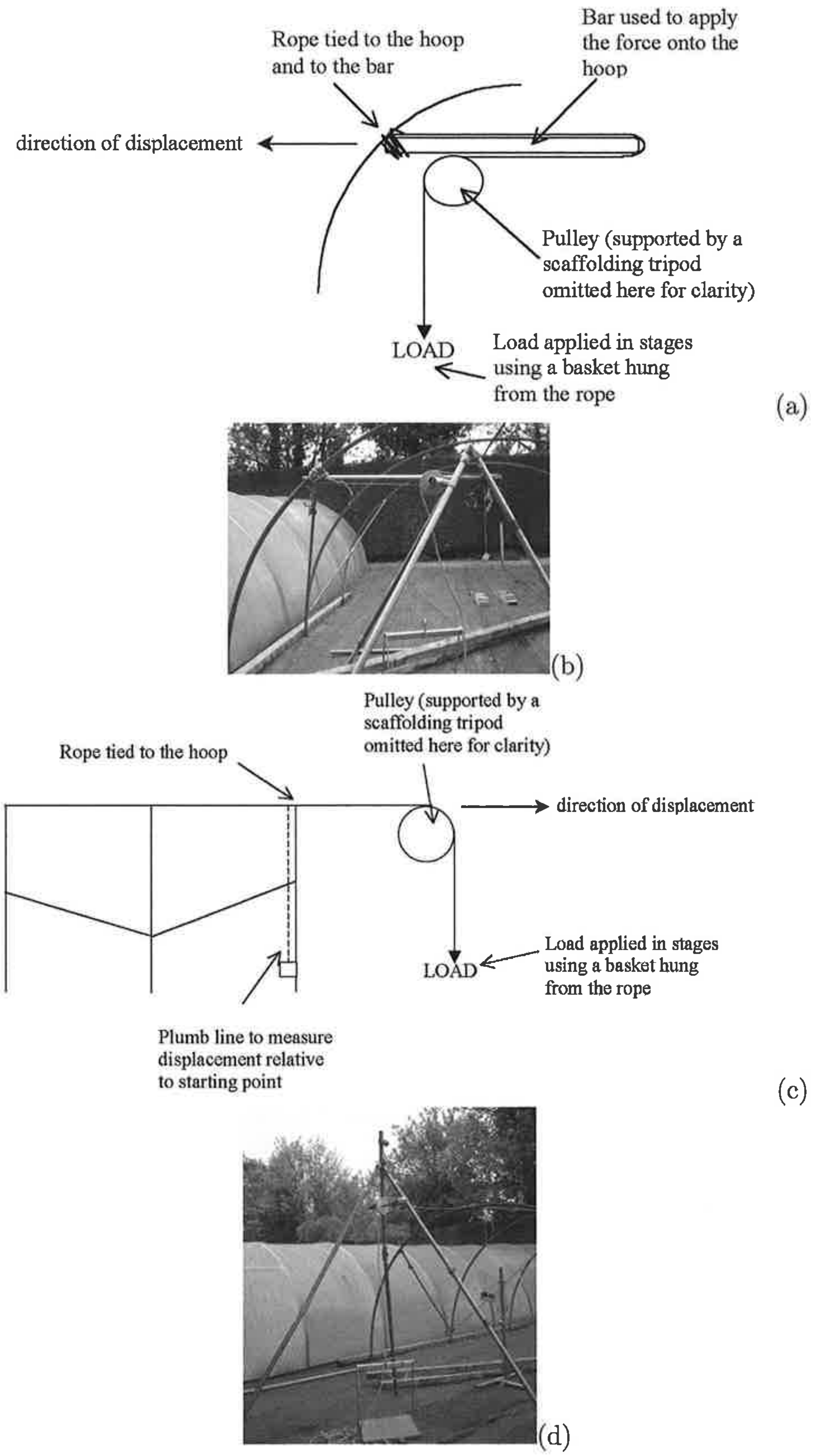


Figure 19: Test setup

7.3 Results

The longitudinal test was carried out on each of the hoops and the results were expected to be similar for each. The graph in figure 20 (a) shows that, although the results are of similar gradient, the first hoop behaves differently at higher loads. This may be due to the end of the shelter lifting up as the final loads were applied in the first test, requiring the test to be repeated with the rear hoop held down. It would appear that a certain amount of plastic deformation occurred while the rear hoop was held down, as when unloaded it only returned to the point at which the large change in gradient occurred.

