Design Procedure for Plane Elements with Skew Reinforcement

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Summary

The paper presents a design procedure for plane elements with skew reinforcement. Such concrete structures occur frequently in practice, and include shells and bridges of skew geometry. The formulation is based on plasticity and concrete is assumed to have no tensile strength. The methodology is similar to Nielsen's equations for membranes with orthotropic reinforcement, and applies Baumann's two-plate approximation for shells. The skew flexural reinforcement is determined considering the complete set of internal forces and the actual angle formed by the reinforcing bars. When compared to the classical solution recommended by the CEB, the proposed formulation presents some important advantages. The problem is defined in the local system, avoiding transformations to the principal axes. Therefore, the procedure simplifies manual and numerical calculations. The third direction reinforcement proves to be dispensable in many conditions. Although the proposed two-way reinforcement increases the total amount of steel, it also improves reinforced concrete detailing. The proposed formulation can be applied to bridge decks with skew reinforcement. The theory is discussed through examples.

Keywords: Shell structures; reinforced concrete; torsional moment; skew reinforcement.

1. Introduction

Reinforced concrete elements with skew geometry are frequently detailed using skew-oriented reinforcing steel layers. Structural analyses based on linear elastic solutions, analytical or numerical, yield approximate stress resultants that are usually considered satisfactory for design purposes. Nevertheless, the punctual verification of the reinforced concrete element must take into account the complete set of internal forces, as well as the angle formed by the reinforcement layers.

This paper investigates the flexural design of reinforced concrete plane elements (plates, slabs and shells) with skew reinforcement. The formulation focuses the detailing using two reinforcing steel layers, even in cases that the CEB-FIP[1] and other approaches indicate a three-layer solution. Although the proposed approach yields a larger amount of reinforcement, the elimination of additional layers can reduce overall construction costs.

The formulation considers the in-plane internal forces. Transverse shear design is not investigated in this paper, and the simultaneous effect of the transverse shear stresses is not taken into account. Membrane design is based on the plasticity solution proposed by Nielsen[2]. The approach is extended, according to Baumann's[3] formulation, to combined membrane and flexural design, by defining two plate elements at the upper and lower faces of the shell, which are calculated separately by distributing the internal forces between both plate elements. After presenting this methodology for orthogonal reinforcement, arriving at the classical design equations recommended by the CEB-FIP[1], the formulation is extended to skew reinforcement.

https://doi.org/10.2749/222137810796024565
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