Structural Response of Foldable Semi-circular Vaults

Mukesh.V.Chauhan[1], Dr.N.K.Arora[2]
[1]Post Graduate Student Applied Mechanics Department, L.D.College of Engineering, Ahmedabad.
[2] Faculty of Applied Mechanics Department, L.D.College of Engineering, Ahmedabad

***Abstract*- The general objective and scope of this study is to develop a new adaptive structure which can transform from planar geometries to hyper surfaces. It can be seen that the most of the structure transform only between "open- closed" and "extended-contacted." positions. Moreover, although some parts of the structures move, rotate, slide etc, and general shape of the space structure never change. Main objective of this study is to meet this need. For constituting this foldable space structure, the study aims to use scissor hinge systems as the structure type these systems have an important transformation capacity because of their extension and rotation properties. In present work, a combination of foldable cylindrical barrel vault and foldable dome has been chosen to cover the given plan area. The basic geometrical shape consists of cylindrical vault at the entrance followed by quarter dome to close other end. The study covers effect of important parameters like span, length of duplet member, angle, spacing of transverse members of vault. All the members are designed optimally to get minimum displacement for given geometry.**

I. I. INTRODUCTION

A space structure is a structural system in the form of a three-dimensional assembly of elements capable of resisting loads which can be applied at any point, inclined at any angle to the surface of the structure and acting in any direction. For thousands of years the cube has been the dominant form in architectural and structural design, in spite of its unstable shape and formal limitations. In recent years the space frame network has been better understood and utilized

However, most of these attempts are found to be of academic interest as the solution lacks in field applicability. David H. Geiger [1] has carried out economic study dealing with space trusses, domes and cable roofs and he observed that cost was much more sensitive to grid spacing than to the span to depth ratio. The behaviour of steel braced barrel vaults due to the effect of laterals, edge trusses and different types of bracing systems has been studied by P. Mahadevappa, N. Subramanian, and L. N. Ramamurthy [6].

A study on the effects of geometric imperfections on single-layer barrel vaults has been carried out by Ahmed El-Sheikh [2] and observed that having more bracing members increases the strength of barrel vaults but are not as effective against joint misplacement. An effect of adopting different single layer barrel vault configurations on the vault strength/weight ratio has been studied by Ahmed El-Sheikh [3] and observation drawn by author that barrel vault configurations that seem to offer the best overall performance are those that have a regular arrangement of longitudinal, transverse and bracing members. Wind load distribution as well as its effects on single layer reticulated cylindrical shells has been studied by Y.Q.Li, Y.Tamura, A.Yoshida, A.Katsumura and K.Cho [5] and observed that for all the cases of wind tunnel tests for the cylindrical models, the largest total wind force coefficients occurred when the wind attack angle is near to 33.75°.

Literature survey indicates that a significant research attention has been given to the optimization of three dimensional space truss [1] to [5]. However, most of these works are related to the fixed geometries and negligible research attention has been given to the foldable curved structural geometries.

WHY USE FOLDABLE VAULT?

Large column free areas are usually required for industrial buildings, sports stadium, swimming pools, exhibition halls, theatres and assembly rooms. . Openness as well as the ability to accommodate variable space requirements are main concern for such structures hence vault structures are ideally suited for such requirements. The cost and time required for construction of rigid jointed vaults is significantly high. Hence, folding type of vaulted structure may provide alternative solution for the same. Foldable vaults are made up of small size components and are very easy to handle, transport and erect, results in significant time saving.

Foldability of structure can be achieved by various forms. The most basic forms of foldable unit, called duplet, is a scissor system. If a hinge is provided at the centre of scissor arms, the scissor expands linearly as shown in figure.1

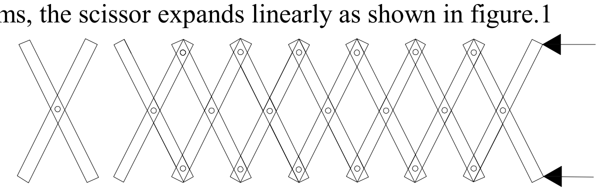

Figure.1A Planar Scissors System

However, when the arms of scissor is not hinged at middle point, the scissor system expands as an arch as shown in Figure.2 by bringing end closer to each other.

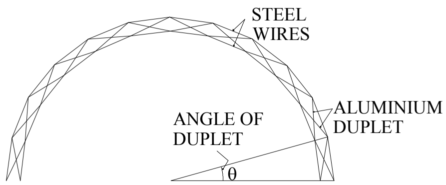

Figure.2 A Scissors Arch System

The sum of internal angles is considered to be 180º is initially divided equally between duplets, so the produced geometry will be half of a circle as shown in Figure.2 In this study the angle of duplet is varied as 4º, 5º and 6º for span 10m, 14m and 20m. However, in span 25 m angle 6º is not possible because in 6º the duplet member are not connect properly.

