

NON-REINFORCED FOAM FILLED MODULES FOR RAPIDLY ASSEMBLED POST DISASTER HOUSING

*Saeed Nemati¹, Pezhman Sharafi², Bijan Samali³, Yahya Aliabadizadeh⁴ and Shahrokh Saadati⁵

^{1,2,3}Centre for Infrastructure Engineering, Western Sydney University, Australia

⁴A & A Structures LLC, Maryland, USA, ⁵GHD, Sydney, Australia

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ABSTRACT: Rapidly assembled structures play an important role in post-disaster housing. This research study introduces a modular non-reinforced foam-filled system for rapidly assembled buildings and studies its structural performance. A novel structural modular construction system using pneumatic formwork is presented and its structural performance as a post-disaster housing system is studied. To that end, this paper presents a numerical analysis using finite element modeling on the foam-filled modular units, together with a set of experimental tests on the elements. Finally, the performance of a real size module made of polyurethane AUW763 against snow and wind loads in critical areas is modeled, using the software ROBOT 2016 and ANSYS. The results demonstrate that the foam-filled modular units successfully meet the standards' requirements for semi-permanent housing even in cyclonic prone areas based on Standards Australia (AS1170.2), International Building Code (IBC-2015) and an American standard as Minimum Design Loads for Buildings and Other Structures (ASCE7-10).

Keywords: *Foam filled structures, Rapidly assembled buildings, Post disaster housing, Crisis management, Structural performance*

1. INTRODUCTION

Crisis management after natural and non-natural disasters such as earthquake, flood, drought, bushfire, flood of refugees, raid and war can be a serious concern of governments. In the event of such crises, fast decision making is an essential element of an effective crisis management system [1]. From the civil engineering point of view, Post Disaster Housing (PDH) is a big challenge in the crisis management field. Every year, due to natural and man-made catastrophes worldwide, millions of people have to be accommodated in the temporary housing. In the USA alone, such disasters happen over 60 times per year [2]. Experts estimate that on average, it can take 5 [3] to 10 [4] years for communities to recover from the effects of a disaster, which highlights the severity of the disaster and the importance of Rapidly Assembled Buildings (RABs) as an effective PDH system [3]. Rapidly assembled panels are used commonly in residential buildings as well as industrial structures [5]. In addition to residential accommodation, RABs can be employed in several other applications such as field hospitals, storehouses and other temporary and semi-permanent facilities [6]. Some rapidly assembled systems have the potential to be used as temporary structures as well as providing long-term serviceability. Temporary accommodation buildings can only remain on-site for a maximum of two years unless the local government approves a longer timeframe before

the two year period expires [7]. Nevertheless, sometimes, the term of "temporary" returns to several years, especially in developing countries [8-12] that can have significant social and economic effects [13-15].

Mobile and rapidly assembled structures play a major role in post-disaster management through building temporary accommodation and shelters. Wise selection of RAB systems has an impact on their performance in an effective crisis management system. For instance, use of large precast units is adopted by most existing PDH systems. Yet, as the dimension of precast elements increases, some significant construction problems appear in transportation, installation and erection phases. Air-liftable origami-inspired deployable systems, pliable structural systems with rigid couplings for parallel leaf-springs, scissor systems [16], elastic grid shell system [17], and structural panels are some popular types of mobile and rapidly assembled structures [18, 19]. Most of these rapidly assembled structural systems suffer from low tolerance in the fabrication and erection phases. They also need skilled labors for installation that will result in an increase in the total costs, and some other constructional problems. For example, air-liftable origami-inspired deployable systems do not have a reliable architectural form and are most uncomfortable for a long stay. The control of heat exchange in such systems is also very difficult. Pliable structural systems with rigid couplings for parallel leaf-

springs have similar problems, in addition to a relative complex design procedure. In addition, in most cases, the elastic grid shell system is limited to non-residential temporary applications. High rate energy loss and expensive construction equipment are some of the other downsides of this system. To respond to such shortcomings, in this study, using pneumatic foam filled panels first, an effective rapidly assembled modular system is presented as a PDH that can be used for post-disaster management as a temporary and semi-permanent housing system. The modules are made of lightweight composite sandwiches fitted in pneumatic formwork that greatly facilitate transportation and installation process. Then, numerical and experimental analyses are performed to investigate the structural performance of this system under severe loading conditions, as a structural feasibility analysis.

2. TEMPORARY HOUSING

A temporary accommodation building can be any class of building as defined under the National Construction Code (NCC). However, they are usually a class 1b (boarding house, guest house, hostel or the like), class 2 (residential units) or class 3 (motel) building, depending on its configuration [20]. The Federal Emergency Management Agency (FEMA)'s recent policy change to discontinue using the mobile homes as a temporary housing alternative will result in a significant increase in the cost of the temporary housing program [21].

In addition, studies have shown that innovative prefabricated housings have 25.1 and 29.7% lower life-cycle energy and cost requirements respectively [22-25]. Use of rapidly assembled panelised systems, especially rapidly assembled lightweight panels, is becoming very popular for cutting the construction time, as well as skilled labor and transportation costs that make them suitable options for PDH projects (Figure 1).

