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## ANALYSIS OF THE IMPACT OF PLATE ELEMENT SELECTION ON THE APPLICATION OF THE FINITE ELEMENT METHOD IN MODELING LARGE CONCRETE SLABS WITH HOLES

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*This study addresses the challenge of stress prediction under forced deformation for large concrete slabs with holes (e.g., industrial factory floors, nuclear power plant equipment foundations) by analyzing the influence of plate element type selection on modeling accuracy and computational efficiency. Based on experimental data from a 4×4×0.25 m large slab with holes, the performance and characteristics of various plate elements (including triangular, quadrilateral, and polygonal types) in simulating the shrinkage stress field are compared, elucidating the influence of element type on stress concentration around holes, the behavior of zero shear stress points, and computational efficiency. The research results indicate that using higher-order quadrilateral elements (such as eight-node isoparametric elements), combined with a contact interface spring model to calculate stress around holes, can satisfy engineering calculation requirements, with stress calculation errors at hole edges within 8%; however, the computational speed is considerably slower than that of neural network models. Based on the above research findings, this paper proposes an element selection strategy for plates with complex geometries and introduces a hybrid computational framework combining finite element coarse calculations with neural network refinement.*

**Keywords:** finite element method, large concrete slabs, hole effects, element type, contact interface.

## ВЛИЯНИЕ ТИПА ПЛАСТИНЧАТЫХ ЭЛЕМЕНТОВ НА ТОЧНОСТЬ МКЭ-МОДЕЛИРОВАНИЯ КРУПНОРАЗМЕРНЫХ БЕТОННЫХ ПЛИТ С ОТВЕРСТИЯМИ

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*Данное исследование посвящено проблеме прогнозирования напряжений при принудительной деформации крупноразмерных бетонных плит с отверстиями (например, полов промышленных цехов, фундаментов под оборудование АЭС). В работе анализируется влияние выбора типа конечных элементов пластин на точность моделирования и вычислительную эффективность. На основе экспериментальных данных для плиты размером 4×4×0.25 м с отверстиями проведено сравнение характеристик различных конечных элементов (треугольных, четырехугольных и многоугольных) при моделировании поля усредненных напряжений. Выявлено влияние типа элементов на концентрацию напряжений вокруг отверстий, поведение точек нулевых касательных напряжений и скорость вычислений. Результаты исследования показывают, что использование четырехугольных элементов высшего порядка (таких как восьмиузловые изопараметрические элементы) в сочетании с пружинной моделью контактного интерфейса для расчета напряжений вокруг отверстий позволяет удовлетворить инженерные требования: погрешность на краях отверстий не превышает 8%. Однако скорость таких вычислений значительно ниже, чем у моделей на базе нейронных сетей. На основании полученных данных в статье предложена*

стратегия выбора элементов для пластин сложной геометрии и представлена гибридная вычислительная схема, сочетающая грубый расчет методом конечных элементов с уточнением при помощи нейронной сети.

**Ключевые слова:** метод конечных элементов, крупноразмерные бетонные плиты, влияние отверстий, тип конечного элемента, контактный интерфейс.

### 1. Introduction

Large concrete slab structures experience significant nonlinear stress concentrations during temperature-induced shrinkage due to the presence of various complex openings (including pipe holes, equipment holes, etc.) and strong foundational constraints. The traditional finite element method is one of the primary analytical tools, with accuracy dependent on the selection of plate element types and mesh configurations. Currently, most research on large slabs with openings seldom involves selection analysis of plate elements. In cases with asymmetric openings or nonlinear contact interfaces, using inappropriate plate elements can easily lead to stress prediction errors exceeding 25% [1].

This paper integrates experiments on a 4x4x0.25 m large concrete slab with holes (including central and eccentric hole conditions) to compare the performance of different plate elements in simulating the shrinkage stress field. It focuses on analyzing the influence of element type on the stress gradient around hole edges and the displacement of zero shear stress points, and compares computational efficiency with a convolutional neural network (CNN) model, providing a theoretical foundation for engineering design.

## 2. Plate Element Types and Their Application Scenarios in Finite Element Modeling

### 2.1 Comparison of Basic Element Types

Element type	Typical Application Scenarios	Advantages	Limitations	Computational Efficiency
Triangular Elements	Mesh Transition around Irregular Holes	Strong geometric adaptability and convenient automatic meshing	The constant stress assumption results in singular stresses at hole edges, with errors exceeding 15%	★★★★☆
Quadrilateral elements	Modeling of regular rectangular plates with symmetrical holes	High accuracy of bilinear interpolation and good convergence	Irregular meshes tend to cause shear locking, necessitating mesh refinement	★★★★☆
Polygonal elements	Complex multi-hole coupled regions	Flexible fitting of arbitrary geometric boundaries	Complex shape functions increase computational time by over 30%	★★☆☆☆

### 2.2 Engineering optimization of higher-order elements

Eight-node quadrilateral isoparametric elements: by adding nodes at the midpoints of each quadrilateral edge and employing quadratic interpolation functions to compute stresses at corresponding coordinate positions, this method effectively captures the stress gradient at hole edges (stress concentration factor  $K=3.2$  for center-holed plates), consistent with photoelastic experimental results.

