

# HIGH TENSION LOAD TRANSFER USING BORED PILES FOR SOUL Apartments, Surfers Paradise

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## ABSTRACT

This paper describes two different methodologies of transferring high tension loads through large diameter bored piles into the ground. The installation of post tensioned stress bars into the piles was considered as one option for the SOUL project however the use of high strength concrete ( $f_c \geq 85\text{MPa}$ ) for the pile shaft had some essential advantages.

The use of high strength concrete for bored piles has hitherto been considered to be problematic. Workability criteria have to be maintained for several hours in order to achieve the required quality. Possible concrete shrinkage of the pile shaft causing cracks, concrete bleeding as well as an ongoing quality control of the concrete mix are only a few of the challenges that have to be considered.

This is particularly the case for the foundation piles of a high rise building where extremely high point loads are transferred through the piles into the ground. All piles have to be constructed to extremely high standards. In most cases geometry constraints and the design requirements of the superstructure make it impractical to install additional piles in the event that a pile does not achieve the required capacity and has to be supported or replaced by an adjacent pile.



Figure 1: Location of the SOUL project in Surfers Paradise, QLD, Australia

## 1 INTRODUCTION

Main Contractor Grocon Constructors (QLD) Pty Ltd was awarded a design and construct contract by developer Juniper to build the land mark project SOUL Apartment Towers in Surfers Paradise, Queensland.

When completed the 77 storey apartment tower will be surrounded by a five storey retail area. SOUL is planned to be one of the highest residential buildings in the Southern hemisphere. With a total height of 277m it will be the third highest residential building in Australia. SOUL is positioned in a prime location at the corner of Cavill Avenue and The Esplanade right on the beachfront and in the heart of Surfers Paradise.

Works on site started in November 2007 with the demolition of the existing buildings. The proposed completion date of the high rise project is August 2010. Piling works started in January 2008 with the installation of CFA piles for the retail area, which was performed in 3 stages. Large diameter bored piles for the apartment tower were installed from March to August 2008.

High profile projects like SOUL require very high design and management ethics and standards, particularly for the design and construction of the foundation piles. Extremely high load capacity piles like those for the main tower of the building require exceptionally accurate project and design preparation.

Grocon Constructors (QLD) Pty Ltd and Piling Contractors Pty Ltd believe that the pile loads for the SOUL apartment tower are probably the highest pile loads that have ever been designed for single piles in Australia. The tower piles have been designed for ultimate loads of up to 90MN (compression) and up to 19MN (tension).

## 2 GEOTECHNICAL CONDITIONS

The geotechnical conditions adopted for pile design for the SOUL project are shown in Figure 2. These were derived from a geotechnical investigation undertaken prior to the works.

The natural groundwater occurred between RL+0.2m and RL+1.0m. Due to tidal influences the main contractor installed a dewatering system to keep the ground water level constant at RL+0.2m. This was required as the working platform for piling activities had to be installed at least 2m above ground water level to ensure a minimum head pressure for the bentonite drilling fluid.

A working platform with a total capacity of 300kpa bearing pressure was provided by the main contractor to accommodate the proposed heavy piling equipment. Pile cut off levels were designed to be 9m and 14m below the working platform at the third basement level and the core section of the tower respectively.

All tower piles were designed with a rock socket of at least one pile diameter into high strength argillite or better to ensure adequate geotechnical capacity.

ELEVATION	BRIEF DESCRIPTION	MASS MODULUS (MPa)
+5m to -1.5m	Fill (loose silty sand and clayey sand)	Ignored for pile design
-1.5m to -21m	Sand (dense to very dense with some sandy clay lenses)	120
-21m to -33m	Sandy clay and clayey sand (ranging from stiff to medium dense)	60
-33m to -36m	Greenstone / Argillite (very weak)	200
-36m to -48m	Argillite (Neranleigh - Fernvale Group)	800
-48m to -60m	Argillite (Neranleigh - Fernvale Group) but RQD > 70%	4,000
below -60m	Massive Argillite	> 10,000

Figure 2: Adopted Geotechnical Model

## 3 DESIGN & CONSTRUCTION PROPOSAL FOR PILING WORKS

The SOUL project represents one of Queensland’s most prestigious projects of the last decade as well as presenting a remarkable technical and organizational challenge. The main contractor invited only a few carefully selected foundation specialists to submit their design and construction proposals for the foundation works for this landmark project.

