Impact Resistance of Defective Grouted Sleeve Joints Using Ultra-High Strength Grout

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Abstract. Assembled buildings need to meet impact resistance requirements during service. Incompact sleeve grouting is extremely common in assembled buildings, which can result in serious grouting defects that can significantly weaken the impact resistance of building nodes, potentially leading to continuous collapse of the assembled building under impact loads such as vehicle and vessel impacts, explosions, and so on. The use of ultra-high strength grout can effectively improve the tolerance of the sleeve to defects. However, the impact resistance of defective grouted sleeve using ultra-high-strength grout is still unclear. For this reason, the impact tensile test was carried out on the defective grouted sleeve joints with ultra-high strength grout and a finite element analysis model was established based on the test results, and the influence of the grout strength change on the grouting sleeve defect tolerance was investigated through the test and the finite element model. The results show that under impact loading conditions, if an ultra-high strength grout with a strength of 110Mpa is used, it is possible to ensure that the sleeve connection is still qualified when the defect rate is not greater than 20%. For every 10Mpa increase in grout strength, the tolerance of the joint to defects increases by about 5%-7.5%. The correlation formula between grout strength and defect tolerance is established. It can provide a theoretical reference basis for defect prevention and performance evaluation of connection nodes in assembled building.

Keywords: Grouting sleeve, Grouting defects, Impact resistance, Ultra-high strength grout, Connection Performance.

1 Introduction

Assembled building is an important development direction of construction industrialisation. In 1968, Yee invented the grouting sleeve connection[1], after which the grouting sleeve connection became one of the most widely used reinforcement connections in

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assembled buildings. There have been a lot of research results on grouted sleeves. Ling et al[2] found that the reduction of the sleeve diameter and the increase of the reinforcement anchorage length will improve the bond performance through unidirectional pullout tests. Huang et al[3] experimentally tested the effects of reinforcement diameter, sleeve size and reinforcement offset on the tensile properties of half-grouted sleeves. Xiao et al[4] explored the seismic performance of grouted sleeve connections after fire. National codes require that assembled buildings must be able to withstand impact loads such as explosions and vehicle and vessel impacts during service to avoid continuous collapse, so Yin et al[5] evaluated the connection performance of fully grouted sleeves at different loading rates through dynamic tensile tests.

Grouting sleeve requires on-site grouting construction, in the actual project, the grouting will be not dense due to various reasons such as leakage, clogging, bubbles and so on. Thus, serious grouting defects are formed. For this reason, Guo et al[6] investigated the effect of several grouting defects such as end grouting defects and grouting strength defects on the connection performance of fully grouted sleeves through uniaxial tensile experiments. Liu et al[7] compared the performance of defective-containing semi-grouted sleeves under unidirectional tensile and seismic repeated loading conditions. The problem of grouting defects has now become one of the most important reasons for jeopardising the safety of assembled buildings. It has been shown[8] that under static loading conditions, increasing the strength of grout can effectively improve the bond between grout and steel reinforcement, so the use of ultra-high-strength grout can guarantee that the sleeve connection is still qualified even if the defect rate is below a certain range, which effectively improves the tolerance of the sleeve connection for defects. However, the current studies on defective grouted sleeve connections are based on static tensile. Under the impact load, the defect tolerance enhancement law of ultra-high-strength grout for defect-containing sleeve connection is still not clear. Therefore, it is necessary to carry out impact resistance studies on defect-containing sleeve connections with ultra-high-strength grout to determine the variation rule of defect tolerance under impact loading.

Based on the above reasons, this paper carried out impact test studies on defective grouted sleeve joints using ultra-high strength grout, and finite element modelling and analysis was carried out on this basis. The correspondence between the grout strength and the tolerance of defective grout sleeve joints under impact loading conditions was obtained. The results of the study can provide a theoretical reference basis for defect prevention and performance evaluation of grouted sleeve joints.

