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Finite Element Analysis on the Effect of Joint Plate Thickness on Neo-Epoxy Resin Concrete Assembled Truss Joint

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Abstract:

In the neo-epoxy resin concrete assembled truss, truss joint serves as a very important core part. The truss joint studied herein is made of neo-epoxy resin concrete, which is connected by a chord member, a web member and a joint plate through the bolt in assembled connection. This paper introduces the theoretical basis of material constitutive relations, analysis hypotheses and boundary conditions, establishes finite element models on K-type joint of neo-epoxy resin concrete assembled truss under three different joint plate thicknesses, performs simulation analysis, studies the impact of joint plate thickness on the stress state of the K-type joint web member, chord member, joint plate and steel bar of the neo-epoxy resin concrete assembled truss. The optimal design recommendations for joint plate thickness are given to lay the foundation for optimizing joint design of neo-epoxy resin concrete assembled truss.

Keywords*: Joint plate thickness, Neo-epoxy resin concrete, Joint connection, Bolt, Finite element analysis, Optimal design.*

I. INTRODUCTION

Neo-epoxy resin concrete exhibits very good properties, which not only has high strength, good durability and good toughness, but also has fast strength growth and short molding time. Because of its obvious advantages, this material is widely used in engineering, such as the bonding and repair of concrete structural members, highway and bridge engineering, local repair and reinforcement of concrete structures, even repair of airstrips and crack reinforcement in engineering, etc., proving its broad application fields [1]. However, in recent years, some domestic scholars have explored mechanical properties of the material, and gradually apply it as a structural material in the field of building structure [2,3].

At present, domestic and international researches on theory and experimental study of truss joints have achieved certain results. In 1936, Rathbumt proposed slope deflection method and applied it to elastic analysis of joints. In 1970, Ronstad and Sumrananian first proposed the

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bilinear model about bending moment-rotation relationship. That is, in connection of most members, compared with rotational deformation, axial deformation and shear deformation are very small, so it was derived from practical engineering experience that only rotational deformation of the connecting piece needs to be considered. Later, Frye and Morris improved the bilinear model and established a multi-mode model to calculate the characteristics of semi-rigid joint. After the 1990s, experts and scholars are no longer limited to the study of mechanical properties of the joint itself, but began to study the impact of joint on the entire structural member. In 1993, the European steel structure design codes EC3, EC4 and the 2000 British code BS5950 gave calculation formulas for judging hinge joints, semi-rigid joints and rigid joints based on joint performance [4]. In China, Liu Yongjian carried out a series of work on rectangular steel tube concrete truss joint [5]. As the first domestic test, the paper carried out bearing capacity test on rectangular steel tube concrete T, Y, X, K type joints and rectangular steel tube Y, X, K type joints, made comparative analysis on effect of parameters such as filled concrete, joint geometric dimension and chord axial force on the joint bearing capacity. It can be used for reference by technicians in the truss design.

The neo-epoxy resin concrete assembled truss joint studied herein is mainly made of neo-epoxy resin. The rod and the joint plate are made independently, which are connected by bolts. To ensure accurate positioning of the bolt during construction, holes are reserved in advance at the bolt holes of the joint plate, chord member and web member. After the members are formed, the bolts are inserted into the holes to form an assembled joint [6-10]. Fig 1 is a schematic diagram of assembled truss joint.

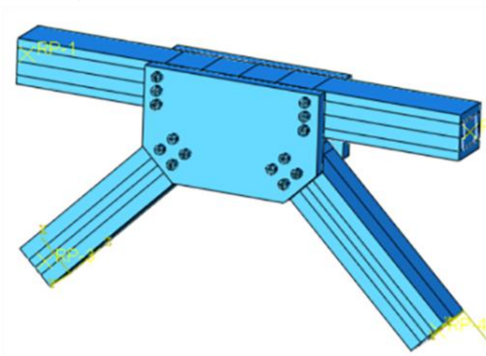

Fig 1:Schematic diagram of assembled truss joint is shown

For the neo-epoxy resin concrete assembled truss joint, due to the characteristics of the material itself and the characteristics of the joint construction scheme, finite element analysis of the truss joint is needed to simulate the stress state, failure mode and ultimate bearing capacity of the joint, thus studying rationality of the joint structure [11]. In this paper, ABAQUS finite element analysis software is used to compare and analyze working performance of neo-epoxy resin concrete assembled truss joint under different joint plate thicknesses [12], thereby providing a basis for the design of neo-epoxy resin concrete assembled truss joint.

