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INOVATIVE SHELTER SOLUTION

BY

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Abstract. Considering the effects and the impossibility to avoid major natural disaster, post disaster measurements need to be considered. In order to be more efficient in case of a natural disaster, important research in being conducted to obtain the best suited shelter for affected people.

In this paper an innovative solution for a shelter in case of natural disaster is presented. The main advantages are that it can be transformed into a permanent building element, can be used at different temperatures and is easy to connect. It can be used as a singular module or can be used as an assembly of more than two modules interconnected in different ways. Computational simulations in all loading cases have been performed according to European design codes, using FEM analysis-based programs. The obtained results have proven the needed strength and stiffness characteristics of the structures are fulfilled. The cost and erection time have been reduced to a minimum, making it highly accessible.

Key words: temporary shelter; kinetic building parts; adaptability; deployable arch; polycarbonate; design and erection.

1. Introduction

Currently, engineers deal with a great challenge to diminish losses from natural disasters. In this direction, research all around the world focused on performing and improving multi-hazard methodologies to detect vulnerable structures, neighborhoods, cities, areas, countries.

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The hazard represents a natural event that has the potential to cause harm or loss to a community. When more than one hazard event impacts the same area, there arises a multi-hazard situation. There different hazard events may occur at the same time or may be spaced out in time. Such multi-hazard event occurred on the 11th of March 2011 in Japan, when the earthquake was followed by tsunami, fire and the nuclear plant explosion.

The severity of the losses depends on the affected population's resilience or ability to recover. In some cases, a hazard event can affect a large number of houses and people need a temporary shelter. Living and storage spaces will have to be available in a matter of days or even hours. Also the environmental problem has to be taken into account, in order to provide a comfortable living space.

In this direction, the paper offers an innovative temporary shelter, made of kinetic deployable arches and polycarbonate envelope.

2. State of the Art

Temporary shelters can be defined as rapid, post disaster household. Their main purpose is to ease the transition following a crisis situation for the affected population, until they move to a more durable housing. In most cases the purpose is to re-use the materials for other similar conditions.

One of the main goals of temporary shelters is to be adaptable to any context or location and to be independent of the soil conditions. Also, after the reconstruction of the affected area, the temporary structures could be moved to another disaster area or recycled.

Fig. 1 – Types of traditional shelter (courtesy of http://www.doubleharvest.org/where/haiti/housing, http://newseq.blogspot.ro/2011/05/poompuhar-safer-homes-post-tsunami.html).

Timber and steel are the main structural materials for building emergency shelters for relief, but the erection duration is quite high (1…2 days for structures in Fig. 1). No specific qualification is needed in order to build such structures.

Maintenance processes and costs have to be as low as possible in order to make the project a sustainable one. Even though traditional steel shelters can be made out of recyclable materials, the structure can not be re-used as a whole. Only some parts of them can be remodeled or used in other constructions.

Fig. 2 – Air shelters (courtesy of http://www.dynamicairshelters.com/, http://www.igreenspot.com/kahuna-the-perfect-shelter-for-post-disaster-situation/).

Fig. 3 – Other types of modern shelters (courtesy of http://www.tuvie.com/haven-rapid-deployment-temporary-shelter-system/, http://changeobserver.designobserver.com/feature/state-of-shelter/12527/, http://www.bodew.com/disaster-victim-shelter-temporary-house-design/).

The main disadvantage of traditional design of temporary dwellings is the loss of materials after their use. Even though recycling is possible, a great quantity of material can be deteriorated or destroyed. Also, if they were to be re-used completely, shelters have no architectural value, since they are designed to be as basic as possible.

Research in optimizing shelter design and functionality increased the choice for temporary houses. In this direction, Figs. 2 and 3 present some of the modern shelter structures available around the world.

3. Innovative Shelter Structure

3.1. Shelter Concept

The strength structure is represented by unique deployable arches, increasing building efficiency, making it easy to transport and to erect. The adaptable system enables numerous spatial layouts for hosting temporary or long-term events, thus addressing the increased demand for adaptability.

Fig. 4 shows the main source for the deployable scissor arch built by students of VRIJE University of Brussels. Deployable structures, unlike conventional structures, are capable of large transformations, automatically changing their shape from a compact to an expandable configuration.

Fig. 4 – Kinetic arch before and after deploying.

Based on the same principle as Lego bricks, the structure comes totally dismantled to the site, in order to facilitate transportation. Each modulated part will be connected to the others by simple, but strong and effective joints. The foldable steel arch has a very high volume ratio, comparing the sizes in the two phases: folded and unfolded. The time in which it could be deployed is less than one minute.

