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Base grouting of bored piles on the Hamilton Section of the Waikato Expressway Project

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ABSTRACT: The Mangaonua Stream Bridge on the Hamilton Section of the Waikato Expressway crosses a deeply incised gully on three spans. The two central piers are required to be supported on bored piles taken through very weak alluvial gully deposits to found in competent non-welded ignimbrites and dense to very dense sands (reworked ignimbrites) at 40 – 50 m depth. Groups of ten piles are used at each pier, with the bridge superstructure sensitive to relatively small pile deflections. A base grouting scheme was developed and implemented to achieve a significant reduction in pile length over the initial proposal of taking the full loads in shaft friction. The design and construction of the base grouting scheme is discussed, with reference to early pile base grouting work undertaken in London in the 1980's and to two previous New Zealand projects. The approach for developing the acceptance criteria for base grouting, and the ultimate suitability of those criteria is described. Noting that there have been very few applications of base grouting in New Zealand and there is no well-defined approach for defining the acceptance criteria, suggestions are made for the design and construction of future pile base grouting schemes.

1 INTRODUCTION

Base grouting of bored piles provides an effective means of stiffening the end bearing response, and reversing to some degree the ground disturbance caused by the pile boring operation. Base grouting has been used overseas for several decades, but has not been widely adopted in New Zealand. As a result, there is little local case study data available to inform fundamental decisions on base grouted pile design and construction control.

This paper attempts to overcome that by presenting the key elements of several New Zealand base grouted pile projects in the context of published case studies from early and more recent work in London.

2 BACKGROUND

Pile base grouting techniques were initially devel-oped on large building projects in London in the 1980's. Documented examples include Canary Wharf (Troughton 1992), South Quay Plaza, and Blackwall Yard (Yeats & O'Riordan 1989). These projects typically used single large diameter bored piles under each column. Pile loads were high and differential settlement between columns was critical. These projects provide a valuable body of load test and construction data. More recently, the Pinnacle development in London (Patel et al 2015) provides useful case study data.

Base grouting is typically used to stiffen the end bearing response of large diameter bored piles. Its effect is to prestress the pile to stiffen the load deflection response at low to moderate loads, and to overcome soil disturbance at base resulting from pile construction. Base grouting doesn't remedy contamination of pile concrete or increase ultimate capacity. Normal care in ensuring a clean pile base prior to concreting is still required.

Load test results presented in Troughton (1992) are reproduced in Figure 1 below and provide a clear comparison of the relative performance of ungrouted and base grouted bored piles. Yeats and O'Riordan (1989) provide additional examples of base grouted test pile performance.

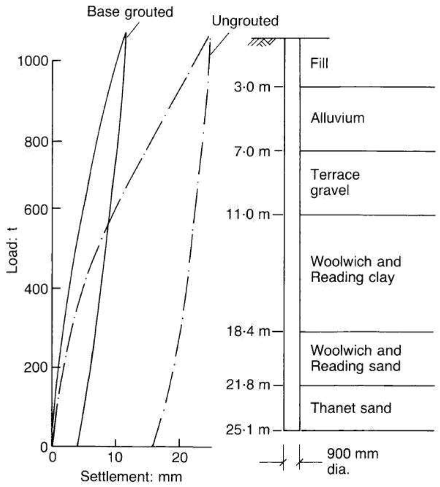

Figure 1. Comparison of load-settlement behaviour of ungrouted and base grouted bored piles (after Troughton 1992)

3 CONSTRUCTION APPROACH

Pile bases are typically grouted through multiple U-tube circuits that are attached to the pile reinforcement, each fitted with a tube-a-manchette (TaM) located close to the bottom of the concrete (Figure 2). Rubber sleeves are used to prevent back flow into the grout tubes. The TaM's need to be opened (using water pressure to crack the underlying concrete) within 24 hours after concreting of the pile. If left for longer, there is a risk that the concrete will be too hard for the TaMs to open.

Figure 2. Grout tube arrangement Waikato River Bridge

The first cycle of base grouting typically commences at least seven days and not later than eight weeks after concreting the piles. Each circuit should be grouted a minimum of two times. Should re-grouting be required, this should take place no later than 24 hours after the initial phase. Grout mix designs can vary between water/cement ratios of 0.45-1.0 depending on ground conditions. Injection is carried out using electro-hydraulic single action oscillating piston pumps controlled using, in our case, a Jean Lutz BAP160 automated control system. This records grout volume and pressure and controls the pumps.