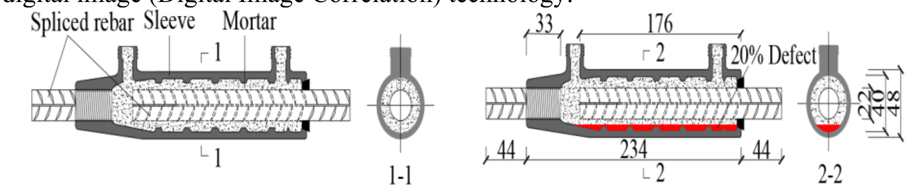
2 Experimental Program

2.1 Specimens and Loading Devices

In order to verify the resistance of grouting sleeves with ultra-high strength grout to defects under impact loading conditions. Specimens of grouting sleeves were designed and poured with ultra-high strength grout and normal high strength grout for comparative analysis. Two levels of defect rates were set at 0% (Comparison specimens without defects) and 20%. (Defect rate can be defined as the ratio of the defect volume to the internal volume of grout material in the sleeve) Three parallel specimens were designed for each parameter. As shown in Fig. 1.

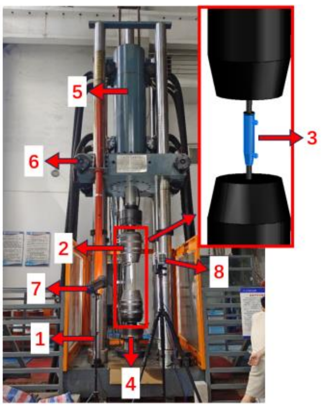
The sleeve is made of QT550-5 ductile iron, the ultimate tensile strength of the sleeve is 550 MPa. HRB400 deformed steel bars with a diameter of 22 mm were used, and the average values of yield and ultimate strength of the measured bars under dynamic loading were 542.17 MPa and 703.41 MPa, respectively. Ordinary high-strength grout and ultra-high-strength grout were adopted as Beijing Sida Jianmao 85MPa grade CGMJM-VI grout and 110MPa grade CGMJM-VIII grout, and the average values of measured compressive strengths were 95.42Mpa and 110.71Mpa, respectively. The performance indexes of grout fluidity and vertical expansion rate were all in accordance with the requirements of Chinese construction industry standard JG/T408[9].

The test was carried out using a high-speed impact testing machine (Fig. 2). The impact velocity of the specimens was set to 600 mm/s. The force was collected by the testing machine, and the displacement was measured and analysed using high-speed digital image (Digital Image Correlation) technology.



(a) 0% Defect (b) 20% Defect

Fig. 1. Sample size and defect details.

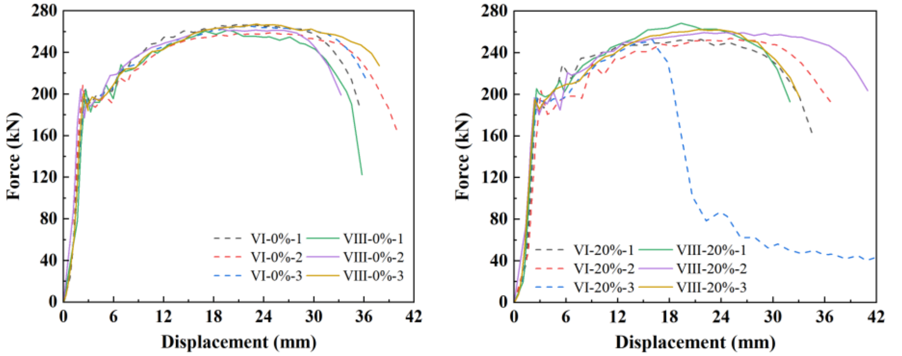


1. Four-column host
2. Forced hydraulic clamp
3. Specimen
4. Load sensor
5. Servo actuator
6. Control valve of loading system
7. Supplementary light source
8. DIC camera

Fig. 2. Loading and measuring system.