Regarding the structural performance of lightweight panels, the use of foam materials has been a good choice for filling material. While many types of foams are available in the market, Polyurethane (PUR) based foams are the most popular types, first introduced into the market in the 1950s. Foams are available in three main categories: flexible (the most popular), semi-rigid and rigid foams [26]. Polyether-based PUR foams are used widely for applications such as furniture, bedding, pillows, padding, and carpet underlay. Polyester-based PUR foams are used for textiles, shoulder pads, noise reduction and other applications. Both are used in automotive, aircraft, household, and footwear industries, too. Nevertheless, showing some good level of

structural strength and durability, these foams have a great potential to be widely used in structural engineering.

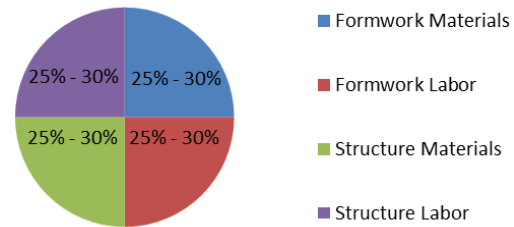


Fig.1 Distribution of costs for usually poured structures [27]

Structural studies on post-disaster housing are mostly limited to some post-disaster shelter design, architectural guidelines or Multi-Criteria Decision Making (MCDM) models for selecting the PDH systems [28-34]. In some research study, new temporary housing planning framework is proposed to offer customized housing plans tailored to the specific social, economic, and psychological needs of displaced families while controlling expenditures [35, 36]. Maximizing temporary housing safety after natural disasters have been studied in other research studies [37].

FEMA has explored a pilot program to evaluate the possibility of providing quickly deployable, affordable housing that can serve both as temporary and permanent housing [13]. In early 2009, FEMA released the first-ever National Disaster Housing Strategy which calls for improved planning and outlines the key principles and policies guiding disaster sheltering, interim housing, and restoration of permanent housing [38].

For disaster relief housing, rapidly deployable shelters must be lightweight, be packaged in a small volume for transportability, and be erected without heavy lifting equipment. In addition, a critical design criterion is also energy efficiency in heating and cooling. To meet these priorities, an optimized solution is found for a thermally insulated rigid wall deployable shelter by Quaglia et al. [39]. Although such rigid wall counterparts provide enhanced insulation, they have high self-weights, limited deploy-ability, and require heavy lifting equipment for placement. To address this downside, United States Army Natick Soldier Research, Development & Engineering Center presented a novel erection strategy for origami-inspired shelters based on the principle of counterweighting as Bascule shelters [40, 41]. Also, some researches proposed modular box systems for post-earthquake homeless disaster victims in line with the standard sustainability criteria [42-45]. The design and methodology of

construction of a shelter for the victims of the typhoon Haiyan in the Philippines were presented by Ravina and Shih [46].

3. FLEXIBLE FORMWORK

An efficient construction system that can be used in rapidly assembled buildings is flexible formwork systems. The most applicable types of flexible formworks are fabric formworks made of synthetic textile sheets of fibers; typically nylon, Polyesters/Polyethylene Terephthalate, Polyolefin or Polypropylene. In casted structural systems, in which a considerable portion of the project budget is allocated to formwork cost, innovative construction systems can play an important part in PDH programs. Using fabric formwork is one of these solutions.

The development of some innovative ideas such as pneumatic formwork has complemented the applications of fabric formwork. The main concept of pneumatic formwork application is ramified from membrane behavior. A common method of pre-tensioning a membrane is to pressurize the interior with air. Sufficient pressure is applied to counteract dead loads so that the membrane actually floats in space. Slight additional pressurization is also used to offset wind and other anticipated loads. Pressure differentials used in practice are not large. They often range between 0.02 and 0.04 psi (3 and 5 psf).

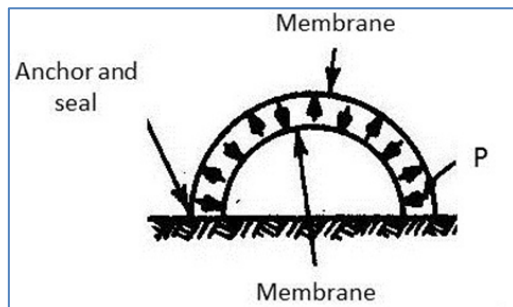


Fig.2 Air-inflated dual wall structures

A good example is air-inflated dual wall structures. Air-inflated dual wall structures (Figure 2) is one of most popular air stabilized structures. Up to now, however, this system scarcely applied as a structural pneumatic formwork. The general application of this technique is mostly limited to the erection and setup of domes and arches[47]. Employing the PUR and a pneumatic formwork, this study develops an effective post-disaster housing system that can significantly contribute to PDH management (Figure 3). In this System, after

inflating the fabric formwork, PUR foam is injected between internal and external fabric layers. Therefore, an integrated volumetric structural system including floor, walls, and roof will be built. Figure 4 shows a schematic perspective of the unit and a cross-section of integrated connections between walls.



(a)



(b)



(c)

Fig.3 Pneumatic formwork installation steps of introducer system (a-c)

The remainder of this paper investigates the structural performance of this foam-filled structural panel with fabric formwork (which can be erected by pneumatic force) as an innovative rapidly assembled construction system. Rapid assembly, low maintenance, high structural quality, and ease of transportation are some key aspects of this system that make it a suitable construction system for temporary and semi-permanent housing.