The first phase of grouting typically targets volume and pressure, and the second phase typically targets pressure and uplift. For deep piles, where pile shortening can mask uplift at the pile head, uplift of the pile toe needs to be measured directly with a rod extensometer with dial gauges set up on an independent reference frame.

Acceptance of base grouting at any pile requires consideration of achieved grout volume, peak and residual grout pressures and pile uplift against target values for each parameter. It is common for acceptable results in two of the three parameters to be deemed adequate. A similar, though somewhat more detailed, acceptance process was developed for the Pinnacle project, and is described in Patel et al (2015). That approach included a subjective assessment of the hardness of the base of the pile bore based on sounding with a weighted tape.

4 EXISTING GUIDANCE

Formal guidance on base grouting for piles is limited. The ICE Specification for Piling and Embedded Retaining Walls (ICE 2017) provides a useful overview of the process, its control and potential problems, particularly in its Guidance Notes. Tomlinson & Wood-ward (2008) provide an example grout tube arrangement which is reproduced from Yeats & O'Riordan (1989). This diagram is reproduced as Figure 3 below.

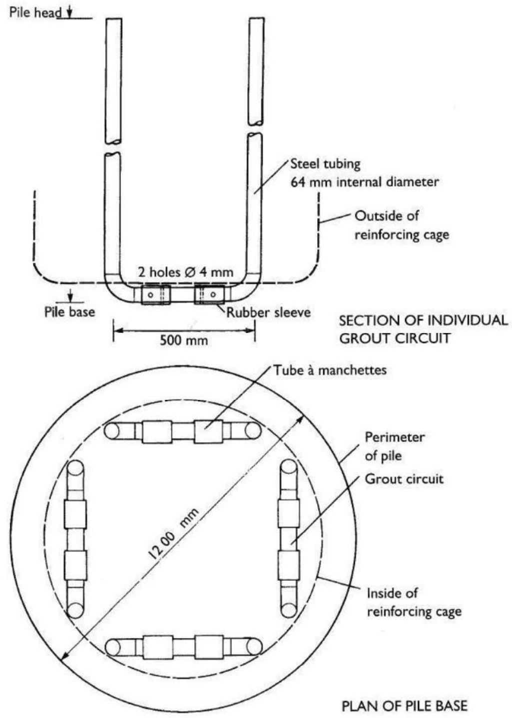

Figure 3. Arrangement of grout circuits (after Tomlinson & Woodward 2008)

5 NEW ZEALAND EXAMPLES

Base grouting of piles is not widely used in New Zealand, so there is an absence of documented case studies and limited experience within the industry. The authors have used base grouting on three bridge pro-jects over the past 10 years – Tauranga Harbour Link (Wharmby et al 2008), Waikato River Bridge on the Ngaruawahia Section of the Waikato Expressway, and the Mangaonua Stream Bridge on the Hamilton Section of the Waikato Expressway.

These are summarised in Tables 1 to 3, together with equivalent data from earlier published case studies.

Table 1. Case study data – pile dimensions and ground conditions

Project	Date	Pile dia (mm)	Pile Length (m)	Toe material	SPT N at toe
Canary Wharf, London	1987	900-1500	25	Thanet Sand	50+
Blackwall Yard, London	1988	1200	38	Thanet Sand	140
Pinnacle, London*	2010	1200-2400	65	Thanet Sand	
Tauranga Harbour Link	2008	900-2300	35	Ignimbrite	50+
Waikato River Bridge	2012	1600	15/23.5	Walton sands	25-30
Mangaonua Stream Bridge	2018	1200	44-47	Walton sands	

