Deployable Structures in the Built Environment

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Abstract

The occurrence of natural disasters has been on the increase for the last decade. One of the most prominent incidences has been the occurrence of floods which has been experienced in developing and developed countries. This has been the experience of Turkey and the United Kingdom. The world has also experienced hurricanes and earthquakes in the recent times. Global temperature change has been blamed for many of these natural disaster occurrences. Man-made disaster incidences have also been recorded such as wars, chemical plant explosions, building failure/collapse and have been on the increase. The consequences of these occurrences have resulted in the loss of lives and properties, displaced communities/stranded communities and also economic stagnation. It is therefore imperative that there should be structures or ways to mitigate the loss of general infrastructures especially housing. These structures should be readily available and meet the temporary needs of the community. Deployable structures are known to be light-weight in nature and characteristic reduced time frame to deploy in its predetermined configuration.

Key Words: *Deployable structures, disaster, lightweight structures.*

1. INTRODUCTION

Disasters can occur at any time in a year. They can occur naturally or man-made. Most of the mitigation methods have been generally non-structural in their approach to disaster mitigation. It also includes providing barriers against an impending disaster. But as seen in certain parts of the UK, floods for example went over the flood defence system because of the rise in water levels which many schools of thought have attributed to global warming. The aftermath of these disasters have led to displaced communities, stranded communities, financial ruins and other knock-on effects. For example, Turkey is mainly prone to three (3) forms of natural disasters which are Earthquakes, Floods and Landslides. Deployable structures tend to provide part of the palliative measures during the aftermath of these natural and man-made disasters.

They are generally structures that have the capacity or capability to change geometry from a compact configuration to an operational configuration and still be able to withstand service loads safely. This main characteristic makes it easy to transport and store. They have been employed in various scenarios, especially as solutions for space related problems. However, their applications as solutions to environmental problems seem to be unknown or have not been fully researched into. This paper is in response to the global climate change experienced in the built environment that has been said to be the cause of most natural disasters in the last decade. It is also to propose ways to overcome these boundaries to improve the sustainability of structures during the aftermath of these natural disasters using deployable structures.

When disasters occur, displaced communities are most times placed in tents which are usually designed for a few days to months. However, the reality is that communities remain in those tents for years as it takes a considerable long time for communities to be given housing or relocated. The tents therefore become dilapidated and in many cases destroyed. These tents also are not energy efficient and therefore occupants are susceptible to diseases as seen in the case of the Haiti disaster a few years ago. It is therefore necessary to design deployable structures to have a considerable life span to give government agencies adequate time to rebuild structures. The materials necessary during the construction of these structures need to be readily available to the local community and also recyclable. The ease of construction of these proposed deployable structures will also have to be low skill. Another consideration should also the flexibility and adaptability of the structural concept. A one solution model is imperative to meet the demands of the changing and dynamic situations after the occurrence of disasters.

In some situations where there is a break out of wars or other forms of man-made disasters (wars and conflicts, explosions, fire outbreaks, poor construction methods and designs) that causes an unexpected destruction of the buildings and infrastructures. Popular solutions provided usually included temporary protective covers, relief materials, temporary shelters, temporary storage and other situations. During the provision of theses, time is consumed to make available and therefore it is imperative that structures that are needed to readily solve the aforementioned issues should be readily available.

Deployable structures is proposed to be the reasonable solution in disaster ravaged communities most importantly in scenarios where it is necessary to evacuate people or to minimize the impact of the flood on the economic activities of communities especially when the main infrastructures have been damaged. "*Deployable structures can be defined as structures that have the capability to be transformed from a bundle of compact configuration to an enlarged operational configuration that can carry load safely under service loads"*. (Umweni, 2011: 9). When deployed into their operational geometry, they can ease storage and/or transportation.

2. GENERAL PRINCIPLE OF PANTOGRAPHS

There are numerous ideological schools of thought on the groups of deployable structures, however, this paper will be concerned with the Pantograph deployable structures. Pantographs usually consist of scissor-link units also known as duplets which is a combination of two uniplets. A duplet element consists of three nodes on the pin-jointed and rotating on their pivot node with one degree of freedom. "*No torsion is produced in the members, axial forces and bending moments can be developed"* (Kaveh & Davaran, 1996).