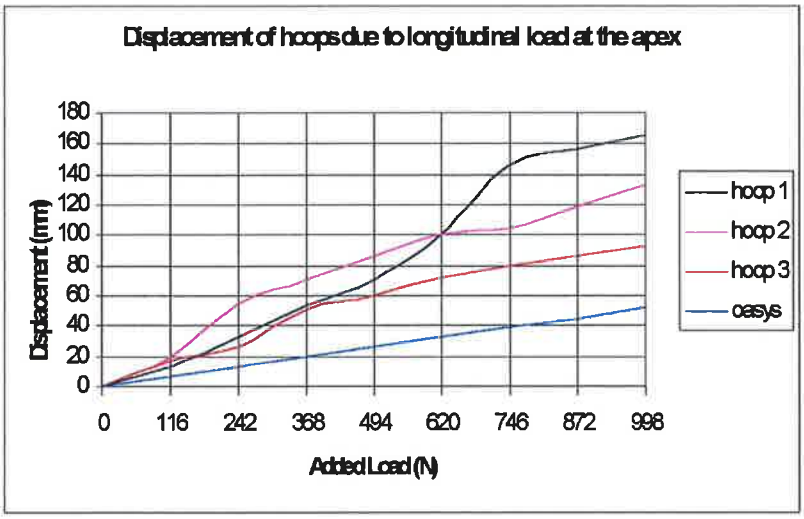
An Oasys model of the whole shelter was created and loading was applied to replicate the testing situation described in figure 19 (c). The deformation according to the Oasys model is shown in figure 20(b). The results are consistent in the gradient but Oasys predicts a lower displacement. This may be due to it not being possible to model the end conditions exactly as the shelter and the fact that the shelter is bolted together and may have settled.

The lateral tests were carried out on one hoop only as it was not possible to attach the bar to the middle hoop and the end hoops were expected to be identical. The graph in figure 20(c) shows that the displacement increased slightly with each loading, which is not unsurprising as it is likely that bolts may have loosened in the loading process. Again an Oasys model was used with the loading applied to replicate figure 19 (a). The Oasys model predicts lower displacements than occurred but is consistent in the gradient. Figure 20 (d) shows the deformation Oasys expects and again this was very similar in form if not magnitude to the actual results.

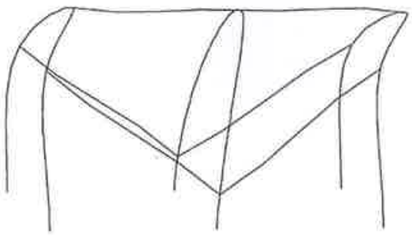
7.4 Validity of tests

The only data available for comparison is the Oasys model and as discussed the end conditions, though not exactly modelled as the shelter, did make a reasonable representation. Although the magnitude of the actual displacements is larger the Oasys model could be considered to give confidence that the results are at least reasonable and this confidence is supported by the magnitude of visible deformation occurring when a small force is applied by hand.