NEED OF THIS STUDY:-

Vaults are mostly used for covering large open areas. Literature indicates that the economics of vaults is very sensitive to the type of configuration chosen. The present work is aimed to carry out parametric study of foldable semicircular vaulted structure to propose an economical solution for the given plan dimensions of vaults.

II- PARAMETRIC STUDY

In present work, a combination of foldable cylindrical barrel vault and foldable dome has been chosen to cover the given plan area. The basic geometrical shape consists of cylindrical vault at the entrance followed by quarter dome to close other end. The 3D view and side view of this model are shown in Fig.3 and fig.4. In present study, span of vault is varied between 10m and 25m whereas angle of duplet is varied from 4^0 to 6^0. The length of vault is keep as 1.25m to have better handling and the spacing of transverse members is kept as 2m. The dome angle is varied such that no transverse member is longer than 2m.

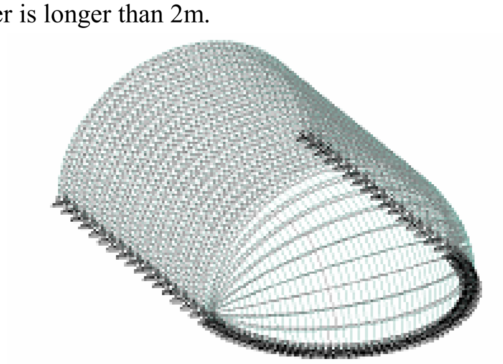

Fig.3 3D model

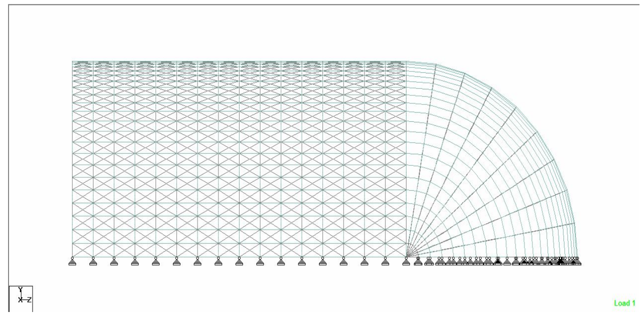

Fig.4 side view of model

LOADS:

The following loads are considered:

(1) Dead load: The dead load includes self weight of the structure and the weight of the roof covering materials.
(2) Live load: The live load depends upon rise/span ratio and it is calculated as per table-2 of IS-875 (Part-II).
(3) Wind load: Wind load is the most important of all and it often controls the design. The Wind load is calculated as per IS: 875–1987(Part-III).

Load Combinations

1. Dead load
2. Live load
3. Wind load parallel to ridge
4. Wind load perpendicular to ridge
5. Dead load + Live load
6. Dead load + Wind load parallel to ridge
7. Dead load + Wind load perpendicular to ridge
8. Dead load + Live load + Wind load parallel to ridge
9. Dead load + Live load + Wind load perpendicular to ridge
10. Dead load + Live load + Dome Wind load parallel to ridge
11. Dead load + Live load + Dome Wind load perpendicular to ridge.

III- ANALYSIS

Though literature indicates that in large span space structures like vaults, the joints should be taken as fixed joints. However, in present case, all the joints are foldable, hence they allow relative rotation therefore analysis is carried out by considering the structure as space truss in STAAD Pro. As the present structure is 3D space structure hence has very complicated geometry. This poses significant problem in getting exact coordinate of joints. An excel program was therefore made to calculate the joint coordinates and same was then imported in STAAD input file. Other necessary parameters like member properties, grouping, loads and load combination etc are input from STAAD console. To make structure light, all the duplet members and transverse members are taken to be of aluminum whereas the all the top joints and all bottom joints of duplets are inter connected by steel wires as shown in FIG.2 Infield practice, section of similar type of members is kept same throughout the vault hence; all the members of vault are divided in four groups viz. chords, transverses, duplet member and dome member. The structural model is then analyzed to determine forces in each member and displacement of joints. The members are then designed using inbuilt designing facility of software. An optimum member size is determined through successive analysis and iterations until a least weight of member is obtained. Furthermore, the geometry is repetitively improved manually so that members do not fail in slenderness ratio and utilizes material strength capacity to fullest extent. Finally, total weight of the structure after the optimization is found out using STAAD PRO software command.