Aside from the temporary shelter function, the structure can be incorporated to other buildings, having also a permanent role, for example covering pedestrian bridges or providing cover on terrace roofs. In case this solution is adopted, special connections should be provided at the base of the arches.

One of the main problems is the necessary insulation, so that proper living conditions are provided. Taking into account the weather conditions, the needed lighting intensity and the need to provide the proper humidity and temperature, the ideal material for the exterior insulation is considered – polycarbonate.

The polycarbonate is a rigid, homogenous, chemically neutral material, with a fine cellular structure. Its moldability is very high and very precise dimensioning can be performed using carpentry or metal shaping tools, with a simple and fast process.

The strength of the material is guaranteed to be at least 100 kPa in compression, contributing to the total stiffness of the structure, without affecting the elasticity coefficient. It can be applied on any type of surface (concrete, metal, wood, etc.) and will copy the layout and shape of the load bearing structure on which it is molded. The polycarbonate is a fireproof material of C class with molecular adherence (each and every pore or crack withing it can be obstructed). The material (Fig. 5) has good thermal conductivity (0.02…0.028 W/mK), high maximum service temperature (90…100°C) and is waterproof. However, because of the greenhouse effect which may appear, double-skin polycarbonate panels have been chosen, in order to create proper ventilation. Up to 10% of the water vapour volume can be transferred through the outer shell. The phonic insulation is also favorable, with values up to 62 dB.

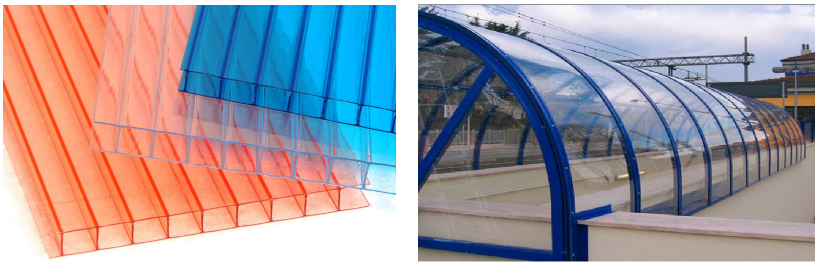

Fig. 5 – Polycarbonate (courtesy of http://www.archiexpo.com/prod/polypiu-plast/curved-polycarbonate-sheets-71669-841504.html).

The insulating polycarbonate shell will be pinned to the arched structure with simple connections. The holes where the connections will be made can be pre-drilled, in order to shorten the building process. A variety of colours can be used, giving the structure great architectural value and facilitating the integration of the structure in different landscapes.

The deployable arched temporary shelter is made of slender steel arches, with polycarbonate coating, using efficiently the materials and considering the chemically neutral composition of the outer shell does not affect the ozone layer and is not carcinogenic. The structure can be considered an environmentally friendly one because of its properties.

3.2. Shelter Design and Numerical Simulation Results

The arch span is of 7 m, height of 3.5 m and length of 6 m (Fig. 6). These dimensions were carefully chosen in order to allow a large number of people and equipment to be fitted inside, while still being easily to transport. If a greater surface is needed, several modules can be assembled in order to get the desired result. The used materials are S235 steel for arches, purlins and bracings and polycarbonate for the covering. Steel provides excellent strength and can be easily assembled or dismantled in order to obtain the final structure.

Fig. 6 – Innovative shelter layout.

The numerical simulation was performed in Axis VM 11 Academic Edition and Graitec. Both softwares are suited for civil engineers projects and use the finite element method (FEM) to obtain stresses with high accuracy.

For polycarbonate the following characteristics were considered: the modulus of elasticity, $E_x = E_y = 2{,}300$ N/mm^2, the Poisson's coefficient $\nu =$ $= 0.2$ and the material density, $\rho = 1{,}200$ kg/m^3.

The considered loads were: self-weight, snow accumulation, wind pressure and suction and seismic action. Live loads are neglected. The numerical values are according to Euro-code EC1 regulations. The snow loading is of 2 kN/m^2 and wind pressure is of 0.7 kN/m^2. The self weight of the structure has been automatically taken into consideration by the software.

For the earthquake scenario, coefficients according to the Romanian design code P100-1/2006 were considered: peak ground acceleration, $a_g =$ $= 0.20$g; vibration period of control, $T_C = 0.7$ s; behavior factor, $q = 2$ and importance factor, $\gamma_I = 1$.

Several load combinations were considered in accordance to CR0 code in order to reveal the most unfavourable scenarios and ensure that the structure will behave as expected.

