Analysis of Factors Affecting Shear Performance of Shear Key in Open-web Sandwich Plate

Panpan Liu and Qiu Yi

ABSTRACT

In order to study the shear properties of the shear key of reinforced concrete open-web sandwich plate, several ABAQUS finite element models are established in this paper. The factors that may affect the shear key’s shear properties are analyzed, and the finite element calculation results are obtained by the above factors. The results of the related formulas in the literature[8-9] and the literature[10] are compared. The results show that the height of the top and bottom rib and the height of the shear bond have obvious influence on the shear capacity and ultimate shear capacity of the shear bond of the concrete open-web sandwich plate with common span. The safety bearing capacity of the shear of shear key of the small-span open-web sandwich plate is close to that calculated in the literature[8-9]; the shear bearing capacity of the long-span open-web sandwich plate is close to that of the literature[10]. Through the parametric fitting correction of the relevant formulas in the literature[8-9] and the literature[10], a more accurate calculation formula of the shear bearing capacity of the shear key is obtained, which provides a calculation basis for the shear performance analysis of the shear key.

KEYWORDS

Shear key, Influencing Factor, Shear Bearing Capacity.

INTRODUCTION

The reinforced concrete open-web sandwich panel is composed of upper ribs, lower ribs and shearing keys connecting the upper and lower ribs, and its structure is shown in Fig. 1. It not only overcomes the weakness of the bad of anti-shear stiffness of the fasting grid, but also retains the advantages of the hollow grid structure[1]. Since its introduction, it has been widely used due to the characteristics of single-layer and multi-layer structures suitable for large-span and wide-opening. Heilongjiang Province and Guizhou Province have successively introduced corresponding norms to guide the application of fast-moving sandwich panels in practical engineering.

In addition to the practical application of engineering, scholars have also carried out many explorations in theoretical research. Literature[2-5] discusses the factors affecting the static performance of open-web sandwich panels, and summarizes the development status of fast sandwich panels and other spatial structures; the literature[6] shows that the steel composite open-web sandwich panels have good seismic performance; Literature[7] shows that the sandwich layer calculation method is more suitable for the
design calculation of large-span open-web sandwich panels. Scholars' research on open-web sandwich panels is mainly focused on the analysis of overall mechanical properties, while the study of shear keys, which are critical to the performance of forces, is rare. In the structure, the shear key mainly bears the shear force transmitted by the upper and lower ribs, and the shear deformation is dominant[1].The literature[8-9] stipulates that the ratio of the height of the shear key to the short side of its cross section should not be greater than 1. At present, the calculation of the force performance of the shear key in China is regarded as the cow's leg. The calculation formula of the bearing capacity of the beef leg and the calculation result of the crack control are used as the calculation formula of the bearing capacity of the shear force and Numerical simulation to study its accuracy and applicability is lack.

In order to analyze the factors affecting the shearing performance of shear key of reinforced concrete open-web sandwich panels, this paper starts with the calculation formula of bearing capacity and gives the factors that may affect the shear performance calculation. Secondly, the factors affecting the shear performance are determined by the finite element analysis results.

**SHEAR CALCULATION FORMULA AND FACTORS AFFECTING SHEAR CAPACITY**

**CALCULATION FORMULA OF REFERENCE [8-9]**

\[
\Delta N_k \leq 0.8 \frac{f_y b h_0}{0.5 + \frac{a}{h_0}}
\]

Where \( \Delta N_k \): The larger of the upper (lower) rib axial force difference on both sides of the shear key calculated according to the load effect standard combination; \( b \): The cross-sectional area of the shear key; \( h_0 \): The effective height of the cross-section of the shear key; \( a \): The distance from the upper rib-shaped mandrel to the lower rib top surface or the lower rib-shaped mandrel to the upper rib top surface.

\[
A_y \leq \frac{\Delta N a}{0.85 f_y h_0}
\]

Where \( \Delta N \): The larger of the upper (lower) rib axial force difference on both sides of the shear key calculated according to the load effect standard combination; \( f_y \): the tensile strength design value of the stirrup; \( A_{sv} \): the total cross-sectional area of the stirrups in the same section of the shear bond; \( s \): the spacing of the stirrups along the height of the shear key.
CALCULATION FORMULA OF REFERENCE [10]

Equation (4) gives the calculation formula for the shear capacity of the inclined section under concentrated load:

$$\left( 1.75 + \frac{1}{\lambda + 1} \right) f_y b h_0 + \frac{(l_0/h - 2)}{3} f_y v A_{sh} h_0 + \frac{(5-1/l_0)}{6} f_{sh} A_{sh} h_0$$

(3)

Where $\lambda$: calculate the shear span ratio, When $l_0/h$ is not greater than 2.0, $\lambda$ is equal to 0.25; when $l_0/h$ is greater than 2.0 and less than 5, $\lambda$ is equal to $a/h_0$ is taken. Where $a$ is the horizontal distance from the concentrated load to the support of the deep flexural member;

Where $l_0/h$: cross-height ratio, When it is less than 2, take 2.

