The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles
Outline

1. Scope

2. Aims

3. Previous Research

4. Present Research

5. Future Research
Outline

1. Scope

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1. SCOPE

Grouted connections

One of the methods currently used in foundations strengthened with micropiles, consists in installing micropiles through existing RC footings which are then sealed with cement grout.

In this case the efficiency of the load transfer mechanism depends on the bond strength at steel / grout / concrete interfaces.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

• Key parameters on grouted connections:

  i. Diameter of the hole;

  ii. Embedment length of the insert;

  iii. Roughness of the hole surface;

  iv. Textured of micropile surface (smooth and textured);

  v. Confinement provided for concrete and reinforcement (Passive / Active)

  vi. Strength of concrete and grout
Outline

1. Scope

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5. Future Research
2. AIMS

The study herein presented describes the behaviour of grout / concrete interfaces. Two major aims have been defined for this research study:

- To quantify the influence of the roughness of the hole surface on the bond strength at grout / concrete interfaces;
- To quantify the influence of different confinement levels in the connection behaviour using different levels of passive confinement.

26 compression tests were performed with a reinforcing bar grouted in RC cylinder blocks: 4 different types of hole surface treatment and 5 different confinement levels were used.
Outline

1. Scope

2. Aims

3. Previous Research

4. Present Research

5. Future Research
3. Previous Research

- Jesús Gómez and Allen Cadden, Schnabel Engineering (2005)
3. Previous Research

- Jesús Gómez and Allen Cadden Schnabel Engineering (2005)

![Graph showing bond stress around insert vs. deflection for textured micropiles](image)

- 100 psi = 0.69 MPa; 1 in. = 25.4 mm
3. Previous Research

• Jesús Gómez and Allen Cadden Schnabel Engineering (2005)

“For textured micropiles, the connection capacity is mostly controlled by frictional effects due to the large dilation that takes place during relative movement at the grout-steel interface. The splitting action induced by shear rings will typically induce yielding of the reinforcement steel of the footing. It was found that, for cased micropiles with shear rings, the frictional effect provided by the footing reinforcing steel may be estimated using the total yield capacity of the reinforcing steel multiplied by a friction factor.”
99 compression and pull-out tests were performed with smooth and textured micropiles inserts grouted in RC blocks and in PVC/steel tubes.

Parameters evaluated:

i. Diameter of the hole (D_h);

ii. Embedment length of the insert (l_b);

iii. Roughness of the hole surface;

iv. Textured of micropile surface (smooth and textured micropiles);

v. Lateral active confinement (Pe).
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

### Materials Properties

#### Concrete
- $f_{cg,28}$ (MPa): 32.8
- $E_{g,28}$ (GPa): 35.2
- Slump (cm): 13.0

#### Grout
- $W/C$ ratio: 0.40
- $f_{cg,28}$ (MPa): 53.0
- $E_{g,28}$ (GPa): 14.2

#### Steel
- Dywidag bar ($\phi=16$mm), Grade 500/550
- $t_r=5$ mm; $b_r=5.5$ mm; $s_r=75$ mm

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12th International Workshop on Micropiles, Kraków, Poland, 12-14 June 2014
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Test set-up and Procedures

![Test set-up diagram]

- LVDT (25 mm)
- Load Cell (100 tf)
- Load cells (10 tf)
- Styrofoam insert
• Failure Modes in Tests Performed with Textured Micropiles

1. Monolithic failure
2. Failure at grout/concrete interface
3. Mixed Bond Failure

Confinement

Level 1

Level 2

Level 3
### Results of Compression Tests with Textured Inserts

<table>
<thead>
<tr>
<th>Test</th>
<th>Hole surface</th>
<th>$D_h$ (mm)</th>
<th>$L_e$ (mm)</th>
<th>$P_e$ (kN)</th>
<th>$P_u$ (kN)</th>
<th>$f_b$ (MPa)</th>
<th>$\delta_u$ (mm)</th>
<th>$K_0$ (kN/mm)</th>
<th>$\delta_y$ (mm)</th>
<th>$\delta_u/\delta_y$</th>
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<td>C 1,2</td>
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<td>102</td>
<td>200</td>
<td>120 (Level 1*)</td>
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<td>350</td>
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</table>
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

**Load / Displacement Curves**

- Load / Displacement Curves
- Micropile failure: 1080 kN
- $P_{y,m} = 925$ kN
- 17, 18
- 15, 16
- 14
- 9, 10
- 7, 8
- 3, 4
- 5, 6
- 1, 2
- 11, 12

*Only one level of prestressing bars*
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

### Bond at Grout / Concrete Interface

- The roughness of the hole surface influence the behaviour of the connection;
- For the same situations considered, it can be seen that the use of indented surfaces guarantee an increase in the connection capacity and prevents failure at grout / concrete interface in the confining region.