Fig.4a Schematic perspective

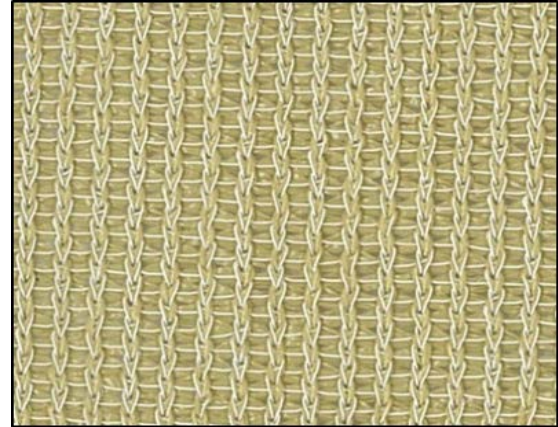


Fig.5a Barrateen fabric



Fig.4b Real cross-section of introduced system

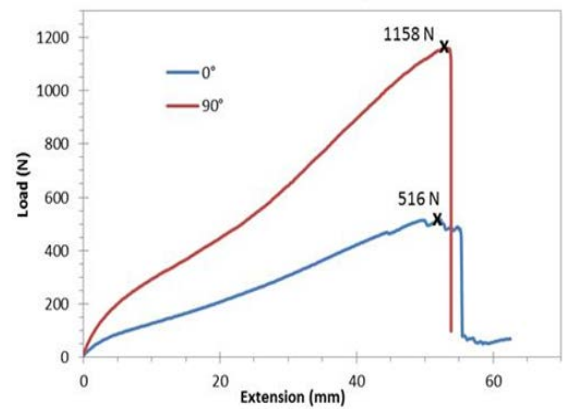


Fig.5b Barrateen fabric tensile behavior in main (90°) and transverse (0°) directions

4. MATERIAL PROPERTIES

The system fabric pneumatic formwork and PUR foam are the main materials used for the system. A research study has been done in the Centre for Infrastructure Engineering (CIE) of Western Sydney University in order to identify the best pneumatic formwork textile [48]. Results showed the Barrateen is the best candidate for being used as fabric formwork. Barrateen is a high-density polyethylene or polypropylene (HDPE) coated by unbalancing woven textile. The coating material is low-density polyethylene and well inflatable, whose tensile strengths in the warp and weft directions are not the same. The result of tensile tests according to ASTM D1980-89 is shown in Fig.5. Also, Polyurethane high-density rigid foam with a density of 192 kg/m³ was used for the core material. Table 1 shows the PU foam's manufacturing and mechanical properties, provided by the manufacturer and validated in the laboratory according to the ASTM 1730 standard [49].

Table 1 Mechanical and manufacturing properties of the selected PU rigid foam

Mechanical properties of the PU foam			
Density (kg/m ³)	Compressive yield strength (MPa)	Tensile strength (MPa)	Shear strength (MPa)
192	2.81	1.896	1.034
Manufacturing Properties			
Cream time	Gel time	Tack free time	Free rise cup density
35-40 sec	94 ± 4 sec	115 ± 5 sec	280 – 300 kg/m ³

Using uniaxial load machine (Figure 2), three cubic specimens (dimensions: 50mm × 50mm × 50mm) were tested based on the ASTM E1730 at a loading rate of 5 mm/min in order to identify the structural properties of the rigid PU foam. Figure 6 illustrates the stress-strain curves in the elastic region and failure graph respectively. The curves show that this type of PU foam, which is made of a

100:110 weight ratio mixture of AUSTHANE POLYOL AUW763 and AUSTHANE MDI, can undertake considerable deformation before the failure. These stress-strain curves are relatively linear in the elastic region, with a yield region at an average stress of 3.51 MPa, and the average elastic modulus of 135.5 MPa.

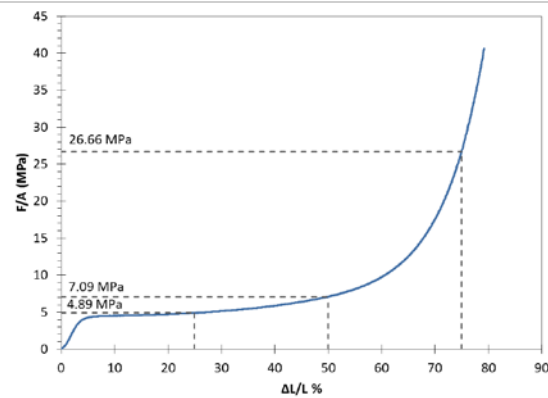


Fig.6a Results of the uniaxial load test on selected PU foam

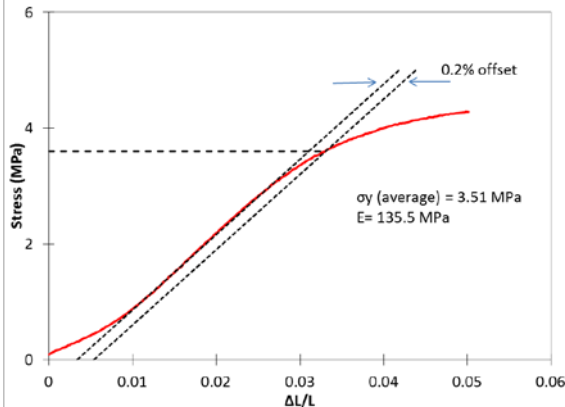
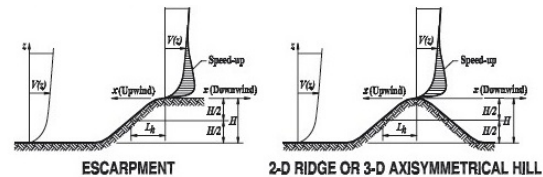


