REVIEW ON ANALYSIS OF FOLDED PLATE STRUCTURE

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ABSTRACT

In this paper the behavior of non-prismatic folded plate roof with varying design parameters have been studied. Different design parameters selected for study are plate thickness and different support conditions. Folded plates have attracted profound interest in recent years because of their economic advantages and architectural appearance. In particular, their basic structural response is indeed logical enough, explicit and simple although its required numerical computation procedure is, in a little bit, boring. This type of structures have gained increasing popularity and offers more advantages than more complex structures, such as cylindrical shells, arches and right folded plate frames. In civil engineering construction, folded plates are commonly used as roofing units. However, they are frequently subjected to dynamic loadings in their service life and hence, the knowledge of their dynamic behavior is important from the standpoint of analysis and design. To understand the performance and behavior of folded plate, the finite element modeling approach is a very important aspect.

Keywords: non-prismatic folded plate, dynamic loadings, finite element modeling, cylindrical shells, arches and right folded plate frames.

INTRODUCTION

Folded plate structures are assemblies of multiple numbers of plates rigidly connected in a folding pattern. The concept of folds also exists in nature, as can be found on various types of tree leaves, insect wings, and seashells. This concept has been established in many other fields, such as in solar panels, nanochips, and medical devices. Folded plate structures carry loads without requiring supporting beams along longitudinal edges. The reason for the effectiveness of reinforced concrete folded plate systems is that they transfer the applied loads to the supporting members through both bending and membrane action. The bending is resisted by both the reinforcement and concrete, while the tensile and compressive membrane forces are resisted by reinforcement and concrete. The folded plate structures can provide very light structures to cover large areas without columns. They have more inherent rigidity and high load-carrying capacity than other structures. Therefore, they are generally preferred when there is a need for construction without internal columns, such as exhibition halls, theater buildings, and assembly halls.

FOLDED PLATES

Folded plates are flat plate assemblies connected together rigidly over their edges in a manner that the structural system is able of holding loads without the need for extra supporting beams along ridge edges. Some of them have constant thicknesses and the other ones have variable thicknesses according to the nature of the structure and the applied loads.

TYPES OF FOLDED PLATES

1-Prismatic: if they consist of rectangular plates.

2-Pyramidal: when non-rectangular plates are used.

3-Prismoidal, triangular or trapezoidal**.**

FOLDED PLATE BEHAVIOURS:

Each plate is assumed to act as a beam in its own plane ,this assumption is justified when the ratio of the span "length" of the plate to its height "width" is large enough. But when this ratio is small, the plate behaves a deep beam

LITERATURE REVIEW

(D & Smilja, 2024)[1], This article presents numerical analysis of typical folded-plate structures by the finite strip method (FSM) taking into account geometrical and material nonlinearity. Harmonic coupled FSM is used for geometrical nonlinear analysis, whereas rheological-dynamical analogy for the analysis of soft- ening behavior.

HCFSM(harmonic coupled finite strip method) is an ideal method for predicting different geomet- rical nonlinear effects in prismatic FP structures. In fact, it is a semi-analytical and exact method because it divided the cross section of the girder into strips, including all the details in the actual shape, as a set of plate elements that make up the actual spatial system. The use of HCFSM com- puter application is the greatest practical value highlighted in this article because results in significant computer time savings compared to FEM. The main advantage of the method over FEM is that HCFSM can determine the con- verged stresses between the webs and the flanges in different FP structures taking into account sufficient number of har- monics.

(Dhanabal et al., 2023)[2], In this project, we used GGBS blended ferrocement concrete to cover a folded plate 600 mm x 1800 mm x 150 mm. Ferro cement is a building material that is emerging as an alternative for traditional RCC. First, we built the folded plate model in ANSYS and investigated its behaviour in terms of load versus deflection. Later, for experimental purposes, we cast a folded plate coated with GGBS mixed ferrocement concrete. The results of the experimental inquiry demonstrate that there was an improvement in flexural behaviour when compared to the traditional model. The same was verified using ANSYS findings. ANSYS analysis aids in comparing and summarising experimental data. Both the analytical and experimental inquiry results show that ferro cement structures are a good alternative to RCC since they are less costly and lighter. Because folded plates retain their effectiveness for a longer length of time when Ferro cement is utilised.