Pile loads and pile geometry was nominated by Grocon’s design team (Grocon, Van der Meer & Glynn Tucker) and the specialist’s proposals for the foundation works were required to comply strictly with those directives.

Piling Contractors submitted their design and construction proposal to Grocon incorporating CFA piles for the retail area and large diameter conventional bored piles constructed under bentonite for the tower piles.

### 3.1 CFA PILES FOR THE RETAIL AREA

CFA piles with diameters of 600mm and 900mm were proposed for the five storey retail area. These piles were required to act as temporary tension anchors only for the construction period to resist water uplift forces for the basement.

CFA Piles were designed and constructed using 40MPa concrete and full length standard reinforcement cages (6N36 or 6N28 bars with N12-300). Pile lengths between 9m and 16m below working platform were proposed.

### 3.2 CONVENTIONAL BORED PILES FOR THE MAIN TOWER

The proposal for the foundation of the 77 storey main tower was governed by the following design requirements and specifications nominated by the main contractor:

- ‘No cracking’ criteria for the pile concrete under tension load, minimum characteristic concrete principle strength ( $f_{ct}$ ) shall be  $0.4\sqrt{f_c}$
- Differential settlement between two adjacent piles not to exceed 5mm or piles/spacing/1000 whichever is lesser
- Compressive concrete strength  $f_c \geq 65\text{MPa}$  or better for the tower piles
- Maximum lateral displacement of pile head under Ultimate Limit State (ULS) load conditions is 5mm
- Maximum settlement of each individual pile under Serviceability Limit State (SLS) conditions not to exceed 13mm
- Use of mechanical couplers for vertical reinforcement splices in tension piles
- Piles to be installed with a rock socket of at least one pile diameter into high strength argillite
- The installation of steel columns in 17 piles, required to transfer the high tension loads from the superstructure into the piles. The steel columns were to be plunged into the fresh concrete up to 8 to 10m

Piling Contractors submitted a proposal using conventional large diameter bored piles constructed under bentonite drilling fluid. The company has successfully carried out foundation works for Chevron Renaissance Towers in Surfers Paradise in the past using similar techniques.

The use of high quality bentonite drilling fluid was proposed in order to ensure that the pile excavation remained stable during the excavation process, the de-sanding process, the placement of the reinforcement and during the final concrete pour.

The pile cut off levels were located at up to 14m (core section) below the working platform level; therefore the precise installation of the reinforcement cage and the placement of concrete under bentonite to 1m above cut off level were identified as some of the biggest construction challenges of the foundation works.

Piling Contractors’ final tender proposal for the main tower consisted of 43 piles with diameters ranging from Ø1200mm to Ø3000mm and rock sockets of 1 to 1.5 pile diameters into high strength argillite.

Grocon awarded Piling Contractors the design and construction contract for the foundation piles at SOUL apartments in December 2007.

#### 4 SECURING WORK AND DEVELOPING PROPOSAL

During the first weeks and months of the project the work load and liaison with the main contractors’ design team was very intense. All parties worked closely together to agree upon verification procedures, documentation systems and testing requirements for the piles. Five piles were nominated for integrity testing using the cross-hole sonic testing technique. Concrete testing was specified to be carried out according to AS3600.

After the award of the piling works Piling Contractors further developed the design of the tower piles. The pile design was carried out in house by Piling Contractors’ design department. The geotechnical and structural design development and optimization was assisted by independent consultants engaged by the company.

In the final design pile diameters and rock socket lengths had been optimized and finally only three different pile diameters were used for the tower pile foundation (Ø1500mm, Ø1800 and Ø2200mm). Drilling depths between 39m and 45m were proposed, depending on socket lengths and geology. Most piles were designed with rock sockets equivalent to one pile diameter; however some piles required deeper rock sockets due to high tension loads resulting from wind loading.

The Ø3000mm piles previously proposed had been downsized to Ø2200mm piles still transferring identical loads into the ground. These downsized and optimized piles were part of a group of seven piles (Ø2200mm), where rock sockets of 3.5m into high strength argillite were necessary. All seven piles required additional measures in order to accommodate the high tension loads for the ultimate load case. The following options were investigated:

- Option 1: The use of longitudinal anchors or stress bars inside the piles (parallel to the longitudinal pile axis) in order to accommodate tension stresses in excess of the pile shaft capacity using 65MPa concrete
- Option 2: The use of high strength concrete  $f_c' > 85\text{MPa}$  for the pile shaft provided additional tensile capacity, hence obviating the need for longitudinal anchors.