Fig.6b Results of the uniaxial load test on selected PU foam

5. LOADING ANALYSIS AND DESIGN

The introducer system is designed to be capable of being used for post-disaster housing in severe weather conditions. Therefore, in this study, a combination of severe loading scenarios is considered to check the performance of the shelter. On the other hand, because the system is light in weight, with regard to the lateral loads, the numerical studies showed that wind loads will govern the design, rather than an earthquake. The International Building Code (IBC-2015) [50] is used for determining the loads as well as the design. In this regard, a 3000 mm x 3000 mm x 3000 mm cubic shelter with 100 mm thick PU foam walls, floor, and the roof has been analyzed and designed. In fact, this cube is a simulation of temporary shelter that can be used in emergency situations. The door and windows are not shown in

the model. The computer model is created in ANSYS workbench. For the wind load calculations, the American Society of Civil Engineers ASCE7-10 “Minimum Design Loads for Buildings and Other Structures” [51], which is adopted by IBC 2015 is used. To analyze the cube for most extreme wind load, the Cube is subject to calculated wind load induced by an 80 mps wind speed, which is the highest speed for such structures. Also, the studied cubic shelter is categorized as risk category II based on Table 1.5-1 in ACSE 7-10, which is neither a low risk nor a high-risk structure. The cube is considered enclosed, so there will be a minimum internal pressure acting perpendicular to the surface. The Exposure category is assumed to be “C” which indicates open terrain with scattered obstruction having a height less than 10000 mm or flat open countryside and grassland, which assumed to accommodate temporary shelters at the time of disasters and emergencies. The topography of the site is assumed to be relatively flat with maximum 5000 mm escarpment height.



Topographic Multipliers for Exposure C										
H/L _s	K ₁ Multiplier			x/L _s	K ₂ Multiplier		z/L _s	K ₃ Multiplier		
	2-D Ridge	2-D Escarp.	3-D Axisym. Hill		2-D Escarp.	All Other Cases		2-D Ridge	2-D Escarp.	3-D Axisym. Hill
0.20	0.29	0.17	0.21	0.00	1.00	1.00	0.00	1.00	1.00	1.00
0.25	0.36	0.21	0.26	0.50	0.88	0.67	0.10	0.74	0.78	0.67
0.30	0.43	0.26	0.32	1.00	0.75	0.33	0.20	0.55	0.61	0.45
0.35	0.51	0.30	0.37	1.50	0.63	0.00	0.30	0.41	0.47	0.30
0.40	0.58	0.34	0.42	2.00	0.50	0.00	0.40	0.30	0.37	0.20
0.45	0.65	0.38	0.47	2.50	0.38	0.00	0.50	0.22	0.29	0.14
0.50	0.72	0.43	0.53	3.00	0.25	0.00	0.60	0.17	0.22	0.09
				3.50	0.13	0.00	0.70	0.12	0.17	0.06
				4.00	0.00	0.00	0.80	0.09	0.14	0.04
							0.90	0.07	0.11	0.03
							1.00	0.05	0.08	0.02
							1.50	0.01	0.02	0.00
							2.00	0.00	0.00	0.00

Notes:

- For values of H/L_s , x/L_s and z/L_s other than those shown, linear interpolation is permitted.
- For $H/L_s > 0.5$, assume $H/L_s = 0.5$ for evaluating K_1 and substitute $2H$ for L_s for evaluating K_2 and K_3 .
- Multipliers are based on the assumption that wind approaches the hill or escarpment along the direction of maximum slope.
- Notation:
 H : Height of hill or escarpment relative to the upwind terrain, in feet (meters).
 L_s : Distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment, in feet (meters).
 K_1 : Factor to account for shape of topographic feature and maximum speed-up effect.
 K_2 : Factor to account for reduction in speed-up with distance upwind or downwind of crest.
 K_3 : Factor to account for reduction in speed-up with height above local terrain.
 x : Distance (upwind or downwind) from the crest to the building site, in feet (meters).
 z : Height above ground surface at building site, in feet (meters).
 μ : Horizontal attenuation factor.
 γ : Height attenuation factor.

Fig.7 ASEC 7-10 Topographic factor, K_{zt} [51]

Table 2 shows the calculation of wind load and maximum applied pressures on walls and roof of shelter based on table 27.2-1, ASCE7-10 [51]. For gravity loads, the structure is assumed to be subjected to 4788 Pa ground snow load as the maximum possible for outside Alaskan locations in the United States (4788 Pa) [51]. In this study conservatively the ground snow load is assumed to be applied to the top of the roof.

