Analytical Study of Trough Type Folded Plate Roof using STAAD.Pro

V. Jagadesh[1] and Dr. D. Shoba Rajkumar[2]

[1]*PG Student, Department of Civil Engineering, Government College of Engineering, Salem, Tamil Nadu.*

[2] *Professor, Department of Civil Engineering, Government College of Engineering, Salem, Tamil Nadu.*

***Abstract* - This paper presents an analytical study on trough-type folded plate roofs using STAAD.Pro, focusing on their structural behavior, design principles, and practical applications in modern engineering. Trough-type folded plates represent a unique structural configuration that integrates the efficiency of folded plate systems with the functional benefits of trough-shaped geometries.**

The study employs analytical methods to investigate various aspects of these roofs, including deflection characteristics, stress distribution, and strategies for material optimization. Through comprehensive analysis, the research aims to elucidate the inherent advantages of trough-type folded plates in terms of structural performance and architectural versatility. Case studies are utilized to illustrate the application of these roofs across different scenarios, highlighting their performance under varying thickness conditions and structural configurations. The findings underscore the significant material economy achieved through the use of trough-type folded plates, emphasizing their suitability for a wide range of engineering projects such as roofs, bridges, and large-span structures. Furthermore, the study explores how STAAD.Pro, a widely-used structural analysis and design software, facilitates the modeling and evaluation of trough-type folded plate roofs. By leveraging computational tools, engineers can effectively simulate and optimize these structures to meet specific design criteria and performance standards.

***Index Terms* - Folded Plate, Roof Thickness, STAAD.Pro, Stresses, Trough Type.**

I. INTRODUCTION

Folded plate structures have aroused attention in recent years because of their economic advantage and architectural appearance. Longer spans may be due to the inherent stiffness without an increase in material requirement. This type of structure has gained increasing popularity and offers more advantages than more complex structures, such as cylindrical shells, arches and frames. 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 like several biological systems such as broad leaf tree leaves, petals and foldable insect wings, are adopted to employ in a new technical way. 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 of 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. To determine the effect of various thickness on deflection, membrane stresses Sx, Sy, Sxy, Bending Stresses Mx, My, Mxy and Shear Stresses SQx, SQy using STADD. Pro. To determine Maximum Load for each thickness (T1, T2, T3).

II. LITERATURE REVIEW

Claude D Johnson et al (1964) A theory is presented for the analysis of long non-prismatic folded plates, which may consist of combinations of tapered and rectangular plate elements. This is a natural extension of ordinary folded plate theory and is based on a method of odal analysis. Corrections are considered for the effects of relative joint displacements. Application of the theory is not limited to cases of similar loadings, and prismatic folded plates can be analyzed as special cases. A computer program developed for applying the theory is described.

Graham H Powell (1965) investigates the fundamental principles underlying several simplified theories for prismatic folded plates (ignoring torsional moments, longitudinal bending moments, and shear deformations) are examined, and the close relationships existing among them are demonstrated.

The theories are classified, and in the process three new methods of analysis are developed.
Fred W Beaufait (1965) analysis the folded plate surface is a shell developed by a series of flat plates, monolithic in the longitudinal direction and supported by transverse diaphragms or bents. Because the folded plate surface offers numerous architectural, structural and economical solutions to the problem of large, clear spans, interest in this structural system has increased within the past ten years. Although this type of structure has been used primarily in the construction of long-span roofing and flooring systems, the folded plate surface has many other possible applications. Design techniques have been developed but only for the single span folded plate surface.

WH Liu et al (1992) analysis the finite element - transfer matrix method is used to study the natural frequencies of folded plate structures. Cantilever folded plate or supported folded plate structures are divided into a series of parallel strips, and each strip is further divided into a sequence of elements. One-fold folded plates and two folded plates with various crank angles, and many-fold cylindrical shell panels with non-uniform and non-circular cross-section are considered. The numerical results are compared with some existing data, and fairly good agreement is achieved.

Alexander C Scordelis et al (1996) conducted an experimental study of the behaviour of two reinforced concrete folded late models, under load, and identical in all respects except for the manner and volume of reinforcement is presented. Reinforcement requirements were determined for the first model by a folded plate analysis based on the elasticity method and requirements for the second model were determined by the elementary beam theory. Experimental results through the elastic, inelastic, and ultimate ranges are examined and compared with theoretical predictions.