#### 5 LONGITUDINAL ANCHORS OR STRESS BARS (OPTION 1)

For the Option 1 proposal stress bars which transfer additional tension loads into the ground would have been installed into steel tubes (to ensure there would be no friction between the stress bars and any surrounding materials). The steel tubes were to be connected to the reinforcement cage and would be attached to a base plate at the pile toe. Design restrictions for the bored piles precluded anchoring the stress bars into the rock below pile toe level. Post tensioning forces applied onto the finished pile cap would have transferred through the stress bars into the base plate where the stresses would be transferred into the rock.

As a result of high tension loads for these piles very complex and heavy reinforcement cages would be necessary. Due to drilling depths of maximum 45m and concrete pile lengths up to 36m it was impractical to install the reinforcement cages without splices. The technical specifications nominated the use of mechanical couplers for any vertical splicing of reinforcement for tension piles.

As the tubes and stress bars would be attached to the inside of the reinforcement cage a separate fabrication and splicing methodology for the installation of the tubes, the stress bars and the grout pipes to the reinforcement cage had to be developed. Figure 3 shows the proposal for general arrangement of the stress bars attached to the inside of the reinforcement cage.

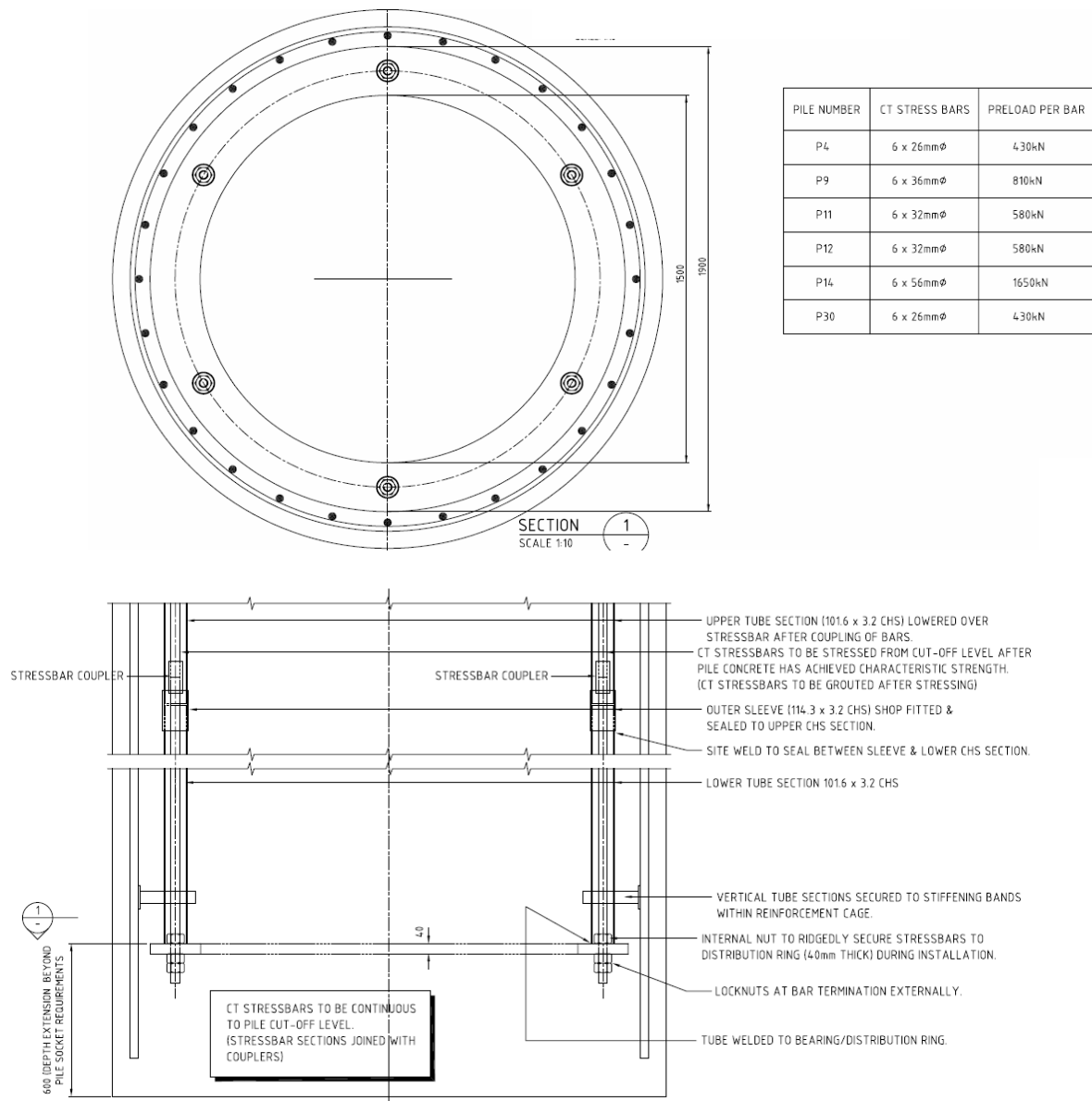


Figure3: General arrangement of stress bars and the reinforcement cage

For this option the full time onsite presence of a specialist post tensioning engineer would have been essential to supervise the works. Method statements and verification checklists for the design, supply and supervision of the works were developed in cooperation and consultation with Ward Strongforce Pty Ltd.

