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Feasibility study of grouted splice connector under tensile load

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HIGHLIGHTS

- Use of standard size steel section to confine splicing of bars.
- Feasibility assessment of grout splice connection under tensile load.
- Derive equations to evaluate the response of splice connection.

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ABSTRACT

The conventional bar lapping approach to connect steel bars requires long development length and always leads to bar congestion problems. For this reason, grouted splice connectors are used to confine the grout surrounding the bars to improve the bond between the grout and the bars. Four series of specimens with a total of 35 specimens were tested under incremental tensile load. These specimens vary in terms of configurations and were assessed for feasibility in the aspects of bond strength, ductility response and failure modes. Equations are derived to evaluate the structural performance of the specimens. The typical modes of failure are bar tensile failure, grout-bar bond failure, grout-sleeve bond failure, and sleeve tensile failure. These failures reveal the factors to be considered during the design of a splice connector. Under confinement, the required anchorage length of the bars can be shortened to nearly nine times the diameter of the spliced bar.

1. Introduction

Ever since the first use of iron reinforced concrete structure by Thaddeus Hyatt in 1853, many researchers started to study the bond between steel and concrete, experimentally and analytically. The scopes of study include the mechanisms of bond [1], the interlocking effects of the geometry and patterns of the ribs on steel bars [2,3], the relative rib area to generate bond strength [4,5], the distributions of bond stress along a bar [6,7], the crack propagation surrounding the steel bars [7–11], etc.

The research developed further to connect steel bars in concrete, by lapping adjacent bars [12–14]. This method requires a long development length of bar for stress to entirely transfer from a bar to another in concrete. It often leads to detailing and bar congestion problems, especially when large diameter steel bars are used in heavily reinforced structures. To solve this problem, lateral forces and confinement were induced to increase the bond strength and to reduce the development length [15–18].

Initially, transverse reinforcements were used to control the development of splitting cracks surrounding the anchorage region [19,20]. This approach could only give passive confinement to a larger region of concrete, but is unable to directly confine a small grouted region along a bar. Nevertheless, it provides essential fundamental for a splice connector, where the bond strength can be increased by controlling the circumference splitting cracks around the bar.

At present, the confinement can be produced in a small region along a bar. It is by surrounding the splice with spirals [21,22], cylindrical pipes [23–25] and fiber reinforced polymer [26]. These approaches need grout as the bonding and load transferring materials, for its high strength and fine particles. It is also utterly essential to ensure the full capacity of bar stress is properly distributed from a bar to another without being compromised by bond capacity. In the ideal condition, the bond strength should outperform its spliced bars.

The splice connectors available in the marketplace [27–34] are proprietary products owned by the inventors and several established companies. The designs of the shapes are rather complex and they generally need advance steel molding techniques for fabrications. Furthermore, there is limited information on the load resisting mechanisms, the distributions of internal stress and the design calculations of a splice connector published academically, except for some feasibility test reports on these established

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products [35,36] on the basis of several prescribed acceptance criteria proposed by relevant standards [37,38].

Based on the reviews from previous research, several principles are extracted:

(a) The alignments of bar in a splice connection, in-line or adjacent, leads to different responses. Adjacent alignment of bars lead to eccentricity. Under tensile load, the load tends to self-align and causes undesired bending deformation of the spliced bars while rotating the couple [39,40]. This affects the performance of the spliced bar, generates excessive deformation, and causes regional failure of the surrounding concrete of the structural elements [39].
(b) The performance of grouted splice is heavily influenced by the quality of the grout in the sleeve. The strength of the grout and the completeness or segregation of grout in the sleeve would affect the capacity of the splice [25,41].
(c) The bar slippage resistance can be generated by the bond between the grout and the bar, or by the frictional gripping between the coupler and the bar, or by using a threaded system to connect steel bars and the couple [23,34,36,39]. Under tensile load, undesired sudden slippage of bar usually occurs when the frictional gripping approach is used [35].
(d) The performance of the bond in a sleeve can be increased by reducing in the diameter of the sleeve and increasing the anchorage length of the splice bars [25].

Based on these fundamentals, grouted splice was studied and the bars were spliced in-line. This study uses standard-sized steel sections (pipes, square hollow sections and aluminum sleeves) to bridge the discontinuity and to confine the grouted region around of steel bars, as initiated by Einea et al. in 1995 [23]. The objective was to determine whether these sections are suitable as the connectors. For this reason, incremental tensile load tests were carried out on a total of 35 specimens with different configurations. The results were analyzed and the feasibility of the specimens was determined based on several evaluation criteria.

2. Experimental program

A test program was carried out on four series of 35 grouted splice connectors with various sizes and configurations to understand the effects of the interacting variable; material properties, sleeve configurations, confinement mechanism, etc.

