International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Origami-Innovative Structural Forms & Applications in Disaster Management

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Accepted 01 Oct 2014, Available online 10 Oct 2014, **Vol.4, No.5 (Oct 2014)**

Abstract

Origami from ori meaning \folding\, and kami meaning \paper\ is the traditional Japanese art of paper folding, which started in the 17th century AD .It has since then evolved into a modern art form. The goal of this art is to transform a flat sheet of paper into a finished sculpture through folding and sculpting techniques, and is now being innovatively extended to architecture and structural forms. Folded structures have their roots in Origami. These are used when there is a necessity to drain a roof surface, using kinked girders in the place of a flat girder supported on both ends. The possibility of intersection of these simply folded structures result in folded frames which can be unfolded or folded easily. The paper presents concepts of Origami and its development into different structural forms .Study of one such innovative form and its evolution is presented in detail based on physical models and a case study. The paper also explores the power of origami (which is developed using paper folding technique) into possibility of being advantageously employed for collapsible structures which can have appropriate use in disaster management as emergency shelters. An overview of form stability which enables origami based forms\' use for appropriate applications, innovative construction materials such as ferrocement etc; is also presented.

Keywords: *Folded structure system, Disaster Management etc.*

1. Introduction

The principle of folding as a tool to develop a general structural shape has been known for a long time. Folded structure systems which are analogous to several biological systems such as broadleaf-tree leaves, petals and foldable insect wings are adopted to be employed in a new, technical way. Aerospace and the automotive industries use this principle to create self-supporting wall, slab elements with high load capacity etc; This stands in contrast to the building industry, where the principle of folding has played a secondary role so far. Folded forms, though structurally efficient, have often been found to be less suitable for habitat use. This is one of the primary reasons for their non popularity in building industry. However, extensive use of these forms can be noticed in large span structures such as auditorium, stadia, and industrial structures.

2. Origami

Ori means ‘folding’ and Kami means ‘paper’. Origami is the traditional art of paper folding, which started in 17th century AD. The goal of this art is to transform a flat sheet of paper into a finished sculpture through folding and sculpting techniques.

Origami doesn’t involve any use of cuts and glues. The number of basic origami folds are small, but they can be combined in a variety of ways to make intricate designs. It is the characteristic feature of any origami structure to have one basic unit which repeats itself in a variety of ways in the whole structure.

In modern times, origami is being widely used in architectural and engineering spheres to make quite innovative structures and designs for building construction. In this paper, structure developed with root idea from origami is presented.

2.1 Use of origami in structural engineering

For structural engineers, origami has proven to be a rich source of inspiration and it has found its way into a wide range of structural applications. The existing applications of origami in engineering can broadly be categorized into three areas.

a) Many deployable structures take inspiration from, or are directly derived from origami folding (*fig 2.1*).

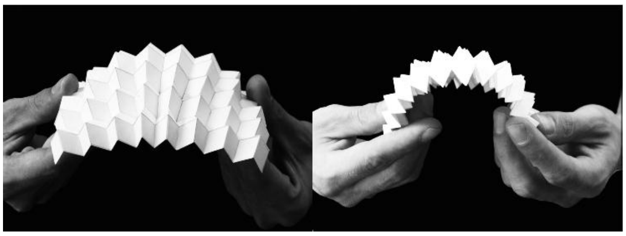

Fig 2.1 Mechanical Behavior of Egg box sheet

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b) Folding is used to achieve an increase in stiffness at minimal expense of weight. In architecture, this principle is also applied ranging from simple folded plate roofs to more complicated designs that unite an increase in strength with aesthetic appeal (*fig 2.2*).

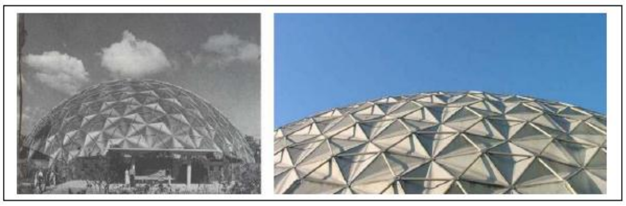

Fig 2.2 *Kaiser Hawaiian Geodesic Dome*

c). Origami patterns have been used to design shock absorbing devices such as car crash boxes.

