Performance of Grouted Splice Sleeves with Tapered Bars  
Under Axial Tension  
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Abstract. Many structural failures in precast concrete buildings are initiated by connection failures. To avoid such failures, the connections should have enough strength to join the reinforcement bars between precast concrete panels. This paper presents the structural performance and behaviour of a proposed splice sleeve connection using generic steel pipe. The connection consisted of steel bars with tapered nuts confined in grouted steel pipes. The connections were subjected to increasing axial tension until failure. The results show that the use of smaller pipes gives better confinement effects and provide higher bond strength. A short embedment length of about 10 times rebar diameter is able to provide full tensile strength of the connected rebars. As compared to long embedment length of conventional lapping of steel bars, the proposed connection is able to provide structural continuity with short embedment length.  

Introduction  
Prefabricated precast concrete components contribute to sustainable practices in terms of integrated design, effective use of materials, less construction waste and less site disturbance. The success of precast construction in terms of speed and stability relies mainly on the structural connections [1-3]. To join loose precast components, grouted splice connections can be used to join two reinforcement bars from two separate precast concrete panels into a single continuous structural element, see Fig. 1. Numerous research works on grouted splice connections have been carried out [4-7]. Recognizing the importance of this connection, this research aims to develop a new splice sleeve connection using generic steel pipes to provide the force transfer continuity. The behaviour and failure modes of the connection subjected to axial tension were observed and the bonding mechanisms were investigated.  

Figure 1. (a). Grouted Splice Sleeve Connection in Precast Wall Panels (b). Actual precast concrete construction
Experimental Programs

The research comprised experimental tests on 16 splice specimens made from ordinary steel pipes as the sleeves, see Fig. 2. The steel pipe was used to join two discontinuous reinforcement bars by grouting. Each of the reinforcement bar to be connected has a special cone-shaped ‘nut’ complete with thread at the connected end.

Two sizes of steel pipe in grade S275 were used; 78.9 mm inner diameter with 5 mm thick and 65 mm inner diameter with 4 mm thick. The grout used for joining the steel rebars was Sika Grout 215. The compressive strengths of grout after 7 days are shown in Table 1. The size of the connected steel rebars was 20 mm diameter deformed bars with an average tensile strength of 219 kN. The specimens were categorized into: (1). N series: consisted of 78.9 mm inner diameter 5mm thick steel pipes with different tapered nuts and internal pipe surface condition. (2) T series: consisted of 65 mm inner diameter 4 mm thick steel pipes with different tapered nuts and internal pipe surface condition.

N series was selected to study the effect of tapered nuts and its inclination angle, infill material, pipe length, and also the internal surface conditions to the performance of the connection. Meanwhile, T series was selected to further improve and verify the performance of the connection.

The bond between the pipe and grout is an important factor in developing a successful grouted connection [4, 5], hence, several specimens with different design models were cast and tested in attempts to develop a successful connection. A successful connection is defined as a connection that can cause the connected steel bars to fracture outside the splice sleeve. In the first attempt, model M1 was done by incorporating two steel rings cut from a smaller diameter pipe and welded to the inside of the pipe at both ends. Another model, M2 was done by applying just a ring of weld material around the inner face of the pipe. These rings act as the ridges or shear keys, see Fig. 2.

The main parameters investigated were: (1) Pipe diameter: N - 78.9 mm inner diameter, T - 65mm inner diameter, (2) Nut inclination angle: 15°, 30°, 45° and 0° (this represents a bare bar without an attached tapered nut), (3) Pipe length: 300 mm, 400 mm, 500 mm, (4) Pipe inner surface condition: O – pipe with smooth surface and without any ridges; M – pipe with ridges as the shear keys in the inner surface of the pipe.

The specimens were named according to these variables in sequence. e. g. NK15-400-O: (N) 78.9 mm ID pipe, (K) Sika grout, (15) nuts with inclination angle of 15°, (400) 400 mm in pipe length and (O) smooth surface pipe.
Results and Discussions

Tensile tests were first carried out to determine the tensile strength of the grouted sleeve connections. Referring to Fig. 3, three connection failure modes were observed; 1: Bond failure between grout-to-rebar, 2: Bond failure between grout-to-sleeve and 3: Rebar fracture. The corresponding failure load, bond stresses are shown in Table 1. Failure mode 3, where the rebar fractured outside the sleeve, is the preferred one as the splice connection is able to provide full tensile strength of the connected rebars.