Table 2 Applied wind load calculation

Parameter	Based on	Amount
Risk category	Table 1.5-1 ASCE 7-10	II
Max nominal design wind speed for risk	Fig. 26.5-1A ASCE 7-10	V _{LRFD} = 180 mph
Structure type	Main concept	Flat ground
Wind directionality factor	Table 26.6-1 ASCE 7-10	K _d = 0.85
Exposure category	Fig. 26.6 ASCE 7-10	C
K ₁	Figure 8	0.775
K ₂	Figure 8	0.815
K ₃	Figure 8	0.22
K _{zt} = (1+K ₁ .K ₂ .K ₃)**2	Eq. 26.8-1 ASCE 7-10	1.297
Gust effect factor (G)	Eq. 26.9 ASCE 7-10	0.85
Approximate natural frequency (na)	Eq. 26.9-4 ASCE 7-10	7.5 Hz
Nominal height of the atmospheric boundary layer (Zg)	Table 26.9-1 ASCE 7-10	330 m
pressure acting away from internal surface (GC _{pi_toward})	Table 26.11-1 ASCE 7-10	0.18
pressure acting away from internal surface (GC _{pi_away})	Table 26.11-1 ASCE 7-10	-0.18
Windward pressure on the wall (P _{wall})		2528 Pa
Leeward pressure on the wall (P _{wall})		-1580 Pa (suction)
Max roof upward pressure (P _{rf})		-4108 Pa (suction)
Max internal upward pressure (P _{int})		669 Pa

The shelter is designed according to Allowable Stress Design (ASD) method. According to IBC2015[50], the reasonable load combinations for this case study are as followings:

D; D + L; D + S; D + 0.75L + 0.75S; D + (0.6W or 0.7E); D + 0.75(0.6W) + 0.75L + 0.75S; D+0.75(0.7E)+0.75L+0.75S; 0.6D+0.6W ; 0.6D+0.7E [52-54]. In which D is dead load, E is earthquake load, L is live load due to occupancy, L_r is roof live load, S is snow load and finally, W is wind load. In this study, since the dead load and earthquake load are considerably lower than the wind load and snow load, the wind and snow loads are conservatively analyzed separately. The shelter, therefore, is analyzed using ANSYS workbench assuming the global Y axis as perpendicular to the ground (The self-weight of the material is applied in -Y direction, and the roof upward force is applied in the +Y direction). The wind load is applied in the X direction, and the side pressures are applied in the Z directions. The internal pressure is applied to all faces perpendicular to the surface. The support of the cube is assumed to be fixed supports at the edges of the walls. The results show under wind loading, both of maximum shear stress and maximum stress intensity are created at the connection of side walls to roof. It is observed that the structure can resist against the maximum tensile stress caused by wind load with a safety factor of $1.896/1.0166 = 1.87$. In addition, the used material can resist against the maximum created shear stress with a safety factor of $1.034/0.5083 = 2.03$ (Figure 8).

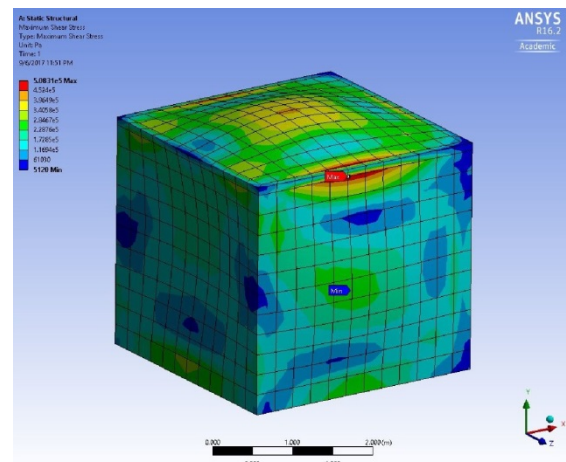
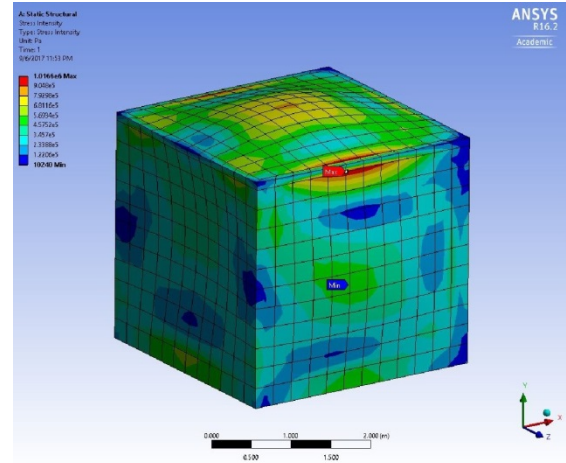


Fig.8 Wind load max stress intensity 1.0166 MPa (up) and max shear stress 0.50831 MPa (down)

The maximum deformation under wind load is also equal to 60 mm upward and is located at the mid center of the roof. This deformation has been compared with the snow's maximum deflection, which is equal to 75 mm downward (Figure 9).

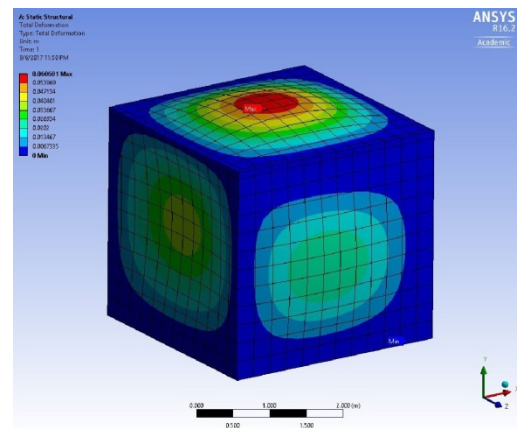


Fig.9a Wind load max deformation, 60 mm (up) vs snow maximum deflection, 75 mm (down)

