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Tensile capacity of grouted splice sleeves

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ABSTRACT

This study tests grouted splices connected by two types of sleeves, namely Welded Bar Sleeve (WBS) and Tapered Head Sleeve (THS). These sleeves are made from non-proprietary pipe sections, where (a) WBS is fabricated by welding the deformed bars to the inner wall of the pipe, and (b) THS is made tapered with smaller openings at both ends. To study the behavior, the splice specimens were tested under incremental tensile load at various bar embedded lengths and sleeve diameters. The degree of confinement generated in the sleeve is found to increase with decreasing sleeve diameter. This improves the bond strength in sleeve, which subsequently increases the tensile capacity of the splice. THS gives a 30% higher tensile capacity compared with WBS. With the active confinement, the required bar embedded length of the splice can be reduced to 8 times the bar diameter. An analytical model is formulated on the basis of the confinement stress as expressed in a function of sleeve dimensions. The model is used to predict the tensile capacities of the splices at a variation range of ±10% of the experimental results. This verifies the correlations among the sleeve dimensions, the confinement stress and bond strength of the grouted splice.

1. Introduction

Steel bars are usually adjacently lapped in reinforced concrete structures. This method requires long lapping lengths, and it is not practical for connecting precast concrete elements. Due to the simplicity of connecting and short bar embedded length, mechanical and welded splices are commonly used for precast concrete structure [1–4].

There are many mechanical splices [5–7]. Some of these splices may not be easily acquired in certain countries as it is not common. This results in a longer duration and additional cost to acquire them. Additionally, some of the splices require high precision to ensure the alignment of the spliced bars due to tight tolerances.

Using non-proprietary pipes to splice steel bars could be a solution in cases of unavailability or when it is too costly to acquire those proprietary splices. With knowledge of the design, steel bars could be easily spliced by using pipe sections, of course, with slight modifications. Also, the designer could easily choose suitable sizes of pipe to fit the tolerance requirements.

The idea of using non-proprietary pipes to splice steel bars was proposed by Einea et al. [8] in 1995. Kim [9] adopted the idea and used pipe sections as the beam-column connection. Since then, researchers have developed grouted splices using various non-proprietary materials, such as mild steel pipes [10–14], corrugated aluminum sleeves [15], spirals [16], square hollow sections [17], and glass fiber reinforced polymers [18–21].

These non-proprietary splices are called grouted splice which is a type of mechanical splice consisting of a sleeve, some grout and two spliced bars. The steel bars are spliced and bonded by grout in the sleeve. The grout mechanically interlocks with the ribs on the bars to prevent the bars from slipping out of the sleeve [11,22–24]. The sleeve confines the grout to increase the bond strength, and subsequently, reduces the required anchorage length of the bars in it [8,13,25,26].

This study intends to develop grouted splices by using pipe sections. While developing grouted splices, the following is considered:

- For the splices which rely on gripping mechanism to prevent the slippage of the spliced bars, gripping-slip usually occurs [27]. The bar slips suddenly under load and it is not recoverable. To avoid this, steel bars should be bonded by using grout.
- When steel bars are adjacently spliced, the load eccentricity causes the connector to inevitably self-align and rotate [28].

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Nomenclature

Symbol	
$A_{c,b}$	contact surface area of spliced bar, mm^2
$A_{c,sl}$	contact surface area of sleeve with grout, mm^2
E_{sl}	modulus of elasticity of sleeve, N/mm^2
F_n	confinement force acting on grout, kN
P_b	bond strength of grouted splice, kN
$P_{b,ths}$	bond strength of THS, kN
$P_{b,wbs}$	bond strength of WBS, kN
P_u	tensile capacity of grouted splice specimen, kN
$P_{u,avg}$	average tensile capacity of grouted splice specimen, kN
$P_{u,exp}$	experimental tensile capacity of grouted splice specimen, kN
$P_{u,pre}$	predicted tensile capacity of grouted splice specimen, kN
R_r	reliability ratio
T_b	tensile capacity of spliced bar, kN
$T_{t,sl}$	transverse tensile force of sleeve, kN
d_b	diameter of bar embedded in the sleeve, mm
d_{si}	inner diameter of sleeve, mm
d_{se}	outer diameter of sleeve, mm
d_{wb}	diameter of bar welded to WBS, mm
$f_{t,sl}$	transverse tensile stress of sleeve, N/mm^2
$f_{u,g}$	ultimate compressive stress of grout, N/mm^2
f_y	nominal yield stress of spliced bar, N/mm^2
l_b	bar embedded length in sleeve, mm
l_{sl}	length of sleeve, mm
s_1	standard deviation of tensile capacity of grouted splice specimen
s_2	standard deviation of displacement of bar
t_{sl}	thickness of sleeve, mm
α	tapered angle of THS, °
δ_u	displacement of bar at failure, mm
$\varepsilon_{t,sl}$	transverse tensile strain of sleeve, mm/mm
u_b	bond stress acting on spliced bar, N/mm^2
$u_{n,b}$	confinement stress acting on spliced bar, N/mm^2
u_n	normal confinement stress in sleeve, N/mm^2

This deformation generates undesired stress at the rotating point of the spliced bars, and therefore, hinges are formed at the spliced bars. For this, steel bars should be aligned end-to-end without eccentricity.

