Effectiveness of Pile Debonding Materials with Pile Global Strain Measurement

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ABSTRACT: Various debonding materials were applied onto the pile shaft surface to reduce the shaft friction transfer to supporting subsoil. Four debonding configurations using heavy-duty mechanical grease, bitumen, bitumen with underlining primer coating and primer coating alone were carefully planned with instrumentation scheme to reveal the effectiveness of the selected debonding materials on pile shaft resistance transfer. The debonding materials were applied on the pile shaft surface of a 600mm diameter prestressed spun pile installed using static jacking injection method, whereas pile instrumentation utilised global strain gauges installed along various segments in the pile body after completion of pile installation. The respective debonding materials applied over 6m segments each along the pile body and the lowest 12m uncoated segment of the pile was used as reference. The effectiveness of the debonding materials was quantified based on the percent reduction in shaft friction of the respective debonding segments normalized to the pile shaft resistance of the baseline reference segment without debonding.

KEYWORDS: Global elastic strain, Shaft friction, Debonding, Bitumen, Grease, Primer, Jack-In pile, Injection pile

1. INTRODUCTION

Debonding of piles is often deployed to minimise the effects of downdrag or negative skin friction which leads to excessive stress exerted onto the foundation pile. Pile debonding is also adopted for situations where load transfer within certain subsoil stratum is undesired, for example load transfer from deep foundations to nearby underground structures such as tunnels or stations. For precast piles, coating the pile with bitumen is common to achieve the debonding effect and reducing the load transfer to the surrounding soil (Tomlinson *et al.*, 2008). The reduction in shaft friction resistance as a result of bitumen coating when correctly applied, typically ranges from 30% up to 90% (Whitworth *et al.*, 1993 and Long, 1982).

This case study presents a fully instrumented test pile installed and coated with various debonding materials to verify the performance of the debonding materials in reducing the shaft friction transfer to supporting subsoil. A 600mm diameter prestressed spun pile with working load of 2,700kN was installed by static jacking injection method up to two (2) times the designated pile working load (i.e. 5,400kN) and terminated at a depth of 42m below the piling platform level, which is believed resting on limestone bedrock.

Four (4) types of debonding configurations were applied to the pile shaft, namely heavy-duty mechanical grease, bitumen, bitumen with primer coating, and primer coating alone, all of which were applied to the pile surface on site (i.e. during injection of the test pile) except for the segment with primer coating, which was pre-applied.

The pile was instrumented using the proprietary Global Strain Extensometer (GLOSTREXT) system (Krishnan *et al.,* 2006) to determine the pile axial shortening along specific segments of the pile coated with various debonding materials. The pile was subjected to a maximum test load of 8,100kN via static load test.

2. DESIGN METHODOLOGY

2.1 Subsurface Information

According to the Geological Map of Kuala Lumpur, published by the Director General of Minerals and Geoscience Malaysia in 2011, the test pile was installed at a site underlain by Kuala Lumpur Limestone formation. A reference borehole was sunk approximately 1m away from the pile location prior to the pile installation. Based on the borehole information, the overburden materials mainly consist of silty SAND with SPT-N blow counts ranging from 3 to 31 before encountering limestone bedrock at about 42m below ground level as shown in Figure 1.

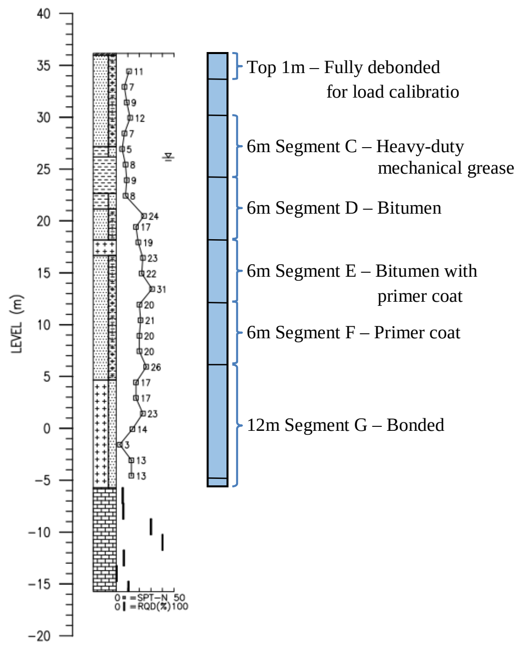

Figure 1 Reference Borehole Profile

2.2 Pile Installation

The 600mm diameter prestressed spun pile was installed using high capacity static injection machine with installation termination at end bearing condition. The termination criteria adopted for the pile installation was to jack the pile to two (2) times the designated pile working load and the static jacking procedure repeated three (3) times for assurance of consistency with stable termination. For each repetition, the corresponding maximum pressure was held for a minimum of 20 seconds with pile head settlement not exceeding 2mm. The pile termination readings were taken for all three (3) sets of repetition with an interval of not less than three (3) minutes between each set. The injection pressure exerted onto the pile during installation process was recorded using an automated data-logger.