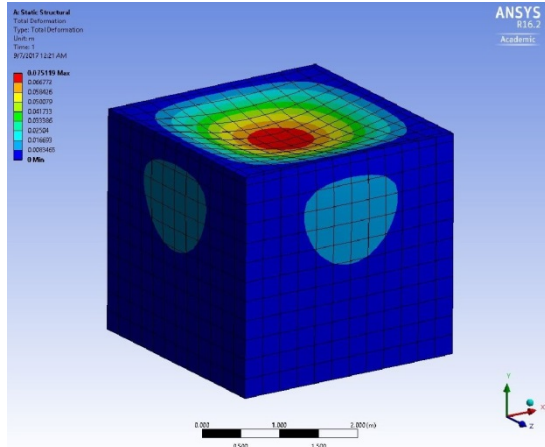


Fig.9b Wind load max deformation, 60 mm (up) vs snow maximum deflection, 75 mm (down)

Nonetheless, the results indicate the structure can tolerate these deformations without any fracture. Because the used material can resist the maximum tensile stress under snow loading with a safety factor about $1.896/0.8662 = 2.19$ (Figure 10).

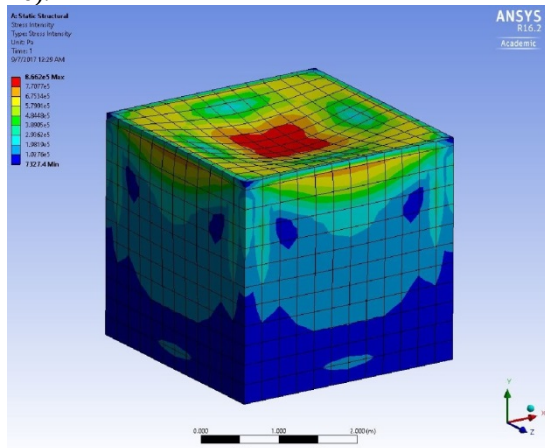


Fig.10a Equivalent (Von Miss) stress (up) and stress intensity (down) caused by snow loading

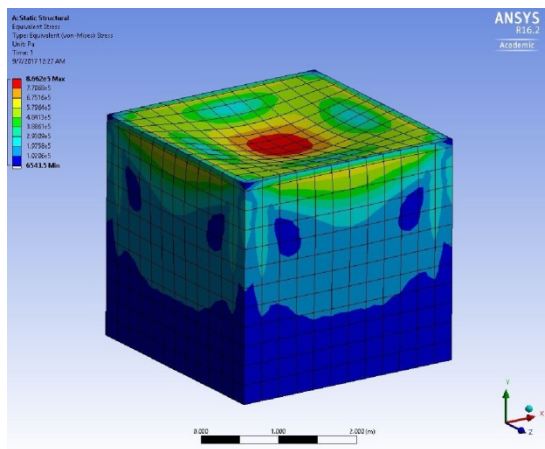


Fig.10b Equivalent (Von Miss) stress (up) and stress intensity (down) caused by snow loading

In addition, the location of the maximum shear stress under snow loading is exactly in the middle of the span of the roof. The structure can resist the maximum shear stress caused by snow loading with a safety factor about $1.034/0.4331 = 2.39$ (Figure 11). Therefore, the unit can conservatively withstand highest wind and snow loads.

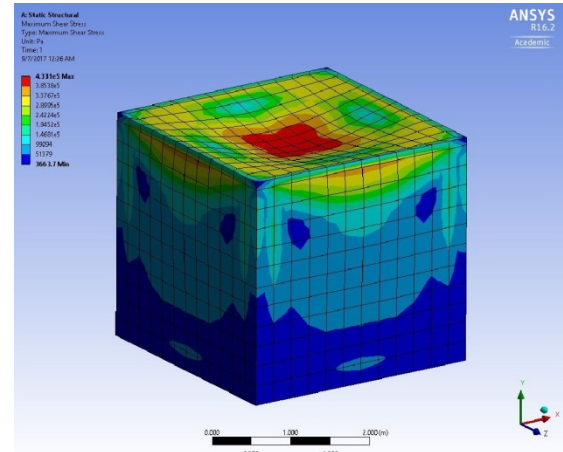


Fig.11 Shear stress distribution caused by snow loading

The reaction forces under snow and wind loading are calculated and shown in Table 3. The shelter needs to support the above-mentioned loads in its base. For soft ground areas, the system needs to a weight around 40207 N. The perimeter of the unit is $4 \times 3 \text{ m} = 12 \text{ m}$, therefore, the minimum weight of the unit length of the foundation is equal to $40207\text{N}/12\text{m} = 3350 \text{ N/m}$. If the weight is provided by concrete, knowing that the density of concrete is $2.5 \times 10^4 \text{ N/m}^3$, the area of cross section will be calculated as follows: $A = 3350/25000 = 0.134 \text{ m}^2$. A $30 \text{ cm} \times 50 \text{ cm}$ foundation has area of 0.15 m^2 . Figure 12 shows a typical foundation for this system.

Table 3 Applied wind load on shelter

Loading	Direction X (N)	Direction Y (N)	Direction Z (N)
Wind Load	- 39437	- 40207	0
Snow Load	0	57728	0

In harder soils, the shelter can be supported with an alternative method using anchoring rods (figure 13). As shown in figure 13, the anchoring rods will provide required horizontal and vertical reaction forces. The lateral 39437 N will be distributed on $0.10 \text{ m} \times 3 \text{ m} = 0.3 \text{ m}^2$ area of angle. The bearing stress is equal to $39437 \text{ N} / 0.3 \text{ m}^2 = 0.131 \text{ MPa}$, which is lower than the allowable stress of 2.81 MPa.

