Analysis of the influence of key parameters of UHPC-annular reinforcement wet joint

Shao Changfei¹, Qin Kaiqiang², Xiao Wei¹
¹CCCC Second Highway Engineering Co., Ltd., Xian, 710000, China
²CCCC Highway Bridges National Engineering Research Centre CO., Ltd., Beijing, 100088, China
qinkaiqiang@bnerc.com

Abstract. Based on the connection line reconstruction project of Shanghai Road High-speed Railway Station in Suqian City, this paper carried out the impact analysis of the key parameters of UHPC-circular steel bar wet joints, including the influence of steel bar arrangement spacing, steel bar diameter, and wet joint width on the mechanical properties of the joints. From the research results, the steel bar diameter, the steel bar spacing and the width of the wet joint have an impact on the load-bearing capacity performance and normal use performance of the joint structure, but the degree and regularity of the impact are not consistent, and the reinforcement ratio increases. Larger and the increase of the width of the wet joint has a more obvious contribution to the improvement of the ultimate state of the load-bearing capacity of the UHPC-annular steel wet joint, but it has a small impact on the normal use performance. Therefore, the actual design should proceed from the actual project, comprehensively consider the carrying capacity and normal use requirements and rationally design each parameter.

1. Introduction
The research members of this project conducted an analysis and research on the performance of UHPC-annular reinforcement wet joints and the influence of concrete strength in the early stage. From the research results, UHPC-annular reinforcement wet joints have good mechanical properties, especially the post-cast wet joints. The increase in concrete strength has a significant improvement in the performance of the joints in the province, but the improvement in the performance of the entire structure is not very obvious. Therefore, this article will conduct further research on the influencing factors of wet joints, including the influence of the width of wet joints, the form of steel bars and the reinforcement ratio on the mechanical properties of UHPC-annular steel wet joints[1-3].

At present, some scholars at home and abroad have carried out some researches on the wet joint structure and structural optimization of prefabricated structures, but they have not formed systematic results. In the research of UHPC as a wet joint, the design method and construction technology that can effectively guide the design and construction have not been formed. Therefore, this article is based on the UHPC-ring steel wet joint performance analysis carried out by domestic and foreign scholars and members of this research group, and the analysis of the influence of the strength of the joint concrete on the wet joint performance, and the UHPC-ring steel wet joint The analysis of the impact of key joint parameters, combined with the research results, selects the 1~2 spans of the Minbian River ground bridge and the 1~2 spans of the ancient Yellow River ground bridge precast box girder deck joints as the verification of the new joint construction project studied in this paper. According to the
implementation of the supporting project, a comprehensive assessment of the advantages and disadvantages of the new joint structure will provide a reasonable basis for the optimization of the results of the project\cite{4-6}.

2. Finite element model and configuration parameter settings

2.1. Finite element model

The finite element analysis uses ABAQUS software to carry out elastoplastic analysis of the UHPC-annular steel bar wet joint. The concrete adopts the ABAQUS CDP model, and the steel bar adopts a completely elastoplastic model that does not consider the stress strengthening effect of the steel bar.

At present, a large number of scholars at home and abroad have conducted corresponding researches on the constitutive relationship of UHPC (Ultra High Performance Concrete) materials, and have obtained many research results. However, there is still no unified standard for stress-strain curve in the concrete structure design code at home and abroad.

In this paper, the elastic-plastic analysis constitutive relationship of UHPC refers to the relevant regulations in the concrete structure design specification. The tension-compression constitutive relationship of ultra-high performance concrete UHPC120 and ordinary concrete C50 is shown in the figure below.

![Compressed constitutive relationship](image1)

![Tension constitutive relation](image2)

The length of the finite element analysis model is 2m, the width (down the bridge) is 0.6m, the thickness is 0.2m, the width of the middle joint is L, the material is UHPC 120, the applied load is 100kN, and the loading method is four-point bending loading. The bottom support is located at 10cm from the beam end, and the upper loading point is located at 70cm from the beam end. The overall finite element analysis model and the internal reinforcement finite element analysis model are shown in the following figure.

