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BOND STRENGTH OF MICROPILE/GROUT/ CONCRETE INTERFACES IN RC FOOTINGS STRENGTHENED WITH MICROPILES

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the title of this presentation is bond strength of micropile/grout/concrete interfaces in RC footings strengthened with micropiles and in this

- 1. MICROPILE TO FOOTING CONNECTIONS**
- 2. AIM OF THE WORK**
- 3. EXPERIMENTAL PROGRAMME**
- 4. RESULTS AND DISCUSSION**
- 5. CONCLUSIONS**



1. MICROPILE TO FOOTING CONNECTIONS

2. AIM OF THE WORK

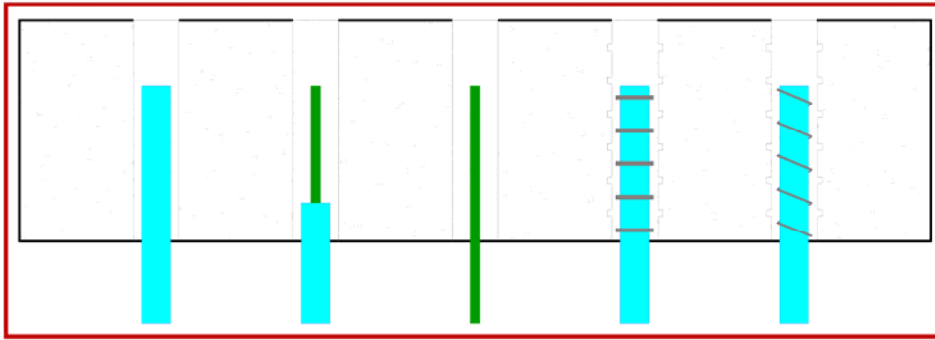
3. EXPERIMENTAL PROGRAMME

4. RESULTS AND DISCUSSION

5. CONCLUSIONS



1. MICROPILE TO FOOTING CONNECTIONS



The type of connections varies depending on the required capacity, the type of micropile reinforcement and the details of the pile caps.

To increase the bond strength of the insert-grout interface, steel rings or a spiral steel bar can be welded around the perimeter of the casing.

To improve the bond strength of the grout-concrete interface, grooves can be made into the wall of the hole.



1. MICROPILE TO FOOTING CONNECTIONS

2. AIM OF THE WORK

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2. AIM OF THE WORK

- (1) Texture of the pre-drilled hole surface;
- (2) Diameter of the pre-drilled hole
- (3) Embedment length of the micropile;
- (4) Texture of the micropile surface;
- (5) Confinement strengthening of the existing footing



This experimental study was performed to assess the influence of the following parameters:

- (1) texture of the pre-drilled hole surface;
- (2) diameter of the pre-drilled hole;
- (3) embedment length of the micropile;
- (4) texture of the micropile surface;
- (5) confinement strengthening of the existing footing.

One hundred and four (104) micropile/grout specimens and micropile/RC footing specimens were submitted to monotonic testing, both in compression and in tension.

1. MICROPILE TO FOOTING CONNECTIONS

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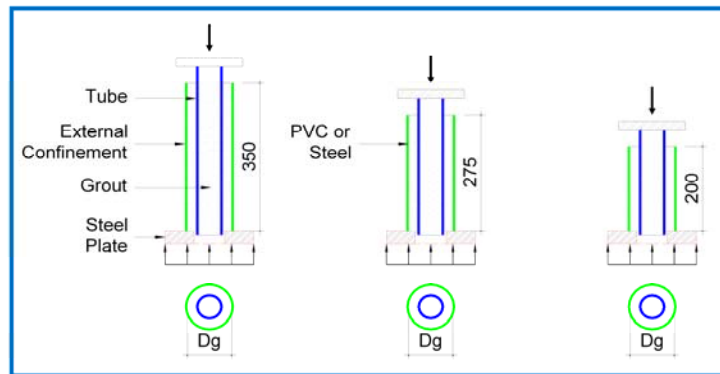
5. CONCLUSIONS



3. EXPERIMENTAL PROGRAMME

3.1 TESTS SPECIMENS

PHASE I - Push-Off Tests on Micropile Inserts in Confined and Unreinforced Mass of Grout - 40 tests



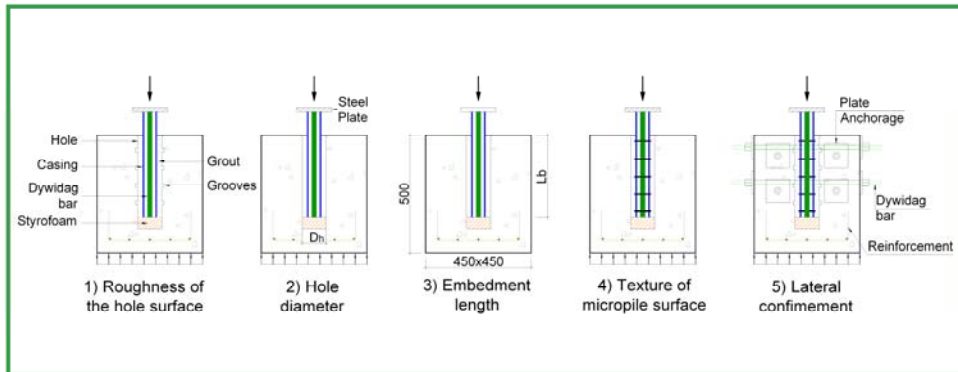
For this set of tests, 40 specimens were constructed with smooth micropiles inserts grouted in a confined and unreinforced mass of grout.

The main propose of these tests was the evaluation of the influence of 3 parameters: diameter of grout mass, embedment length and confinement level in the connection capacity.

This figure shows the geometry and the parameters analyzed. three diameters of grout mass, three embedment lengths and two levels of confinement (PVC tube and steel tube) were considered.

In the bottom of each specimen a steel plate with a central hole was used to allow the slippage of the inserts during compression tests

PHASE II - Push-Off Tests on Micropile Inserts Grouted in Reinforced Concrete Footings - 34 Tests



For Phase II of tests (push-off tests), thirty four specimens of concrete reinforced footings, with dimensions $450 \times 450 \times 500 \text{ mm}^3$, were constructed.

This figure represents the different parameters analysed in these set of tests:

- (1) roughness of the surface of the hole, drilled into the foundation;
- (2) hole diameter;
- (3) embedment length of the micropile;
- (4) surface texture of the micropile;
- (5) active strengthening of lateral confinement of the existing footing.

In these tests were considered three diameters of predrilled holes and three embedment lengths.