E Ahmed, et al (2000) conducted a folded plate structures constructed with profiled steel sheeting connected to dry boards by self-drilling, self-tapping screws (known as the PSSDB system) are being proposed as an alternative to traditional forms of roof construction. This paper describes the analysis, testing, and the structural behavior of such kind of structures. The proposed efficient and load bearing structural system consists of an assembly of individual PSSDB panels connected by steel angle plates at the ridges, formed to the required shape, width and span.
Sang-Youl Lee et al (2004) investigates the dynamic behavior of multiply folded composite laminates analyzed the high order plate theory. Using the third order finite element program developed for this study, the effects of folding angles and ply orientations on the transient responses for various loading and boundary conditions are studied. The numerical results obtained are in good agreement with those reported by other investigators. Furthermore, the new results reported in this paper show the interactions between folding angels and layup sequences.

Sreyashi Pal et al (2008) analyzing nine nodes flat plate element, considering first order transverse shear deformation and rotary inertia with five degrees of freedom per node, is used to compute element stiffness and mass matrices for composite plates. The stiffeners are visualized as parts of the folded plate. The formulation works well. New results for stiffened folded plates are reported with different arrangements of stiffeners to observe their effects.

S Haldar et al (2011) analysis a high precision composite plate bending element has been presented and its application to the analysis of isotropic and composite folded plates has been shown to study the performance of the element. In the present element the effect of shear deformation has been considered. Numerical examples have been solved by the proposed element and the results obtained in the form of bending moment, in-plane force and deflection have been compared with the published results (where available) to show the potentiality of the element.

Wojciech Gilewski et al (2014) conducted on Origami is an old art of paper folding. From a mechanical point of view origami can be defined as a folded structure. In the present paper a comparative study of four origami inspired folded plate structures is presented. Longitudinal, facet, egg-box and Miura-ori origami modules are used for the analysis. The models are based on six-parameter shell theory with the use of the finite element method. Convergence analysis of each module is presented.
Andrae Static et al (2015) analyses the potential of different possible folded form topologies for

generating timber folded surface structures. By offering an integral way of construction, which fulfils both a supporting as well as a covering function, very lightweight structures are achieved. Timber folded structures consist of a large number of discrete, thin plane elements, mutually connected to form an overall folded surface. Therefore, proper edgewise connection details are needed to ensure an efficient load bearing system.

Pranoti Satish Bhamare (2017) investigated the behavior of various parameters namely angle of inclined plate, radial angle, width to depth ratio, transverse moment developed at the joint, longitudinal moment at the midspan, deflection is being studied. There is a requirement of study the behavior of parameters for achieving economy in constructions. The classical methods such as Whitney's method and Simpson's method are the approximate method of analysis.

Aradhana Mehta (2019) analysis the value of deflections is higher for less plate thicknesses while transverse moments, principal stresses and longitudinal moments are lower. When rigid diaphragms are provided at two ends of folded plate, deflections decrease at mid span and quarter span while longitudinal moments increase.

Joanna Fulton (2022) analysis general simulation framework for numerically generating the equations of motion of any structure that complies with a set of pattern assumptions is presented. The framework is built through application of the articulated body forward dynamics algorithm and the tree-augmented approach for closed-chain forward dynamics. These are multi-body dynamics approaches developed in the literature for complex robotic manipulator systems.

Metin Katla et al (2023) investigated the effect of plate thickness and fiber hybridization on the flexural performance of V-shaped RC-FPs produced from self-compacting concrete (SCC). With this study, the experimental moment–curvature tool was used for the first time to evaluate the flexural performance of V-shaped RC-FP.

Kazim Turk et al (2024) investigated the effect of different rebar arrangements on the structural behavior of reinforced concrete (RC) folded plates was investigated. For this purpose, RC folded plate specimens having various rebar arrangements fabricated from high-strength hybrid steel fiber-reinforced self-compacting concrete were tested by subjecting them to four-point bending loading. Then, the structural behavior properties of RC folded plates, such as crack patterns, failure mode, load-midspan displacement relationship, flexural stiffness, ductility, load-strain behavior, and moment-curvature response, were compared and thoroughly assessed.

III. ANALYSIS OF FOLDED PLATES

Folded plates trapezoidal (trough type) shapes are generated using STADD. Pro. The folded plates are analyzed to determine the influence of slab thickness for Membrane Stresses Sx, Sy, Sxy, Bending Stresses Mx, My, Mxy and Shear Stresses SQx, SQy using STAAD. Pro software.