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II. THEORETICAL BASIS

2.1 Constitutive Relation

The constitutive relation between steel bars and bolts in the study is simulated using a metal-plastic model to satisfy the strengthening criterion and Von Mises yield criterion. Stress-strain curves of Q235, Q345 and other common steel are shown in Fig 2, which consists of the elastic phase, the elastoplastic phase, the plastic phase, and the strain strengthening phase. f_p is the proportional limit, which is the maximum stress value of the straight line segment in the stress-strain diagram; f_y is the yield limit, after which the stress remains unchanged and the strain develops sustainably. f_u point is the tensile limit.

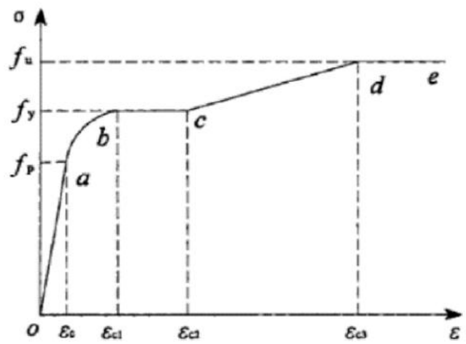

Fig2: Steel stress-strain curve is shown

The five-segment expression is as follows:

$$\sigma_s = \begin{cases} E_S \\ -A\varepsilon_S^2 + B\varepsilon_S + C \\ f_y\left[1 + 0.6\dfrac{\varepsilon_s - \varepsilon_{e2}}{\varepsilon_{e3} - \varepsilon_{e2}}\right] \\ 1.6f_y \\ fy \end{cases}$$

Where, $\varepsilon_e = 0.8 f_y / E_S$, $\varepsilon_{e1} = 1.5\varepsilon_e$, $\varepsilon_{e2} = 10\varepsilon_{e1}$, $\varepsilon_{e3} = 100\varepsilon_{e1}$, $A = 0.2f_y/(\varepsilon_{e1} - \varepsilon_e)^2$, $B = 2A\varepsilon_{e1}$, $C = 0.8f_y A\varepsilon_e^2 - B\varepsilon_e$

To simplify the calculation, this paper adopts a two-stage double-broken line strengthening model. Fig 3 shows the stress-strain relationship of the steel bar. The slope of the ascending section in the figure is the elastic modulus of the steel bar, which is 206GPa, and the Poisson's ratio of the steel bar is 0.3.

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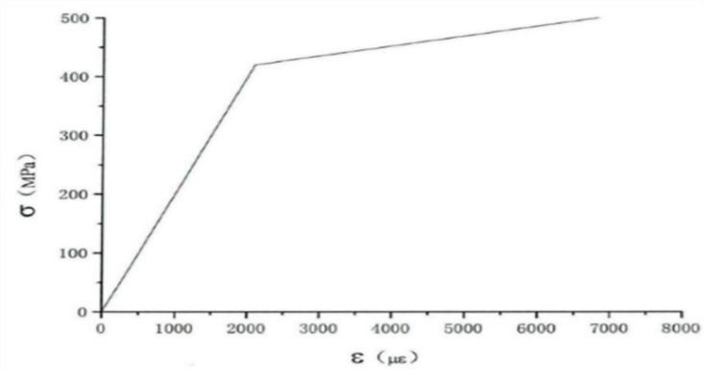

Fig 3:Stress-strain curve of steel bar is shown

Simulation of constitutive relationof the epoxy resin concrete adopts the Concrete Damaged Plasticity Model in the software. In ABAQUS, this model is a continuous linear damage model based on tensile and compressive isotropy, which is suitable for simulating mechanical performance of concrete under complex stress conditions.