Modal and static analyses were performed in both software environments. Table 1 shows the result from the modal analysis, where F is the natural frequency, T the period and ω is the pulsation. It can be noticed that the results for the fundamental vibration mode are similar in both analyses.

Table 1
Modal Analysis Results

	Graitec			AxisVM		
	F, [Hz]	*T*, [s]	*ω*, [rad/s]	*F*, [Hz]	*T*, [s]	*ω*, [rad/s]
1	2.25	0.44	14.12	2.34	0.428	14.69
2	5.32	0.19	33.42	4.03	0.248	25.34
3	9.03	0.11	56.76	4.08	0.245	25.63
4	10.04	0.10	63.10	5.02	0.199	31.55
5	10.21	0.10	64.16	5.17	0.193	32.47

A linear static analysis was performed in order to check the chosen cross section of the elements. The internal forces obtained through a linear static analysis are presented in Fig. 7. It can be noticed that the results are similar. If the stresses and strength are compared for the Ultimate Limit State, the following results are obtained: the maximum principal tensile stress by seismic combination, 7.66 N/mm^2, is significantly less than the tensile strength of the polycarbonate membrane, 63 N/mm^2. In terms of compression, the maximum

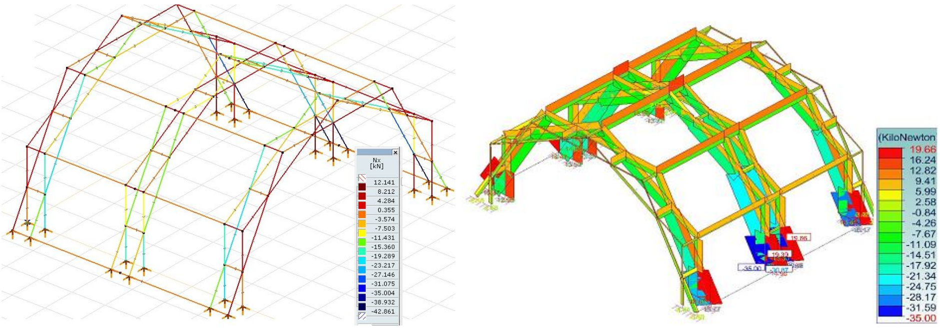

Fig. 7 – Results for axial internal effort in Axis and Graitech.

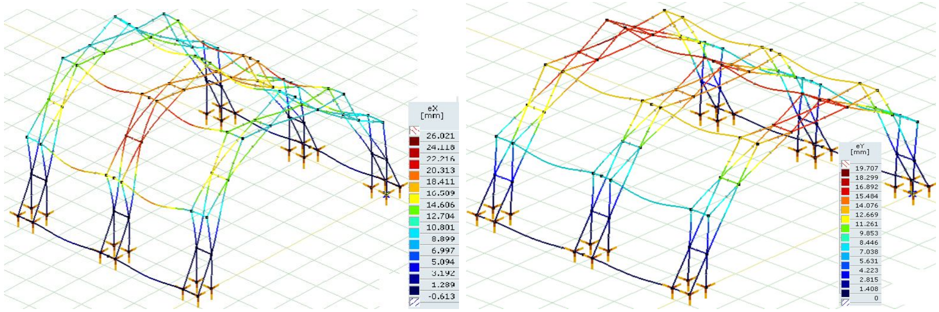

Fig. 8 – Displacement results on vertical and horizontal direction.

compression stress by fundamental combination is 5.83 N/mm^2 less than 78 N/mm^2 that is the compressive strength of the polycarbonate membrane.

In terms of maximum displacements the results were also within the maximum allowable limit (Fig. 8). For the vertical displacements a 15 mm displacement was obtained which is less than 40 mm, meanwhile for the maximum horizontal displacement a 13 mm displacement resulted, less than the maximum allowable horizontal displacement which is 20 mm.

4. Supplementary Architectural and Technical Solutions

In order to prevent deformations or deflections, from the very beginning of the designing process, a big challenge was to confer the structure flexibility against wind forces. High lateral wind pressures and turbulences could make the structure unstable or vulnerable to collapse, that is the reason why was proposed the use of longitudinal viscous dampers between the arches.

When a visco-elastic material is deformed, it provides a velocity-dependent viscous restoring force, which adds damping to the structure, as well as a displacement - dependent elastic restoring forces. There are several benefits of using the dampers. First of all, adding distributed damping, we reduce the wind and earthquake vibrations, accelerations, velocities and displacements. The design is more efficient and the safety and resilience against hurricanes and earthquakes increases, reducing earthquake induced vibrations through added damping to the lateral modes of vibration. They can enhance the dynamic performance significantly and decrease the time to occupancy or level of repair.