The length of the roof is 5m. For trapezoidal shape or trough-type folded plate, three specimens of various thickness are generated.

MODELLING OF FOLDED PLATES (TROUGH-TYPE)

FPT1 – Trapezoidal Folded Plate with Thickness I (T1 = 75mm)

FPT2 – Trapezoidal Folded Plate with Thickness II (T2 = 100mm)

FPT3 – Trapezoidal Folded Plate with Thickness III (T3 = 125mm)

MATERIAL PROPERTIES:

Material Property	Value
Modulus of Elasticity, E	21.718 kN/m^2
Poisson's ratio, μ	0.178
Density, ρ	2402.615 kN/m^3

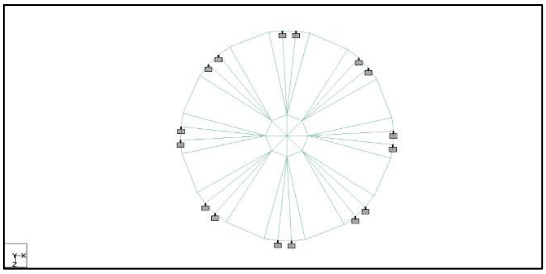

Fig.1 Plan View

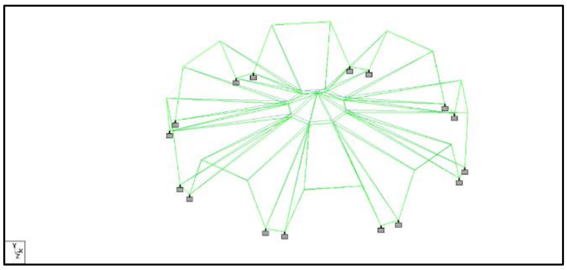

Fig.2 Displacement

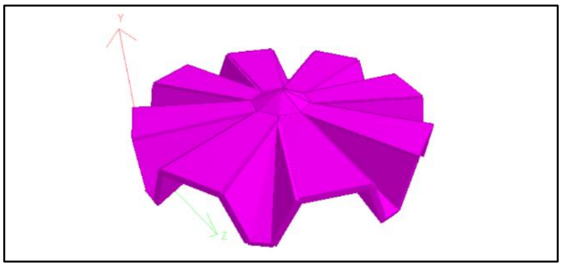

Fig.3 3D Rendering View

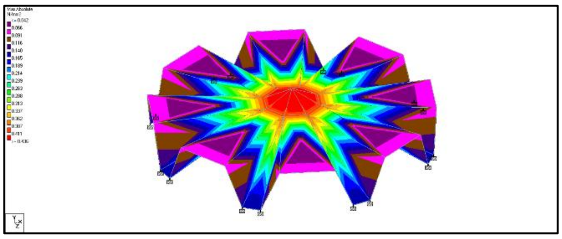

Fig.4 Maximum Absolute Stress for FPT1

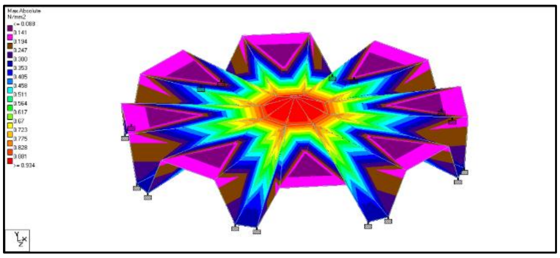

Fig.5 Maximum Absolute Stress for FPT2

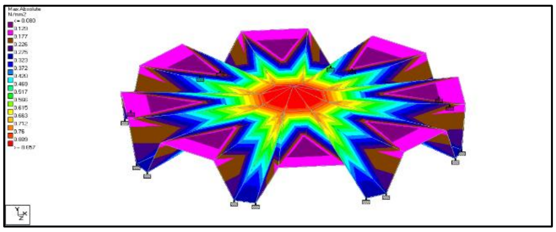

Fig.6 Maximum Absolute Stress for FPT3

VI. RESULTS AND DISCUSSIONS

The Membrane Stresses Sx, Sy, Sxy, Bending Stresses Mx, My, Mxy and Shear Stresses SQx, SQy are obtained by applying a concentrated load of 1kN is applied at the Centre of the folded plate section along y-direction. From the analysis of trapezoidal folded plates of various thickness, the following results are obtained and are tabulated below.