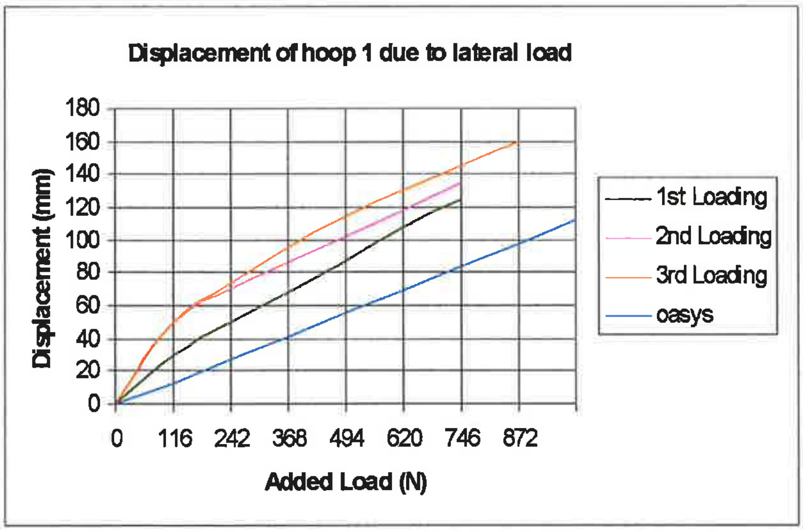
The method of measuring the displacement allowed estimates to be made to 1mm. A more accurate method would have been to use a theodolite, however the space at the test site made this an impractical option.



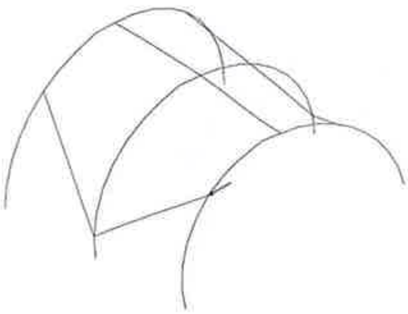
(a)



(b)



(c)



(d)

Figure 20: Test results

8 Shelter Evaluation

Having constructed the frame of the shelter it is important to consider whether it meets the performance specifications outlined in section 3.4. The relevant specifications for the frame are shown in table 3 below, alongside the data for the frame constructed.

Specification	Constructed frame
Useable area of $17.5m^2$ for a family of 5	• Frame floor area = 3.6x4.4 = $15.84m^2$ • Allowing $1m^2$ at each end provided by vestibules = $17.84m^2$
33% of floor area should have height of 1.8m	• 51% of total floor area • 57% of frame floor area
Must not fail in peak wind speeds of 100km/h	Did not fail when force applied equivalent to 68km/h in lateral and longitudinal direction
Total weight 40-60kg	Frame weight = 42kg
Packed length 1.5-2m	Longest member 1.73m
Maximum cost $100	Frame cost £170
Component count kept to a minimum	3 different joints and 3 different members

Table 3: Frame evaluation

As can be seen from the table the majority of specifications have been met. The main area where the frame has not met the specification is with cost and it is likely that on mass production this cost may be greatly reduced, making the frame a viable solution to the specification. This expected reduction in cost is supported by a quote from the polytunnel manufacturer Firsttunnels (£46 + VAT for a slightly smaller frame than designed). The steel supplier used for the prototype also suggested that, when bought in bulk, prices for material and manufacturing processes such as rolling would be lower.

Areas where the specification has only just been met are the weight and the component count. If further optimisation of the member sizes is carried out and if the reinforcing bar used to locate the hoops is replaced by circular hollow section then it may be possible to reduce the weight. Further weight savings and a reduction in the number of components may be possible if time is spent developing the jointing system such that all the joints can use the same component.

The estimated additional area provided by the vestibules is very conservative as the $1m^2$ at each end is effectively 0.25m of extra length provided at full width. The vestibules are actually more likely to give an extra 0.5m at least in length which equates to $2.2m^2$ at each end of the shelter. This brings the shelter much closer to a 6 person shelter in hot climates or a 5 person shelter when equipped for cold climates.

It should be noted that the MSF plastic covering suggested in the design brief meets the specifications relating to political sensitivities and waterproofing, but fixing the covering around the frame requires consideration. The development of the vestibules should also be considered alongside the detailing of the covering. Recommendations for further work that may build on these areas is discussed in the following section.