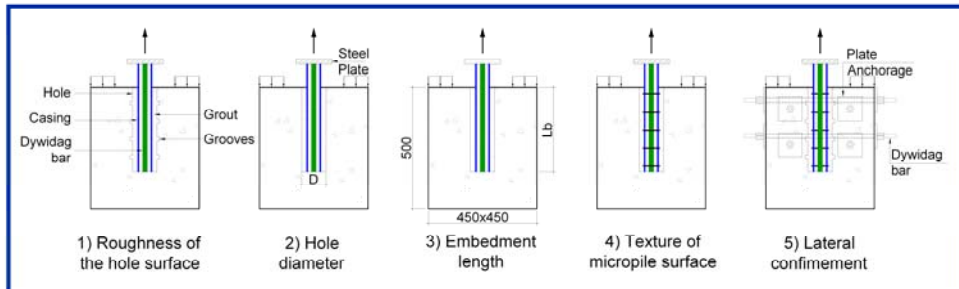
For the treatment of the hole surface, three roughness techniques were adopted: left as drilled; wire-brushed; and chipped grooved (groove with dimensions of 10 mm depth and 15 mm height).

Two type of micropiles were used: smooth and textured with welded shear rings.

Three levels of confinement were adopted, corresponding to: Level 1=30 kN, Level 2=45 kN and Level 3=60 kN applied in each bar.

A compressible insert (polystyrene-styrofoam) was installed in the bottom of

PHASE III - Pull-Out Tests on Micropile Inserts Grouted in Concrete Footings - 30 Tests



For Phase III (pull-out tests), thirty specimens of concrete reinforced footings, with dimensions $450 \times 450 \times 500 \text{ mm}^3$, were constructed.

The main difference between this and Phase II is that the preparation of the concrete footings was made outside and the concrete was placed in the formwork from the chute of a concrete truck by free fall method.

The parameters analysed in this set of tests are the same analysed in Phase II

3.1 PREPARATION OF SPECIMENS

PHASE I



**Confinement and
micropile inserts**



Grouting



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this figure shows the specimens used in the first phase of compression tests.

From the right figure it is possible to see the expansion of the grout one hour after the grouting of the specimens.

PHASE II and PHASE III

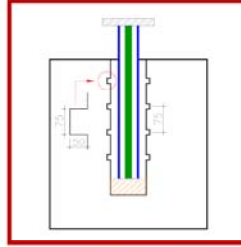
Casting



Drilling



Grooves



Grouting



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Laboratório de Estruturas

These figures show different phases of the preparation of the concrete footings.

A commercial steel formwork was used to construct the blocks. Inside the formwork wooden panels were placed spaced 450 mm to construct each block.

The ready mix concrete was placed from a bucket by free fall method.

After 28 days of indoor curing, each footing was drilled using a diamond coring system.

Prefabricated micropiles inserts (smooth and textured) were set into each hole and sealed with non-shrink grout.

3.2 MATERIALS

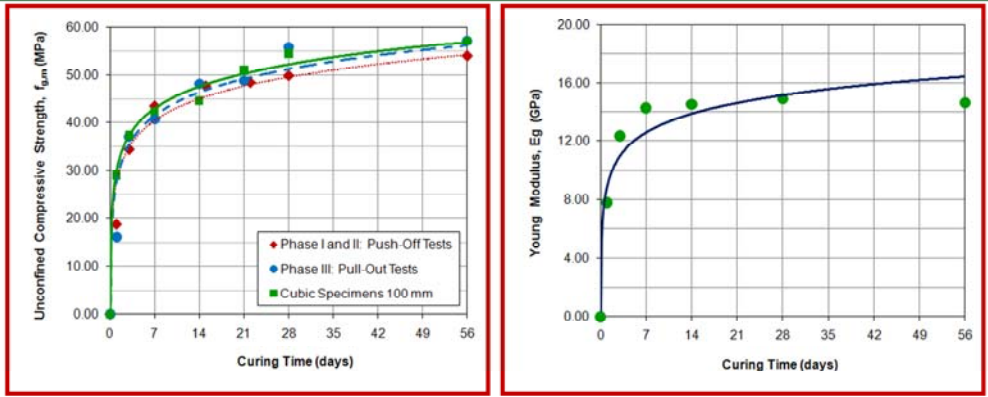
GROUT



We made several mixes in order to understand the influence of water/cement ratio and the proportion of the admixtures used. We used to admixtures: a high water reducer and a expansive mixture. The grout used has a water/binder ratio 0.4

The main purpose to make an expansive grout was to prevent (or at least reduce) shrinkage. If the expansion of expansive grout is confined by steel tube or concrete, pre-tensioning occurs in the steel tubes reacting against the expansive grout. This may be helpful to grout–steel and grout-concrete interfaces bond

According to EN 445 [5] flowability, bleed and volume change were measured. The results from these tests were between the limits imposed by EN 447 [6]. Table 3 shows the summary of the grout measured mechanical and physical properties.



| $E_{g,28}$ (GPa) | Air content (%) | $f_{cg,28}$ (MPa) | Flowability (s) | Bleed (%) | Volume Change (%) |
|---------------------|--------------------|----------------------|--------------------|--------------|-------------------------------|
| 14.88 | 1.5 | 49.98 | 11.0 | 0.45 | 0.0 |
| Limits from EN 447 | | ≥ 30 MPa | ≤ 25 s | $\leq 2\%$ | $-1\% \leq \Delta V \leq 5\%$ |



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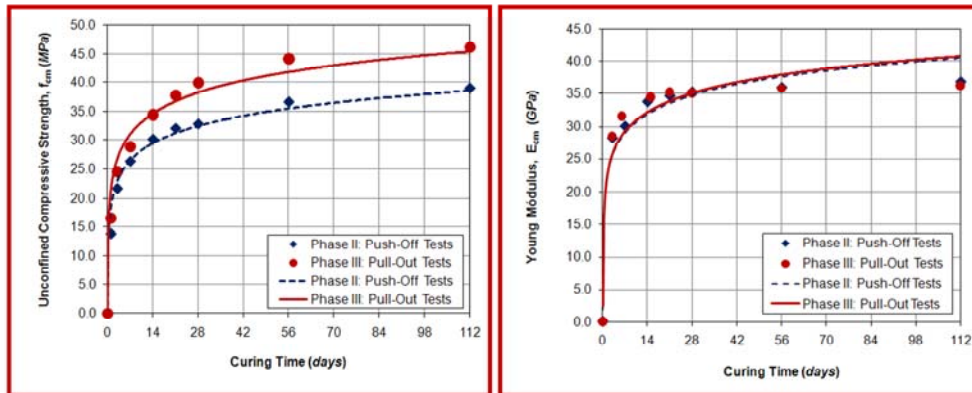
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The obtained unconfined compressive strength and Young modulus values are summarized in this figures.