In the finite element simulation, the expansive angle of the epoxy resin concrete is 30° based on consideration of concrete, the eccentricity is 0.01, the ratio of the nominal strength and single-cycle strength of the epoxy resin concrete is 1.16 when the biaxial pressure is equal, the ratio of stress invariantson tension and compression meridian is 0.667, and the viscosity parameter value is 0.0005. The data derived fromsampling test of elastic modulus is 4445 kN/mm2, and the Poisson's ratio is 0.45.The neo-epoxy resin concrete adopts the constitutive relation under the optimal mix ratio for finite element simulation.

2.2 Analysis Hypotheses

When establishing the geometric model on K-jointof the neo-epoxy resin concrete assembled truss, four hypotheses are adopted: 1) The bolt is equivalent to a capped cylinder; 2) The model placement mode does not affect the calculation results; 3) The chord member and web member are ideal axial load-bearing members; 4) No prestress is required in the analysis.

2.3 Boundary Conditions

Considering the actual stress conditions of the joint in this paper, the following boundary conditions are to be adopted: epoxy resin concrete chord members are only allowed to move in the loading direction, and the translational degrees of freedom in the other two directions are constrained; similarly, the web members are only allowed to move in the loading direction, while the translational degrees of freedom in the other two directions are constrained. Reference points RP1, RP2, RP3, and RP4 are established for the cross section of the chord member and web member, respectively, as shown in Fig 4-7. Control points are selected while making sure that the pointsare coupled with the cross section of the point, and constraint is set as coupling constraint.

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III. THE EFFECT OF JOINT PLATE THICKNESS ON THE K-TYPE JOINT MEMBERS OF THE NEO-EPOXY RESIN CONCRETE ASSEMBLED TRUSS

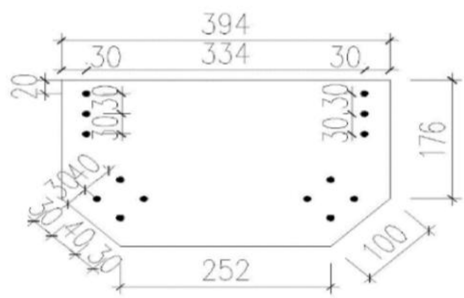
In this paper, the K-type joints under three joint plate thickness are studied to investigate the effect of joint plate thickness on the mechanical properties of the neo-epoxy resin concrete assembled truss joint.

3.1 Dimension of JointPlate Model

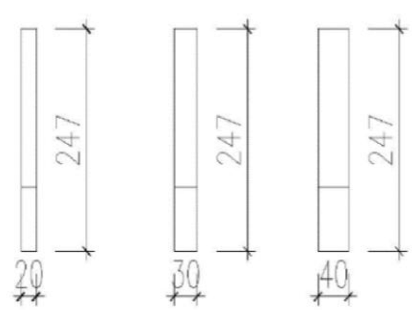
The joint plate thickness is 20mm, 30mm, 40mm. The dimensions of K1, K2 and K3 joint models are shown in TABLE I. The schematic diagram of the joint plate is shown in Fig 4.Where, (a) is front view of the joint plate under three thicknesses, (b) isside view of the joint plate under three thicknesses. The joint load value increases linearly until the truss joint can no longer bear the load.

TABLEI. Dimension of three kinds of joint plate models are shown

Joint type	Bolt diameter (mm)	Joint plate thickness(mm)	Distance between bolt and edge of joint plate (d_0 is bolt diameter)	Cross-sectional dimension of chord and web members (mm)
K1 type joint	10	20	$3.0d_0$	100×100
K2 type joint	10	30	$3.0d^0$	100×100
K3 type joint	10	40	$3.0d_0$	100×100



