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Composite Hypar Shell Roofs with Stiffeners under Point Load: Optimization of Stiffener Arrangement

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Abstract: -An eight noded curved shell element combined with three noded stiffener element is used to model the stiffened composite hypar shell. The applicability of the model is tested by solving a benchmark problem and it is further used to solve stiffened hypar shells of different laminations and boundary conditions by varying the number and depth of stiffeners. The results are examined to propose optimal solutions of stiffener arrangement in order to reduce central deflection of hypar shells under concentrated load.

Keywords: Optimization, composite, stiffened hypar shell, point load, finite element analysis

1. INTRODUCTION

Skewed hypar shells can offer a number of civil engineering advantages particularly when the material is laminated composite with high strength to weight ratio. A perusal on the literature on shell [1-5] shows that stiffened isotropic hypar shells received attention only from Nayak and Bandyopadhyay [2] with respect to free vibration. Although other forms of stiffened shells were studied by several authors as reported by Sinha and Mukhopadhyay [6] but attempts towards optimization of stiffener arrangement to minimize the material consumption of composite hypars is missing in the literature defines the scope of the present study.

2. MATHEMATICAL FORMULATION

2.1 Finite Element Formulation for Shell

A laminated composite hypar shell of uniform thickness h and twist radius of curvature R_{xy} is considered. Keeping the total thickness same, the thickness may consist of any number of thin laminae each of which may be arbitrarily oriented at an angle θ with reference to the x-axis of the co-ordinate system. An eight-noded curved quadratic isoparametric finite element is used for hypar shell analysis. The five degrees of freedom taken into consideration at each node are u, v, w, α, β. Sahoo and Chakravorty [5] reported the strain displacement and constitutive relationships together with the systematic development of stiffness matrix for the shell element.

2.2 Finite Element Formulation for Stiffener of the Shell

Three noded curved isoparametric beam elements are used to model the stiffeners, which are taken to run only along the boundaries of the shell elements. In the stiffener element, each node has four degrees of freedom i.e. u_{sx}, w_{sx}, α_{sx} and β_{sx} for x-stiffener and u_{sy}, w_{sy}, α_{sy}, and β_{sy} for y-stiffener. The generalized force-displacement relation of stiffeners can be expressed as:

$$x\text{-stiffener: } \{F_{sx}\} = [D_{sx}]\{\varepsilon_{sx}\} = [D_{sx}][B_{sx}]\{\delta_{sxi}\};$$

$$y\text{-stiffener: } \{F_{sy}\} = [D_{sy}]\{\varepsilon_{sy}\} = [D_{sy}][B_{sy}]\{\delta_{syi}\} \qquad (1)$$

where, $\{F_{sx}\} = [N_{sxx} \quad M_{sxx} \quad T_{sxx} \quad Q_{sxxz}]^T$; $\quad \{\varepsilon_{sx}\} = [u_{sx.x} \quad \alpha_{sx.x} \quad \beta_{sx.x} \quad (\alpha_{sx} + w_{sx.x})]^T$

and $\{F_{sy}\} = [N_{syy} \quad M_{syy} \quad T_{syy} \quad Q_{syyz}]^T$; $\quad \{\varepsilon_{sy}\} = [v_{sy.y} \quad \beta_{sy.y} \quad \alpha_{sy.y} \quad (\beta_{sy} + w_{sy.y})]^T$