$$P_d \leq \tau_{gd} \cdot \pi \cdot D_h \cdot n_d \cdot h_d + f_{bd,sr} \cdot \pi \cdot D_h \cdot (l_b - n_d \cdot h_d) + \mu \cdot P_{e,\text{total}}$$

**number of indentations in the hole surface**

**Micropile failure: 1080 kN**

**Micropile yield: 925 kN**

- BC-TT-5,6-wire-brushed surface
- BC-TT-13,14-Indented surface
Lateral Active Confinement

- In specimens with indented hole surface and with confinement a ductile response was observed. The connection capacity and the ductility increases with the confinement level.
- Contrarily in specimens without confinement a brittle failure were observed.
The tension force, initially applied to the Dywidag bars, starts to increase immediately after the failure of the connection, according to the splitting patterns, until a constant value is reached.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

- **Bond strength vs. Lateral Active Confinement**

  - The results of the tests with different confinement levels shows that the bond strength increases linearly with the confinement level.
  - The increase in the connection capacity seems to be proportional to the friction developed in the steel / grout interface.

\[ \Delta P_u = \mu \cdot P_{e,\text{total}} \]
Design Recommendations: Smooth and Textured Micropiles

1. Bond at Steel / Grout Interface

\[ 0.30 + 0.0101K_r \leq f_{bu} \leq 1.75 + 0.0101K_r \]

\[ 4.14 - 0.054 \times e_a \leq f_{bu} \leq 4.83 - 0.054 \times e_a \] (Gómez et al., 2005)

2. Bond at Grout / Concrete Interface

\[ P_d \leq \tau_{gd} \cdot \pi \cdot D_h \cdot n_d \cdot h_d + f_{bd,sr} \cdot \pi \cdot D_h \cdot (l_b - n_d \cdot h_d) + \mu \cdot P_{e,total} \]

→ number of indentations in the hole surface

3. Local Crushing in Grout

\[ P_d \leq n_r \cdot F_{Rdu,g} \rightarrow \text{number of shear rings} \]

\[ F_{Rdu,g} = \nu \cdot f_{cd,g} \cdot A_0 \cdot \sqrt{A_1 / A_0} \leq 3.0 \cdot \nu \cdot f_{cd,g} \cdot A_0 \]

4. Punching Shear

5. Structural Capacity of Micropile
Most Relevant Conclusions: Textured Micropiles

1. The behaviour of a grouted connection with textured micropiles depends on: the hole diameter, the hole surface treatment, number of shear rings, confinement level, grout and concrete strengths;

2. Textured micropiles provide a higher connection capacity than smooth micropiles. The bond mechanism is controlled essentially by bearing and friction;

3. The roughness of the hole surface influence the behaviour of the connection;

4. Active confinement increase the connection capacity and the ductility and spread cracking in concrete blocks;

5. The bond strength decreases with the increase of the hole diameter and increases with the embedment length;

6. Textured micropiles reached yield at embedment lengths substantially less than predicted by design codes for RC structures (6 to 7.5 bar diameter).
Outline

1. Scope

2. Aims

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4. Present Research

5. Future Research
**Experimental Programme**

26 compression tests were performed with a reinforcing bar grouted in RC cylinder blocks

- **4 different types of hole surface treatment and 5 different confinement levels were used.**

![Diagram showing different specimen configurations](image)
Materials

Grout:
- W/C = 0.36; Flow time = 15 s;
- Air content = 1.1%
- $f_{c,g} = 64.6$ MPa; $E_g = 16.9$ GPa

Concrete:
- Class C20/25;
- Consistence S3

Steel (S400NR):
- Reinforcing bar 25 mm
- Transverse reinforcement: 6 mm
### Geometry of the specimens

- **Hole surface treatment** *(Specimens without transverse reinforcement)*

1. **Left as drilled**
2. **Sandblasted**
3. **Helical**
4. **Indented**
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

**Geometry of the specimens**

**Level of Confinement (Specimens with transverse reinforcement)**

Tests were performed in specimens with a indented hole surface and different levels of confinement, considering four different levels:

- (1) 3 stirrups; (2) 4 stirrups; (3) 5 stirrups; and (4) 6 stirrups.
## Test Programme