Table shows the summary of the grout measured mechanical and physical properties

CONCRETE



Ready Mix 1 – Push-Off Tests

| $f_{cm,28}$ (MPa) | $E_{g,28}$ (GPa) | Slump test (cm) |
|----------------------|---------------------|--------------------|
| 32.81 | 35.19 | 13 |

Ready Mix 2 – Pull-Out Tests

| $f_{cm,28}$ (MPa) | $E_{g,28}$ (GPa) | Slump test (cm) |
|----------------------|---------------------|--------------------|
| 39.85 | 35.06 | 12.5 |



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From each truck of ready mixed concrete, corresponding to the push-off and pull-out tests, twenty four cubic specimens and two prismatic specimens were prepared.

The blocks and the tests specimens from push-off tests were cured inside laboratory in the same conditions.

The blocks and the tests specimens from pull-out tests were cured outside the laboratory in same conditions, except the prismatic specimens for assessing the Young modulus that were cured inside the laboratory.

MICROPILE INSERTS

Smooth Inserts



Tube API N80

D=60 mm, t=6.0 mm



Tube K55/J55

D=60 mm, t=5.5 mm

Textured Inserts

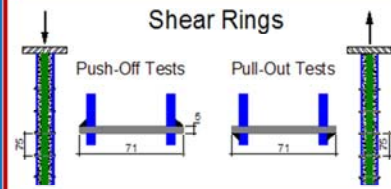


Reinforcing Bar



Dywidag Bar

D=16 mm
Grade 500/550



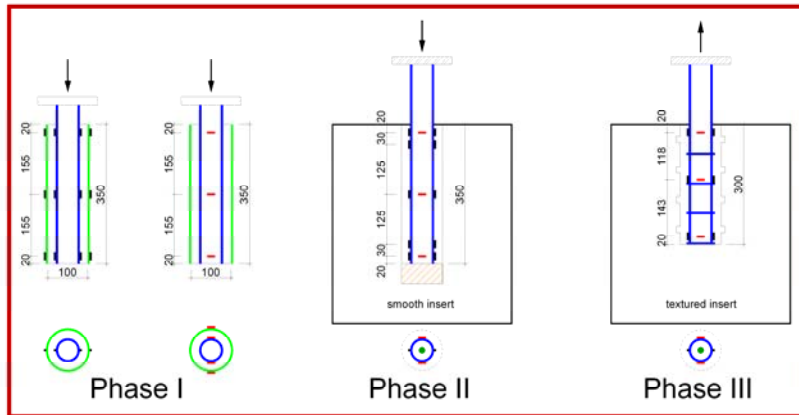
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3.3 INSTRUMENTATION



Strain gages - TML FLK-6-11 (120Ω)



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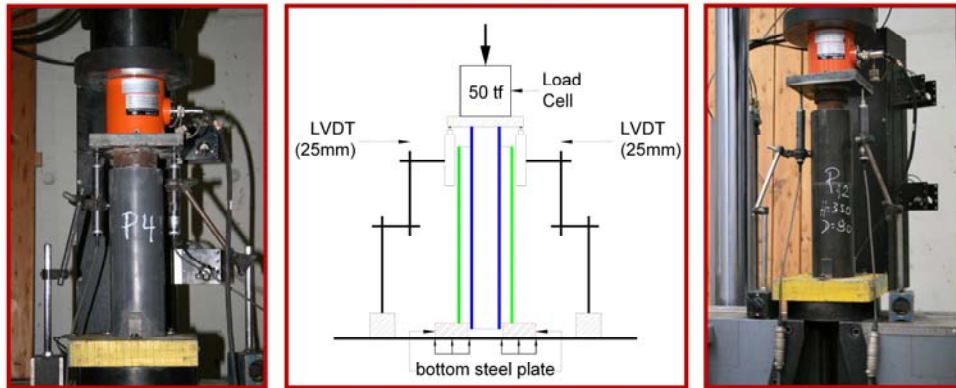


In each phase of the experimental program some of the inserts were instrumented to monitor vertical and horizontal deformations at the insert/grout interface.

3.4 TESTS PROCEDURES

Tests were conducted using **displacement-control procedures**. The specimens were tested at a **load rate of 0.025 mm/s**. All tests continued after failure in order to obtain data on the residual connection capacity.

PHASE I



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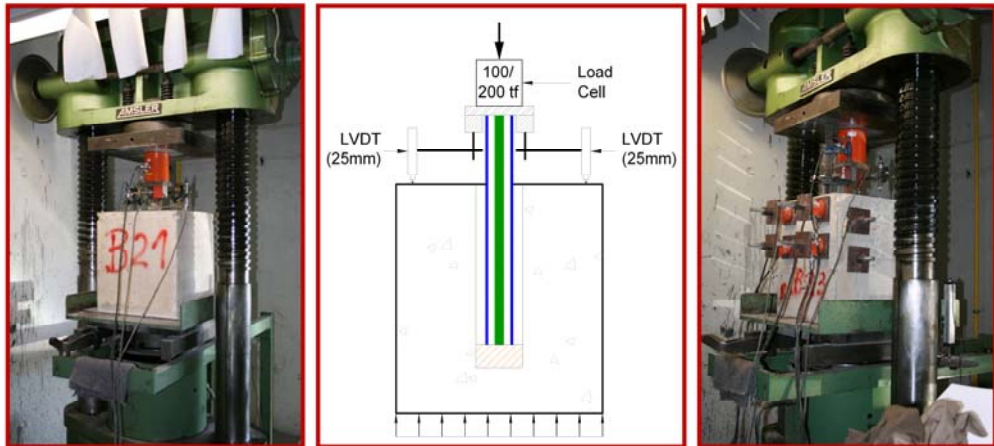


In Phase I, loads were applied using a universal testing machine of 60 tf. In each test, two TML CDP-25 displacement transducers were used to measure the relative displacement between the loading plate and the surface of the grout mass.

The load was monitored using both the machine pressure gauge and an external TML CLC-50 load cell placed on top of the loading plate.

Figure 11 shows the test setup adopted in Phase I.

PHASE II



In each phases the output of load cells, LVDTs and strain gauges were connected to a TML TDS 303 data logger.



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In Phase II loads were applied using a testing machine of 500 tf.

Deformations were monitored using two TML CDP-25 displacement transducers to measure the relative displacement between the top of the insert and the top surface of the concrete footing.

The load was monitored using both the machine pressure gauge and an external TML CLC-100 or TML CLC-200 (for some tests performed with textured inserts) load cells placed on top of the loading plate.

In the tests performed with textured inserts TML CLC-50 load cells were placed between anchor plates, in both ends of two Dywidag bars placed in the same direction, to monitor the confinement load.

The test setup adopted in Phase II is shown in Figure 12.