9 Conclusion

The performance specifications developed for a family emergency shelter have reached a stage where they are being considered and discussed by a number of humanitarian aid agencies, particularly those mentioned as having made comments on early versions as discussed in section 3.4. The process towards acceptance and use will be slow but a step forward in the shelter sector has been made.

Developing a tent that meets the performance specifications has been difficult, as the specifications have been continually refined changing key values that the design has been based on, such as the wind speed at which the structure should not fail. However the shelter design largely fits the specifications that are related to the frame as is shown by section 8. It is close to the limit on weight if the covering is included, has more floor area at 1.8m head height than is necessary and is too expensive when made as a one-off item. All of these are areas where improvements should be considered. Due to cost and time constraints of this project the prototype was not galvanised, however to fit the specification for lifetime this would be necessary in any future shelter.

The only means of comparison with theory for the frame design was the Oasys model. The prototype end conditions were not fully replicated in the Oasys model but the moment diagram, deformation shapes and displacements were consistent with that calculated and observed in testing the prototype.

The results from the testing were similar in magnitude to that expected, however the tests were carried out on the frame only. It would have been beneficial to measure the displacement of the shelter when the covering is trenched in around the shelter providing some restraint to uplift. It would also have been beneficial to test to destruction the shelter to quantify the actual limits on the size of members used allowing the shelter to be optimised further.

Had there been more time it would have been useful to model the behaviour of the shelter with point forces applied to each hoop simultaneously. If comparisons could be made between a FE model such as that created in Oasys and testing of a prototype this would give further indication of the likely performance in the field and highlight areas where optimisation could be carried out.

9.1 Recommendations

Having spent time evaluating the shelter with *shelterproject* a number of recommendations were made to improve the shelter and make it a better solution to the specifications. The main suggestions were:

- Reduce the weight of the frame. As standard sizes of circular hollow section have to be used this may involve testing to destruction various sizes until a safe limit has been found.
- Reduce the component count by making the side bracing members the same as the ridge members and making up the difference in length with a new larger joint system on the centre hoop.
- Consider in more detail swaging as a jointing method as this would reduce the number of bolts required and would reduce the wearing of the cover that may occur with the joints used in the prototype.
- Ensure a surface finish such as galvanising is used on future shelters.

9.2 Further Work

Further work is being carried out on the shelter to turn it into a realisable product by a team of *shelterproject* volunteers and this will include investigating the recommendations listed above.

In addition a funding application has been made to develop a scheme of simple structural tests. This will also benefit the future development of the shelter as it will give a benchmark for the confidence and performance of the shelter.

References

[1] Diagrams courtesy of shelterproject.

[2] http://131.111.144.57/shelter/research/tents.asp.

[3] http://www.sphereproject.org/handbook/hdbkpdf/hdbk_c4.pdf.

[4] http://www.unhcr.ch/cgi-bin/texis/vtx/basics.

[5] *USAID/OFDA Plastic Sheeting Usage And Construction Techniques*, (provided by shelterproject).

[6] Joseph Ashmore. Personal communication.

[7] Joseph Ashmore. Personal communication.

[8] Babister L. University of Cambridge. *Dissertation for a Diploma in Architecture*, 2001.

[9] Guttridge P University of Cambridge. *MEng Project*, 2002.

[10] Sean Barker of First Tunnels Polytunnels. Personal communication.

[11] Davis I. Oxford Polytechnic Press. *Shelter after disaster*, 1978.

[12] Shelterproject. *Overview of shelter in 6 refugee camps in Herat province, Afghanistan*, 2002.

[13] Shelterproject. *Technical comparison of tent specifications*, 2003.

Acknowledgements

I am most grateful to Allan McRobie, Tom Corsellis, Joseph Ashmore, Steven Hunt, shelterproject volunteers, Martin Touhey and Simon Holder for their help and advice throughout the course of the project.