DESIGN OF A MODULAR SPACE TRUSS AS A DISASTER SHELTER USING EVOLUTIONARY COMPUTATION

Peter VON BUELOW  
*Assistant Professor, TCAUP, University of Michigan, Ann Arbor, Michigan, USA*  
*E-mail: pvbuelow@umich.edu*

**KEYWORDS**  
Space truss, modular, rapid erection, shelter, evolutionary computation, genetic algorithm

**ABSTRACT**  
There is a need for low cost, rapidly deployable, modular shelter systems for use as disaster relief structures around the world. Recent worldwide events such as hurricanes, tsunamis, and earthquakes provide numerous examples of the need. The Modularch family of shelters, originally developed for the US Marine Corps [1] responds well to such criteria. An erection procedure is outlined that allows even long span structures to be erected from the ground using only man power. The shelter system has been designed for high wind and snow load capacity. The family of shelters shares the same component parts with a range of five sizes spanning 9 m, 13 m, 15 m, 22 m and 30 m. In addition these spans can be produced in any desired length. The structural system is a rigid space truss, which can support either fabric or thin composite HP-shell elements. A foundation is provided by spread anchor plates. Entrance and end enclosures are also shown. It was determined that the Modularch system as developed has good potential as a disaster shelter.

An alternate geometry was investigated using Evolutionary Computation to find minimal weight configuration based on the snow load for the 3D truss system. This geometry is compared to the original modular geometry.

**INTRODUCTION**  
The Modularch design was originally developed in response to criteria set by the US Marine Corps. The Corps has need for shelters that can be quickly erected without heavy equipment, anywhere in the world. These shelters are termed "expeditionary" because they are setup in
advance of the arrival of cranes or any construction equipment. They need to be setup by six men using hand powered tools. These same requirements would very well suit any first response disaster shelter that might be used as immediate weather protection for displaced refugees, field supply or hospital facilities following a large natural disaster. Some of the overlapping design objectives for these shelters include:

- Multiple sizes using modular parts
- Erectable without heavy equipment or high skill
- Repetitive components
- Low shipping weight
- Small packing cube
- Low overall cost

The shelters are designed to be stored in ISO shipping containers that could be air lifted to remote areas. Because they can be erected by hand, without heavy power equipment or electricity, they are well suited for disaster situations where local equipment and power may be lacking.

Figure 2. Perspective view of the 22 m Modularch

MODULAR GEOMETRY

The entire family of five shelters shares the same components with the exception of the end closure systems which are unique to each size. The basic components include:

1. edge member poles – 100 mm diam.
2. splice lengths – 18 cm, 71 cm, and 183 cm
3. fabric panels (A and B in Figure 3)
4. hub joint (Figure 4)
5. base skirt
6. base anchor and stakes (Figure 5)

Frame members and panels

In concept the shelters are all made from just two panel types that have equal edge lengths on all four sides. One panel (A) is deeper and the other (B) is flatter. In the two panel sizes, only one bracing member changes length, the edges are all the same. There are also two hub angles, but with the pivoting design, one hub is used in both conditions. Figure 3 shows the locations of the panel types.
The basic pattern is shown on the left in Figure 3. For this, the 15 m size, the panels alternate ABAB. To increase the span to 22 m, a pair a A's are inserted on either side. The pattern then follows ABAAAB.

For the smaller 13 m size the top 5 panels are used and in the smallest 9 m size, panel A is left out. A larger 30 m span is also possible using an ABAAAAAB pattern, but it carries a reduced load. The arches can be joined in these patterns to form any length needed.

The fabric panels attach individually with locking cap strips so that they are held on the entire edge. This also allows them to be replaced individually in case of damage.

**Pivoting Hub**

With only two hub types it would not add much to the complexity to have fixed hubs. In the prototype it was decided to design one hub that could pivot to either of the two angles needed. The hub components were cast out of a zinc aluminum allow, ZA-27, which had good strength without tempering. Figure 4 shows the assembled hub. The edge members sleeve over the hub bosses, and are attached by snap pins.

**Base Anchor**

The frame attaches to "half hubs" at the base, which are hinge connected to a base plate. The base plate acts as a footing to spread the dead load on softer soils, but primarily provides for numerous tie-down anchors in the form of engineering stakes. Figure 5 shows the anchor plate design.
The concept for the Modularch shelters is to be deployed in advance of heavy erection equipment like cranes. This might mean an air drop of the packing container and a small erection crew. The planned procedure could be carried out entirely from the ground with hand operated jacking equipment. No component of the shelter system weighs more than 23 kg [50 lbs] with the exception of the anchor plates and the main end enclosure system (fabric).