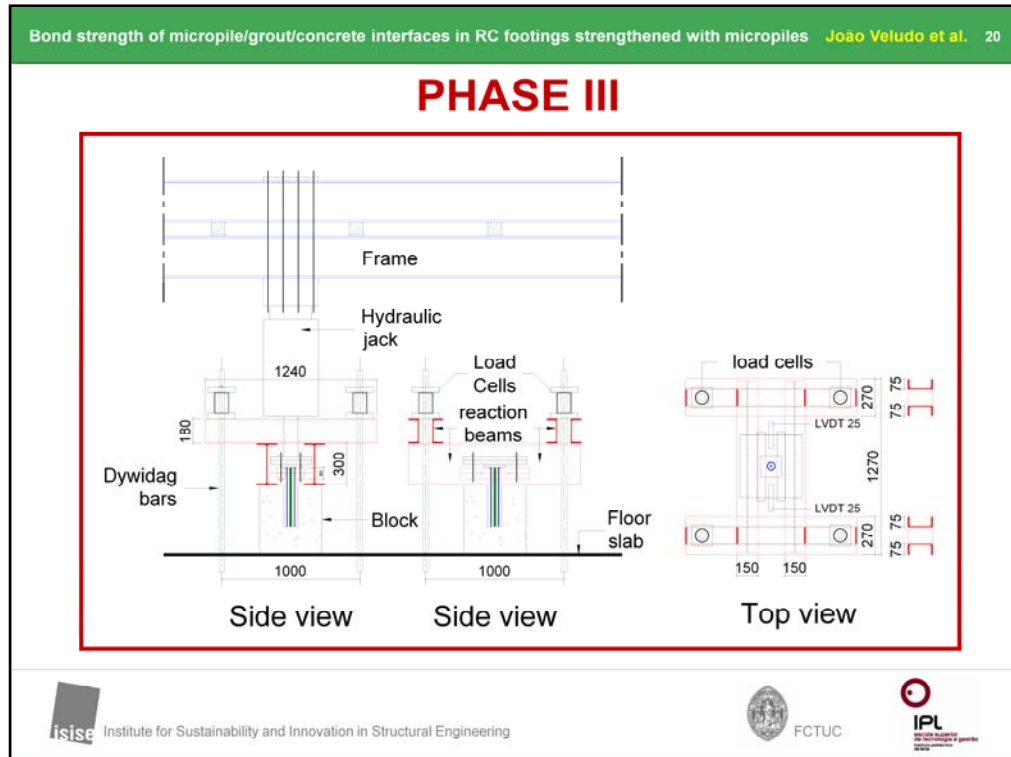


Figure 13 shows the testing system used in Phase III. A hydraulic actuator of 100 tf, linked to a loading frame, was used to apply the axial pull-out load to the top plate of each micropile inserts.

In tests performed with textured inserts the top steel plate used in micropile inserts had a thickness of 40 mm and two stiffeners welded to the micropile tube and to the top bearing plate.

The blocks were fixed to the laboratory reaction slab using a system of two orthogonal pairs of steel beams and Dywidag bars. Redundant readings of the applied load were obtained from the load cells placed on top of Dywidag bars and directly from the actuator.

Deformations were monitored using two TML CDP-25 displacement transducers to measure the relative displacement between the top of the insert and the surface of concrete footing. Two displacement transducers TML CDP-10 were used to monitor the axial displacements in the reaction beams.

PHASE III



Smooth Inserts



Textured Inserts



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Pull-out tests performed with smooth and textured inserts are shown in these figures

1. MICROPILE TO FOOTING CONNECTIONS

2. AIM OF THE WORK

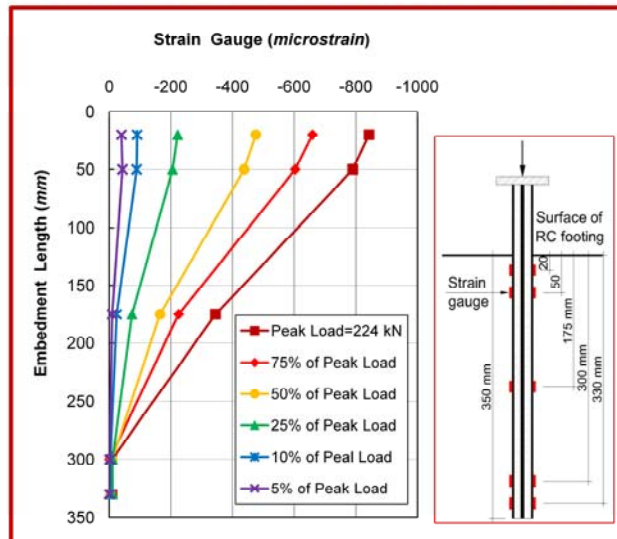
3. EXPERIMENTAL PROGRAMME

4. RESULTS AND DISCUSSION

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4. RESULTS AND DISCUSSION



Average bond strength along the insert/grout interface was considered, for smooth inserts, and average bond strength along grout/concrete was considered, for textured inserts

Average Bond Stress

$$f_b = \frac{P}{\pi \cdot d_m \cdot l_b}$$



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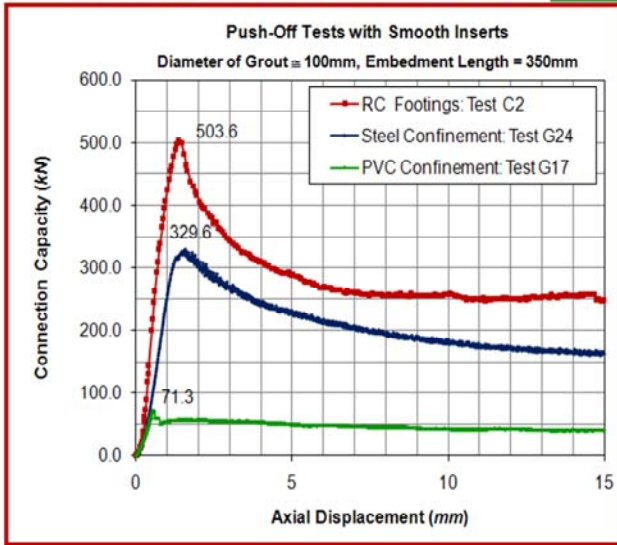
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To discuss results, average bond strength along the insert/grout interface was considered, for smooth inserts, and average bond strength along grout/concrete was considered, for textured inserts.