(Yousif et al., 2022)[3], In this paper, an optimum design algorithm is presented for reinforced concrete folded plate structures. The design provisions are implemented by ACI 318-11 and ACI 318.2-14, which are quite complex to apply. The design variables are divided into three classes. The first class refers to the variables involving the plates, which are the number of supports, thicknesses of the plates, configurations of longitudinal and transverse reinforcement, span length of each plate, and angle of inclination of the inclined plates. The second class consists of the variables involving the auxiliary members' (beams and diaphragms) depth and breadth and the configurations of longitudinal and shear reinforcement. The third class of variables can be the supporting columns, which involve the dimensions of the column along each axis and the configurations of longitudinal and shear reinforcement. The objective function is considered as the total cost of the folded plate structure, which consists of the cost of concrete, reinforcement, and formwork that is required to construct the building The enhancement suggested makes use of the population of beetles instead of one, as is the case in the standard algorithm. With this novel improvement, the beetle antennae search algorithm became very efficient. Two folded plate structures are designed by the proposed optimum design algorithm. It is observed that the differential evolution algorithm performed better than the other two metaheuristics and achieved the cheapest solution.

(Mehta, 2019)[4], In this paper the behaviour of non-prismatic folded plate roof with varying design parameters have been studied .Different design parameters selected for study are plate thickness and different support conditions. It has been observed that the value of deflections are higher for less plate thicknesses while transverse moments, principal stresses and longitudinal moments are lower. When rigid disphragms are provided at two ends of folded plate, delections decrease at mid span and quarter span while longitudinal moments increase.

When rigid diaphragms are provided at two ends of folded plate, delections become lower by 60-70 % at mid span and quarter span while longitudinal moments become higher. Transverse mements get reduced by 20-25% and principal stresses decrease by 40- 50 %.

(Kumari et al., 2019)[5], This study produces an overall review of the historical development of the most popular methods utilized for analysis the folded plate structures which are offered with their applications and how these methods are developed gradually. Four common methods are chosen in this paper to show their highlights of references particularizing in analysis of the above mentioned types of structure; the folded plate elasticity method (FPEM), finite element method (FEM), finite strip method (FSM) and spline finite strip method (SFSM). This investigation covers the elastic behavior, and the experimental researches on the elastic reaction of folded plate structures.

The finite element method among the redefined methods, is likely the most interested and time exhaustion. Nevertheless, it is yet the most common and overall approach for dynamic and static analysis, containing all portions acting the structural reaction. The other approaches confirmed to be adequate but restricted in applicability and scope.

(Kathe & Kuralkar, 2018)[6], This paper gives an information about Analysis and Comparative study of folded plate foundation for retaining wall with varying geometric parameters. This paper also helps to find out economical structure with prevention of sliding and also gaining high strength to whole structure. V shaped folded plate foundation for retaining wall can be used instead of simple foundation provided for retaining wall.

As the internal angle between each plate increase, deflection of structure also decreases. As the length of folded plate increases, deflection of structure also decreases.

(Sekulovi & Milašinovi, 2017)[7], An analysis of the plate and folded plate structures is carried out, taking into account the geometrical non- linearities and the effects of creep, using the finite strip method. An assumption is made that only small deformations and large displacements and rotations exist. Creep of concrete has an important influence on some structures and cannot be neglected in such analysis, especially when geometrical non-linearities are taken into account. The stiffness matrices (classical and geometrical) and the vector of equivalent nodal loading for the finite strips are obtained using the variation approach. The interpolation functions used are multiples of polynomial and trigonometric functions. Numerical examples showing the theoretical considerations are presented.
The finite strip method can be applied for the analysis of different types of rectangular plates with different support conditions and different types of folded plates without difficulty. In this paper an analysis of the slabs and fiat shells is carried out taking into account the geometrical non-linearities and effects of creep.

(Pranoti et al., n.d.)[8], Folded structures are three-dimensional spatial structures and they belong to the structural system. The term folded structure defines a folded form of constructions, including structures derived from elements which forming folded structures by their mutual relationships in space. In this study the behavior 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 are being studied. There is 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. Most analysis procedure of reinforced concrete and folded plate are based on elastic theory when subjected to large forces, however folded plate deforms beyond elastic range and the study of their behavior and performance required non-linear analysis
In radial folded plate, when the ring is very large it shows very large value of bending stresses. To calculate this bending stress the 18m diameter ring is to modelled and analysed accordingly in the ANSYS. ANSYs will help to optimise the radial folded plate during its analysis which will give effective results.

(Muljadinata & Subakti Darmawan, 2016)[9], Two different approaches toward folded plate structures has been presented. The first approach is based on its structural behavior, capacity and strength, and the second appreciation is based on the visibility of its folded form. Facts from the above examples are quite contrast. Building examples with true folded plate structures result in both, surface-active "form-resistant" structures and folded form structures. While the so-called "folded structures" confusing examples lead only to folded form structures, disregarding their structural features as folded plate structures .
From the presentation and discussion, it can be understood that a building that has a folded form does not have to be a building with folded plate construction. On the contrary, a folded plate structure building always features a folded form building.