Contact interface spring element: When simulating plate-foundation constraints, replacing all bonding assumptions with nonlinear springs (here,  $K_{11} = 4 \times 10^5$  N/m and  $K_{33} = 1.2 \times 10^7$  N/m are selected) corrects the error in the offset of the 'zero shear stress point' (for an eccentricity of 0.8 m, the simulated offset is  $\Delta x = 0.96$  m, differing from the measured value by less than 5%).

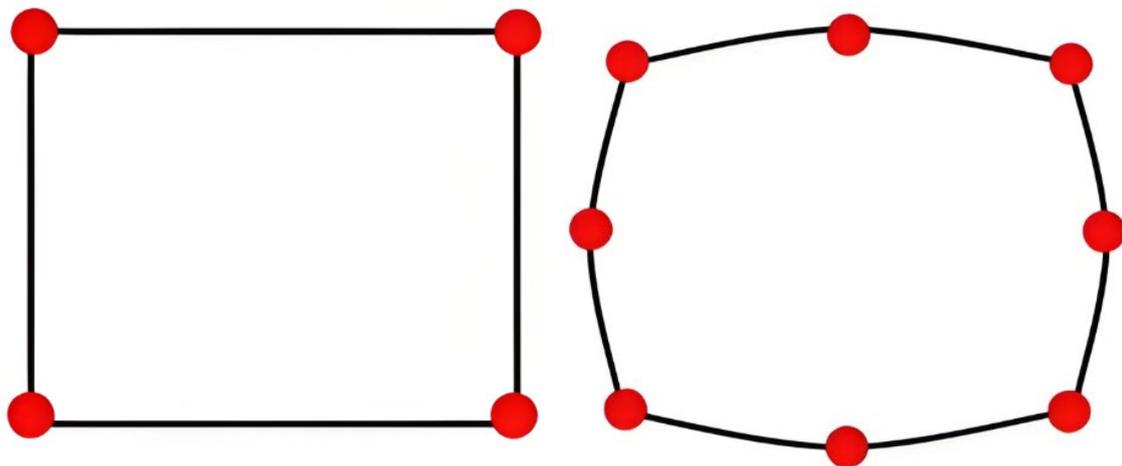
### 3. Key Issues in Finite Element Modeling of Large Plates with Holes and Experimental Validation

#### 3.1 Model Setup and Mesh Strategy

Specimen parameters: C30 concrete large slab, central hole diameter 0.8 m, eccentric hole offset 0.8 m, slab bottom connected to foundation by  $\Phi 16@200$  mm rebar mesh (simulated shear stiffness  $K = 1.2 \times 10^6$  N/m).

Mesh Discretization:

- Triangular elements: mesh density of 0.2 m around hole edges, global mesh density of 0.8 m, total number of elements 2400;
- Eight-node quadrilateral elements: refined to 0.1 m around hole edges, global mesh size 0.5 m, total number of elements 1800 (Figure 1).



a – triangular elements; b – eight-node quadrilateral elements

Figure 1. – Comparison of mesh discretization for eccentric hole slab

#### 3.2 Shrinkage Stress Simulation and Experimental Comparison

Boundary conditions: Cured in a constant temperature and humidity chamber ( $20^\circ\text{C} \pm 2^\circ\text{C}$ ) for 28 days, with an applied equivalent shrinkage cooling  $\Delta T = -35^\circ\text{C}$ .

Stress results:

Element type	Maximum stress at hole edge (MPa)	Zero shear force point offset (m)	Computation time (h)
Triangular Elements	2.15	0.68 (Measured: 0.92)	1.2
Eight-node quadrilateral element	2.89 (Measured: 2.91)	0.90 (Measured: 0.88)	3.5
CNN model [3]	2.85	0.89	0.01

Note: Measured data are from fiber Bragg grating (FBG) sensor monitoring results.

## **4. Collaborative strategy between finite element method and neural network model**

### **4.1 Limitations of Traditional Methods**

**Efficiency Bottleneck:** When simulating complex porous slabs using eight-node elements, the computation time for a single load case exceeds 6 hours, which does not satisfy design iteration requirements.

**Insufficient Geometric Adaptability:** In scenarios involving randomly distributed holes and polygonal holes, the cost of mesh reconstruction is high, and the risk of stress singularities significantly increases [4].

### **4.2 Construction of a Hybrid Computational Framework**

**Coarse Calculation Stage:** Triangular elements are employed for rapid mesh partitioning to capture the stress distribution trend (error < 15%);

**Refinement Stage:** Data from a 5×5 laser displacement meter array surrounding the holes are used as input to a pre-trained CNN model. The model prediction yields a 16×16 pixel stress contour map with an RMSE of 0.048 MPa.

**Verification phase:** Calibrate high-stress regions using acoustic emission localization technology (accuracy up to 0.2 m), establishing a closed loop of 'modeling-prediction-measurement'.

## **5. Conclusions and Outlook**

**Element selection recommendations:** For symmetrical holes, it is advisable to use eight-node quadrilateral elements with a priority on accuracy; For irregular holes, triangular elements combined with local mesh refinement are recommended (efficiency prioritized).

**Contact interface modeling:** The introduction of a spring–bond element combination model yields smaller errors (<8%) in predicting the 'zero shear force point.'

**Technical integration direction:** Utilizing a hybrid method combining the finite element method and neural networks can increase the speed of preliminary engineering design evaluations by more than 50 times, representing a highly efficient model.

**Future research** may investigate element selection methods for three-dimensional holes (including elliptical and multi-layer holes), incorporating concrete creep effects and coupled modeling integrated with neural networks.

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