The average bond stress, f_b (MPa), at any stage during loading is the applied push-off/pull-out load, P (N), divided by the nominal surface area of the embedment length, l_b (mm), of the micropile insert. For a micropile insert with diameter, d_m (mm), this is given by the follow relationship

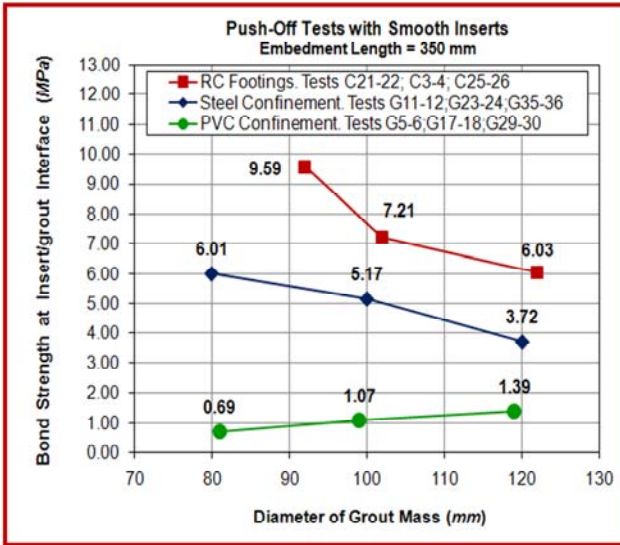
PHASE I AND PHASE II – SMOOTH INSERTS



1. Connection capacity increases with the confinement level

2. Higher capacities and a higher rigidity were obtained under conditions of higher radial confinement

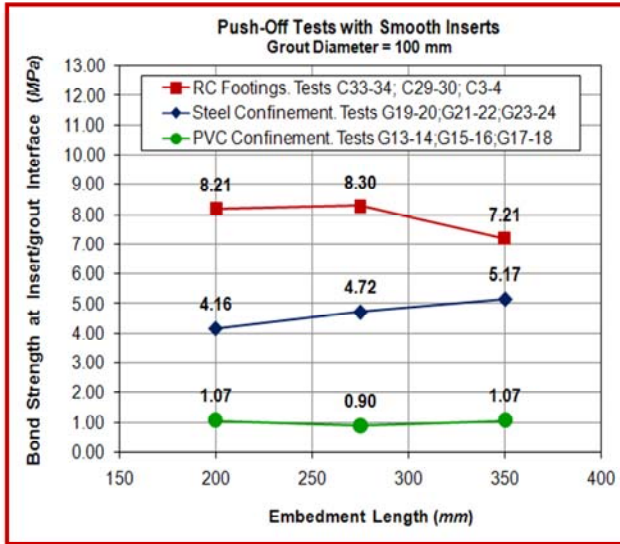




Specimens confined with PVC tubes, increases with the diameter of the grout mass around the insert (thick-wall pressure vessel theory)

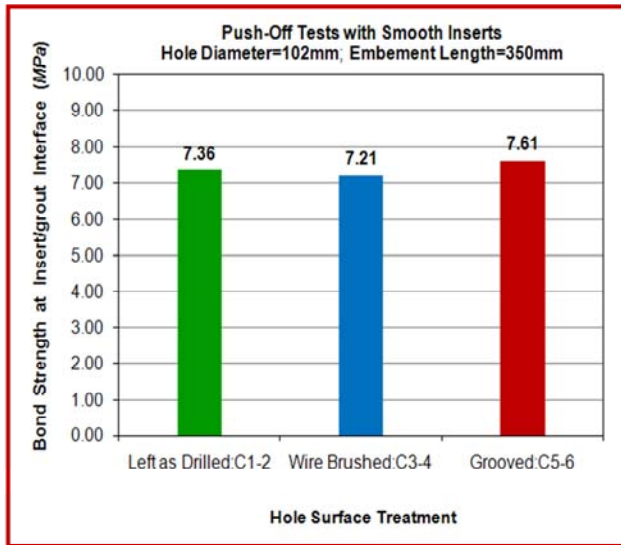
In specimens confined with steel tubes and for specimens grouted in RC footing, bond strength decreases with the increases of radius of the grout mass around the insert.





For smooth inserts the embedment length has little effect on bond strength.

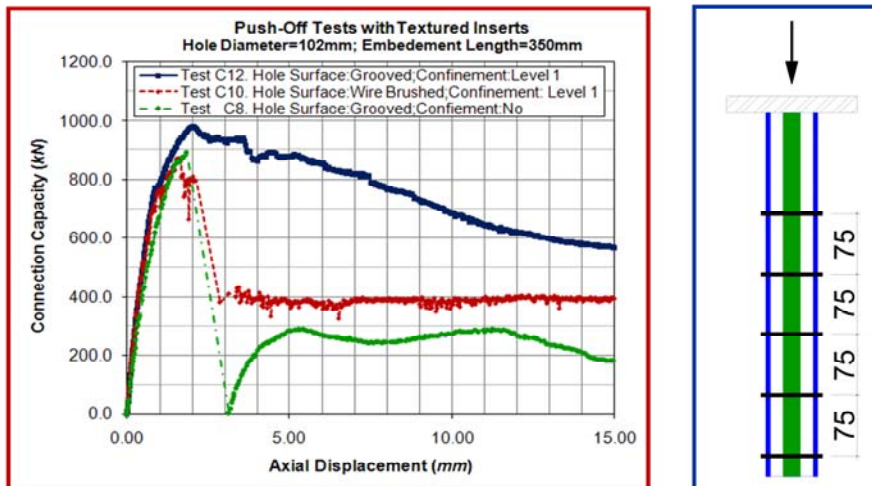




Results did not reveal the influence of this parameter, in this case, since failure occurred at the insert/grout interface.



PHASE II – TEXTURED INSERTS



Failure seems to have occurred at the concrete/grout interface



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It should be mentioned that failure, observed in these tests, seems to have occurred at the concrete/grout interface

The figure shows different types of connection failure. Specimens without confinement and with a wire brushed hole surface as well as specimens with a low confinement level and with a grooved hole surface exhibited a brittle failure.

Specimens with higher confinement levels and with grooved hole surface exhibited a plastic response.

To guarantee adequate bond strength at the grout/concrete interface, it is necessary to make grooves in the hole surface.



Test C8



Test C9



Test C12



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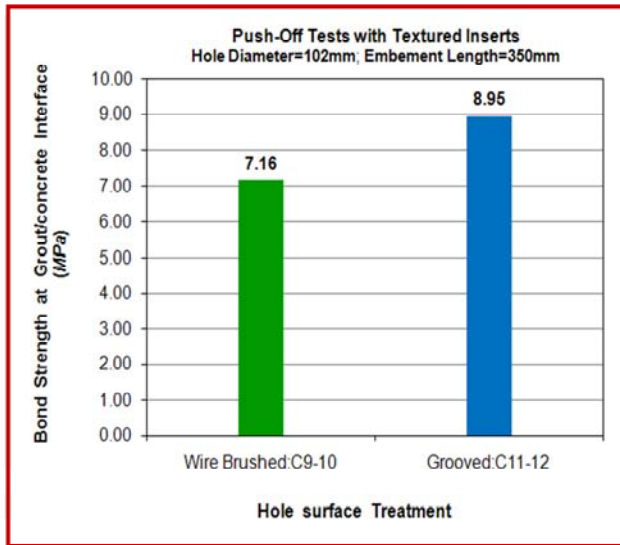


When textured micropiles are used (with welded shear rings), forces acting on the micropile head are transmitted by the shear rings to the grout injected in the predrilled hole.