3. Resulting Folded Structures

When origami designs are used for engineering purposes , their action under load, stability criteria at the bearings and edges, etc; come into picture. Study of such structures comes under the concept of folded structures. Hence, for the practical usage of origami, study of folded structures is mandatory.

3.1 Principle of folding

Their special structural behavior is due to their structural subdivision arrangement in pairs which correlate with each other and so they are connected through a shear connection. The structural characteristics of the folded structures depend upon the shape of the folding, on their geometrical basic shape, on its material, on the connection of the different folding planes and on the design of the bearings. The characteristics of the folding structures are interactive related to each other.

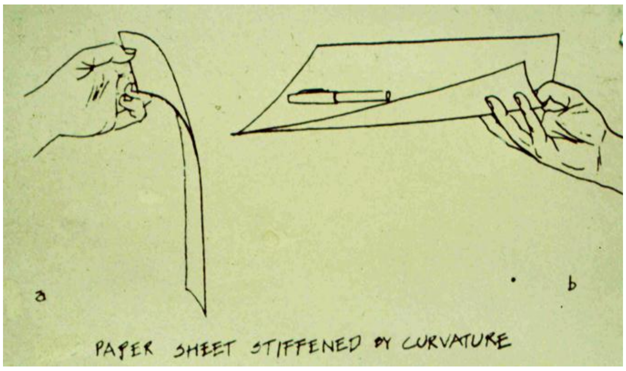

Fig 3.1 *Concept of stiffness generation*

3.2 Different types of folded structures

There are different types of folded structures as enumerated below.

a). Prismatic structures: These are the structures formed by longitudinal folding. A longitudinal folding is characterized through uninterrupted and linked folding edges where parallel and skew up folds and down folds alternate. These structures are composed of rectangular and transverse panels, or stiffeners, which are fixed against each other. The stiffeners can be replaced by frame structures (*fig 3.2*).

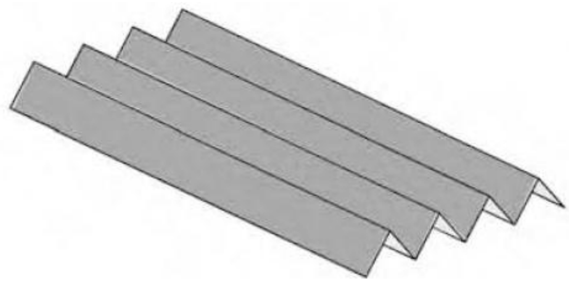

Fig 3.2 Prismatic structures

b). Pyramidal structures: These structures are formed by spot or facet folding. A spot or a facet folding requires that several folds intersect like a bunch in one single spot. This results in pyramidal folds with crystalline or facet like planes. Facet folding can either be based on triangular shape or on a quadrangular shape. A single or double layered facet folding resembles the load bearing structure of a plate and can be compared to space frames. So, these structures are mostly composed of triangular panels (*fig 3.3*).

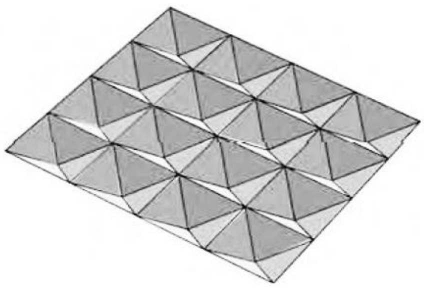

Fig 3.3 Pyramidal structures

c). Semi-prismatic structures: These structures take an intermediate position between prismatic and pyramidal structures. One can visualize a semi-prismatic structure as a pyramidal structure with the apex cut off so that a pyramidal frustum is produced. Semi prismatic folded structures consist of rectangular, triangular or parallelogrammatic panels (*Fig 3.4).*

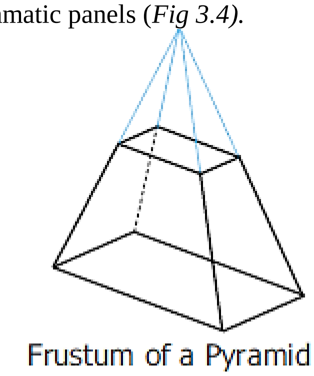

Fig 3.4 Semi-prismatic structures

d). *Curved structures* : Curved folded structures which are better known as bent folded structures are the structures in which the panels are formed along a bent longitudinal axis (*Fig 3.5*).