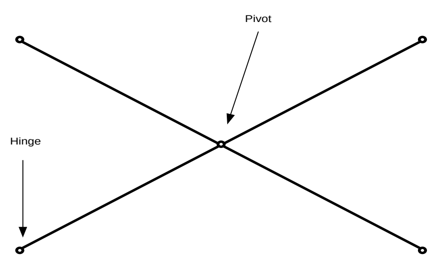

Figure 1: A duplet (by author)

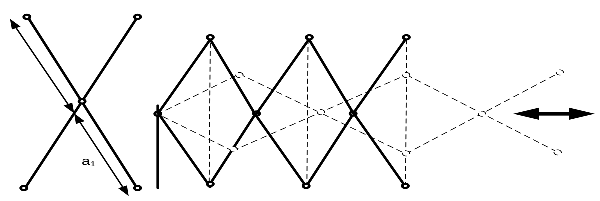

Figure 2: A duplet and a Pantograph (direction of deployment) (by author)

The concept of the pantograph to proffer a solution in form of a deployable bridge or modified for a deployable shelter will be discussed. It can be applied in disaster ravaged communities in developing countries like Nigeria and other similar scenarios in other countries such as

Turkey who are disaster prone. To attain this arrangement, the duplet units must be parallel to each other before and after deployment process.

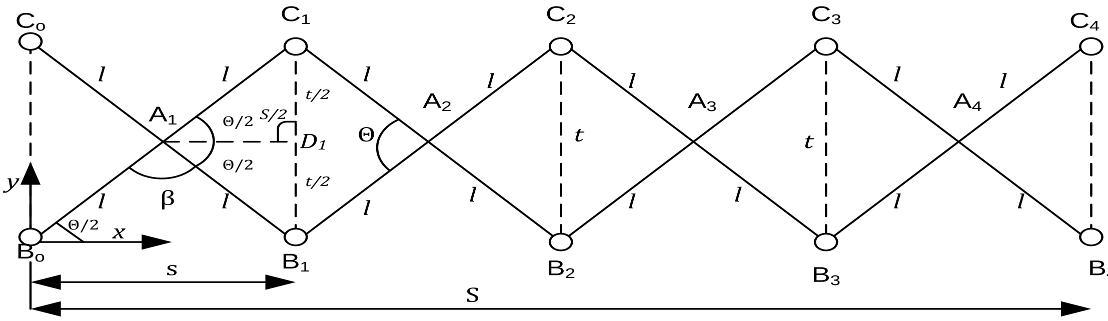

Figure 3: Rectilinear Scissors Mechanism (by author)

In a rectilinear scissors structural mechanism, the scissors-like units have bars that have the same length and the pivot is at the midpoint of the bars as shown in the figure above. Based on this configuration, a perfect planar surface is attained. Its deployment criteria is given by:
$a_{i-1} = b_{i-1} = a_i = b_i = a_{i+1}$

$$= b_{i+1} = \cdots = a_n = b_n = l \text{..........................1}$$

Where *(s)* is the span of a duplet, *(N)* is the number of duplets, *(θ)* is the angle between beams or bars, *(S)* is the span of the entire pantograph structure, *(β)* is the deployment angle, *(t)* is the unit thickness and *(L)* is the length of beams or bars. If at least three of the variables are known, analysis can be carried out for the other unknowns. Since L$(2l)$, *S* and *θ are* known, and angles *θ* and *β* the same by geometry;
Hence, the span *(s)* of a duplet is given by

$$s = 2l\cos\frac{\emptyset}{2} \text{................................ 2}$$

Based on the above equation *N* can therefore be calculated. Consequently the cosine rule of triangles can be applied for triangles $A_1B_0B_1$, and β can be obtained using the equation below

$$N = \frac{S}{s} \text{................................. 3}$$

$$\beta = \cos^{-1}\left[1 - \frac{s^2}{2l^2}\right] \text{...........................4}$$