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Hole Surface Treatment</th>
<th>Transverse Reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 - L3</td>
<td>Left as drilled</td>
<td>No confinement</td>
</tr>
<tr>
<td>R1 - R3</td>
<td>Sandblasted</td>
<td>No confinement</td>
</tr>
<tr>
<td>H1 - H3</td>
<td>Helical</td>
<td>No confinement</td>
</tr>
<tr>
<td>A1 - A3</td>
<td>Indented</td>
<td>No confinement</td>
</tr>
<tr>
<td>C3.1 - C3.3</td>
<td>Indented</td>
<td>3 stirrups (s=130 mm)</td>
</tr>
<tr>
<td>C4.1 – C4.3</td>
<td>Indented</td>
<td>4 stirrups (s=87 mm)</td>
</tr>
<tr>
<td>C5.1 – C5.3</td>
<td>Indented</td>
<td>5 stirrups (s=65 mm)</td>
</tr>
<tr>
<td>C6.1 – C6.3</td>
<td>Indented</td>
<td>6 stirrups (s=52 mm)</td>
</tr>
<tr>
<td>T1-T2</td>
<td>Indented</td>
<td>6 stirrups (s=52 mm)</td>
</tr>
</tbody>
</table>

s = spacing of the transverse reinforcement
• **Preparation of the Test Specimens**

The hole surface treatment was prepared on the internal formwork tubes (75 mm diameter), prior to the concrete cast.

1. The left as drilled surface condition was obtained by cast against the PVC formwork without further treatment.
2. The sandblasted surface condition was simulated by glued sand on the formwork.
3. The indented surfaces were obtained by creating an irregular shape in the hole surface. The grooves for the indented and helical hole surfaces were 12.5 mm high and 10.0 mm deep.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

• Preparation of the Test Specimens

a) Formwork  b) Smooth surface  c) Rough surface  d) Helical surface

e) Indented surface  f) Reinforcement  g) Cast  h) Grouting
• **Instrumentation Details**

- The axial strain gauges were used to evaluate the load transfer between the grout and the reinforcing steel bar and the horizontal ones to evaluate the tensile stress of the stirrups and the level of passive confinement.

- Two TML PFL-10-11 (120Ω) strain gauges were bonded in the surface of each stirrup in horizontal direction and two were mounted in vertical direction.
• Tests set-up and Procedures
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

**Instrumentation**

**Load / Displacement Curve**

- The load / displacement curve shows a ductile behaviour of the connection.
- The response is almost linear until the value of 400 kN is reached and then becomes nonlinear.

**Load / Axial Strain**

The load supported by the bar is about 60% of the total load.

Composite axial stiffness

\[ EA = E_s A_s + E_g A_g \]
Tests set-up and Procedures

Load / Tangential strain variation left side

Load / Tangential strain variation right side

![Graphs showing load vs tangential strain for left and right sides](image-url)
• **Failure Modes**

- In all the specimens splitting radial cracks are visible at the surface of the concrete, three or four cracks in each specimen.
- The cracks propagate along the entire length of the concrete cylinder.
- For the specimens with indented hole surface the failure occurs by shearing in the grout in the grooves and shear in concrete.
### Summary of results

<table>
<thead>
<tr>
<th>Test</th>
<th>Hole surface treatment</th>
<th>Transverse Reinforcement.</th>
<th>$L_g$ (mm)</th>
<th>$P_{\text{max}}$ (kN)</th>
<th>$\delta_{\text{Pmax}}$ (mm)</th>
<th>$P_r$ (kN)</th>
<th>$f_{\text{bu}}$ (MPa)</th>
<th>$K_0$ (kN/mm)</th>
<th>$K_{\text{Pmax}}$ (kN/mm)</th>
<th>$\delta_y$ (mm)</th>
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<td>L1</td>
<td>Left as cast</td>
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<td>290</td>
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<tr>
<td>L2</td>
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<tr>
<td>L3</td>
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<tr>
<td>R1</td>
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<td>C6-1</td>
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<td>6 Stirrups</td>
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<td>387.9</td>
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<td>370.0</td>
<td>5.23</td>
<td>353.1</td>
<td>179.1</td>
<td>1.97</td>
<td></td>
</tr>
<tr>
<td>C6.3</td>
<td>Indented</td>
<td>6 Stirrups</td>
<td>296</td>
<td>382.7</td>
<td>2.339</td>
<td>354.6</td>
<td>5.49</td>
<td>361.5</td>
<td>163.6</td>
<td>2.21</td>
<td></td>
</tr>
</tbody>
</table>

$L_g$ - Embedment length of the grout pocket; $P_u$ - Peak load; $f_{\text{bu}}$ - bond strength; $\delta_{\text{Pmax}}$ - total displacement of grout pocket at peak load; $K_0$ - initial stiffness; $K_{\text{Pmax}}$ - final stiffness; $\delta_y$ - displacement at yield; $\delta_y/\delta_u$ –ductility
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

- **Load / Displacement curves**

  Specimens without transverse reinforcement and different hole surface treatments

  ![Graph showing load vs. displacement for different specimens](image)