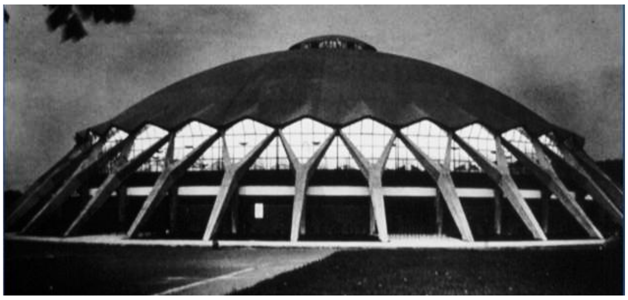

Fig 3.5 Curved structural forms

3.2 Structural behavior of folding

The inner load transfer of folding structure happens through the twisted plane, either through the structural condition of the plate or through the structural condition of the slab. At first, the external forces are transferred due to the structural condition of the plate to the shorter edge of one folding element. There, the reaction as an axial force is divided between the adjacent elements which results in a strain of the structural condition of the slabs. This leads to the transmission of forces to the bearing as shown in *fig-3.6*.

Folded structures represent one category of plane structural surfaces, alongside with plates and slabs. They may be defined as the surface girders composed of flat panels arranged so as to obtain a spatial load bearing capacity.

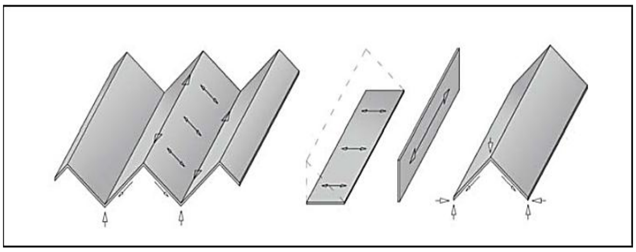

Fig 3.6 Forms & Forces in folded plates

4. Ferrocement & Suitability for Origami Structures

The term **ferrocement** is most commonly applied to a mixture of Portland cement and sand applied over layers of woven or expanded steel mesh and closely spaced small-diameter steel rods rebar. It can be used to form relatively thin, compound curved sheets to make hulls for boats, shell roofs, water tanks, etc. The term ferrocement was given to this product by its inventor in France, Joseph Monier. In 1875 he created the first steel and concrete bridge.

Ferro concrete has relatively good strength and resistance to impact. Many innovative structures are built using ferrocement which include boats, large span shell roofs, folded plates etc.

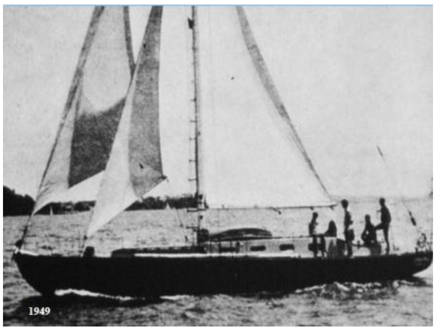

Fig 4.1 Ferrocement Boat (6)

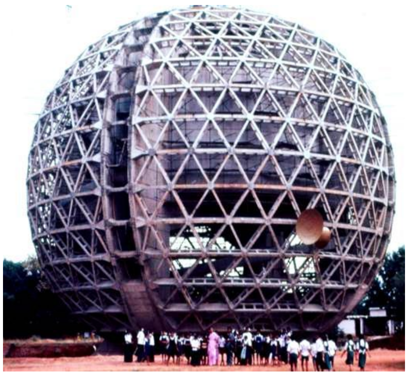

Fig 4.2 Matri Mandir, Auroville (6)

5. Case Study

Case study presented here below is based on a live project taken up by Prof Anupama at Auroville and my practical training on the project. Work included model preparation, fabrication of cages for ferrocement and onsite application.

5.1 Construction of origami and ideal way of folding for the present structure

In the original concept given by the architect, the paper folds itself into hexagonal patterns which was easy to fold and unfold. However, it was also found that pentagons can be formed by changing the location of largest diagonal as shown. Hence, it is possible to get an ideal way of forming structural system.