During a review meeting with Grocon’s design team the requirement for precise location and orientation of the plunged columns into the piles was reassessed. Design development now required some columns to be made from two individual steel members welded together with shear studs and shear plates connected between them. Those columns were to extend to the 77th storey of the building and their accurate location and orientation in the pile was crucial. The available installation area for the plunge column in the pile was restricted by the space requirements of the reinforcement cage and the stress bars.

With a vertical pile tolerance of 1:100 the minimum distance between the stress bars and a column with a toe level of 20m below working platform would need to be at least 200mm. This was not available even if the pile were to be installed inside the specified pile tolerances as indicated in Fig. 4. As a result of these potential problems further consideration was given to the use of high strength concrete for the pile shaft.

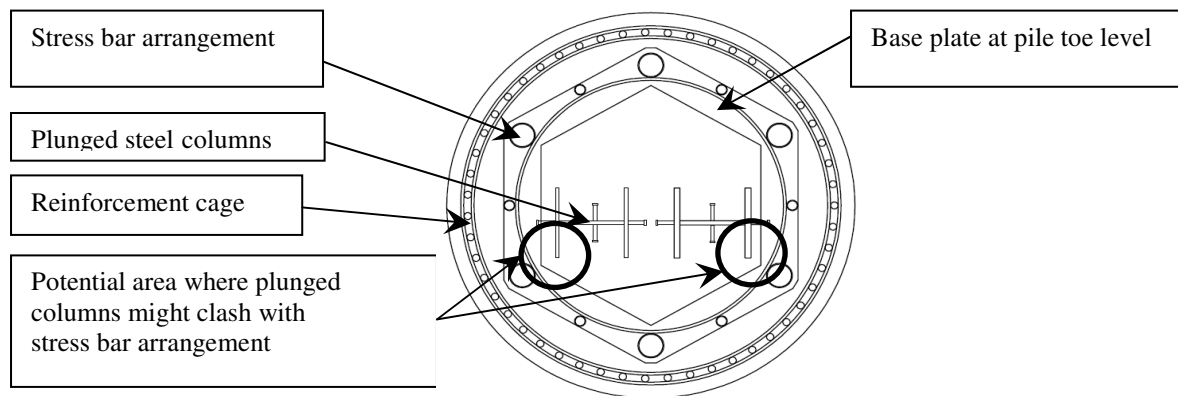


Figure 4: Arrangement of stress bars and plunged columns showing potential clash between plunged columns and stress bars

## 6 USE OF HIGH STRENGTH CONCRETE (OPTION 2)

The use of a high strength concrete with an indirect tensile strength of at least  $f_{ct} \geq 5\text{MPa}$  was specified by Grocon's designers to provide sufficient tension capacity without the use of anchors. It was still necessary to achieve the minimum characteristic concrete principle strength ( $f_{ct}$ ) of  $0.4\sqrt{f_c}$ .

Previous experience suggested that the tensile strength of concrete would be approximately 5 to 8% of the maximum compressive strength. A high strength concrete with a maximum compressive strength of  $f_c \geq 85\text{MPa}$  was therefore targeted.