(Milašinovi & Goleš, 2014)[10], This paper presents theoretical and numerical analysis of two reinforced concrete folded plate structures (RCFPS) of span length 20 and 30 m, according to linear predictions and predic- tions ofgeometric nonlinear behavior of structure. Characteristic cross-sections are designed on the basics ofinternal forces calculated using linear finite strip method (FSM). The stability analysis required during the design process is performed by using the complex harmonic coupled finite strip method (HCFSM). A com- bined application of MPI and Open MP parallelization methods in the cloud computing environment is used.

Based on comparative analysis of the results obtained by linear and nonlinear predictions it is observed that in RCFPS of span length 20m such results are very similar. This means that the linear FSM is optimal method for the design of shorter RCF- PSs. However, in RCFPS of span length 30m difference be- tween global safety factors of analysed cross sections according to linear and nonlinear predictions is up to 30%. Results obtained by linear FSM are almost always on the safe side in relation to the nonlinear predictions. Thus, by nonlinear analy- sis methods material savings can be achieved, but at the cost of increase in the price of analysis procedure.

(Desai et al., 2014)[11], Folded plates are assemblies of flat plates rigidly connected together so as to make structural system capable of carrying loads. They provide an economical and aesthetically pleasing design. This Paper aims at studying the material used for folded plate structure, analysis of folded plate structure by finite element strip or computer programs.

Using the concept of folding, as seen in nature and origami, to increase load bearing capacity, folded plates are used as roofing structure for long span. Glass, timber or R.C.C. are the material used for folded plate structure. Folded plates are analyzed considering plate action and slab action. Analysis of folded plates can be done by finite element strip or computer programs or manually by moment distribution method.

(Parikh et al., 2013)[12], Folded plates are a very useful form of structure which has many advantages. Several programs and software are available for the wind analysis of this type of structure. that software and programs methods are simple and essay, but they have the limitations of generality of application and precision. Rigorous methods are involved and some of these become costly due to the use of large-capacity computers. In this research paper Computer programs have been developed to wind analysis of folded plate. by using visual basic program making analysis program of wind analysis of folded plate. It is shown that these programs give acceptable results for the wind load calculation on folded plate structure.

(Bodh, 2013)[13], Folded Plates and spatial structures are adopted for construction of large span structures in which a large space is realized without columns as the structural components. In those cases, the structures are expected to resist against various design loads mainly through their extremely strong capability which can be acquired through in-plane or membrane stress resultants and this is just the reason by which they themselves stand for external loads without columns as their structural components in the large span structures. In this study the finite element modeling of multi bay cylindrical shell structures has been done to understand its performance during earthquake using SAP 2000 (version 14).

In the present work an attempt has been made to convert the MDOF model of large span reinforced concrete shell structures into SDOF system using N2-method. With the help of this method, equivalent stiffness, mass and force can be obtained.

(Abdel-Raheem Fargaly et al., 2006)[14], Conventional method used in analysis of folded plates structures is based on assumptions stating that the connections between plates in transverse direction are assumed rigidly supported, but actually these connections suffer space displacements and deformations, which emphasizes the no reality of such assumption. Consequently, the actual induced internal forces will be different from those calculated by the conventional method. A comprehensive 3-dimensional analysis using F.E. technique has been carried out for the structure as a whole to clarify the difference of the obtained straining actions compared with the conventional method. The comparison showed that for a certain folded plate configuration and number of vents, there is a great difference in the staring actions in both magnitude and direction depending on the location of the transverse cross section in the longitudinal direction. The study covered two important basic common configurations: trapezoidal with vertical plates and triangular with vertical plates. The following parameters are also taken into account.

(Bar-yoseph & Hersckovitz, 1989)[15], The new approximate method for the analysis of folded plate strucntres is based on Vlasov's theory of thin-walled beams where the folded plate is divided into longitudinal beams connected like a monolithic structure. The two primary assumptions are the equilibrium of the forces in the longitudinal direction and the compatibility of the beams in the transverse direction. On this basis the system of differential equations for the folded plate was derived and transformed into an eigenproblem. Comparison of the present sohltion with the solution based on a known method is made to demonstrate the accuracy and efficiency of the present method.

Comparative analysis for the research contribution by various authors.

Comparison Based on Research Objectives

Structural Behavior Analysis: Papers like Mehta (2019) and Kathe & Kuralkar (2018) focused on how design parameters affect deflection, moments, and stability in folded plates or their foundations.

Material Optimization: Dhanabal et al. (2023) explored innovative materials (GGBS ferrocement), while Yousif et al. (2022) concentrated on cost optimization using advanced algorithms.