5.2 Hexagon based form: Take an A4 paper and divide it into the number of divisions as shown. With the pattern of diagonals, we get a hexagon (*fig. 5.1*)

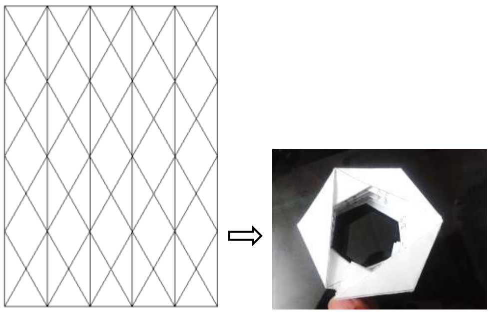

Fig 5.1 Formation of Hexagon

5.1 Pentagon based form: Take an A4 paper and divide it into the number of divisions as shown. With the pattern of diagonals, we get a pentagon (*fig. 5.2*).

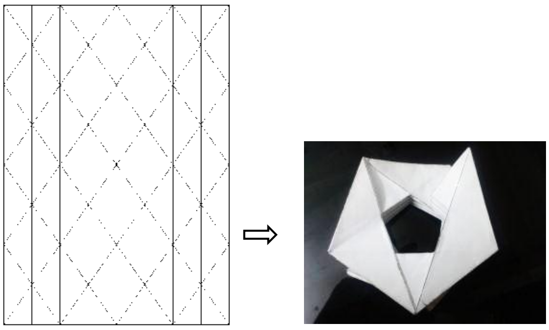

Fig 5.2 Formation of Pentagon

The advantage with the hexagonal pattern is that it is openable and hence becomes an ideal option for a structure construction when compared to a pentagon (*fig. 5.3*)

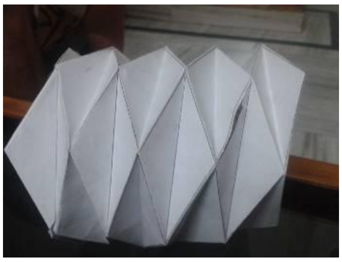

Fig 5.3 Side elevation of hexagon

Fig 5.4 Side elevation of pentagon

The problem that was realized with the pentagon was that it locks itself into an non-openable pattern (*fig. 5.4*). It is also possible to get new patterns of folding by resorting to alternate way of folding.

Basic unit is Rhombical unit which itself repeats to form the system, Final structural system is given in Fig 5.5

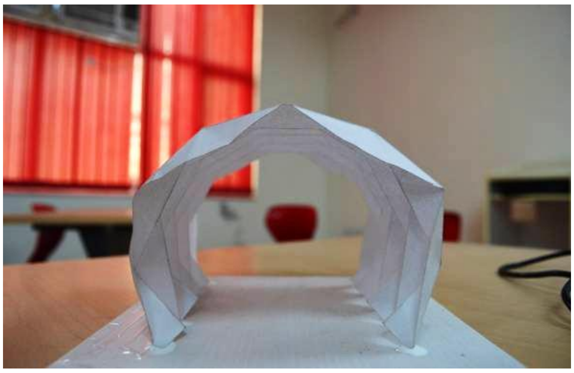

Fig 5.5 Model of the structure built

5.2 Force Mechanisms In The proposed Structure

Usually these structures have only self weight and wind forces acting on them. This being a low height structure, only self weight governs the design. Self weight is considered to be acting on surfaces which give rise to in plane forces as shown. There is also bending in the triangular plates which is not appreciable as per the theory of folded plates.

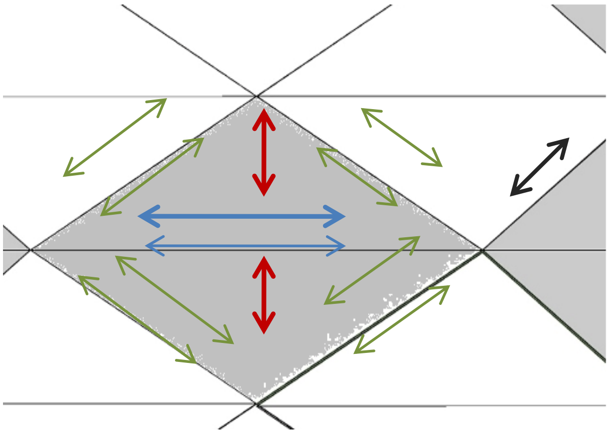

Fig 5.6 Forces acting on a basic unit

5.3 Construction

The structure was built using ferrocement The following is the procedure for the construction of origami structure:-