Concrete supplier CEMEX provided information from two indirect tensile strength laboratory tests they had previously carried out using a 70MPa concrete mix. The results for both specimens showed an indirect tensile strength of 5.5MPa after 28 days.

The project team therefore decided on a compressive concrete strength of  $f_c \geq 85\text{MPa}$  as the minimum requirement in order to achieve indirect tensile strength of 6 to 7MPa, which would be well above the required 5MPa.

Figure 5 shows the general arrangement of an indirect tensile strength concrete test set up in the laboratory. The concrete cylinder is crushed along its longitudinal axis – applied load along the length of the cylinder causes the cylinder to split open. The required stresses to crush the cylinder are measured and are used to calculate the indirect tensile strength of the concrete cylinder.



Figure 5: Jig without a test cylinder (A), Jig with a test cylinder (B) and the jig with a test cylinder inside the hydraulic compression machine (C).

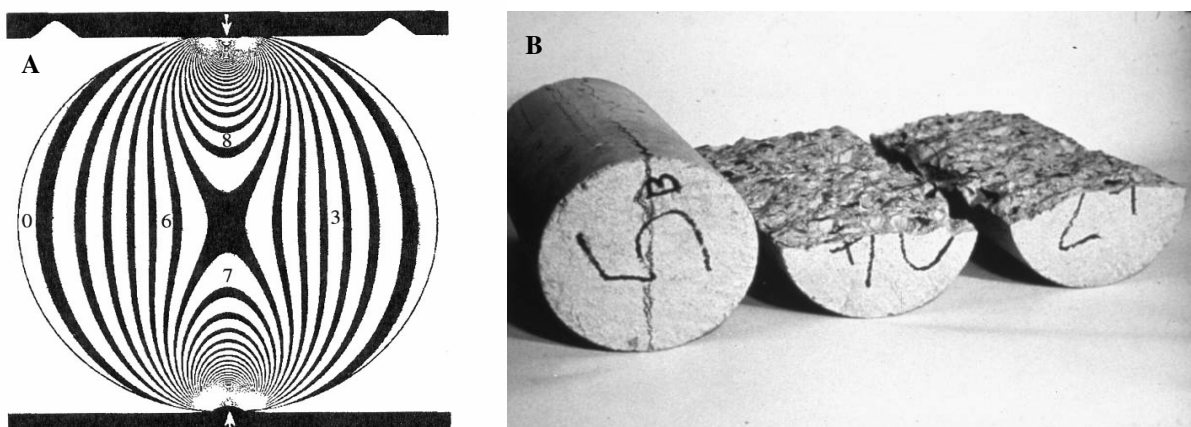


Figure 6: Modeled stress distribution inside the test cylinder (A), cracked concrete probes (B) – Figure 6 is provided by Cement & Concrete Services

A series of tests had to be carried out using three different trial mixes to assess the tensile capacity of high strength concrete  $f_c \geq 85\text{MPa}$ . All base mixes were identical, but one contained added macro synthetic fibers and another had a reduced quantity of retarder. It was considered that the fibers would further increase the tensile strength of the concrete, which was shown to be the case. However there were concerns that the fibers might influence and reduce the workability of the mix. The required workability would need to be maintained about 8 to 10 hours for site use.

The trial using synthetic fibers demonstrated that the fibers made the mix stiffer and the required workability could only be maintained for 5 to 6 hours. The third mix with reduced retarder produced unsatisfactory results. For workability results please refer to Figure 7

