Construction and Building Materials 152 (2017) 96–104

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Tensile behavior of half grouted sleeve connections: Experimental study and analytical modeling

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HIGHLIGHTS

- Tensile behavior of half grout sleeve splicing are studied experimentally.
- The failure modes include rebar tension fracture, bond failure and thread sliding failure.
- Analytical model is established to calculate the tensile capacity.
- Satisfactory agreements are made between the predictions and test results.

ARTICLE INFO

Article history:
Received 28 March 2017
Received in revised form 24 May 2017
Accepted 26 June 2017

Keywords:
Half grout sleeve connection
Failure mode
Bearing capacity
Strain
Analytical model

ABSTRACT

Half grouted sleeve connections, consisting of a threaded end and a grouted sleeve end, are a convenient and economical solution in joining rebars together in precast concrete construction. In order to study the tensile properties of this connection, 15 half grouted sleeve splices for steel bars were tested under static tensile load. The main parameters of the experimental research are bar diameter, sleeve dimensions and rebar offset. The tests show that the specimens exhibit three categories of failure, namely rebar tension fracture, rebar pull out due to bond failure, and thread shear failure. Rebar offset due to construction error has a negligible influence on the load carrying capacity of the specimen. An analytical model is established to calculate the tensile capacity of the specimens with bond failure considering the confinement effect of the sleeve. Satisfactory agreements are made between the predictions and test results. The issues leading to thread failure are discussed. A design method is proposed to prevent specimens from premature thread failure.

1. Introduction

Grouted sleeve connections are widely used in precast concrete construction for joining rebar at precast joints [1–4]. Fig. 1 shows typical details for a vertically-connected precast concrete wall structure using grouted sleeve connections [5]. A number of sleeves are embedded at the bottom of an upper precast wall panel. The distance of sleeves is determined by design requirements. Usually the aim of design is to ensure that the sleeve connection have the same performance as cast-in-situ connection. When the sleeves are placed onto the ribbed rebar protruding from the top of the lower precast wall panel, they are filled with high-strength and low-shrinkage grout. At the time the grout attains its specified strength, a strong bond will develop through interaction among the sleeve, grout and rebar. When the wall panel is subjected to lateral loads, such as wind and seismic demands, the overturning moment at the bottom section will result in tension and compression at the opposite sides of the section. The main function of the grouted sleeve connections is to resist tension induced by these effects.

Two types of grouted sleeve connections are typically used. They are full grouted sleeve connection and half grouted sleeve connection. A full grouted sleeve connection has grouted sleeve joints at both ends so that two bars are grouted into the coupler to form the connection. Full grouted sleeve connection reduces the connection length comparing to lapped connection because of the confinement effect of sleeve [6–8]. It also reduces the precision required during construction because the inner diameter of the sleeve is large enough to accommodate moderate construction errors. The behavior of full grouted sleeve connection has been studied by a number of researchers. The idea of grouted sleeve connection came from the observation that confinement in concrete increases bond strength of rebar [9–11].

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http://dx.doi.org/10.1016/j.conbuildmat.2017.06.154

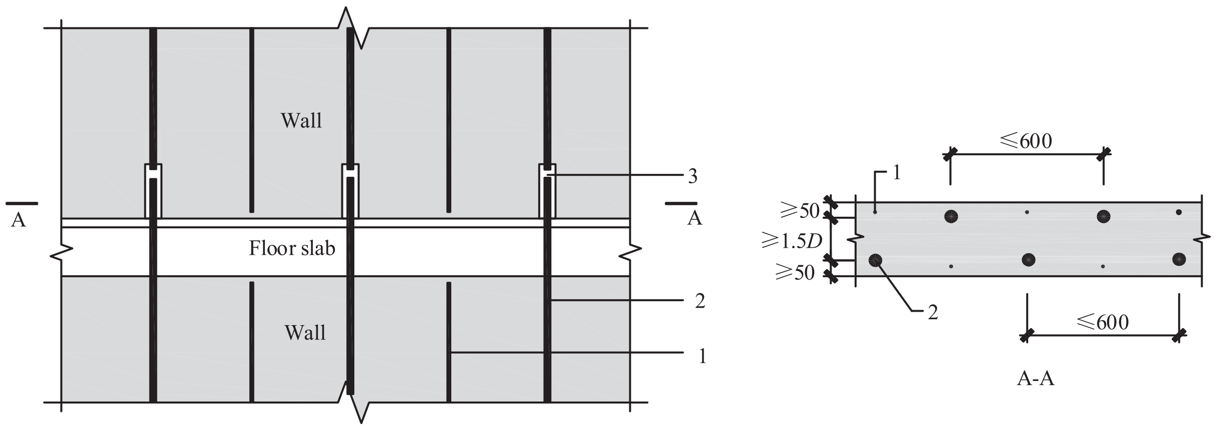

Fig. 1. Grouted sleeve connections used in precast concrete wall.