FACTORS AFFECTING SHEAR CAPACITY

Considering the influencing factors in formulas (1)-(4), the upper and lower rib heights, the shear bond height, the shear bond longitudinal reinforcement ratio and the stirrup volume ratio are the factors that may affect the shear capacity of the shear bond. In the next section, the finite element calculation results obtained from the above several parameter changes are compared with the shear capacity of the shear key calculated in [8-9] and [10].

SHEAR KEY SHEAR PERFORMANCE ANALYSIS

REFERENCE MODEL OVERVIEW

Through the calculation of SAP2000, the cross-sectional dimensions of the shear bond of the 16-24 m spanned sandwich panel are obtained, as shown in Table I. For the convenience of analysis, the finite element model with the shear key height of 300mm and the upper and lower rib section height of 300mm is used as the reference model in Table I, of which the data unit is mm. The parameters are changed according to the reference model.

| Numble | Shear key section | Shear key height | Upper (lower) rib section |
|--------|------------------|----------------|--------------------------|
| 1      | 600*600          | 300            | 600*300                  |

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INFLUENCE OF HEIGHT OF UPPER AND LOWER RIBS

The unit of calculation result in the table is kN. When the height of the upper and lower ribs is analyzed to affect the shear capacity of the shear key, the height of the upper and lower ribs is changed, and the remaining parameters are consistent with the reference model. Table II gives the results calculated by ABAQUS: when the heights of the upper and lower ribs are changed, the finite element calculation results are more obvious.

| Height of Upper and Lower Ribs | Result  |
|-------------------------------|---------|
| 300                           | 1046.23 |
| 400                           | 1301.59 |
| 500                           | 1010.00 |

INFLUENCE OF HEIGHT OF SHEAR KEY

The unit of calculation result in the table is kN. It can be seen from Table III that the change of the finite element calculation result is obvious when the shear key height is changed. As the height of the shear key increases, the finite element result decreases first and then increases.

| Height of Shear Keys | Result  |
|----------------------|---------|
| 300                  | 1046.23 |
| 400                  | 939.60  |
| 500                  | 978.72  |

INFLUENCE OF CONCRETE STRENGTH

The unit of calculation result in the table is kN. It can be seen from Table IV that when the concrete strength grade is changed, the calculation result changes obviously and shows an increasing trend. The concrete strength grade of this paper is determined according to Chinese specifications.
TABLE IV. COMPARISON OF CALCULATION RESULTS OF CHANGE OF CONCRETE STRENGTH.

| Concrete Strength | Result   |
|-------------------|----------|
| C45               | 1046.23  |
| C50               | 1051.60  |
| C55               | 1155.58  |

INFLUENCE OF REINFORCEMENT RATIO OF SHEAR KEY

The unit of calculation result in the table is kN. When analyzing effect of the longitudinal reinforcement ratio of the shear key, the longitudinal reinforcement ratio is changed to 1.33% or 2.19% by changing the longitudinal reinforcement diameter to 25mm or 32mm, respectively, within the range specified in[10]. It can be seen from Table V that when the ratio is changed, the finite element calculation result changes little.

TABLE V. COMPARISON OF CALCULATION RESULTS OF CHANGE OF THE LONGITUDINAL REINFORCEMENT RATIO.

| Longitudinal reinforcement ratio | Result |
|----------------------------------|--------|
| 1.33%                            | 998.88 |
| 1.67%                            | 1046.23|
| 2.19%                            | 1233.80|

INFLUENCE OF THE HOOP RATIO OF THE STIRRUPS OF SHEAR KEY

The unit of calculation result in the table is kN. When analyzing effect of the volume hoop ratio of shear key, the volume hoop ratio is changed to 1.14% or 1.64% by changing the diameter of the stirrup to 10mm or 12mm, respectively. It can be seen from Table VI that when the volumetric hoop ratio of the stirrup is changed, the finite element calculation results increase.

TABLE VI. COMPARISON OF CALCULATION RESULTS OF CHANGE OF THE HOOP RATIO OF THE STIRRUPS.

| Longitudinal reinforcement ratio | Result |
|----------------------------------|--------|
| 0.73%                            | 1046.23|
| 1.14%                            | 1264.79|
| 1.64%                            | 1273.20|

SUMMARY

Through parameterized analysis method, the factors that may affect the shear bearing capacity of shear key are analyzed. It is found that the height of upper and lower ribs has the most significant influence on shear capacity, followed by longitudinal reinforcement ratio, concrete strength grade and shears bond height as well as hoop ratio.
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