* Refer Patel et al 2015 for more details

Table 2. Case study data – grout circuits and acceptance criteria

Project	Number of circuits	Acceptance criteria**			
		Grout pressure (bar)		Grout volume (l)	
		Peak	Residual	Cycle	Total
Canary Wharf, London	4	30	15 at 2 minutes	100	-
Blackwall Yard, London	4	60 (max)	-	-	296
Pinnacle, London*	4 up to 1800 dia 6 for 2100 8 for 2400	30	15	Min 5	Varies with size
Tauranga Harbour Link	2 up to 1200 dia 4 for 1500+	35	-	100/m^2	200/m^2
Waikato River Bridge	4	15/20 (20-50)	-	200 (50-180)	400 (230-500)
Mangaonua Stream Bridge	2	40	15 at 2 minutes	110	225
ICE Piling Specification 2017		30-60	15 for 2 minutes	-	-

* Refer Patel et al 2015 for more details
** Values in brackets denote results achieved

Table 3. Case study data – acceptance criteria

Project	Acceptance criteria**	
	Pile uplift (mm)	
	Toe	Head
Canary Wharf, London	-	0.1-2.0
Blackwall Yard, London	-	1 (max)
Pinnacle, London*	0.1	2
Tauranga Harbour Link	0.2-2.0	-
Waikato River Bridge	0.2-2.0 (0.1-1.9)	-
Mangaonua Stream Bridge	0.2-2.0	- (0)
ICE Piling Specification 2017	0.3-2.0	-

* Refer Patel et al 2015 for more details
** Values in brackets denote results achieved

5.1 *Mangaonua Stream Bridge*

Te Hamilton Section of the Waikato Expressway is being undertaken by the City Edge Alliance for the New Zealand Transport Agency as Client. The Mangaonua Stream Bridge forms part of this project, and crosses a deeply incised gully on three spans. The two central piers are required to be supported on bored piles taken through very weak alluvial gully deposits to found in competent non-welded ignimbrites and dense to very dense sands (reworked ignimbrites) at 40 – 50 m depth. Groups of ten piles are used at each pier, with the bridge superstructure sensitive to relatively small pile deflections. A base grouting scheme was developed and implemented to achieve a significant reduction in pile length over the initial proposal of taking the full loads in shaft friction.

The base grouting design for Managonua Stream Bridge involved consideration of grout pressure and volumes, and of the resulting pile uplift, in order to be confident that acceptably stiff end bearing response would be achieved without adversely affecting skin friction behaviour. These piles are relatively long, so the simple and convenient approach of measuring uplift at the head of the pile was not sufficient.

The number of grout circuits (two for these 1.2m diameter piles), Figure 4, was based on recent project precedent. Peak grout pressure was derived from consideration of pile end bearing loads and an assumed area of application from each circuit. The intention was to preload the pile base to the equivalent end bearing pressure under working load.

Pile uplift at the toe followed ICE (2017) recommendations, with a view to mobilising a component of skin friction and thus preload that portion of pile capacity. Pile head uplift was to be recorded but was not specified. No pile head movement has been observed on any of the piles grouted to date. This reinforces the importance of uplift measurement at the pile toe.

Figure 4. Grout tube arrangement Mangaonua Stream Bridge

Target grout volumes were derived with consideration of expected pile uplift and compaction of the material immediately beneath the pile toe. All of the specified limits were compared against ICE (2017) guidance.

6 SUGGESTED CRITERIA

A number of criteria need to be considered when developing and executing a base grouted piling programme, and these are discussed in turn.

Firstly, it is necessary to determine the number of grout circuits to be provided. Early schemes used four circuits, distributed around the perimeter of the pile cage. More recently, that has reduced to two for smaller diameter piles (say up to 1200mm) and increased for larger ones (over 1800mm dia). The Pinnacle project (Patel et al 2015) used an assumption of a maximum grout flow distance of 600mm to determine the number of circuits. This approach seems reasonable.

Measured pile uplift, at toe and head, provides confidence that the base grouting has mobilized the weight of the pile and some skin friction resistance. Early work used pile head movement as a control. Such an approach seems appropriate for shorter piles (say up to 25m length) at relatively low end bearing pressures. Longer piles and high target end bearing pressures may exhibit significant axial shortening during base grouting operations, so measurement of pile uplift at the toe provides better control. Current ICE guidance to measure uplift at the pile toe (ICE 2017) is recommended to be followed in all cases. Target uplift values have not changed significantly over the past 30 years, and again the ICE guidance of 0.3mm to 2.0mm provides a useful starting point.