![Overall finite element model](image3)

![Finite Element Model of Internal Rebar](image4)
2.2. Wet joint analysis parameter setting

The elastoplastic analysis model for wet joints is 2m long, 0.6m wide, and 0.2m thick. The precast part uses C50 concrete, and the wet joint position uses UHPC ultra-high performance concrete. The bridge deck is arranged with double-layer HRB400 steel bars with a diameter of 16mm, the longitudinal spacing of the steel bars is 100mm, the horizontal spacing is 150mm, and the thickness of the steel reinforcement protection layer is 20mm.

A total of 3 parameters including the width of the joint, the spacing of the steel bars, and the diameter of the steel bars are set to analyze the influence of the parameters. They are JF1 (the influence of joint width), JF2 (reinforcing bar layout spacing), and JF3 (rebar diameter). For each influencing parameter, 3 sets of parameter influence analysis are carried out. The specific component analysis parameters are shown in the following table.

| Parameters | Width (cm) | Diameter (mm) | Spacing (cm) | Strength (MPa) |
|------------|------------|---------------|--------------|----------------|
| JF1        | 30         | 12            | 10           | UHPC120        |
|            | 40         | 12            | 10           | UHPC120        |
|            | 50         | 12            | 10           | UHPC120        |
| JF2        | 30         | 12            | 10           | UHPC120        |
|            | 30         | 14            | 10           | UHPC120        |
|            | 30         | 16            | 10           | UHPC120        |
| JF3        | 30         | 12            | 10           | UHPC120        |
|            | 30         | 12            | 12           | UHPC120        |
|            | 30         | 12            | 15           | UHPC120        |

3. Parameter influence analysis

In order to better analyze the influence of the three parameters of steel bar arrangement spacing, steel bar diameter, and wet joint width on the mechanical properties of joints, the cracking load, steel yield load and ultimate load under the three sets of working conditions analyzed by each influencing parameter are extracted. Explain here that the cracking load mentioned in this article corresponds to two positions: one refers to the load when the concrete of the post-wet joint part reaches its corresponding axial tensile strength standard value (wet joint cracking load), and the other refers to the load when the concrete reaches its corresponding axial tensile strength standard value (precast slab cracking load).

3.1. Influence of steel bar diameter

This section analyzes three groups of Abaqus models with different steel bar diameters, and extracts the ultimate state of steel bar diameters of 12mm, 14mm, 16mm, bar yield state, wet joint cracking state and precast slab cracking state. The calculation results and the law of change are shown in the figure below.
It can be seen from the figure that as the diameter of the steel bar increases, the load in the limit state of the structure, the yield state of the steel bar, the cracked state of the wet joint, and the cracked state of the precast slab all increase accordingly. Among them, the ultimate load and the yield load of the steel bar have obvious changes, indicating that the diameter of the steel bar has a significant influence on the ultimate load and the yield load of the steel bar. Although the cracking load increases, its impact is relatively small. The results show to a certain extent that the increase in the diameter of the steel bar, that is, the increase in the reinforcement ratio, has improved the ultimate load-bearing capacity of the joint itself and the normal use load-bearing capacity, especially the increase in the ultimate load-bearing capacity is more significant.

3.2. The influence of rebar spacing
This section calculates and analyzes three groups of Abaqus models with different steel bar spacings, and extracts the limit states of steel bar diameters of 10cm, 12cm, and 15cm, the steel bar yield state, wet joint cracking state and prefabricated slab cracking state loads. The calculation results and the law of change are shown in the figure below.

It can be seen from the figure that with the increase of the steel bar spacing, the structural limit state, the steel bar yield state, and the load under the wet joint cracking state are all reduced, while the precast slab cracking load hardly changes. Among them, the change law of the yield load of the steel
bar is more obvious, and it basically changes linearly. The ultimate load and the cracking load of wet joints have relatively consistent changes. The cracking load of precast slabs is basically not affected by the spacing of steel bars. The results show to a certain extent that the increase in the spacing between the steel bars, that is, the decrease in the reinforcement ratio, reduces the ultimate load-bearing capacity of the joint itself, but has a smaller effect on the normal use load-bearing capacity of the joint.