The thickness of a duplet *t* can be derived using Pythagoras' theorem of triangles $C_1A_1D_1$. Other variables for the ***Nth*** duplet units can be derived in accordance to origin B_0 of the system:

$$t = 2\sqrt{l^2 - \frac{s^2}{4}} \text{................................5}$$

$$x_{B_N} = x_{C_N} = N2l\cos\frac{\emptyset}{2} \text{..........................6 for nth number of spans in the x- direction}$$

$$y_{B_N} = 0 \text{ and } y_{C_N} = 2l\sin\frac{\emptyset}{2} \text{..................................7 for nth number in the y-direction}$$

3. NOVEL DEPLOYABBLE BRIDGE STRUCTURE PROPOSAL FOR A DEPLOYABLE SCISSORS UNIT

Adaptability is the ability of an element to accommodate different requirements for different situations or changes in the lifetime of the structure. The adaptability concept can be categorised into five main strategies (Moffatt and Russell 2001);

- Flexibility
- Convertibility
- Expandability
- Durability
- Design for disassembly.

This proposal is as a result of the study of pantographs as deployable structures. The structure is characterized by a novel topology for the Scissors like element MG-SLE (Modified gear-SLE). This will enhance the scissors structure to provide a wide variety of configurations with the same span to cover and also a multiple applications in various or as when needed scenarios. The MG-SLE morphology is expected to provide a framework for the design of deployable structures and static structures in general. It will also allow the concept of sustainability to be integrated into structural engineering designs.

For pantograph structures, their form and ability to change position for the resulting structures is determined by the topology and geometry of the Scissors element. There have been three main topologies identified for pantographs influenced by the shape of bars and position of hinge. They could be rectilinear, polar and angulated. Through these topologies, lines and grinds, arches and vaults, domes have been designed for deployable structures by various designers. These topologies were the foundation for the new forms of Scissors element Solutions or alternatives for deployable structures. Yenal Akgun (2011) proposed to include a hinge on each bar of the Scissors element. This allowed changing from a rectilinear to angulated scissors like elements.

Daniel Rosenberg (2009) design a scissors structure where the middle hinge between the bars for an oblong union is switched from a symmetric to an asymmetric unit. Sala and Sastre (2013) proposed that the use of a telescopic system in combination with the scissor like mechanism. The resulting structure was able to switch from a symmetrical to an asymmetrical units by changing the length of the bars. Most of the designers noticed that from changing the basic Scissors element or duplet, it is possible to alternate the shape and find formal options with a single structural solution. Even with this knowledge, most topologies have only catered for deployable roofing systems. One of the forms of pantograph mechanisms is the rectilinear pantograph mechanism. Below is a footbridge spanning 5m (with 1.5m in width x 2m high) by using the above equations. The ANSYS workbench software was used to model the bridge.