In order to enhance the behavior of the structure, especially in case of permanent house, the use of dampers at the foundation level was proposed. The fundamental period increased from 0.428 s to 1.77 s, the dimensions decreased from 12.5 cm to 1.2 cm and also the strains in the elements decreased due to the dampers introduction.

Due to the low cost and efficient use of materials, the total cost has been reduced, offering the possibility to buy the adaptable structure for a low price. Given the fact that polycarbonate is a relatively cheap material (up to 30 \$/m^2 for larger quantities) and that the needed steel quantity is low, the cost of a module is estimated to be around 4,500 \$.

An unlimited number of basic modules can be connected in several ways, so that the proper functionality can be achieved. Apart from basic living and storage transitional spaces, the structure can also have the role of a medical clinic, religious sanctuary, cafeteria or workshop. A practically unlimited number of modulated shelters can be interconnected, in various ways, depending on the need. Up to 4 modules can be connected at their extremities, with a center pavilion between them (Fig. 9). Also, after the natural disaster effects have passed and the structures are no longer needed by the affected people, they can be re-used and connected to other existing structures or simply, as stand-alone elements (Fig. 9).

The majority of temporary shelters is designed to a very basic level and provides no architectural value. The shape of the innovative proposed shelter is a simple one, providing universality to the attempt to integrate it to other structures or landscapes. Thus the structure can adopt a large range of destinations, from covering pedestrian bridges or terrace rooftops, to rain shelters or even greenhouses (Fig. 10).

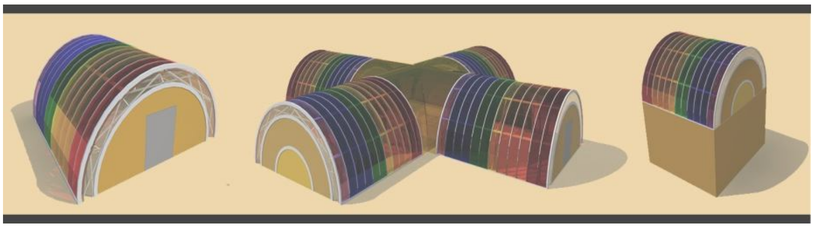

Fig. 9 – Applicability of the basic modulus.

Fig. 10 – Various possible post-mitigation uses for the structure.

The use of polyurethane confers the structure individuality and personality, especially because of the fact that we can use practically any colours for the outer shell. Different shades of the same color can be provided in order to integrate the structure in a setting of buildings, or different colours can be used for a high visual impact. The astonishing effect that light creates when passing through the polycarbonate, especially if there are more tones or colours, provides the people inside the building with an eye-pleasing, spectacular effect.

5. Conclusions

The main goal of this project was fast mitigation strategies in case of natural disasters. The importance of temporary shelters for humanitarian help has become higher and higher. Thus, the proposed project is easy to erect in a very short time, has a good deploying ratio and is cost-effective.

The originality of the project is sustained by several elements. First of all, the use of kinetic arches proves that scissor like elements could be used, at a larger scale, in the future as reliable structural parts. Also, the use of polycarbonate is an innovative way of creating a great quality indoor space, from both technical and architectural points of view. Last, but not least, re-using the structure is one of the aims of this project, having temporary structures incorporated further on to permanent buildings.

The structure is an environmentally friendly one bringing architectural value to any location where a temporary shelter is needed, and not only.

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SOLUȚIE INOVATOARE PENTRU ADĂPOSTURI

(Rezumat)

Măsurători post-dezastru trebuiesc luate în considerare, având în vedere efectele şi imposibilitatea de a evita catastrofe naturale. Pentru a fi mai eficienți, cercetări importante se desfăşoară în scopul de a obține o soluție optimă pentru adăpostirea persoanelor afectate.

Lucrarea prezintă o soluție inovatoare pentru un adăpost în caz de calamitate. Principalul avantaj este că poate fi transformat într-o construcție permanentă, poate fi folosit în orice zonă şi poate fi conectat uşor. Poate fi folosit ca un modul singular sau ca un ansamblu de mai multe module interconectate în moduri diferite. Au fost efectuate simulări numerice în conformitate cu normele de proiectare europene, folosind programe de analiză bazate pe FEM. Rezultatele obținute au demonstrat îndeplinirea condițiilor de rezistență şi rigiditate. Costul şi timpul de execuție au fost reduse la minim.