Table.1 Resultant Stresses

Stress	Units	FPT_1 (75mm)	FPT_2 (100mm)	FPT_3 (125mm)
Max Absolute	N/mm^2	0.099	0.088	0.080
S_x	N/mm^2	0.044	0.03	0.021
S_y	N/mm^2	-0.001	-0.002	-0.002
S_{xy}	N/mm^2	0.005	0.003	0.002
M_x	kN-m/m	0.252	0.489	0.808
M_y	kN-m/m	0.253	0.491	0.812
M_{xy}	kN-m/m	0.002	0.003	0.004
SQ_x	N/mm^2	0.037	0.031	0.024
SQ_y	N/mm^2	0.024	0.031	0.037
Deflection	mm	0.177	0.122	0.097

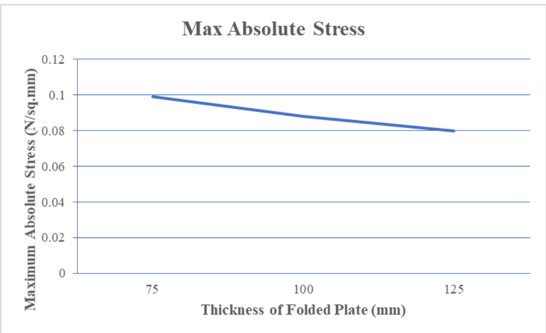

Fig.7 Trapezoidal FP - Maximum Absolute Stress

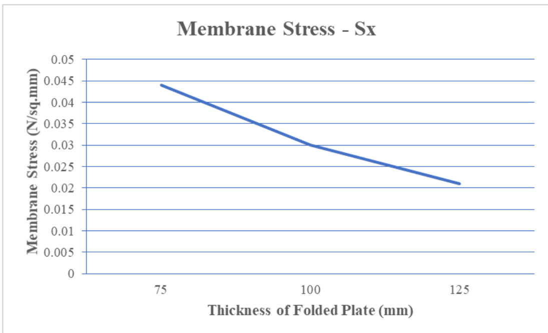

Fig.8 Trapezoidal FP - Membrane Stress (Sx)

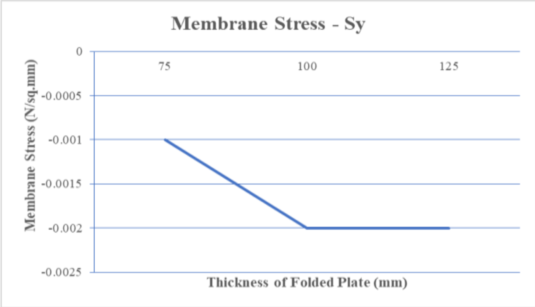

Fig.9 Trapezoidal Folded Plate - Membrane Stress (Sy)

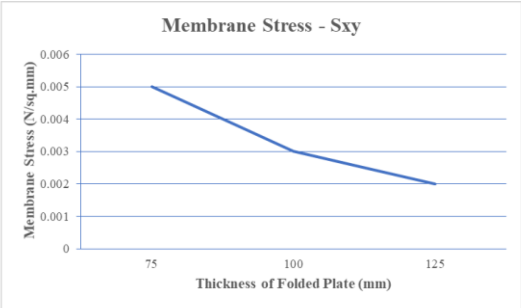

Fig.10 Trapezoidal FP - Membrane Stress (Sxy)

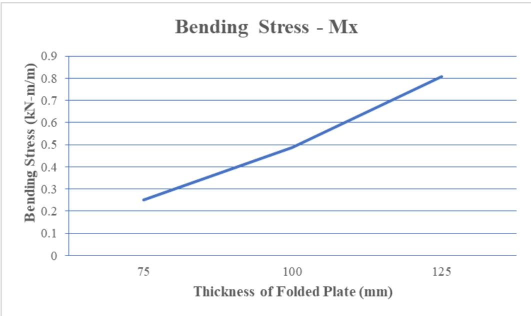

Fig.11 Trapezoidal FP - Bending Stress (Mx)

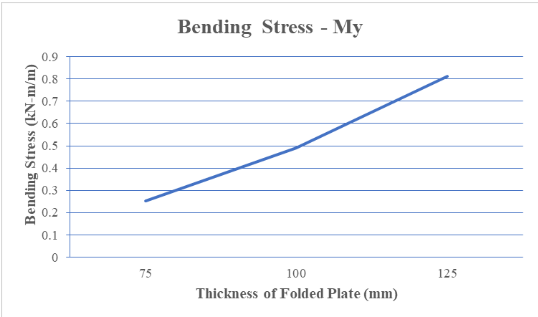

Fig.12 Trapezoidal FP - Bending Stress (My)