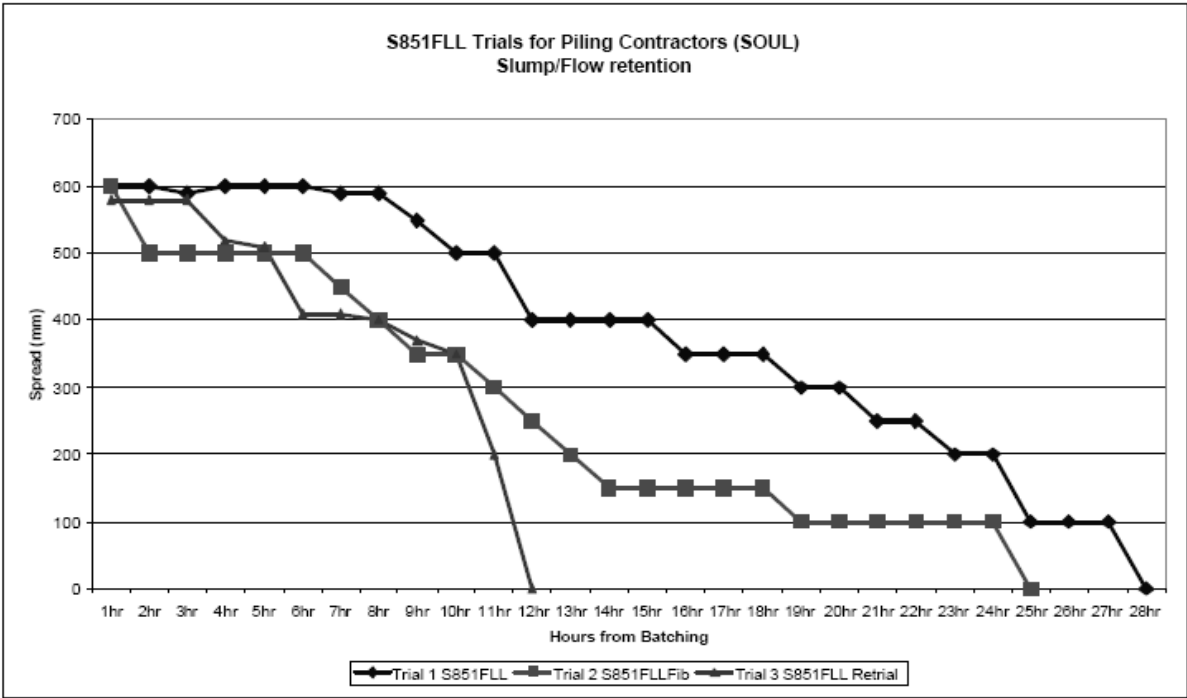


Figure 7: Workability times against spreads for the three different trial mixes

There was also a concern that the fibers would get caught on the reinforcement cage and as a result the fibers would not be uniformly distributed throughout the concrete shaft of the pile. The possibility of having a concrete cover between soil and reinforcement with almost no fibers was not acceptable. In the trial the fibers caught up in the mesh used to simulated pile reinforcement as shown in Figure 8.



Figure 8: Synthetic fibers added into the concrete mix increased the tensile strength but reduced the concrete workability.

After the trial mix a series of compressive and tensile strength tests for the 85MPa mix with and without fibers were undertaken. All tensile strength test results were well above the predicted and required range and confirmed that the design criteria could achieved. Figure 9 shows the early test results (albeit a limited data set) which are already above the 5MPa at 28 days tensile strength requirement.

Trial	Age [days]	Compressive Strength $f_c$ [MPa]	Tensile Strength $f_{ct}$ [MPa]	Ratio [%] $f_{ct}$ to $f_c$	Ratio Improvement with fibers
S851FLL	5	79.0	5.2	6.6%	
S851FLLFib	5	73.5	5.4	7.3%	12%
S851FLL	7	89.5	5.6	6.3%	
S851FLLFib	7	80.0	6.4	8.0%	11 to 28%
S851FLL retrial	7	90.5	6.3	7.0%	

Figure 9: The early test results confirm the target strength was achieved

Following the successful yard trial it was decided to undertake a full scale site trial using a pile with no working tensile capacity requirement.

The following week the site trial was undertaken with the 85MPa mix (S851FLL without fibers) and the workability performance of the concrete was excellent. After the pour was completed a plunge column was successfully installed to the required depth and within the specified tolerance.

The tensile and compressive test results for the trial pile were well above the required range and it was therefore decided to proceed to construct the seven critical piles with this concrete mix.

During construction of those seven piles one concrete sample was taken for every 50m<sup>3</sup> of concrete delivered. The workability and tensile strength results were excellent and after 28 days all test results were above the nominated tensile design requirement of 5MPa.

Concrete testing for all piles of the project was carried out in compliance with AS3600.

