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Experimental bond behavior of deformed rebars in half-grouted sleeve connections with insufficient grouting defect

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HIGHLIGHTS

- The bond behavior of insufficiently grouted sleeve connection was investigated.
- The shifting failure mode was identified with the defect level of insufficient grouting.
- The bond strength and slip were analyzed with the effect of insufficient grouting.
- A constitutive model of bond was proposed for insufficiently grouted connection.

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ABSTRACT

Insufficient grouting of sleeve connection in precast concrete (PC) structure will significantly decrease the bearing capacity of connection joints and increase the risk of premature failure of PC structures. To evaluate the bond behavior of insufficiently grouted sleeve connection, a total of 126 specimens with four types of insufficient grouting configuration (uniform, longitudinal, radial and inclined) have been experimentally investigated. The influences of the configuration and defect level of insufficient grouting on the bond failure mode and bond stress-slip curves were analyzed. The test results show that the specimens fail in the shifting failure mode from the tensile fracture of rebar to the pulling out of rebar with the increase of defect level for all types of grouting defects, especially when the defect level excesses 30%. Moreover, the bond strength and the slip are found to decrease with the increasing of defect level, and empirical expressions have been presented for both the normalized bond strength and slip. Finally, a bond stress-slip constitutive model has been proposed considering the failure modes under different defect levels, which is helpful to the assessment of structural performance of PC structures in practice.

1. Introduction

A precast concrete (PC) structure is an assemblage of prefabricated concrete elements which are connected by connection joints to resist gravitation and lateral forces. Due to the considerable advantages over cast-in-place concrete structure, particularly in reducing the demanded construction period, PC structure has been widely adopted in structure engineering. Therefore, numerous investigations have been carried out on the mechanical performance of both the precast elements and the whole precast structure, including unbonded precast reinforced concrete [1], precast concrete walls using carbon fiber strips [2], friction-damped precast concrete [3], precast concrete for steel stud construction [4], precast concrete segmental bridge columns [5].

As the most crucial part of PC structure, the connection joint enables the PC structure to transfer forces among PC elements and then provide bearing capacity and ductility. Therefore, a favorable mechanical performance of connection joint is necessary for PC structure, but it can be affected by many factors. Nzabonimpa et al. [6] studied the dry mechanical beam-column connection joints for PC frames while Jin et al. [7] investigated the shear capacity of unbonded PC beam-column joints. Yu et al. [8] tested the behavior of PC beam-column joints under low reversed cyclic loading. The position of beam-column joint was found influence the behavior of PC structure [9]. The investigations showed that with well-designed and well-fabricated connection joints, PC structure possesses the equivalent structural performance comparing with the cast-in-place concrete structure. Moreover, guidance for the detailing of PC construction is provide by America Concrete Institute (ACI) to emulate a cast-in-place detailing [10]. In this point of view, the design principle for cast-in-place concrete structure is applicable to the design of PC structure.

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Grouting sleeve has been widely used to connect the reinforcing bars at the connection joints. Based on the mechanism of load transferring, the connection of grouting sleeve can be classified into full-grouting connection and half-grouting connection. After the invention by Yee in 1967 [11], the connection of grouting sleeve was first applied to a 38-floor hotel in the 1970s. With the development and improvement, thereafter, this connection technology has acquired the worldwide application in the PC industry. Lamport et al. [12] investigated the influences of loading form, the relative position of shear connector and the grout strength on the bond strength of grouted pile-to-sleeve connection. The test results show that the ultimate bearing capacity of the sleeve connection is related to the square root of the grout strength. Hayashi et al. [13] tested the distribution of bond stress along the deformed rebars embedded in grout-filled steel sleeve, and the relationship is presented between the maximum local bond stress and the slip of rebar. Through utilizing the different metal sleeve with and without stirrup and shear connector, Ling et al. [14–16] studied the mechanical property and failure mode of sleeve connection subjected to axial loading. The results showed that the required embedded length of the splice rebar can be reduced to 8 times the bar diameter with the presence of confinement. Einea et al. [17] presented four types of grouting sleeves with different inner structures by modifying the steel tubes, the bond strength was theoretically derived with considering the restraining action of sleeve and then compared with the pullout test results of grouting joints. Zhou et al. [18] investigated the influences of the anchorage length and the ratio of inner diameter of sleeve to bar diameter on the monotonic bond-slip response of stainless reinforcing bar. Phenomenological nonlinear bond-slip relationship was developed based on the free-end slip of rebars. Furthermore, Ling et al. [19] researched the grouted splices connected by other two types of sleeves, namely Welded Bar Sleeve (WBS) and Tapered Head Sleeve (THS). Sayadi et al. [20] carried out an investigation on the connection behavior of glass fiber reinforced polymer (GFRP) sleeve in PC structure. The influences of the embedded length of reinforcing bar, the material property of GFRP layer and the position of the sleeve ribs on the bond capacity of GFRP sleeve have been experimental examined.