2.2 Load-Displacement Curves

The load-displacement curves of the grouted sleeve specimens are shown in Fig. 3 and Table 1(The No. VI and VIII indicate that CGMJM-VI and CGMJM-VIII grout were used, respectively). As can be seen from the table and figure, when the defect rate is 20%, all the sleeve joints with ordinary grout showed pull-out failure under impact loading, while all the sleeve joints with ultra-high strength grout showed reinforcement fracture failure. This shows that when the defect rate is less than 20%, the use of ultra-high-strength grout can effectively reduce the probability of failure of the sleeve connection.



(a) 0% Defect (b) 20% Defect

Fig. 3. Force displacement curves of specimens with different grouting defects.

Table 1. Dynamic tensile test results.

No.	Ultimate loads F_u / kN	Average ultimate load F_u / kN	K_r^b	Failure mode
VI-0%-1	267.23			Reinforcement fracture failure
VI-0%-2	258.73	263.73	-	Reinforcement fracture failure
VI-0%-3	265.22			Reinforcement fracture failure
VI-20%-1	252.91			Pull-out failure
VI-20%-2	253.91	253.18	-	Pull-out failure
VI-20%-3	252.72			Pull-out failure
VIII-0%-1	261.19			Reinforcement fracture failure
VIII-0%-2	263.54	264.05	↑0.12%	Reinforcement fracture failure
VIII-0%-3	267.42			Reinforcement fracture failure
VIII-20%-1	268.45			Reinforcement fracture failure
VIII-20%-2	259.45	263.44	↑4.05%	Reinforcement fracture failure
VIII-20%-3	262.43			Reinforcement fracture failure

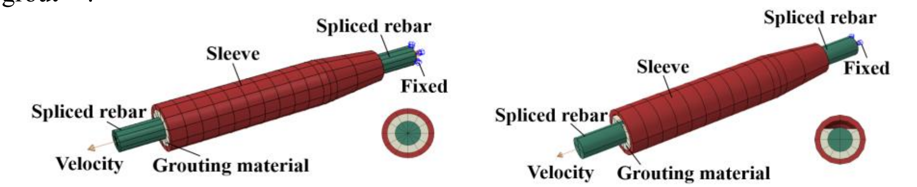
Note: ${}^{b}K_r = (F_{u,\text{VIII-}r} - F_{u,\text{VI-}r}) / F_{u,\text{VI-}r} \times 100\%$, where r denotes the grout defect rate.

3 Finite Element Analysis

3.1 Finite Element Model

ABAQUS was used to establish the finite element model of the grouting sleeve, as shown in Fig. 4.

The elastic-plastic follower strengthening constitutive model[10] was chosen for the steel reinforcement, while the Mander constitutive model[11] was used for the grout constitutive, which can effectively respond to the change of performance of the grout after being restrained by the sleeve, and the plastic damage model was used to respond to the damage of the grout[12]. The dynamic intensification factor DIF[13] for steel reinforcement and concrete were referred to the research literature[14-15], respectively. Grout, reinforcement and grouting sleeves were simulated using C3D8R units[16]. Bond-slip relationship was used to describe the bond-slip relationship between reinforcement and grout[17].

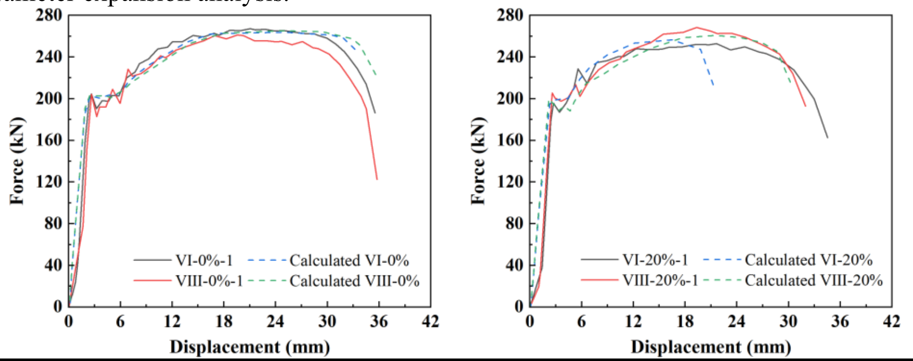


(a) 0% Defect (b) 20% Defect

Fig. 4. Finite element model.