(a) Front view of the joint plate under three thicknesses is shown



(b) Side view of the joint plate under three thicknesses are shown

Fig 4: Schematic diagram of the joint plate

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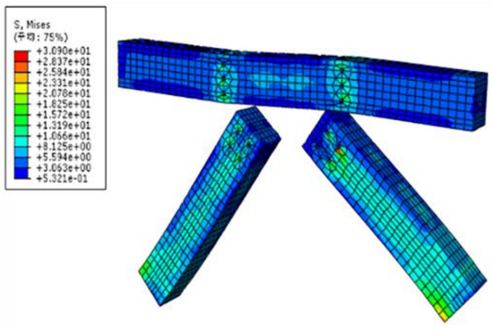
3.2Analysis of CalculationResults

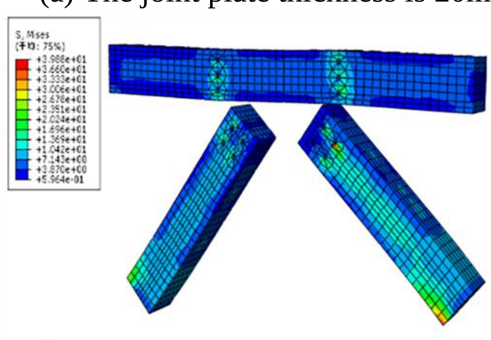
Based on the above basic conditions, the K-type joint of the neo-epoxy resin concrete assembled truss is analyzed under joint plate thicknesses of 20 mm, 30 mm, and 40 mm, respectively.

3.2.1 Stress Distribution of ChordMember andWeb Member

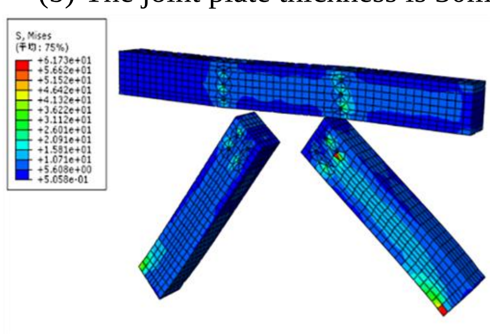
The chordand web members in the model are mainly used to withstand the truss load and transfer the load to the bolts and joint plates at the joints. Linear loading is performed in the analysis until the truss joint can no longer bear the load. Fig 5 is the Mises stress distribution cloud diagram of the neo-epoxy resin concrete chord member.Where, (a) (b) (c) are the stress cloud diagrams of the chord and web memberswhen the joint plate thickness is 20mm, 30mm, and 40mm, respectively.



(a) The joint plate thickness is 20mm



(b) The joint plate thickness is 30mm



(c) The joint plate thickness is 40mm

Fig 5: Stress cloud diagrams of the chord and web membersare shown when the joint plate thickness is 20mm, 30mm, and 40mm, respectively

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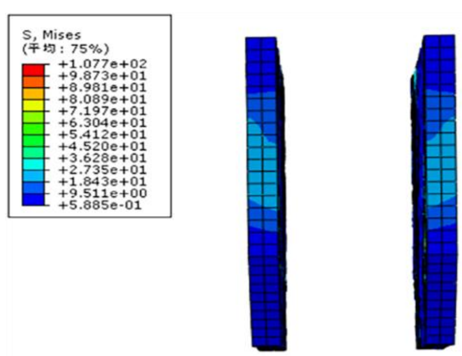
Through the analysis of the stress cloud of the web and chord members, it is found that:

- Under different joint plate thicknesses, failure modes of chord and web members are almost the same;
- The stress on the upper chord member of the neo-epoxy resin concrete shows a regional layered distribution along the chord member in the longitudinal direction, which decreases toward the middle. The stress is basically evenly distributed on the middle chord member of the neo-epoxy resin concrete, while the stress distribution is concentrated at the bolt hole of the upper chord member, which gradually decreases toward the exterior of the bolt hole;
- As the joint plate thickness increases, the stress concentration at the bolt hole is relieved. When the joint plate thickness is 20mm, the load cannot meet the requirements of service load, that is, when the joint plate thickness is 20mm, the joint design requirements are not met;
- The diagonal web member has a larger stress near the loading end, and the stress distribution in the middle is uniform and stable. In the coverage area of the joint plate, regardless of tension rod or compression rod, the stress gradually increases, showing complicated stress state, and the maximum stress occurs around the bolt hole. However, the stress on the chord and web members is very small, with most load transferred to the bolt and the joint plate, and the epoxy concrete deformation is also very small at this time;
- Due to the assembled connection between the web member and the joint plate, at the joint between the web member and the joint plate, the stress is simultaneously transmitted on the web member and the joint plate, and the load on the two is relatively small.