- Some splices require the spliced bars to be threaded for the purposes of installation. However, threading causes damage to the bar. It degrades the bond and the tensile capacity of the spliced bar [11,23,29]. Thus, it should be avoided.

Grouted splices are usually tested under incremental tensile load [8,14,17,29]. Based on ACI-318 [30] and AC-133 [31], the tensile capacity should be at least 125% of the nominal yield strength of the spliced bars. This sets the evaluation criteria to determine the feasibility of the splices.

This paper fills the gap of knowledge in the study of grouted splices. Some researchers performed regression analysis to predict the response of the splice under tensile load [12]. The effect of the confinement stress is not incorporated in the model, although it is generally agreed to increase the bond strength [20,25,32–34]. Some studies successfully correlate the bond stress with the confinement stress [8,26]. However, it is still a distance away from obtaining the tensile capacity of a grouted splice, as the capacity may not always be governed by the bond strength.

This paper presents the experimental results of two new grouted splices. The performance of the splice under tensile load is evaluated with respect to two parameters, the bar embedded length and the sleeve diameter. An analytical model is formulated to predict the tensile capacity on the basis of (a) the approach used to measure the confinement stress in the sleeve, which is proposed by Einea et al. [8], and (b) the model correlating the bond stress with the confinement stress, as demonstrated by Untrauer and Henry [26].

Studies show that the degree of confinement generated in the sleeve is somehow governed by the dimensions and the configurations of the sleeve [8,11,29]. Hence, the equations for predicting the tensile capacity are expressed as a function of the sleeve dimensions. This is done by correlating the stress parameter with the dimension parameters in the equations. To justify this, the equations are then verified by the experimental results.

As an overview of this paper, the test specimens and the experimental program are described in Section 2. The experimental results are presented and discussed in Section 3. Section 4 presents the formulation of an analytical model to predict the tensile capacity of the grouted splice. The model is then evaluated for reliability in Section 5. Finally, in Section 6, the conclusions of the study are presented.

2. Test methodology

2.1. Test specimens

This study tests two grouted splices, namely Welded Bar Sleeve (WBS) and Tapered Head Sleeve (THS) (Fig. 1). The sleeves are made from mild steel pipes with the inner diameters, d_{si}, of 50 mm, 65 mm and 75 mm (Table 1). Steel bars, with the nominal yield strength of 500 N/mm^2 and the nominal diameter of 16 mm, are spliced at the embedded lengths, l_b, of 75 mm, 125 mm and 175 mm (Table 1).

Welded Bar Sleeves (WBS) are fabricated by welding four steel bars (nominal yield strength of 500 N/mm^2 and bar diameter of 10 mm) to the inner surface of the pipes (nominal yield strength of 250 N/mm^2). The ribs on these welded bars interlock with the grout to prevent the grout from slipping out of the sleeve.

Tapered Head Sleeves (THS) are made tapered with small openings at both ends of the pipe (d_{se} = 35 mm). The space volume

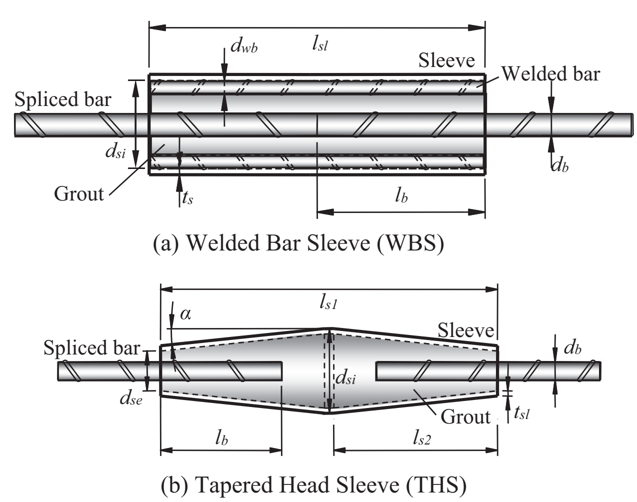

Fig. 1. Schematic design the grouted splice specimens.