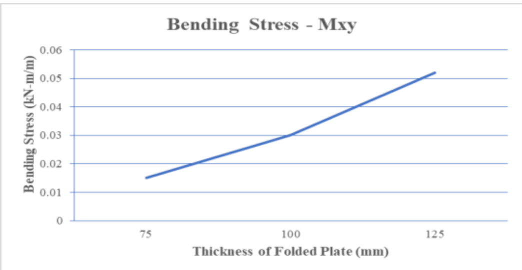

Fig.13 Trapezoidal FP - Bending Stress (Mxy)

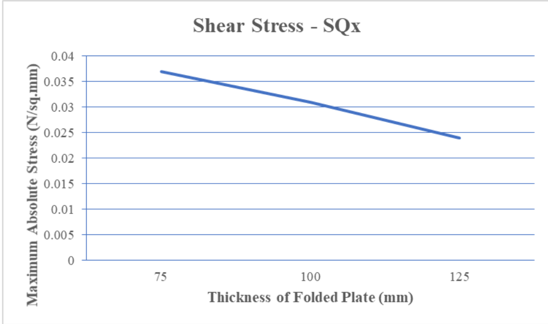

Fig.14 Trapezoidal FP - Shear Stress (SQx)

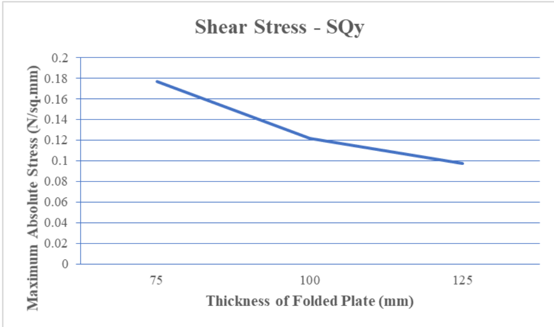

Fig.15 Trapezoidal Folded Plate - Shear Stress (SQy)

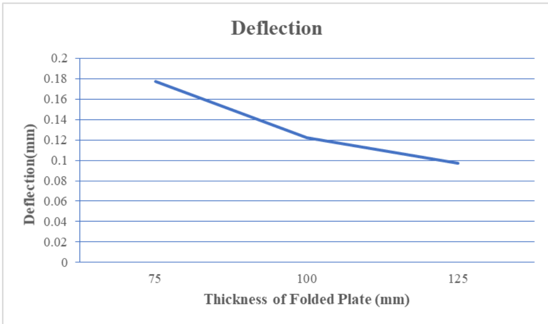

Fig.16 Trapezoidal Folded Plate - Deflection

V. CONCLUSION

The analysis of trapezoidal folded plates using STAAD. Pro software yields several key insights regarding the structural behavior under varying thicknesses:

- There Stress is a significant reduction in maximum absolute stress as the thickness of the folded plate increases.
- Membrane Stresses also decrease with the increase in plate thickness, indicating improved stress distribution and structural integrity. This is because membrane stress primarily depends on the axial forces and the cross-sectional area (which increases with thickness).
- Bending stress increases with thickness, especially if the plate is subjected to bending

moments. This is because the moment of inertia of the plate cross-section increases with the square of the thickness. Higher bending stress occurs at the edges and corners of the plate where bending moments are typically highest.

- Shear stress decrease with thickness, particularly along the cross-section where shear forces act. Thicker plates provide more resistance to shear due to increased area, but shear stresses can still concentrate in specific areas depending on the loading conditions.
- Variations in the number of elements used in modelling cause slight deviations in bending stress, shear stress, and maximum absolute stress.
- The maximum loads that the trapezoidal folded plates can bear increase with thickness. Specifically, the maximum loads are 36kN, 41kN, and 46kN for thicknesses of 75mm, 100mm, and 125mm, respectively. This demonstrates that thicker plates can support higher loads.
- Thicker plates have a higher moment of inertia and increased cross-sectional area compared to thinner plates. This increased stiffness means that thicker plates can resist deformation (deflection) more effectively under the same load conditions.
- Among the studied configurations, folded plates with the highest thickness (T-III) exhibit superior resistance to failure compared to those with lower thickness (T-I and T-II). This indicates that the geometric configuration significantly influences the structural performance.

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