Grout pressure needs to be developed on a project basis, with consideration of design end bearing pressures and confining pressure at the pile toe. Residual pressure after a hold period is also important, to demonstrate that the intended improvement in pile stiffness is achieved. The ICE (2017) guidance provides a valuable starting point.

Grout volume must be assessed on a case by case basis, with consideration of the likely area affected by each cycle of grouting, expected pile uplift, expected compression of the underlying ground and other possible flow paths. An initial target of $100 l/m^2$ of pile area per cycle appears from the literature to be a common starting point.

In all cases, close scrutiny of all parameters is required during the base grouting operation. There are often surprises, and in many cases, acceptance is based on achieving two of the three criteria. Patel et al (2015) set out a relatively sophisticated methodology for assessing base grout adequacy at the Pinnacle development, and their logic could be applied to other projects. A flow chart showing the approach used on the Mangaonua Stream Bridge is presented in Figure 5 below.

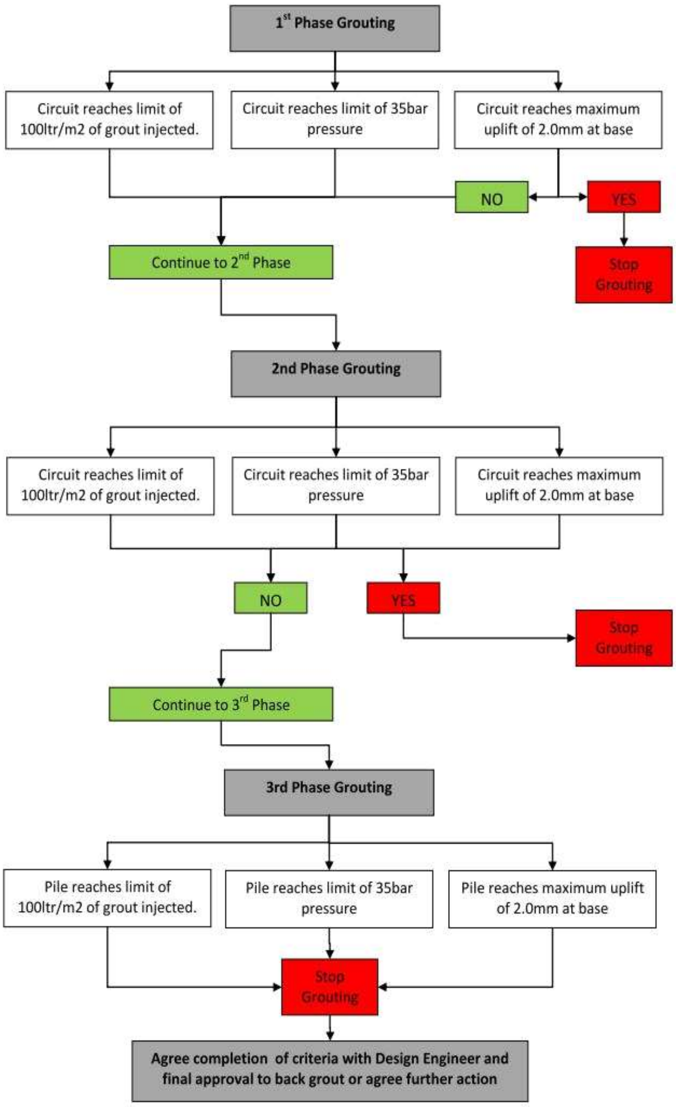

Figure 5. Base grouting flow chart

7 CONCLUSION

The variability of ground conditions in NZ, the high cost of pile testing and small number of sufficiently large projects means testing of base grouted bored piles is likely to be limited. A design and construction approach based on UK precedence has been adopted to date and has achieved acceptable performance.

Base grouting of bored piles is predominantly used in granular soils where pile design includes a significant end bearing component and load settlement performance is critical. In many situations, base grouting to utilise a significant portion of end bearing capacity at sufficiently small displacement can greatly reduce pile length. This was the case at the Mangaonua Stream Bridge, and resulted in a reduction in pile length and consequent shortening in the duration of pile boring and concreting at that site. This led not only to cost savings but also increased confidence in pile performance.

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