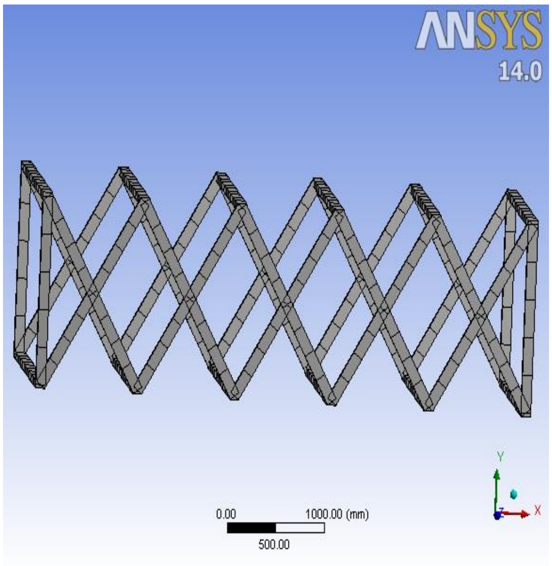

Figure 4: 3-D model of Bridge model

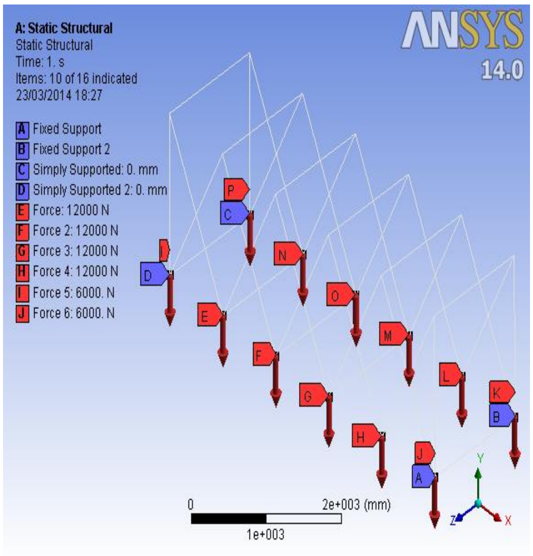

Figure 5: Forces applied to structure

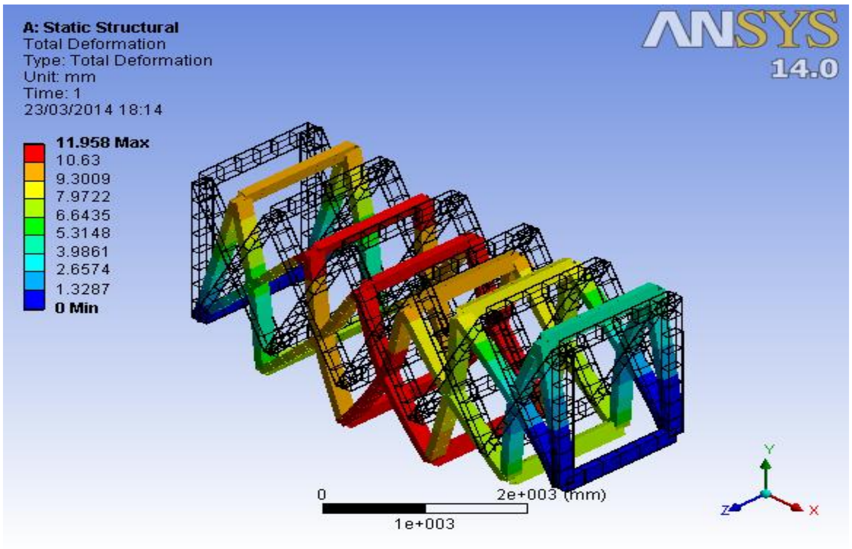

Figure 6: Total Deflection of Novel Deployable Bridge