To guarantee adequate bond strength at the grout/concrete interface, it is necessary to make grooves in the hole surface.

Results of C9 and C10 tests confirmed this statement.

Moreover, this is in accordance with other studies: when textured micropiles are used the boring of the hole surface must be made by percussion methods or grooves must be formed to allow transfer of a high loads [2,18].

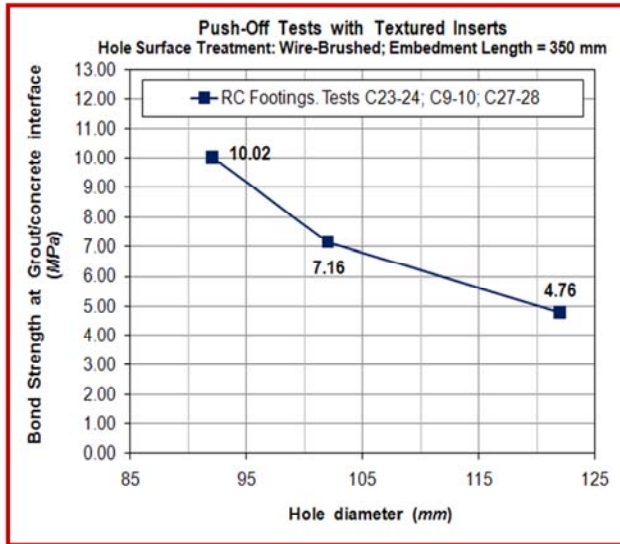


Since failure took place at the concrete/grout interface, it was possible to conclude that the bond strength varies with the roughness of the hole surface, as expected



This figure presented the influence of the roughness condition of the hole surface on the bond strength, registered in tests with textured inserts performed in Phase II.

Since failure took place at the concrete/grout interface, it was possible to conclude that the bond strength varies with the roughness of the hole surface, as expected.

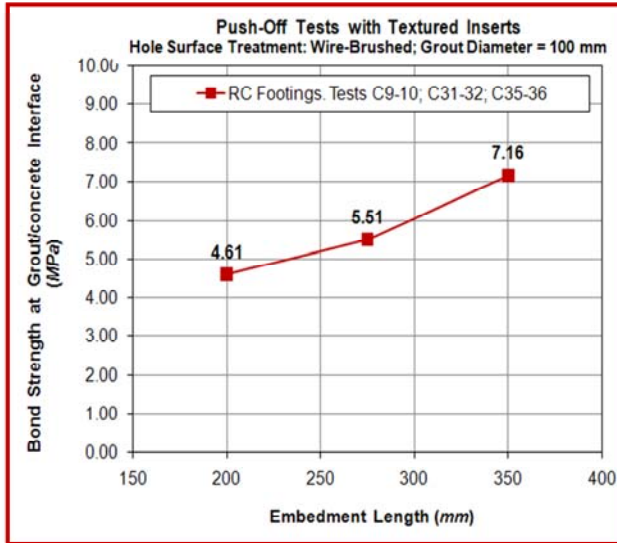


Results clearly indicate that the bond strength of the grout/concrete interface increases with the decrease of the hole diameter.



This figure illustrates the relationship between the diameter of the hole and the bond strength at the grout/concrete interface in tests performed with textured inserts in Phase II.

Results clearly indicate that the bond strength of the grout/concrete interface increases with the decrease of the hole diameter.



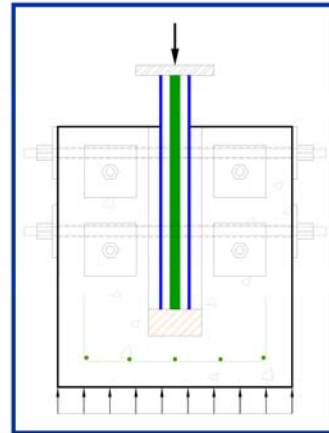
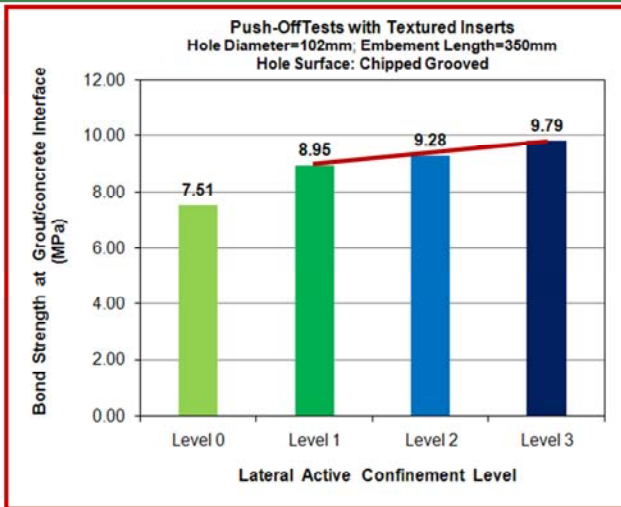
Bond strength increases with the increase of the embedment length for textured inserts.

These results are not consistent with those obtained by other authors



This figure illustrates the relationship between the diameter of the hole and the bond strength at the grout/concrete interface in tests performed with textured inserts in Phase II.

Results clearly indicate that the bond strength of the grout/concrete interface increases with the decrease of the hole diameter.



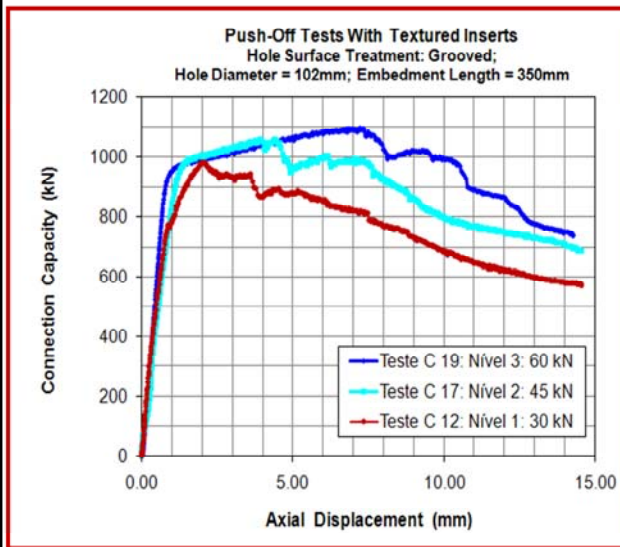
Textured inserts provide a larger connection capacity than smooth inserts.