A total of 74 indirect tensile strength tests were carried out for the SOUL project and the results are summarized below and shown graphically in Figure 10:

- 2 early strength tests after 2 days: results between 5.2 – 5.4MPa
- 23 early strength tests after 7 days: results between 4.3 – 6.4MPa
- 8 strength tests after 28 days: results between 6.6 – 7.5MPa
- 43 strength tests after 56 days: results between 6.6 – 8.5MPa

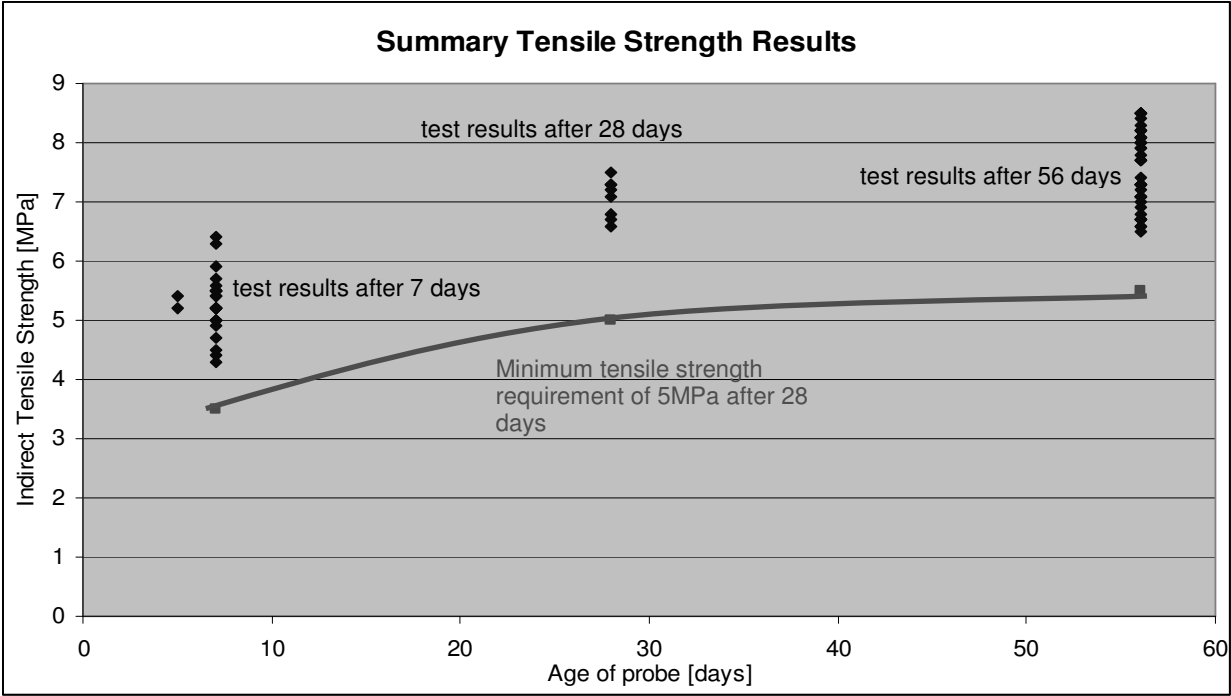


Figure 10: Summary graph of all indirect tensile stress results for the tower piles of the SOUL project

7 ON SITE CONSTRUCTION

Pile drilling works were carried out with a Bauer BG28 drilling rig, a 50T service crane and a 120T service crane. The bentonite plant on site provided a capacity of approximately 500m<sup>3</sup> of drilling fluid which enabled Piling Contractors Pty Ltd to drill and de-sand two 2200mm piles at the same time. Figure 11 shows the excavated piles after bulk excavation.



Figure 11: Plunged columns and tower piles after bulk excavation

The project work was supervised on site by an external geotechnical engineering consultancy (Morrison Geotechnic Pty Ltd) on behalf of Piling Contractors. Rock quality and rock socket lengths for all piles were certified. In addition the supervising geotechnical consultant witnessed the bentonite testing procedures and certified that the sand content in the bentonite was <2% before each concrete pour. This was undertaken because it was essential to provide excellent pile base cleanliness to maximize the benefits of using high strength concrete.

Low strain pile integrity tests were undertaken by Grocon to confirm pile shaft continuity. In addition the specified five cross hole sonic logging tests were undertaken to verify pile shaft quality.

All these tests proved good pile integrities and examples of the results are displayed in Figure 12.