1.To visualize the structure ,a paper model was made. This helped us understand the action of structure in a miniature size.
2. Taking the actual dimensions, plan, section and elevations were drawn.
3. At the construction site, raised plinth was made in brick masonry with proper foundations and sub base.
4. The basic unit of this structure is a rhombus with both sides inclined about the longer diagonal. The required number of such basic units were made in the workshop using 8mm dia bars. Tor steel was used .
5. Two layers of GI (Galvanized Iron) chicken mesh (22 standard wire gauge, 0.8mm dia) were used and all units formed with these meshes.
6. Then the basic panels were arranged in position to a required height with the help of wooden logs which are made to the same length of the height.
7. Then the ends were welded to keep them in position.

Fig 5.7 Model of the structure built

8. Over this finished framework, CM 1:2 (cement mortar) was applied.
9. Thus, the structure is erected. The structure is cured for 10 days. Completed structure is as shown in fig.

Fig 5.8 Finished structure

6. Origami in Disaster Management

Given the fundamental nature of development of Origami , by virtue of foldability makes it ideal for conceiving portable structures for disaster to make emergency structures. Cardborigami corrugated origami shelter is found to have been conceived for such applications as shown in fig 6.1

Cardborigami is the brainchild of Los Angeles-based designer Tina Hovsepian, and is said to draw inspiration from the Japanese paper-folding art of origami. The unit is actually produced in two iterations, with a sizable version 1.0 aimed toward humanitarian crises, while the more portable 2.0 is conceived for single-person use by the homeless. Cardborigami 2.0 weighs 10.5 pounds (almost 5 kg), and is finished with fire-retardant and water-resistant coatings. It folds easily, and can be erected in under a minute by one person – no assembly required.

At present, Cardborigami is still in the prototype stage, and Hovsepian is seeking to collaborate with like-minded organizations and investors in order to get the project off the ground. The project is also the subject of a crowd-funding campaign on GoFundMe.

Fig 6.1 Cardborigami structure

In our present work also , efforts have been made develop foldable structure using card board and iron bars as shown in fig VI.2.

Fig 6.2 Cardborigami structure using card board (Courtesy: Anumapa Kundoo).

It is further conceived that such systems can be developed using material like canvas etc. Hence, proposed structural system has the potential for disaster management for emergency shelters.

Conclusion

It is shown through the study of this paper that through origami, innovative folded structures can be developed. Such folded structures can be easily visualized for its structural behavior. Ferrocement is found to be ideal for the construction of such forms. Proposed foldable systems developed using origami can be advantageously used as emergency shelters in disaster management.

Acknowledgment

I am deeply indebted to Prof.Anupama Kundu of Queensland University, Australia, Ms.Yashoda Joshi, Architect for providing me with an opportunity to work on this project including construction. I am also thankful to

Mr. Sekhar, engineer at Auroville for explaining about the ferrocement construction. My sincere thanks are due to my parents for encouraging me to do such a work and my brother Master Siva Sai Pavan who helped in model making.

References

Mark Schenk and Simon D. Guest (2011), *Origami Folding: A Structural Engineering Approach* In Origami5, A Bibliographic Sourcebook, pp. 291-304, CRC Press(A.K.Peter's)

Fred Angerer (1961), *Surface Structures in buildings,* Volume 6 Reinhold Publishing Corporations

Ing Martin Trautz,Ing Ralf Herkrath (March 2013), *The application of folded plates on spatial structures with regular, irregular and free-form geometries*, Wiley Online library- Stahlbau, Vol 82, Issue 3, pp. 208- 213.

University of Belgrade (2012.), Folded Structures in Modern Architecture, Architecture and Civil Engineering series- Facta Universitatis, Vol 10, pp.1-16.

(April 2013), *Origami-inspired Cardboard Homeless Shelters, To help People Get Off The Streets*, Adele Peters, Fast company magazine.