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Review of optimal design of composite structures under uncertainty

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Abstract-This study represents optimization of hollow circular, rectangular and airfoil composite beam by using sub problem approximation method in ANSYS. A three dimensional static analysis of large displacement type has been carried out for hollow circular, rectangular and airfoil composite beams. Weight of beam was objective function, material parameter, geometrical, ply thickness, ply angles and load. In order to validate the results, one loop of simulation is benchmarked from results in literature. Ultimately, best set of optimized design variable is proposed to reduce weight under static loading condition.

Key words: - hollow circular, rectangular and airfoil composite beam, sub problem approximation method

1. Introduction:-

In reality, the structural design problem may be subject to uncertainties. As an inherent characteristic of nature, uncertainties appear everywhere and cannot be avoided. Uncertainties may enter every aspect of engineering problems, such as model validation, model verification, design improvement, and so on. Particularly, in the problems of engineering structural design, uncertainties may arise from fluctuation and scatter of external loads, environmental conditions, boundary conditions, geometrical parameters and material properties. Some of these uncertainties are rather uncontrollable in practice. Nevertheless, incomplete knowledge about the parameters that enter the design process as well as the model errors are usually also considered as uncertainties.

For a structural system, uncertainties may be involved in four stages of its lifecycle, namely in system design, in manufacturing process, in service time and in the ageing process (Figure 1.2). These uncertainties will give rise to structural performance variations during its whole life-cycle.

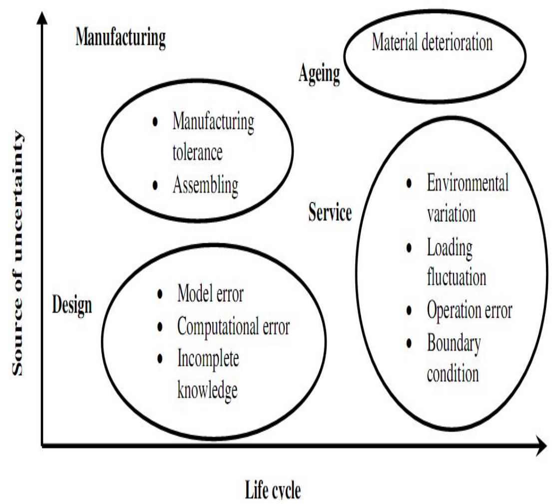

Figure 1.2: Sources of uncertainty [3]

In conventional design procedures, it is a common practice to neglect the uncertainty when setting up the analysis model of a structural system. Then a deterministic model of the structural system is established, where only ideal/nominal values of parameters are considered. The structural performance is calculated based on deterministic structural analysis. To

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compensate for performance variability caused by system variations, a safety factor defined as the ratio of capacity to demand is introduced. Larger safety factors are correlated with higher levels of uncertainty. Under an ever increasing demand on efficiency and reliability of the design process, the shortcomings of conventional design procedures need to be overcome by the computer aided structural optimization techniques.

Conventional structural optimization problems are formulated under deterministic assumptions and the uncertainties involved in the problem are not addressed in rational way. In such a formulation, the objective function and the constraints are calculated with nominal values of the parameters. Based on results of the deterministic analysis of the idealized numerical model, optimal design can be attained with optimization tools [8].

Structural optimization is seeking the best set of design parameters defining a structural system. This technique provides a powerful tool to improve the engineering structural design in a rational manner and has been proved to be much more efficient than the conventional trial and error design process. Design optimization has become a standard tool in many industrial fields and covers applications in mechanical engineering, automobile engineering and more particularly, structural optimization techniques have been intensively employed in the design practice of aerospace and aeronautical engineering. .

2 Literature Review

2.1 Literature Review on Composite Beams:-

Numerous researches have been done and books published in the area of composite beams. In review of composite beam study, discussions are divided into three areas: analytical studies, experimental studies, and Finite Element Analysis.

2.2 Literature Review on Design under Uncertainty for Composite Beams:-

Composites with superior stiffness to weight and strength to weight ratios are preferred structural materials in several applications. Since these applications generally involve special and severe working conditions, and the inherent anisotropy of composite materials leads to a high sensitivity of strength to load conditions and other factors, it is critical for the requirement of the high reliability performance. Fortunately, the design flexibility of composites provides the designers a wide range of choices in enhancing the structure's performance.