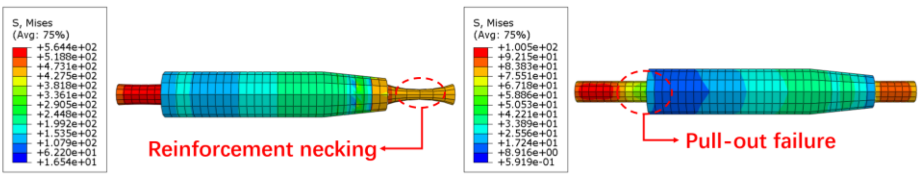
3.2 Model Validation

Fig. 5 and Fig. 6 show the comparisons between the finite element analysis results and the experimental results, which show that the failure mode and load-displacement curves of the model are in good agreement with the experimental results. It shows that the parameter settings of the model are reasonable, and the model can be used for parameter expansion analysis.



(a) 0% Defect (b) 20% Defect

Fig. 5. Comparison of force displacement curves of specimens with different grouting defects.



(a) Reinforcement fracture failure (b) Pull-out failure

Fig. 6. Comparison of typical failure modes.

4 Parameter Analysis

In order to obtain the influence of grout strength on the tolerance of defects of the sleeve, the finite element models of the grouted sleeve connections with grout strengths of 85 MPa, 95 MPa, 110 MPa, and 120 MPa was established, and the damage morphology of the connection was studied when the defect rate was 5%, 7.5%, 10%, 15%, 20%, 25%, 30% and 35%, respectively. The results show that when the grout strength is 85 MPa, 95 MPa, 110 MPa, 120 MPa, the connection still meets the basic requirements of the specification when the defect rate does not exceed 7.5%, 15%, 25%, 30%, respectively, as shown in Fig. 7, and according to Fig. 7, a correlation curve can be fitted between the strength of the grout and the tolerance of the defects, as Equation (1) shown. From the Fig. 7, it can be seen that when the grout strength meets the minimum requirements of the specification (85 MPa), the sleeve has about 7.5% defect tolerance. For every 10 MPa increase in grout strength, the tolerance of the sleeve to defects increases by about 5%-7.5%.

$$r = 0.647M - 46.897 \quad (1)$$

where r denotes the Maximum tolerable defect rate, M denotes the Grouting strength.

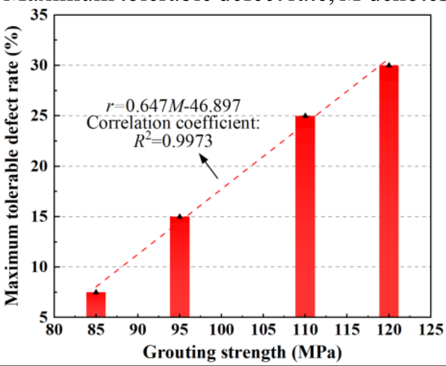


Fig. 7. Probability of specimen failure mode occurrence.

5 Conclusions

(1)The use of ultra-high strength grout can effectively improve the tolerance of the sleeve to defects. Test results show that, under impact loading conditions, if the use of ultra-high strength grout with a strength of 110Mpa, it can ensure that the defect rate is not greater than 20 per cent, the sleeve connection is still qualified.

(2)When the grout strength meets the minimum requirements of the specification (85 MPa), the sleeve has a defect tolerance of about 7.5%, and for every 10 MPa increase in grout strength, the sleeve's tolerance for defects increases by about 5-7.5%.

(3)A correlation calculation formula between grout strength and defect tolerance was established. It can be used to evaluate defect tolerance at specified grout strengths.

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