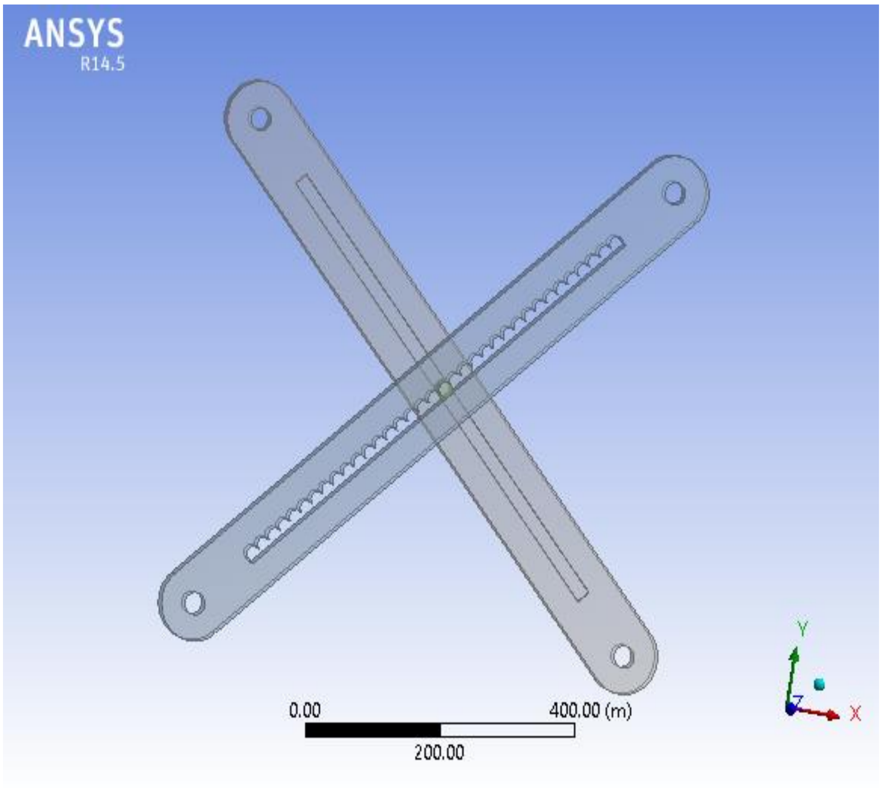

Figure 7: MG-SLE model (author)

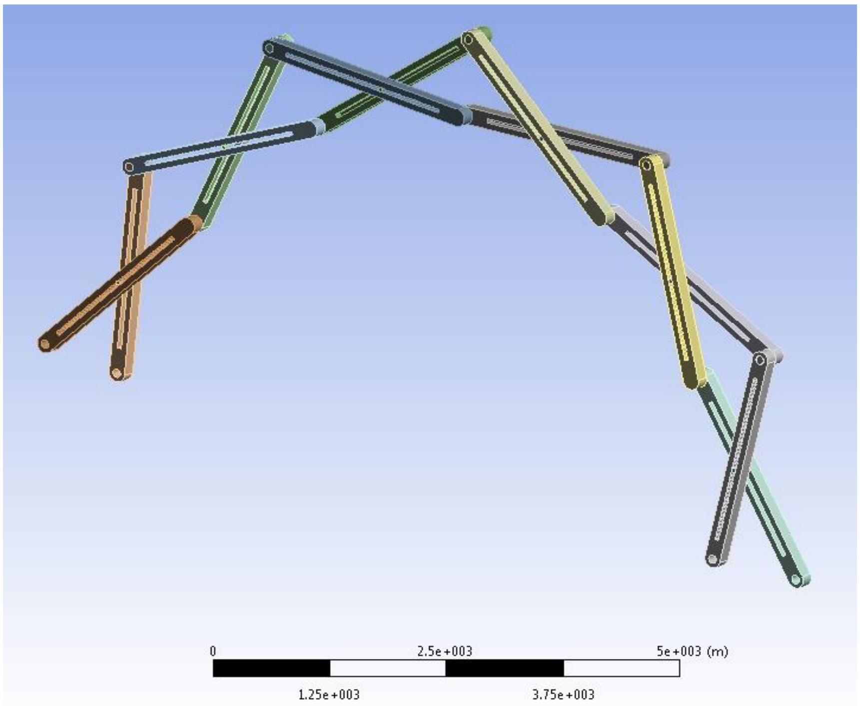

Figure 8: Deployable Shelter model (author)

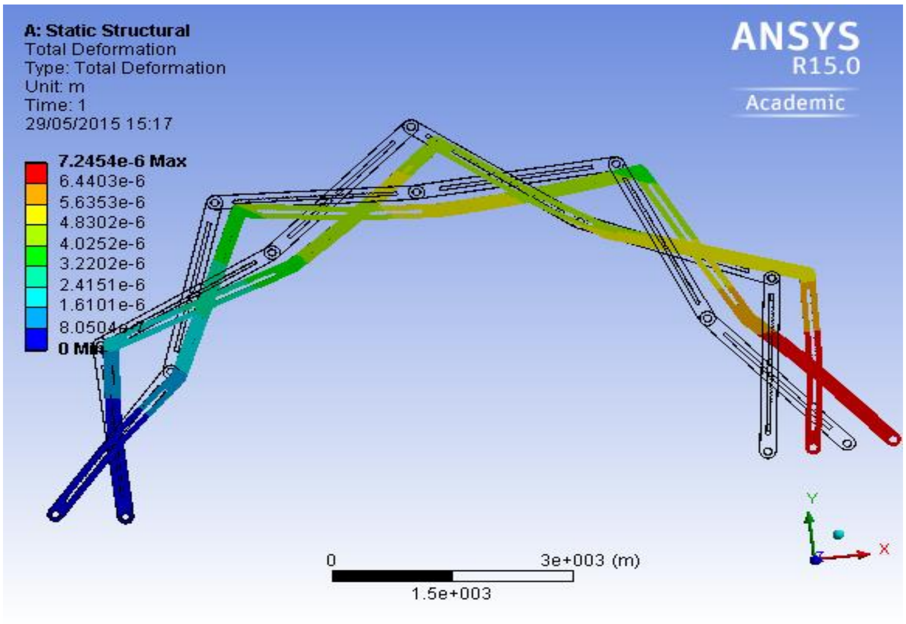

Figure 9: Deployable Shelter model (author)