IV-RESULTS & DISCUSSION

The weight of all the vaults under consideration is determined per unit surface area of foldable vault in table no-I

TABLE-I

Weight/unit area (Kg/m^2)

Member Length = 1.25 m				
angle	weight/ unit area (Kg/m^2)			
	Span=10m	Span = 14 m	Span = 20 m	Span = 25 m
4	11.00	10.43	7.66	8.28
5	7.90	8.61	5.11	7.33
6	6.82	7.34	6.24	

Above results show that the weight per unit surface area of vault decreases with increase in angle of duplet for all the spans. For a given duplet angle, weight per unit surface area of vault decreases with increase in span of vault. Among all the cases accounted in present study, span of 20m with duplet angle 5^o gives least weight per unit surface area.

The results in terms of displacement (Y)/Arc length of different span semicircular vaults are listed in Table- II.

TABLE-II

Displacement (Y)/Arc Length

Sr No	An gle	Displacement (Y)/Arc Length							
		Span=10m		Span = 14 m		Span = 20 m		Span=25m	
		Ymax	Ymin	Ymax	Ymin	Ymax	Ymin	Ymax	Ymin
1	4	5001	-764	5147	-715	1609	-411	1361	-341
2	5	7111	-1287	6656	-758	1467	-451	924	-254
3	6	5602	-875	6676	-784	993	-257		

Above results show that the displacement/arc span ratio of vault in Y direction due to applied loads decreases with increase in span indicating reduction in structural stiffness with increase in span. In general, for given span, this value first increase from 4^0 to 5^0 but later again reduces at 6^0, indicating higher stiffness of vaults at 5^0 angle of duplet for all the spans.

The results in terms of displacement (Z)/arc Length of different span semicircular vaults are listed in Table- III

TABLE-III

Displacement (Z)/Arc length

Sr No	An gle	Displacement (Z)/ Arc Length							
		Span=10m		Span = 14 m		Span = 20 m		Span=25m	
		Zmax	Zmin	Zmax	Zmin	Zmax	Zmin	Zmax	Zmin
1	4	175	-635	201	-824	268	-814	346	-1396
2	5	300	-866	251	-986	620	-1765	927	-1940
3	6	237	-818	344	-1318	615	-1764		

Above results show that the displacement/arc span ratio of vault in Z direction due to applied loads increases with increase in span indicating reduction in structural stiffness with increase in span. In general, for given span, this value increases in all angle, indicating higher stiffness of vaults at all angle of duplet for all the spans.

The maximum displacement/arc span ratio in Y- direction is observed to be 254 and in Z direction it is 237. Though there is no clear cut guidelines for the limiting value of displacement to arc span ratio, above values seems to be practical.

V-CONCLUSIONS

The study has been carried out to check the feasibility of folded structure in vaults. The span length and angle of duplet war varied and analysis had been carried out. Analytical results and subsequent design following conclusions can be drawn based on

A. For 6^o angle is provide minimum weight per unit area which is less in comparison with load provided per unit area with different angle which is good and desirable.
B. Up to 15m span is kept 6^o angle, it gives less displacement which is desirable.

VI-REFERENCES

[1] David H. Geiger, “A cost evaluation of space trusses of large span”, AISC Engineering Journal, April, 1968, Page No. 49-61.
[2] El-Sheikh Ahmed, “Effect of geometric imperfections on single-layer barrel vaults”, International Journal of Space Structures, Vol. 17, No. 4, 2001.
[3] El-Sheikh Ahmed, “Performance of single-layer barrel vaults with different configurations”, International Journal of Space Structures, Vol. 16, No. 2, 2001.
[4] Ramaswami G. S., Fekhout Mick & Suresh G. R., “Analysis Design And Construction Of Steel Space Frames”, Thomas Telford Publishing, London, 2002.
[5] Y.Q. Li, Y. Tamura, A. Yoshida, A. Katsumsra, K. Cho, “Wind loading and its effects on single-layer reticulated cylindrical shells”, Journal of Wind Engineering and Industrial Aerodynamics, 94(2006), 949-973.
[6] P. Mahadevappa, N. Subramanian, L. N. Ramamurthy, “A study on the behaviour of steel braced barrel vaults”, Building and Environment, Volume 15, Issue 3, 1980, Pages 191-195.
[7] Makowski Z. S., “Analysis, Design and Construction Of Braced Barrel Vaults”, Elsevier Applied Science Publishers, London, 1985.
[8] Subramanian N., “Principles Of Space Structures”, Wheeler Publishing, New Delhi-Allahabad, 1999.