Additionally, various grouting defects could take place in sleeve connections, including insufficient curing of grout, position deviation of reinforcement and insufficient grouting. Wu et al. [21] found that the tensile bearing capacity and the slip of the splice rebars in sleeve connection were largely reduced at the early curing time. Huang et al. [22] studied the influence of the position deviation of reinforcement on the load carrying capacity of the connection joint. Moreover, Zhu and Ye [23] pointed out that the insufficient grouting has been found in PC infrastructure due to certain reasons during construction process, and presented the grading standards for grout compactness and classified grouting defects into four levels. In order to study the bond property of half-grouted sleeve connection, Zheng et al. [24] investigated the influences of the characteristics of grouting defect, including the location, length, number of longitudinal grouting defects, the reinforcement deviation and the grout type, on the bond capacity and deformation on sleeve connection specimens. Experimental studies have been undertaken on the bond performance of half-grouted sleeve connections with several grouting defects, however, rare investigation has been carried out on the mechanical behavior of the insufficient grouting sleeve connections. Since the insufficient grouting of sleeve connection can be occasionally found in the PC structures, a clear understanding of the bond behavior is critical and pre-requisite for the evaluation of the structural performance and the assessment of the failure risk for PC infrastructure.

This paper presents a systemic experimental investigation on the bond performance of the half-grouted sleeve connection with insufficient grouting defects. A total of 126 specimens of half-grouted sleeve connection with four types of defects were tested in this research, and the influences of the configuration and degree of grouting defects on the bond behavior were experimentally investigated. The failure mode, and bond capacity and the critical slip of sleeve connection were related to the characteristics of grouting defect, and finally a bond stress-slip constitutive relationship has been proposed which is helpful to the analysis of structural performance for PC structures.

2. Experimental program

2.1. Materials and specimen preparation

In this study, half-grouted sleeve was utilized to server as the connector for connecting deformed reinforcing bars in PC structure. Commercial half-grouted sleeves with the configuration as shown in Fig. 1 were prepared for the tests and the detailed geometric parameters are listed in Table 1. The commercial sleeves were manufactured by QT550-5 steel (with the ultimate strength of 550 MPa) in accordance with Chinese profession standard JGT 398-2012 [25]. HRB400 deformed reinforcing bars with a diameter of d_b = 20 mm were used in tests, whose material composition and mechanical performance were manufactured conforming to Chinese profession standard JGJ 1499-2007 [26]. The test yielding and ultimate strengths are 458 MPa and 588 MPa, respectively, and the Young's modulus E_s and the Poisson's ratio υ_s are respectively 210 GPa and 0.3 according to the manufacturer's specifications. Mortar of grade M85 was used as adhesive material in accordance with Chinese profession standard JGJ 107-2016 [27], which had a test compressive strength of 91.85 MPa.

All sleeve connection specimens were fabricated with the standard anchorage length of L_0 = 143 mm based on the design requirements for the commercial half-grouted sleeve. The fully grouted sleeve connection specimens were taken as the reference group (Type A). In the construction of PC infrastructures, grouting defects could be resulted by the pores in mortar due to the hydration of cementitious adhesives, and insufficient grouting of mortar which could be parallel and perpendicular to the rebar surface and at an inclined angle. To investigate the influence of the insufficient grouting characteristics on the bond behavior, four types of grouting defects have been designed to model the insufficient grouting in PC structure. These four types of insufficient grouting defects are noted as uniform grouting defect (Type B), longitudinal grouting defect (Type C), circumferential grouting defect (Type D) and inclined grouting defect (Type E) with an inclination angle of around 15°, which are schematically illustrated in Fig. 2. For fabricating specimens with different grouting defects, the mortar was uniformly mixed with small foam particles with the diameter of 0.5–1 mm to simulate the uniform distribution of pore formed in hydration process for the specimens of Type B, and soil with designed shape and volume was injected into the sleeves in advance to model the possible insufficient grouting defects for the specimens of Types C–E. Each type of insufficient grouting was rated into different levels in term of the volume-ratio of the insufficient grouting portion to the whole grouting portion, which is shown in Fig. 2. For specimens with Type B grouting defect, the volume-ratio of insufficient grouting was varied from 0 to 25%, whilst the volume-ratio was varied from 0 to 50% for Types C–E. Six replicas were prepared for each group of designed specimens, therefore, a total of 126 specimens (21 groups) have been fabricated for the experimental program.

2.2. Test arrangements

To test the bond stress-slip response of experimental samples, the connection specimens were loaded in tension by an electro-hydraulic servo testing machine, as schematically shown in Fig. 3. The two ends of the sample were fixed by the fixtures of testing machine, and the tensile loading was applied at a loading rate of 0.5 kN/s. The applied tensile load was measured by the inbuilt load cell, and the slip of reinforcing bar to sleeve was monitored by LVDTs (Linear Voltage Displacement Transducers).

The nominal bond stress τ is determined by dividing the pulling force F by the contact area between the reinforcing bar and mortar, i.e. $\tau = F/(\pi d_b L_0)$, where d_b is the bar diameter and L_0 is the standard anchorage length. The bond slip s was taken as the average of the slips at the loaded-end of reinforcing bars. It should be noted

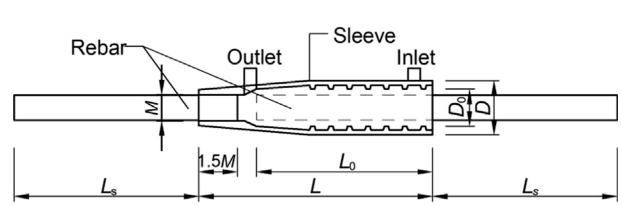

Fig. 1. Half-grouted sleeve connection specimen.