2.1. Specimens

Fig. 1 illustrates the details of the grouted splice connectors. These connections were used to splice 16 mm diameter high strength bars of 460 N/mm^2 specified yield strength. The configurations of the connectors are briefly described as follows:

- AS-Series – bars were spliced, in-line or adjacent, with the surrounding grout confined by a corrugated aluminum sleeve with 43 mm diameter and 1 mm thick.
- BS-Series – 65 mm diameter and 4.5 mm thick mild steel pipes with the specified yield strength of 250 N/mm^2 were used to splice in-line bars. 10 mm Diameter high strength steel bars were welded to sleeves BS-01 to BS-06 from both ends to interlock with the grout. The amounts and the provided lengths of the 10 mm diameter bars varied among these specimens. For specimens BS-08 to BS-11, 30 mm holes were provided at 50 mm and 100 mm from the ends of the pipes. The holes provide space to be occupied by the grout to engage a large shear area for interlocking with the pipes to prevent slippage of the grout. Specimens BS-12 and BS-13 used rings of welded ribs of 2 mm height. These welded ribs were located at 25 mm and 50 mm from the ends of pipes to interlock with grout. Also, taper nuts of 37° inclined angle were welded on the bars to give more bearing area for interlocking with grout.
- CS-Series – specimens CS-01 to CS-09 comprised sets of two semi-cylindrical mild steel pipes. Two steel plates, 5 mm thick and with 22 mm opening, were welded to the pipes to lock the movement of nuts on the spliced bars. The threaded length of the bars was 70 mm so that the nuts can be flexibly adjusted along it to fit in the compartment between the two steel plates.
- DS-Series – specimens DS-01 to DS-11 were modified from mild steel square hollow section (SHS). Plates of 3 mm thick were inserted through the four corners at 20 mm, 50 mm and 100 mm from the ends of SHS. These plates interlock with grout to resist slippage of grout. For specimens DS-08 to DS-11, several bolts were used to laterally compress on the spliced bar. This generates an additional resistance to prevent slippage of the spliced bars.

2.2. Test plan and setup

The specimens were made by inserting bars from both ends of the sleeve before high strength Sika Grout-215 (proportion of 25 kg grout: 4 l water) was poured in, to fill the void in the sleeve. The specimens were ready for testing after the grout had achieved the intended strength of 40 N/mm^2. The incremental tensile load was applied at a rate of 0.5 kN/s by a hydraulic actuator with a capacity of 250 kN (Fig. 2). The relationships of the applied loads versus the longitudinal displacement of the bars were plotted and recorded for analysis.

3. Test results

The displacements of the bars corresponding to the applied load were measured throughout the test and the largest axial force measured was considered as the ultimate capacity of the specimens, as shown in Table 1.

Based on the results, due to limited specimens available, it is difficult to distinguish the effects of different configurations of BS-Series. All the specimens failed in the same mode – bar tensile failure. For this reason, the enhancements like (a) the tapered nut at the end of the bars, (b) the interlocking bars welded throughout the length of BS-01, (c) the extra shear area provided by the grout occupying the holes on sleeve BS-08 to BS-11, and (d) the interlocking ribs welded to the inner surface of sleeve BS-12 and BS-13, might not be necessary.

Fundamentally, as long as (a) the sleeve is strong enough to withstand the tensile stress induced by the load, (b) the bond between the bar and the grout is sufficient to prevent slippage of bar, and (c) the bond between the grout and the sleeve is sufficient to resist the grout from slipping out of the sleeve, the splice connection would adequate. Fabrication wise, it is more practical to induce a minimum efforts of modification to the pipe section. Thus, the interlocking bars welded to the inner surface of the sleeve should be of a minimum length, but just adequate to prevent the grout from slipping out of the sleeve. No tapered nut is required for this series of specimens.

As observed from DS-Series, tapered nut indeed improves the bond between the bar and the grout, especially when the development length is inadequate. The specimens with the tapered nuts at the ends of the bars (DS-01 and DS-03) always outperform the specimens without the tapered nuts (DS-02 and DS-04).

The ribs at the corner of the SHS of DS-Series seems to provide bond-slip resistance for the grout only. As observed from DS-01, DS-03, DS-05, DS-06 and DS-07, the capacities of the connection were about the same regardless the amount and the positions of the ribs provided. Similarly, when the ribs generate sufficient bond-slip resistance to the grout, an addition of shear areas provided by the grout that occupied the holes of the sleeve would not be necessary.

The test results show that BS-Series is more efficient in providing confinement to the splicing of bars in the sleeve as compared with DS-Series. The bar embedded lengths of BS-03, DS-02 and DS-04 were same, and tapered nut was not provided at the ends of the bars. BS-03 apparently outperformed DS-02 and DS-04 with a higher ultimate capacity without symptoms of bond failure. The square section (DS-Series) appeared to be less superior to the circular section (BS-Series), especially when it is used to generate confinement to the splicing of bars. The circular section is more efficient in generating tangential tensile resistance to confine the grout surrounding the spliced bar.