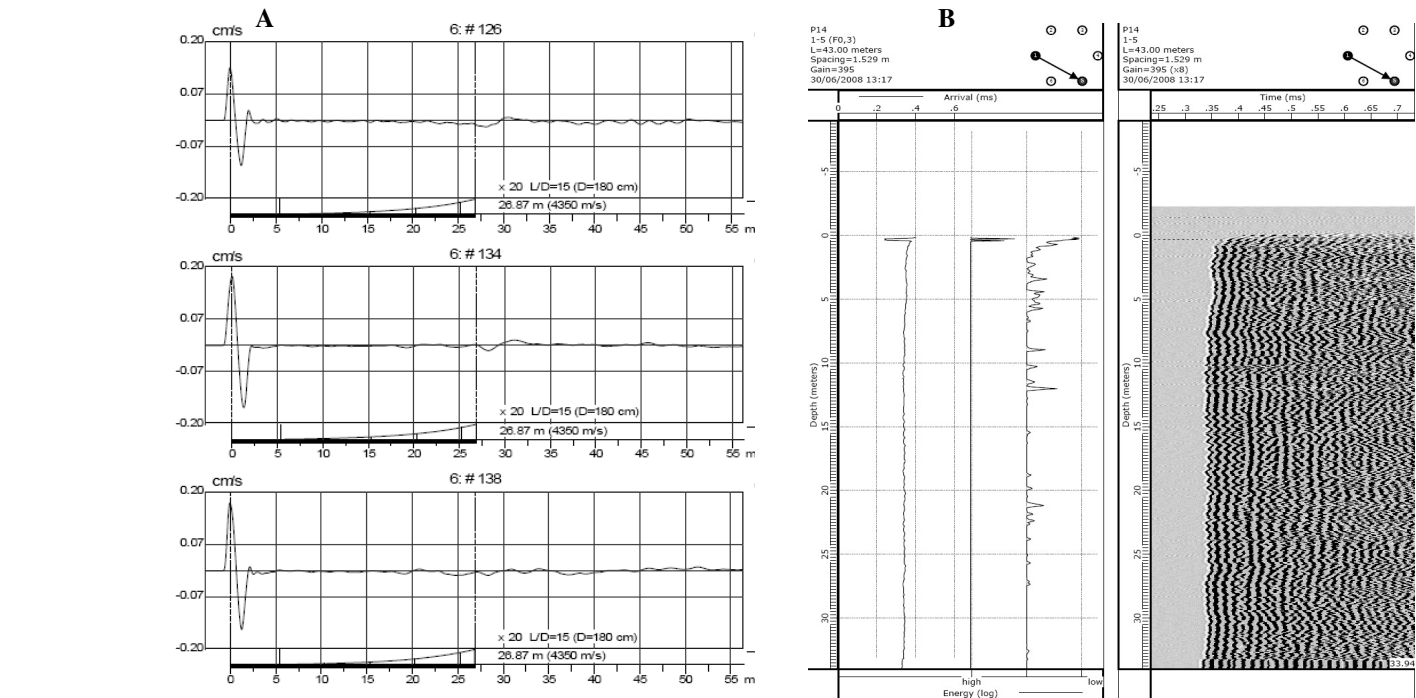


Figure 12: Quality control using pile integrity test: low strain pile integrity test results (A) and sonic cross hole logging tests (B)

## 8 CONCLUSIONS

The installation of stress bars parallel to the longitudinal axis of the pile allows post tensioning loads to be controlled and monitored very precisely after the pile installation. This method requires very accurate design, planning and execution procedures yet can deliver some significant advantages as post tensioning loads can be adjusted as required. For many foundation projects without complex reinforcement splices and restricted installation areas within the pile shafts this option might be the preferred solution.

The use of high strength concrete is dependant on ground conditions and chemistry of the groundwater as well as on the experience and performance of the concrete supplier and the site crew.

For the SOUL project high strength concrete  $f_c \geq 85\text{MPa}$  was used for the foundation piles of the apartment tower and significant risks presented by the use of stress bars were eliminated.

Tensile strength of the concrete mix design used was shown to be in a range between 6.6 to 8.5MPa and the average compressive strength was between 110 to 120MPa. The numerous test results confirmed the assumption that the indirect tensile strength of the mix was between 5 to 8% of the compressive concrete strength. The concrete mix had excellent workability characteristics and pile integrity tests indicated no cracks or inhomogeneous sections in the pile shafts. No shrinkage cracks have been detected during pile integrity tests or after excavation and pile trimming works.

## 9 ACKNOWLEDGEMENTS

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