3.2.2 Joint Plate Stress Distribution

Joint plate connects the chord member and the web member to form a whole, so that they are stressed together. Joint plate is a very critical part of the joint model, which involves complicated stress distribution. Fig 6 shows stress distribution cloud diagram of the joint plate when the joint plate thickness is 20mm, 30mm and 40mm respectively.



(a) The joint plate thickness is 20mm

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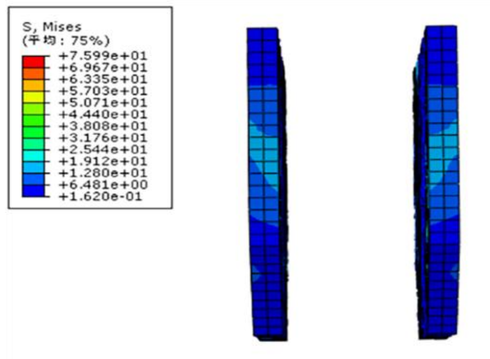
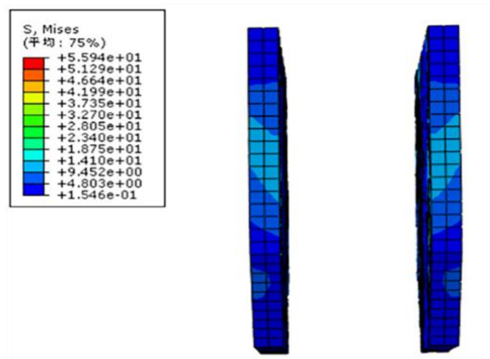


(b) The joint plate thickness is 30mm



(c) The joint plate thickness is 40mm

Fig 6: Stress distribution cloud diagram of the joint plate are shown when the joint plate thickness is 20mm, 30mm and 40mm respectively

In Fig4, (a) (b) (c) show stress distribution cloud diagrams of the joint plate when the joint plate thickness is 20mm, 30mm, 40mm. By analyzing the above stress cloud diagram, the conclusions are:

- The stress distribution trend of the neo-epoxy resin concrete joint plate is approximately the same. The bolt hole and the compression diagonal web member of the joint plate have higher stress, with relatively high stress at the bolt hole due to the stress concentration;
- The connecting part of the compression diagonal web member and the joint plate also shows stress concentration, and the stress of other parts is lower than its ultimate stress level;
- When the joint plate thickness is 20mm, the maximum stress reaches 107Mpa, which has exceeded the compressive strength of epoxy resin concrete, and the concrete at this part will crack;
- As the joint plate thickness increases, the stress on the joint plate shows a downward trend, while the concentration area basically shows uniform distribution, and the internal and external stress distribution trend of the joint plate is approximately the same.

3.2.3 Steel BarStress Distribution

Fig7 (a) (b) (c) show steel bar stress distribution cloud diagrams of the neo-epoxy resin