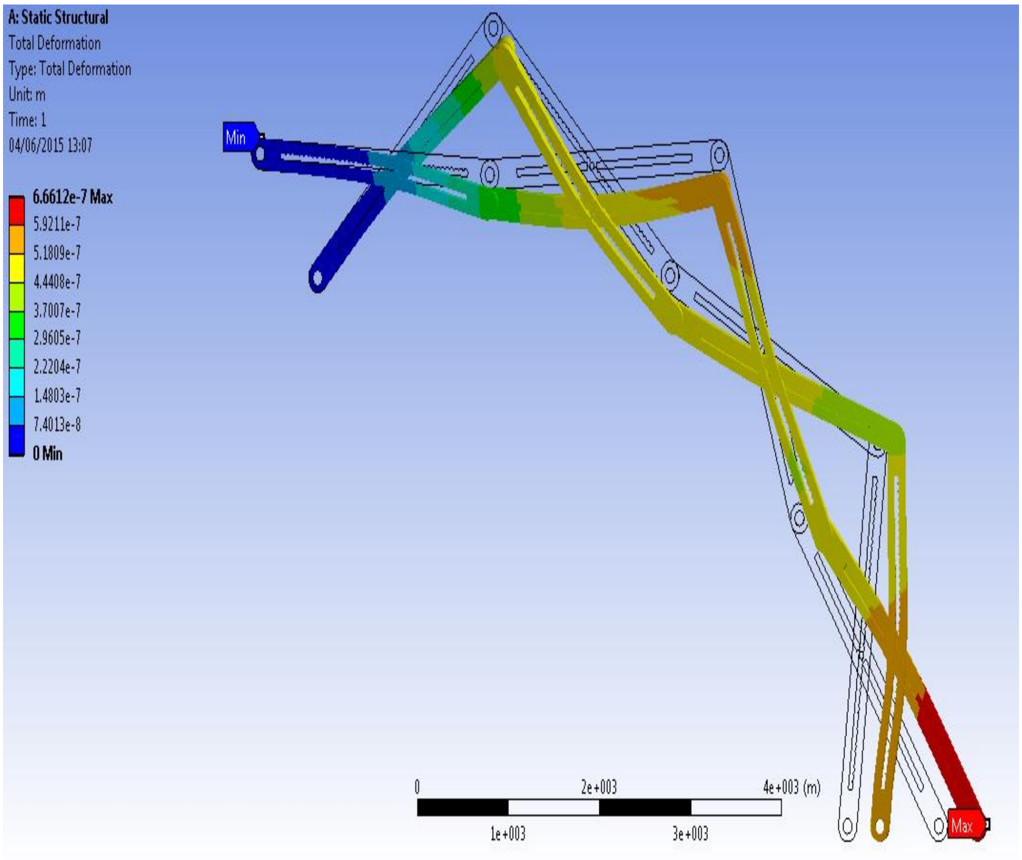

Figure 10: Deployable Canopy model (author)

4. CONCLUSION AND FURTHER RESEARCH

The purpose of the work presented is to develop a novel concept for deployable bar structures for the challenges experienced today which is a variation from existing concepts.

This will lead to an architectural, sustainable and structurally viable solution for deployable applications. Another objective was to provide designers with the means for deciding on how to cover a space or overcome barriers in a disaster aftermath or as part of a static structure with a rapidly erectable deployable structure, based on the geometry of pantograph structures. Finally, further research is beening undertaken for material and structural optimisation with the use of lighter materials such as fibre reinforced plastics as deployable structures should be as light and foldable as possible.

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