3.3. Influence of the width of the wet joint
In this section, three groups of Abaqus models with different joint widths are calculated and analyzed, and the ultimate load of joint widths of 30cm, 40cm, and 50cm, steel bar yield state load, wet joint cracking load and precast slab cracking load are extracted.

It can be seen from the figure that as the width of the wet joint increases, the structural ultimate load and precast slab cracking load increase, while the steel bar yield load and wet joint cracking load decrease slightly. The ultimate load change of the structure is more obvious, and basically linear. The precast slab cracking load has increased to a certain extent, but the magnitude of the change is small. The change trend of the yield load of the steel bar and the cracking load of the wet joint is the same, and the change is not obvious. The results show to a certain extent that the increase in the width of the wet joint has a significant improvement in the ultimate load-bearing capacity of the joint itself, but has a smaller effect on the normal-use load-bearing capacity of the joint.

4. Conclusion
In this paper, on the basis of the analysis and research on the performance of UHPC- annular reinforcement wet joints, the impact analysis of key parameters of UHPC- annular reinforcement wet joints is carried out. The main research conclusions are as follows:

(1) With the increase of the steel bar diameter, the structural ultimate load, steel bar yield load, wet joint cracking load and precast slab cracking load all increase accordingly. To a certain extent, it shows that the increase in the width of the wet joint has a significant improvement in the ultimate load-bearing capacity of the joint itself, but has a smaller effect on the normal-use load-bearing capacity of the joint.

(2) With the increase of the steel bar spacing, the structural ultimate load, steel yield load, and wet joint cracking load are all reduced, while the precast slab cracking load hardly changes. To a certain extent, it shows that the increase in the spacing of the steel bars reduces the ultimate load-bearing capacity of the joint itself, but has a smaller effect on the normal use load-bearing capacity of the joint part.

(3) As the width of the wet joint increases, the ultimate load of the structure and the cracking load of the prefabricated slab increase, while the yield load of the steel bar and the cracking load of the wet
joint decrease slightly. To a certain extent, it shows that the increase in the width of the wet joint has a significant improvement in the ultimate load-bearing capacity of the joint itself, but has a smaller effect on the normal use load-bearing capacity of the joint.

From the research results, the steel bar diameter, the steel bar spacing and the width of the wet joint have an impact on the load-bearing performance and normal use performance of the joint structure, but the degree and law of their influence are not consistent. The increase of the reinforcement ratio and the increase of the width of the wet joint have a more obvious contribution to the improvement of the ultimate state of the UHPC-annular steel wet joint load capacity, but its impact on the normal use performance is relatively small. Therefore, the actual design should proceed from the actual project, comprehensively consider the carrying capacity and normal use requirements and rationally design each parameter. At the same time, this paper only studies the impact of each key parameter on the structural performance of UHPC-annular steel wet joints from the perspective of numerical analysis. It is recommended that the next step is to conduct related research in conjunction with experiments to further verify the rationality of the conclusions and improve the reliability of the conclusions.

Authors
(1) Name: Shao Changfei
   Employer: CCCC Second Highway Engineering Co., Ltd.
   Address: Huazhong E-commerce Industrial Park, Taizihubei Road, Wuhan Economic and Technological Development Zone, Wuhan
   Post code: 430056
   Tel: 15871730080
   mail box: 6789640@qq.com
(2) About the first author:
   Name: Shao Changfei
   Gender: Male
   Date of birth: August 1980
   Nationality: Han
   Native place: Wuhan
   Degree: Bachelor of Engineering, Liaoning Technical University
   Employer: CCCC Second Highway Engineering Co., Ltd.
   Title: Senior engineer
   What kind of work: Bridge construction management

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