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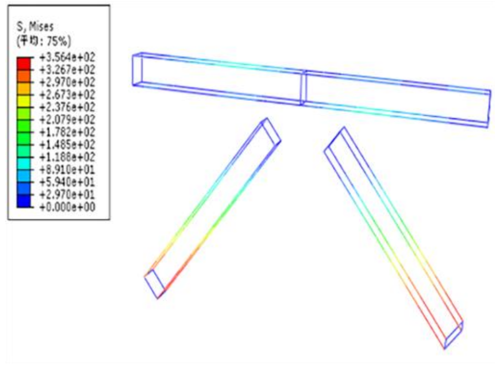
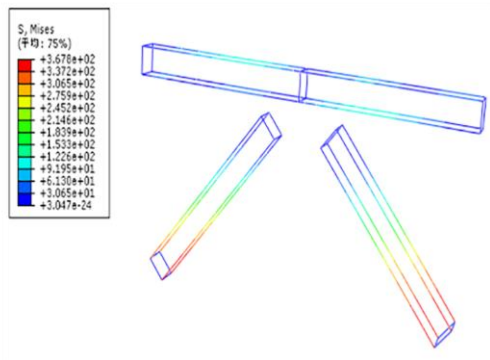
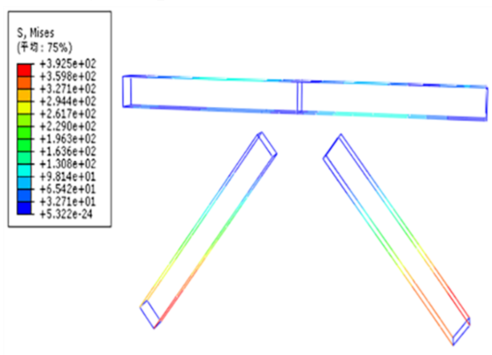
concrete when the joint plate thickness is 20mm, 30mm and 40mm.



(a) The joint plate thickness is 20mm



(b) The joint plate thickness is 30mm



(c) The joint plate thickness is 40mm

Fig7: Steel bar stress distribution cloud diagram are shown when the joint plate thickness is 20mm, 30mm and 40mm

As can be seen from the stress cloud diagram:

- The stress size and condition of the steel bar of different thickness are almost the same, which does not exceed the strength value of the steel bar.
- At the loading end of the diagonal web member, the steel bar and the neo-epoxy resin concrete jointly bear the axial tensile force and pressure. At the joint of the joint plate, chord member and diagonal web member, the steel bar in the neo-epoxy resin concrete is less stressed. Steel bar plays a role in preventing concrete crack.

IV. CONCLUSIONS

The effects of joint plate thickness on the K-type joint of the neo-epoxy resin concrete assembled truss are analyzed, and the main conclusions are drawn as follows:

- The effect of joint plate thickness on chord and web members. The joint plate thickness has little effect on the stress of the chord and web members, and also has little effect on the failure modes of the chord and web members. The stress on the upper chord member shows a regional layered distribution along the chord member in the longitudinal direction, which decreases toward the middle. The stress is basically evenly distributed on the middle chord member of the neo-epoxy resin concrete, while the stress distribution is concentrated at the bolt hole of the upper chord member, which gradually decreases toward the exterior of the bolt hole. As the joint plate thickness increases, the stress concentration at the bolt hole is relieved. When the joint plate thickness is 20mm, the load cannot meet the requirements of service load, that is, the joint design requirements are not met. Therefore, the joint plate thickness cannot be 20 mm;
- The effect of joint plate thickness on the joint plate itself.The study finds thatthe stress distribution trend of the joint plate is approximately the same. The bolt hole and the compression diagonal web member of the joint plate have higher stress. Stress concentration appears at the connecting part of the bolt hole, the compressiondiagonal web member and the joint plate, showing relatively high stress. When the joint plate thickness is 20mm, the maximum stress reaches 107Mpa, which has exceeded the ultimate strength of the neo-epoxy resin concrete. The material cannot bear the corresponding stress. Therefore, the joint plate thickness cannot be 20mm;
- The effect of joint plate thickness on the steel bar. The stress size and condition of the steel bar of different thickness are almost the same, which does not exceed the strength value of the steel bar. At the loading end of the diagonal web member, the steel bar and the neo-epoxy resin concrete jointly bear the axial tensile force and pressure. At the joint of the joint plate, chord member and diagonal web member, the steel bar in the neo-epoxy resin concrete is less stressed. Steel bar plays a role in preventing concrete crack.

Investigation is madeinto the effect ofjoint plate thicknesson K-type joint of the neo-epoxy resin concrete assembled truss structure.Based on stress status and economy of the above members,a comprehensive analysis shows that joint plate thickness is optimal at 30mm, which provides reference suggestions formember dimension in the experiment.

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