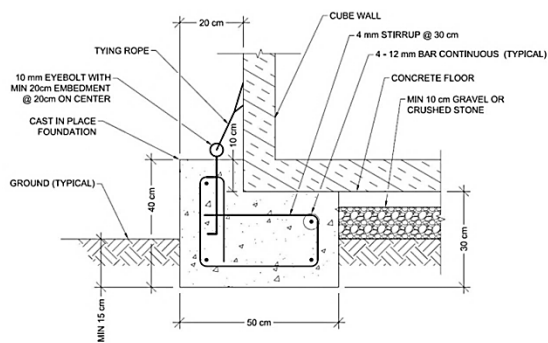


Fig.12 Precast or cast in place foundation detail

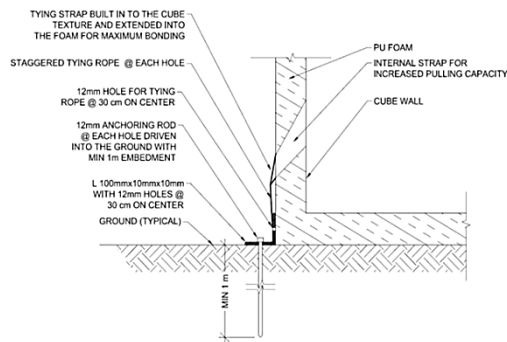


Fig.13a Ground anchoring detail

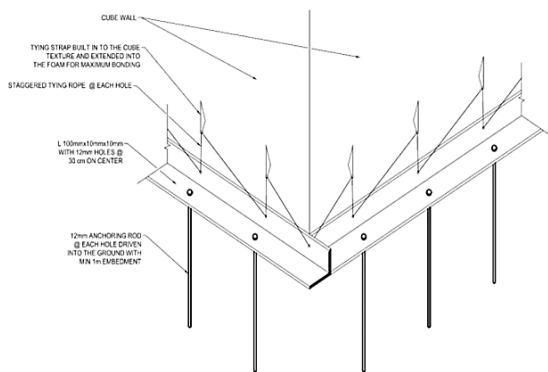


Fig.13b Ground anchoring detail

According to the above calculations, the 3m x 3m x 3m structure can withstand most severe wind and snow as well as other applicable loads as per the International Building Code. Analysis and design of some similar structures with various dimensions (from 3 m to 8 m) showed if both of length and wide increase from 4 m simultaneously, the system will increase the risk of collapse with a safety factor below 1 (Figures 14 and 15 and table 4). For results confirmation, another series of analyses and designs have been conducted on the introduced system (3m x 3m x 3m) based on the Australian Standards [55, 56]. In this regard, wind load of the cyclonic area (88 m/s for region D) with annual probability return of 500 years is applied on the shelter. In this regards the shelter is analyzed using a professional loading, analyzing and design software, ROBOT 2016. Also, the most conservative identified load combination ($0.9G + W$) was used [56].

Based on the Australian standards, the wind is applied to the shelter with both angles of 90° and 45° separately (Figure 16). However, since the wind speed with respect to IBC and AS1170.2 are almost the same, only the oblique wind is used for confirmation. The results show all of the maximum amounts of deformation, main stress and shear stress caused by the oblique wind are lower than design limits. As an example, Figure 17 shows the Maximum deformation of shelter caused by oblique wind is only 42mm, which is less than the related amount of IBC (60mm). In addition, the results indicate that the maximum uplift force under wind loading 45° is equal to 35300 kN, which is less than the amount used for design (40207 kN).