The bond strength increases almost linearly with the confinement level.



The bond strength increases almost linearly with the confinement level.

Textured inserts provide a larger connection capacity than smooth inserts.

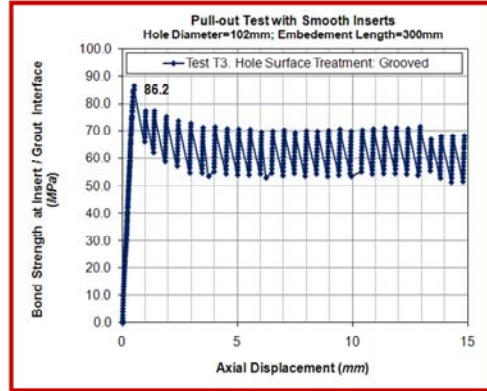
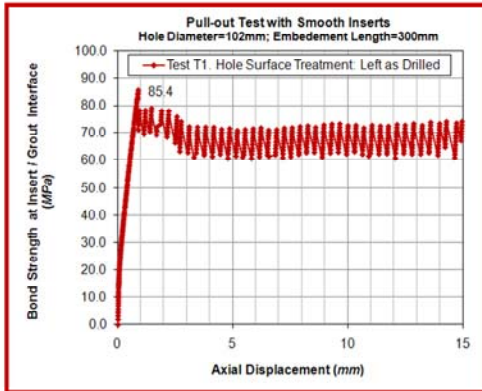


The active confinement significantly reduces cracking and increases the ductility of the connection.

This figure shows the relationship between the connection capacity and the axial displacement for different confinement levels initially applied to the concrete footing.

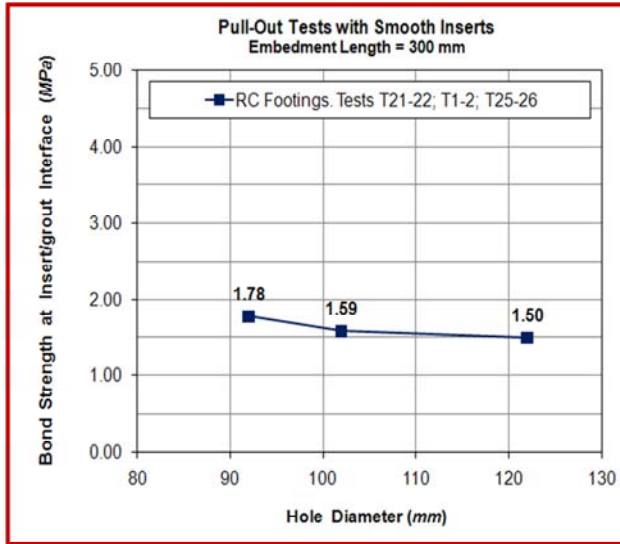
The active confinement significantly reduces cracking and increases the ductility of the connection.

PHASE III – SMOOTH INSERTS



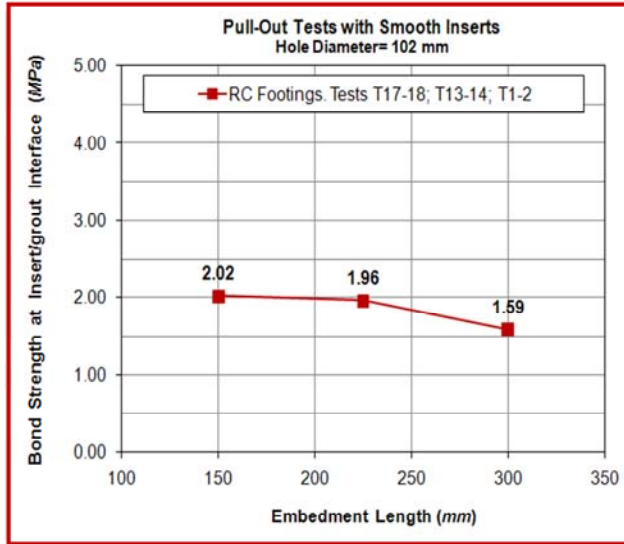
Similar load-displacement responses were observed in all tests performed with smooth inserts in Phase III: After the peak load, the connection exhibits significant residual bond strength.





Bond strength
slightly decreases
with the increase of
the hole diameter





Bond strength did not vary significantly with embedment length

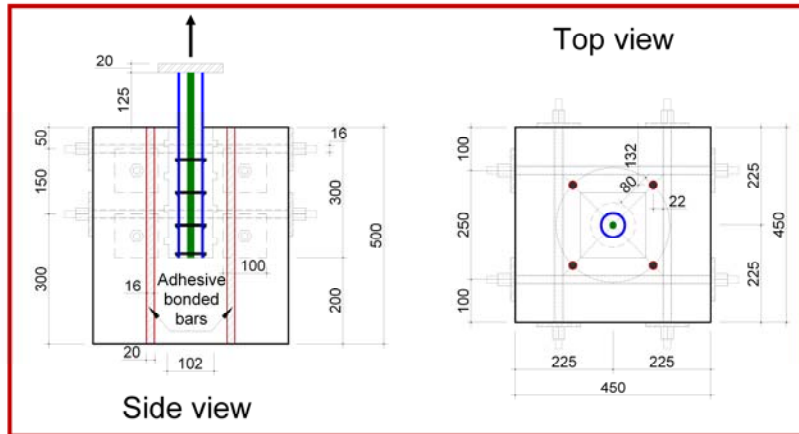


From the results previously presented, it can be stated that highly smooth micropile casing cannot be used in retrofitting RC footings.

The bond strength at the insert/grout interface is in this case much smaller than that obtained with a rough micropile casing. This may be due to smaller frictional component of the bond strength.

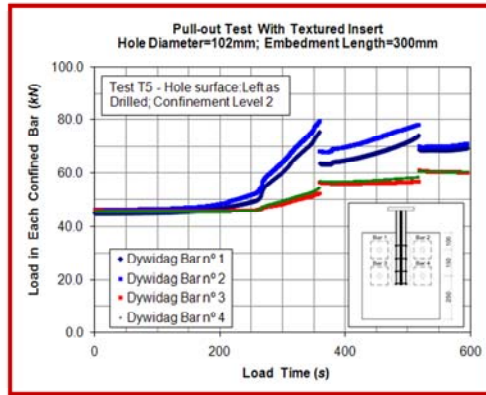
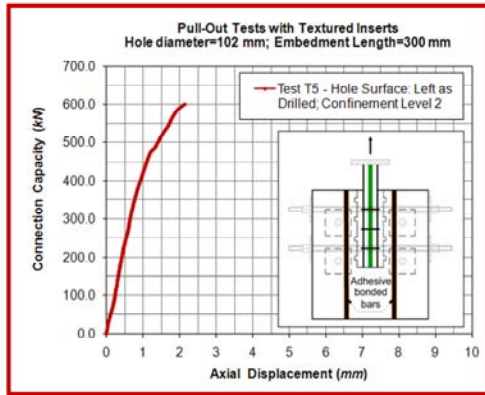