In 1995, Einea et al. used grouted pipes to join steel bars. He studied the tensile behavior of reinforcing bar splice using grout-filled standard steel pipe and spirally confined lap splices of deformed steel bars [12,13]. He concluded that the confinement effect provided by the pipe could result in significant reduction of the required lap length. Zhao et al. tested grouted sleeve connections under high temperature. They found that the ultimate load decreases linearly with temperature difference between outer and inner tubes increases [14]. Belleri et al. investigated the seismic behavior of grouted sleeve connections. They concluded that grouted sleeves ensure seismic performance similar to those of traditional connections [15]. Ling et al. conducted a number of studies on tensile behavior of grouted splice connector [16–18]. Ameli et al. tested 3 column–to–cap beam joints connected by half grouted sleeve connections. They concluded that the joints are expected to perform well in moderate to high seismic regions [19]. Sayadi studied the bond behavior of splice sleeves by flexural tests of beams and tensile tests of connections. The results showed that increasing the confinement in elastic length of sleeve caused reduction in bond strength [20,21]. Henin and Morcous introduced a non-proprietary bar splice sleeve that is economical and easy to produce [22]. Their test results indicated that the proposed bar splice sleeve satisfies the design requirement to fully develop connecting bars. Seo proposed a head-splice-sleeve and explored its bond strength by static tests [23]. They recommended that a suitable diameter ratio between head and bar is 1.3 for the design purpose. Hosseini and Rahman studied in the bond behavior of grouted spiral connection [24]. The influence of spiral confinement is highlighted. They founded that the spiral diameter provides more dominant confinement effect than spiral pitch distance in increasing the bond strength.

Half grouted sleeve connection, namely threaded and grouted sleeve connection, has a threaded joint at one end, usually embedded in a precast component, and a grouted sleeve connection at the other end. The schematic of half grout sleeve connection is illustrated in Fig. 2. Half grouted sleeve connection has a number of advantages over fully grouted connections. It requires a shorter connection length because the length of a threaded connection is typically less than two times the diameter of the rebar, while the length of a grouted sleeve connection usually requires six to eight times the diameter of the rebar. Half grouted sleeve connections allow for increased precast construction times because the installation of the threaded connection is easy. It also reduces construction error since the threaded joint embedded in a precast component can be placed with a high precision.

Despite its advantages, the behavior of half grouted sleeve connection has not been fully addressed in the literature. And the effect of rebar offset due to construction error has rarely been studied. This paper presents an experimental research program on the tensile behavior of half grouted sleeve connection. Two parameters are examined in the test. They are the diameter of the connecting rebar and the offset of the protruded rebar from the center line of the sleeve. The performance of the connections is assessed by a criterion based on ACI-318 [25] and JGJ 355 [26]. An analytical model is developed to predict the tensile capacity of half grouted connections considering the confinement effect of the sleeve. Some design suggestions are made for the design of half grouted sleeve connections.

2. Test program

Four sizes of half grout sleeve are tested in this research. They are used for rebar diameters of 14 mm, 18 mm, 22 mm and 25 mm, respectively. Details of the half grout sleeve connections are shown in Fig. 2. The sleeve is made of ductile iron [27] with a tensile strength of 610 MPa. The dimensions of the sleeve are listed in Table 1. In precast concrete construction, a rebar with a straight thread end [28] is screwed into the threaded end of the sleeve at first. The grout hole and the vent hole are connected to corrugated hoses extending to the surface of the panel for the later grouting. Then the rebar and sleeve are cast into the bottom of a precast wall panel. When the protruded rebar from a lower precast wall is inserted into the sleeve on the upper panel, grout is filled into the sleeve from the grout hole by a grout pump. If grout outflows from the vent hole, pumping is stopped and the sleeve is assumed to be fully filled with grout. Then the grout hole and the vent hole are sealed with a foam plug for protection.

Fifteen specimens are tested with two parameters being studied. One parameter is the diameter of rebar ranging from 14 mm to 25 mm which are commonly used in practice. The other is the offset of protruding rebar from the center line of the sleeve to account for the effect of construction error, as shown in Fig, 3. Wood form work are constructed to assure the rebar to be positioned accurately in the grout sleeves, which also permit the stability of the specimens during the curing process. Threaded bars are installed in the sleeves by a pipe wrench. Then a torque wrench is used to check that the values of torque are no less than 100 Nm and 200 Nm for GS14 and GS18, respectively. For GS22 and GS25, the minimum value of torque is 260 Nm. Table 1 summarizes the details of the specimens.