  - A brittle failure was observed in all the tests.
  - First, a linear elastic branch is identified, presenting similar values of tangent stiffness, until the failure of the connection.
  - After the failure of the connection, a sudden loss of the connection capacity is observed.
  - Residual value is about 30 to 40% of the maximum load.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

• **Load / Displacement curves**

Specimens with transverse reinforcement and an indented surface

- A ductile failure was observed in all the tests.
- First, a linear elastic branch is identified, presenting similar values of tangent stiffness, until the appearance of the first splitting cracks in concrete top surface.
- The response becomes non-linear at 80-90% of the peak load.
- After the peak load is reached, the confinement provided by transverse reinforcement guarantees a high capacity and ductility of the connection.
• **Bond strength vs. hole surface treatment**

- Specimens with helical and indented hole surface lead to an increase in the bond strength of approximately 35%.
- The bond strength obtained for specimens prepared by sandblasting is lower than the initially expected value due to an excessive use of release agents.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

- **Bond strength vs. confining pressure**

  ![Graph showing bond strength vs. confining pressure](image)

  - Bond strength increase with the confining pressure provided by passive reinforcement.
  - A high correlation coefficient is observed (0.94).
  - These results are consistent with those obtained by Veludo (2013) in tests performed with textured micropiles grouted in predrilled holes in RC footings with active confinement.

- The volumetric ratio of transverse reinforcement \( (\rho_w = \frac{w_w \cdot f_{cd}}{f_{yd}}) \), in percentage, for each specimen obtained is: 0.34 for Level 1; 0.51 for Level 2; 0.68 for Level 3; and 0.85 for Level 4. The latter provides an increase in the bond strength of 27%.

\[
 f_{bu} = 1.2718\sigma_2 + 3.6138; \quad R^2 = 0.94
\]
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• Most Relevant Conclusions

1. From previous studies it can be stated that confinement is the most relevant parameter in grouted connections. Active and passive confinement has a notable increasing effect in ductility and in the load capacity of the connection.

2. From the research study herein described, it was concluded that:
   i. specimens without transverse reinforcement show a brittle failure and in specimens with transverse reinforcement a ductile behaviour was observed;
   ii. the use of an indented hole surface leads to the highest bond strength at the grout / concrete interface;
   iii. the use of an indented hole surface in grouted connections provides an adequate load capacity and ductility of the connection if the concrete specimen has sufficient reinforcement. In this situation, by increasing the volumetric ratio of transverse reinforcement the bond strength at grout / concrete interface increases.
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Outline

1. Scope

2. Aims

3. Previous Research

4. Present Research

5. Future Research
• Strut and Tie Models

• To develop Strut and Tie Models to design foundations strengthening with micropiles according to:
  i. Minimum embedment length;
  ii. Variation in geometric characteristics and type of micropile;
  iii. Applied force (concentric / eccentric) and location of active prestressing and the amount of existing reinforcement;
  iv. Influence of combined loading, relative shear ring and grooves location, and grout strength;
  v. Grout constitutive relationships.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

• Strut and Tie Models

• Modeling grout connections

\[ P_f \] - force carried by compression strut due to friction
\[ P_g \] - force carried by compression strut due to shear ring bearing; \( P_e \) active prestressing force
\( e_a \) - annular width; \( \sigma_{t,g} \) - tensile stress of grout; \( \tau_g \) - shear stress of grout
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

- Strut and Tie Models
  - Concentric Load

  - The value (and location) of the resulting of tensile forces as well as the possibility of using the direct load transfer depend on the embedment length.
  - This may lead to the need to increase the thickness of the existing foundation.
  - How to balance tensile forces?

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Miguel Lourenço
• **Strut and Tie Models**
  
  • **Concentric Load**
  
  • Model for grouted connections with lateral confining bars (prestressed), active or passive.
  
  • The anchorage of tensile force introduces compression in the connection zone.
  
  • The solution with prestressed bars also improves the state of stress on the anchorage zone of the micropiles.
  
  • If the prestressing force introduced is greater than necessary to balance $\Delta N$, it is possible to have load transfer between the soil and the micropiles.
The value (and location) of the resultant of tensile forces, acting in the upper and lower faces of the foundation, as well as the ability to use the direct transfer of loads, depends:

- on the embedment length of the micropile (which may act in compressive and tension);
- on the reinforcement in tension in column section.
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

• Strut and Tie Models

• Enlarge Existing Spread Footing and Overlay

Shear at the interface between concrete cast at different times

\[ v_{Rd,i} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_{yd} \cdot (\mu \cdot \sin \alpha + \cos \alpha) \leq 0.5 \cdot \nu \cdot f_{cd} \]
The influence of hole surface treatment and confinement level in the connection capacity between RC footings and strengthening micropiles

12th International Workshop on Micropiles, Kraków, Poland, June 2014

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