The basic erection procedure is the same for all shelter sizes. Only the assembly order of the panel types and their number are changed to produce the different size shelters (see Figure 3). The basic erection steps are as follows:

1. Place and secure all anchor plates on one side.
2. Attach frame and hubs to complete the first row of panels
3. Attach fabric to frame as you go
4. Jack up the leading hub to a height which allows the insertion of the next panel.
5. Repeat steps 2 through 4 until all panels are assembled.
6. Fix the last row of members to the row of anchor plates on the far side.
Figure 7 shows the sequence of steps. Figure 6 shows all of the steps in an overlay drawing.

Figure 7. Overview of the erection sequence.

ACCESS DOORS

Main Access
The main access doors form the end closure for the shelter system. For the original Marine Corps requirements these doors needed to provide full access of the opening to allow passage of aircraft and equipment. Additionally, it was desirable to divide the large area of fabric into sections so that it could be handled manually during erection. The large openings were divided vertically into panel sections which match the frame panel widths (about 4.8 m [16 ft]). These can be joined by large scale zippers, which operate using ropes and pulleys. The larger surfaces are tensioned between anchors on the ground and points near the top (the crosses). This system would allow for optional degrees of access as shown in Figure 8.

Figure 8. Main end doors on the large shelter showing different degrees of access.
Side Access
The side panels are also large enough to allow personnel access, and can be fitted with different kits to allow for special functions. These would include a smaller door for personnel, small truck access, line and duct access for power equipment that would remain outside such as a generator, heater, or simply open ventilation. Figure 9 shows 3 of these options.

Figure 9. Side access options. Left: ventilation, Center: personnel, Right: truck access

HURRICANE BRACING

Design Loads
The system is designed to carry a snow load of 1kN/m² [20 psf] and a wind load of 120 kph [75 mph]. With the addition of a hurricane kit the 22 m shelter is design to carry a wind load of 195 kph [120 mph]. Figure 10 shows the hurricane kit for the 22m shelter. The smaller shelter can carry the 195 kph load without the kit. This 195 kph wind load was a requirement for the military version of the shelter. It is not expected that this high a loading would be needed for a disaster shelter, since the “disaster” is presumably past. Because this was the governing load case for the larger shelters, all frame members are sized for the 195 kph wind load. If this load were not considered the pipe sizes could be reduced, and the shelter made lighter and more practical for transport and erection.

Figure 10. The 195 kph hurricane bracing kit for the 22 m size
GEOMETRY OPTIMIZATION

Optimization Method Used
The 2D truss optimization and exploration program developed by the author and referred to in other papers as the Intelligent Genetic Design Tool (IGDT) [2] was expanded to include 3D truss optimization for weight for this project. The program is based on a Genetic Algorithm which can explore both topology and geometry in 2D, but is limited at this point to geometry optimization in 3D. The 22 m arch was analyzed for a 1 kN/m² [20 psf] snow load in addition to a 145 kph [90 mph] wind load. The snow load was taken as symmetric and over the full span. The wind load was broken into three zones (three Cp factors) applied asymmetrically as two loadings (once from each side). The results shown in Figure 12 can be compared with the original arch geometry shown in Figure 11. The GA optimized arch for the snow load is broader at the base where compressive load is maximum. The wind load arch is primarily loaded in tension and develops a thinner profile. With members in both arches being sized for snow load only, the original arch is 30% heavier than the GA geometry. Of course what is lost is the modularity of members. Also, it is desirable to avoid slender members that might be damaged in erection or disassembly. Nonetheless, further geometry as well as topology exploration might yield a more efficient design.

CONCLUSIONS

From this review of the Modularch family of shelters, it can be seen that there is good overall potential for their use as disaster relief structures. It can be seen that some criteria that were determining in the military version, in particularly the 195 kph wind load, could be relaxed. This would allow a redesign of the member sizes which would reduce weight and make erection easier. From experience with prototype sections of the Modularch, the hub design was found to cause difficulties during erection. It would be recommended to redesign the hub. Problems stem from the sleeve connection which is too angle sensitive during erection. Also, the weight of the casting makes the hub difficult to install off the ground. There might be a simpler solution with part of the connection being incorporated into the strut members.

The initial weight optimizations for snow and wind loadings using the GA program, indicate that reconsidering the geometry could yield a lighter system. Although the current geometry for the Modularch seems to fall somewhere between the geometries found for snow and wind load
separately. Further investigation, perhaps with parametric generative software linked with the GA optimization program might be fruitful.

Figure 13. Isometric view of the 22 m Modularch system

Figure 14. Isometric views comparing the shelters optimized for snow load (left) and wind load (right)

REFERENCES


[also at: http://elib.uni-stuttgart.de/opus/volltexte/2007/3160/pdf/PvB_diss.pdf ]