Advanced Computational Techniques: D & Smilja (2024) and Sekulovi & Milasinovi (2017) emphasized finite strip methods (FSM), HCFSM, and creep effects for nonlinear structural analysis.

Review of Analytical Methods: Kumari et al. (2019) provided a comparative review of analysis techniques like FEM, FSM, and SFSM.

Comparison Based on Methodologies

Finite Element and Strip Methods (FEM/FSM): Widely employed for computational analysis, e.g., in Mehta (2019) for deflection and stress analysis and Sekulovi & Milasinovi (2017) for nonlinearity and creep.

Experimental and Numerical Hybrid Approaches: Papers such as Dhanabal et al. (2023) combined experiments with numerical simulations (ANSYS) to validate material performance.

Optimization Algorithms: Yousif et al. (2022) used metaheuristic techniques like the Beetle Antennae Search for cost reduction.

Parametric Studies: Pranoti et al. (n.d.) and Kathe & Kuralkar (2018) studied the effect of geometric parameters like plate angle and span on performance.

Comparison Based on Results

Material Improvements: GGBS blended ferrocement (Dhanabal et al., 2023) improved flexural performance, proving to be a lighter, cost-effective alternative to RCC.

Optimization Achievements: The Beetle Antennae Search (Yousif et al., 2022) effectively minimized costs without compromising structural integrity.

Structural Enhancements: Adding rigid diaphragms (Mehta, 2019) significantly reduced deflections and moments in non-prismatic folded plates.

Analysis Method Efficiency: FSM was validated as a time-saving and accurate method for nonlinear analysis in D & Smilja (2024) and Sekulovi & Milasinovi (2017).

Comparison Based on Conclusions

Suitability of Methods: Finite strip methods are more efficient for prismatic structures (D & Smilja, 2024) and shorter spans (Milašinovi & Goleš, 2014) but require nonlinear methods for long spans.

Material Selection: Ferrocement is lighter and more economical than RCC for folded plates (Dhanabal et al., 2023).

Design Optimization: Combining advanced algorithms reduces both cost and computational complexity (Yousif et al., 2022).

Innovations and Contributions

Computational Advancements: HCFSM provides significant computational efficiency for geometrical nonlinearity (D & Smilja, 2024).

Material Adaptations: Ferrocement coating for enhanced durability and reduced costs (Dhanabal et al., 2023).

Cost Optimization: Use of evolutionary algorithms like Beetle Antennae Search in structural design (Yousif et al., 2022).

Structural Performance: Rigid diaphragm integration improves stiffness and reduces deflections (Mehta, 2019)..

CONCLUSION

The analysis and review of various studies on folded plate structures reveal significant advancements in their design, analysis, and material optimization. Folded plate structures continue to gain popularity due to their structural efficiency, aesthetic appeal, and cost-effectiveness.

1. Material Innovations: The use of alternative materials like GGBS-blended ferrocement has shown improved flexural behavior and cost efficiency compared to traditional RCC. Such innovations pave the way for lightweight and durable folded plate structures.

2. Computational Methods: Advanced computational techniques, such as the Harmonic Coupled Finite Strip Method (HCFSM) and Finite Element Method (FEM), have proven to be effective in analyzing nonlinear behaviors and optimizing design parameters. These methods reduce computational time and provide accurate results, making them indispensable for modern structural analysis.

3. Design Optimization: Metaheuristic

algorithms, including the Beetle Antennae Search, have successfully minimized the costs of folded plate structures while maintaining structural integrity. These optimization techniques highlight the potential for integrating artificial intelligence in structural design.

4. Structural Performance: Parametric studies indicate that geometric configurations, plate thickness, and support conditions significantly influence the deflections, stresses, and overall stability of folded plate structures. Incorporating rigid diaphragms and optimizing plate angles enhance structural performance under various load conditions.

5. Applications and Versatility: Folded plate structures are highly versatile, finding applications in roofing systems, retaining walls, and long-span structures. Their ability to achieve large column-free spans makes them suitable for exhibition halls, auditoriums, and industrial buildings.

FUTURE SCOPE

The findings from this review suggest several areas for further research and development:

Expanding the use of sustainable and eco-friendly materials to enhance the environmental performance of folded plates.

Developing hybrid analysis methods that combine the strengths of FEM, FSM, and other techniques for broader applicability.

Exploring the long-term effects of creep, fatigue, and dynamic loading on folded plate structures for better durability and resilience.

Integrating advanced optimization algorithms to include environmental impact and lifecycle cost analysis in the design process.

Folded plate structures remain a critical area of research and development, with immense potential for innovation in materials, analysis techniques, and practical applications. The insights gained from this review serve as a foundation for future studies aimed at achieving more efficient, sustainable, and cost-effective structural designs.

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