![Figure 3. Failure modes of connection; 1: Grout-to-rebar bond failure, 2: Grout-to-sleeve bond failure and 3: Bar fracture](image)

Table 1: Ultimate load of splice connection

<table>
<thead>
<tr>
<th>Specimen number and identification</th>
<th>Embedded length (mm)</th>
<th>Grout strength (MPa)</th>
<th>Failure load (kN)</th>
<th>Bond stress grout-pipe (MPa)</th>
<th>Bond stress grout-bar (MPa)</th>
<th>Failure mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERIES 1</td>
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<td>1.NK0-300-0</td>
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<td>167.74</td>
<td>4.83</td>
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<td>191.49</td>
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<td>3.NK0-500-0</td>
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<td>12.TK15-400-M</td>
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</table>

Influence of Nuts

It is seen in specimens 1, 2 and 3 that by using a bare bar without tapered nuts, the connections failed due to bar pullout, which was caused by the failure of the bond between grout and bar. By incorporating tapered nuts as seen in specimens 4 to 8, the failure occurred due to bond failure between the grout-to-pipe interface, indicating that the bond between rebar-to-grout had increased due to the presence of tapered nut. However, the higher the inclination angle of nut, the lower the ultimate load it can sustain. Then, by adding ridges or shear keys to the internal pipes, as seen in
specimens 9 to 11, the bond between the grout and the pipe improved significantly to the extent that the connected rebars failed by fracture.

**Influence of Pipe Diameter**

The T-series specimens used a smaller pipe of 65 mm inner diameter as compared to N-series with 78.9 mm inner diameter. A smaller pipe gives better confinement effects and thus results in higher bond strength. It is seen, the new configuration results in bar tensile failures as opposed to failure by bar pull-out. However, T-series specimens 15 and 16 give lower ultimate load in comparison to the N-series specimens 6 and 11 results respectively due to low grout compressive strength.

**Influence of Grout**

As mentioned above, the low compressive strength of grout in specimens 15 and 16 affects the the ultimate strength of the connections. Therefore, the strength of grout is also an important factor in determining the performance of the connection.

**Stress-strain Relationships**

Three specimens in T-series were mounted with strain gauges to measure longitudinal and tangential strains in the pipe as well as axial strains in the bars. Fig. 4 shows the stress-strain curve for the reinforcing bars. Both specimens 13 and 14 showed bar fracture failure. As for specimen TK45-400-O, the specimen fails in bond between the grout and pipe. Therefore the axial strains in the pipe are generally very small.

![Figure 4](image-url)  
(a) Specimens 13 and 14  
(b) Specimen 15

Fig. 5 shows the relationships between the stress in the bar versus the tangential and longitudinal strains in the pipe for all three specimens. All three longitudinal strain gauges show linearly increasing tension strains against applied stresses. The tangential strain values deserve special attention. TK30-400-M and TK45-400-M exhibit almost similar trend of stress-tangential strain curves. Tangential strain gauges indicate compression strain initially and then reverse where the pipes experience expansion. For specimen TK45-400-O, compressive strain continues until the specimen fails in bond. It is believed that the pull-out force that is applied to the bar causes the grout to be pulled out together with the bar, allowing the pipe to reverse back to its original state. Due to the smooth inner surface of the specimen pipe, TK45-400-O, poor bonding causes the grout to eventually slip out. By having ridges on both ends of the pipe, as in the case of specimens TK30-400-M and TK45-400-M, the motion of the grout is impeded and results in a radial expansion of the pipes until the bars reach their ultimate tensile strength. The tangential strain results show that the pipe undergoes compression at initial loading and the pipe expands as the loading increases until the bar ultimate strength is reached.
Conclusions

The results of this study show that the splice connection using steel pipe is feasible as it allows continuity between two connected rebars. Further conclusions are as follows:

1. The use of nuts changes the failure mode of bond failure between grout and bar to a bond failure between grout and pipe.
2. Shear keys by means of weld ring or steel plate at both pipe ends prevents the bar and grout slippage and subsequently mobilizes the grout confining action resulting in high bond strength, and then causes the connected steel bar to fracture outside the sleeve.
3. A grouted connection using steel pipe with shear keys, steel bar embedment length of 190 mm (about 10 bar diameter) with tapered angle is able to provide the full tensile strength of the connected rebars.
4. The compressive strength of grout plays a very important role in this type of connection as it serves as a medium to transfer the force from one bar to another.

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References

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