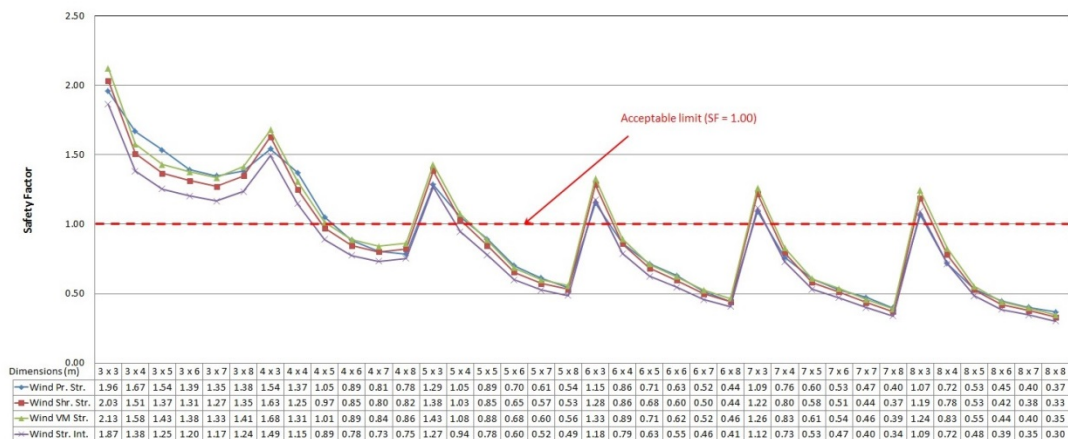


Fig.14 Variation in Safety Factor for different room dimensions - Wind load

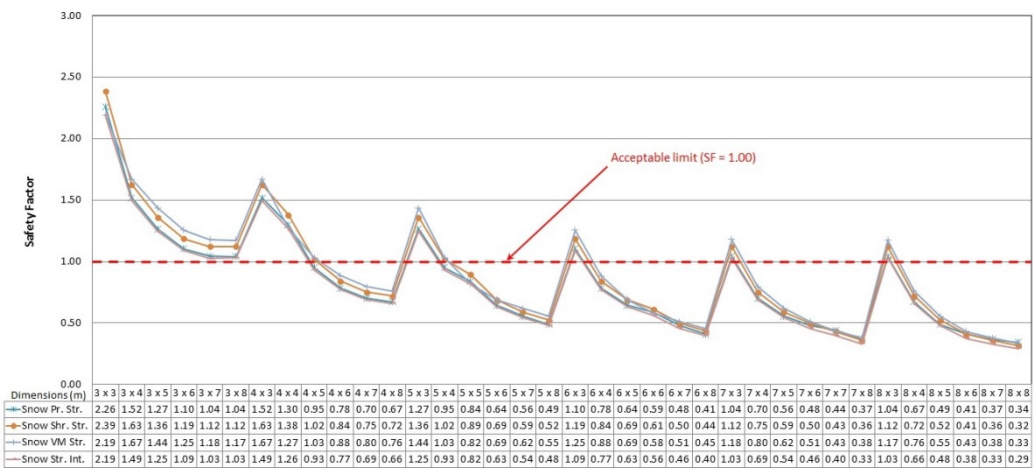


Fig.15 Variation in Safety Factor for different room dimensions - Wind load

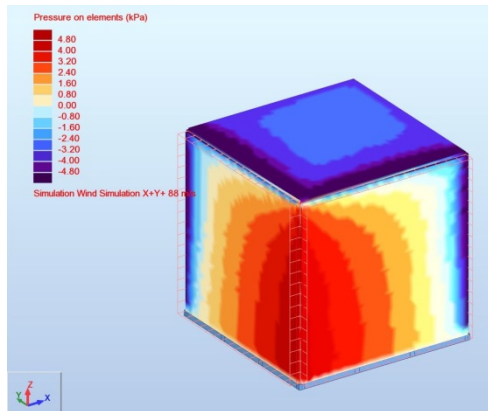


Fig.16a Applied wind loading on the shelter based on AS1170.2 with angles of 45°

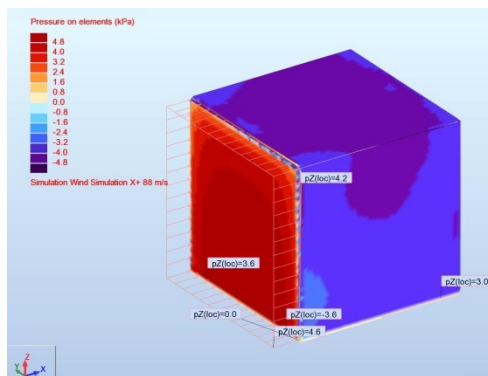


Fig.16b Applied wind loading on the shelter based on AS1170.2 with 90°

6. CONCLUSION

An innovative rapidly assembled system, mainly developed for quick assembly of modular post-disaster housing, was studied. The material properties as well as the entire structure of the units we investigated experimentally and by finite element modeling, respectively.

Table 4 Safe dimensions of the shelter

Dimensions (m)	Wind (IBC)				Snow (IBC)				Restricting load
	Principle stress	Shear Stress	VM Stress	Stress intensity	Principle stress	Shear Stress	VM Stress	Stress intensity	
3x3	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
3x4	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
3x5	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
3x6	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
3x7	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
3x8	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
4x4	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	
4x5	O.K.	N.G.	O.K.	N.G.	N.G.	O.K.	O.K.	N.G.	Wind and Snow
4x6	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
4x7	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
4x8	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
5x5	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
5x6	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
5x7	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
5x8	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
6x6	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
6x7	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
6x8	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
7x7	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
7x8	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow
8x8	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	N.G.	Wind and Snow

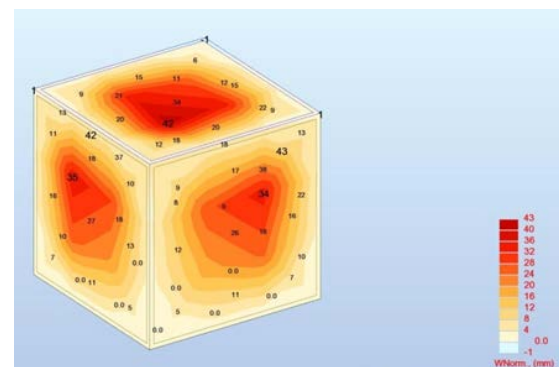


Fig.17 Maximum deformation of shelter caused by oblique wind

Each unit is composed of panels made of a high-density polyethylene or polypropylene (HDPE) coated by unbalancing woven textile as the skins, filled with high-density Polyurethane (PU) foam as the core. Material characterization tests and finite element modeling were performed in accordance with some international building

codes to evaluate the performance of the modular units in severe weather conditions. Results demonstrate that the developed rapidly assembled building unit exhibit very good structural performance, and can meet the standards' requirements.

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