Traditionally, probabilistic design requires complete statistical information of uncertainties. These uncertainties are treated stochastically and assumed to follow certain probability distributions [4]. Several methods have been developed recently to assess the structural reliability non-probabilistically. Guo and Lu [5] developed a hybrid probabilistic and non-probabilistic approach based on the interval analysis for structural reliability design. Kang and Luo [6] discussed the description and numerical solution of non-probabilistic reliability-based structural optimization problem based on the convex model description. Chen et al. [7] established a semi-analytical approach for calculating the index of non-probabilistic reliability based on the interval analysis. Another challenge for probabilistic design is the high computational expense while doing using in-house tools or algorithms [8]. Therefore, it is an important subject to carry out probabilistic design under uncertainties

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considering all input variables within the framework of FEA tool ANSYS.

2.3 Literature Review on Optimization of Composite Beams:-

Adali et al. [9, 10] presented optimal design of composite laminates under buckling load uncertainty. The laminates were subjected to biaxial compressive loads and the buckling load was maximized under worst case in-plane loading which was computed using an anti-optimization approach. The magnitudes of the in-plane loads were not known a priori resulting in load uncertainty subject to the only constraint that the loads belong to a given uncertainty domain. Results were given for continuous and discrete fiber orientations which constitute the optimization problem coupled to load anti-optimization problem leading to a nested solution method.

Sandeep et al. [11] presented a formulation that deals with optimization of hybrid fiber reinforced plastic laminated plates subjected to impact loading. Finite Element Method (FEM) and Genetic Algorithm (GA) have been used to obtain optimum laminate in terms of minimizing the cost, weight or both cost and weight of graphite/epoxy (T300/5208)–aramid/epoxy (Kevlar 49) hybrid laminates while maximizing the strength. Impact induced delamination and matrix cracking have been used as failure criteria for the optimization of laminate. Fiber orientation, material and thickness in each lamina as well as number of lamina in the laminate have been used as design variables. Multi-objective approach has been used to achieve the optimum design of a laminate for combined normalized weighted cost and weight minimization.

Riche and Gaudin [12] considered the problem of designing stable composite plates. In first step, in-plane design of composite plates for high stiffness, low thermal and moisture expansion was performed. An expert enumerative algorithm was coupled with an evolutionary search to obtain optimal plates for the in-plane problem. In a second step, a Monte Carlo laminate analysis was introduced i.e. material and geometrical properties were distributed around their nominal value. Implications of property distributions on the optimal design were discussed. Under the effect of property variations, the coefficients of thermal and hygral bending of optimal in-plane designs could take on substantial values. Variations in coefficients of thermal and hygral bending were minimized by changing the laminate stacking sequence.

Kim and Hwang [13] designed a cantilever composite wing to minimize strain energy by random gust loads. For evaluation of the strain energy, the probabilistic characteristics of the wing root bending moment induced by random gust were calculated and the material properties of composite wing were assumed to show Gaussian distribution. With these random variables, the average of strain energy was evaluated by Monte Carlo simulation. The branch and bound method was modified to handle discrete ply angles efficiently for stacking sequence optimization. Numerical results show that bending stiffness to random gust can be considerably improved by optimal design process.

Kim and Sin [14] have developed an algorithm for optimizing laminated plate stacking sequences and determining thicknesses, which incorporates discrete ply angles and considers the uncertainties of material properties in a two-step optimization process. The branch and bound method was modified to handle discrete

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variables; and convex modeling was used to allow the consideration of variable material properties. The numerical results obtained show that the optimal stacking sequences are determined with fewer evaluations of the objective function than might be expected from considerations of the size of the design space.

3. Conclusion:

Multi-objective approach has been used to achieve the optimum design of a laminate for combined normalized weighted cost and weight minimization. Under the effect of property variations, the coefficients of thermal and hygral bending of optimal in-plane designs could take on substantial values. Variations in coefficients of thermal and hygral bending were minimized by changing the laminate stacking sequence.

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