PHASE III – TEXTURED INSERTS



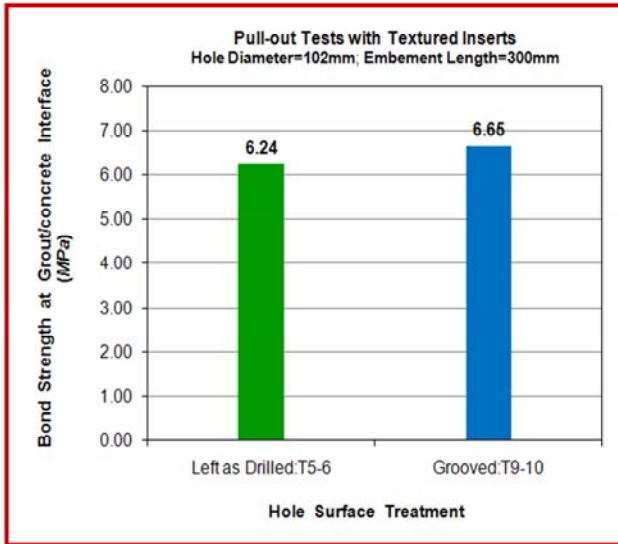
In order to avoid failure at the RC block or excessive cracking of the latter, vertical bars were epoxy bonded inside holes drilled in the RC footing.





The load-displacement curves consist of a linear branch up to 60-80 % of the peak load, followed by a non-linear branch until failure is observed. In all the pull-out tests performed with textured inserts, sudden failure occurred with total loss of the connection capacity.

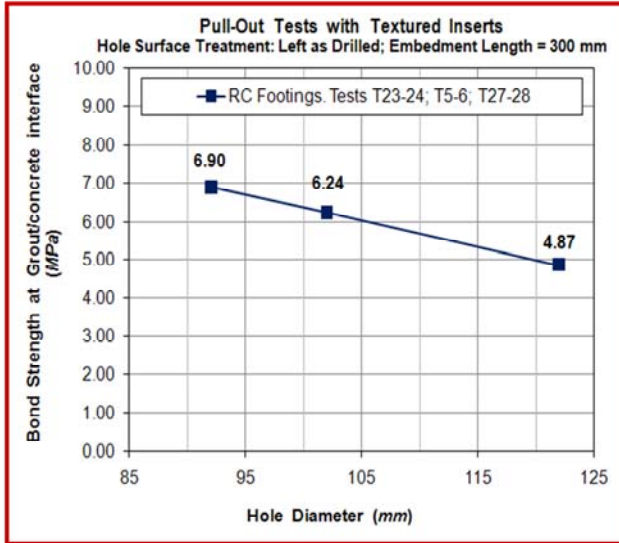




Results reveal that the bond strength varies with the roughness of the hole surface, as expected.

The variation observed was smaller compared with push-off tests

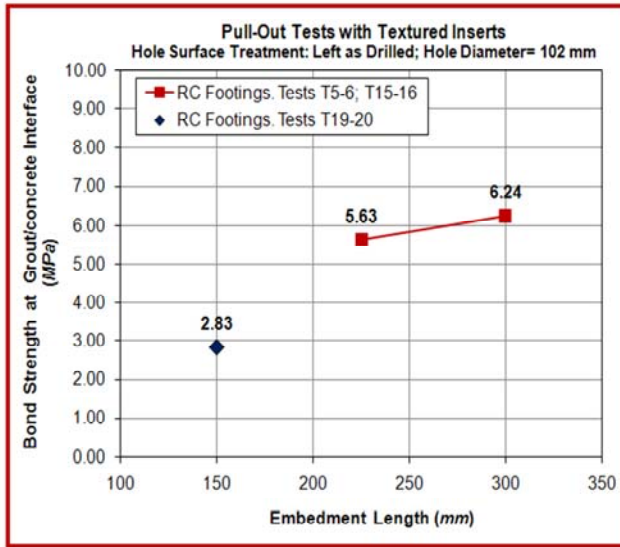




Bond strength increases with the decrease of the hole diameter.

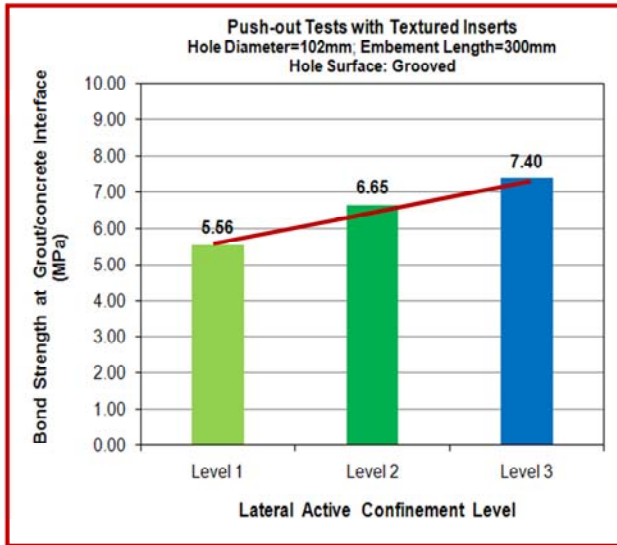
The measured bond strength seems to be proportional to the hole diameter.





In the tests T19 and T20 ($L_b=150$ mm), blocks cracked at a distance to the surface equal to the embedment length of the inserts.

It can be seen that the bond strength slightly increases with the increase of the embedment length.



The bond strength increases almost linearly with the confinement level, which is in accordance with the results obtained in Phase II.



1. MICROPILE TO FOOTING CONNECTIONS

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5. CONCLUSIONS

For smooth inserts, failure occurs at the insert/grout interface, presenting a significant residual resistance.

Bond strength increases with the decrease of the hole diameter.

For smooth inserts the embedment length has little effect on bond strength. For textured inserts, the bond strength increases with the embedment length.

For smooth inserts, the connection capacity is controlled first by chemical adhesion and then by friction at the insert/grout interface. The friction component grows with the radial confining.



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Textured inserts provide higher connection capacity than smooth inserts; failure mode changes from insert/grout to grout/concrete interface.

For pull-out and push-off tests performed with textured inserts, the bond strength increases with the increase of the confinement level.

In all of pull-out tests, performed with textured inserts sudden failure occurs with total loss of connection capacity.

Push-off tests performed with textured inserts and with confinement exhibited a plastic response. Moreover, the confinement strengthening reduces significantly cracking and increases the ductility of the connections.



ACKNOWLEDGEMENTS



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