2.3 Pile Debonding

The four (4) types of debonding materials were applied onto the pile shaft in 6m segments each. The first 6m segment of the pile was coated with heavy-duty mechanical grease, the next 6m segment was coated with 3mm thick bitumen, subsequent 6m segment was coated with 3mm thick bitumen over a pre-applied primer layer for better bonding as per manufacturer's recommendation and the last 6m segment was coated with pre-applied primer layer only. The lowest 12m segment of the pile was not coated with any debonding material and is used as baseline reference for non-debonded segment. Studies (Khare *et al*., 2006) suggest that it is sufficient to apply 2mm to 5mm thick bitumen coating in order to achieve the anticipated debonding effect.

Pile installation via static injection method requires the pile shaft to be gripped and injected into the ground with the applied downward action. Due to this constraint, debonding materials were required to be applied on site below the mechanical grip during installation of the test pile. The application of the debonding materials was carried out within the allowable headroom of the pile injection machine which was approximately 2m only. However, the primer layer can be pre-applied onto the pile body as the primer layer does not remarkably affect the machine grip, is less susceptible to damage and if found damaged, can be easily reapplied in similar fashion as the other debonding materials.

In order to protect the debonding coating on the pile shaft surface, steel collars were welded at all pile joints during pile jointing to create an enlarged annulus of soil wall, reducing scratching of the soils onto the pile shaft surface. The annulus was simultaneously filled with bentonite slurry in the excavated pit around the pile via gravity feed to fill the annulus gap in between the debonding coating and supporting soil wall. Figures 2 to 5 show the application of various debonding materials during pile installation.


Figure 2 Application of Heavy-Duty Mechanical Grease as Debonding Material during Pile Installation

Figure 3 Application of Bitumen as Debonding Material during Pile Installation


Figure 4 Application of Bitumen with Primer Coating as Debonding Material during Pile Installation

Figure 5 Primer Coat as Debonding Material

2.3 Pile Instrumentation

Proprietary GLOSTREXT pile deformation monitoring system was adopted to measure the axial loads and axial shortening at various levels of the debonding segments along the pile shaft including the pile base. Eight (8) levels of instruments comprising vibrating wire extensometer strain gauges and extensometer anchors were installed in the test pile as shown in Figure 6. For ease of reference, segments C, D, E, F and G correspond to heavy-duty mechanical grease, bitumen, bitumen with primer coat, primer, and no debonding segments respectively. It should be noted that the top level instrumentation with anchorage length of 1m was fully debonded for load-strain calibration and for measurement of non-linear pile elastic modulus corresponding to the given axial compression stress.

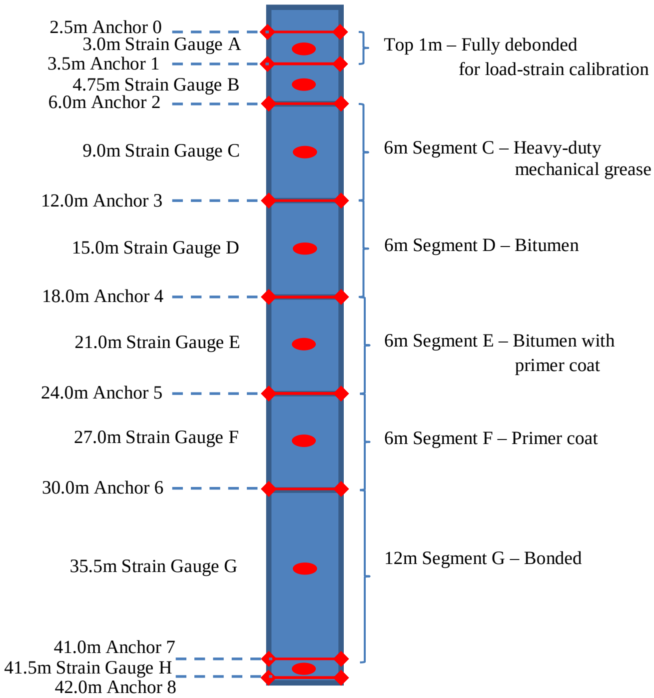

Figure 6 GLOSTREXT Instrumentation Levels

3. PERFORMANCE OF DEBONDING MATERIALS

Figures 7 and 8 show the load-settlement graph of the test pile and the interpreted mobilised shaft friction on the respective debonded pile segments taking into consideration the non-linearity of the concrete's stress-strain relationship.

The maximum pile shaft friction for various segments along the pile shaft and corresponding debonding material configuration is summarized in Table 1. Based on the mobilized pile shaft friction for the bonded segment (G), 118.8kPa is achieved for an average SPT-N value of 15 blow counts, leading to a skin friction factor, f_s of 7.9 (118.8 ÷ 15). Therefore, for a pile that is fully bonded, the mobilized pile shaft friction for other segments can be estimated by adopting 7.9 × N.

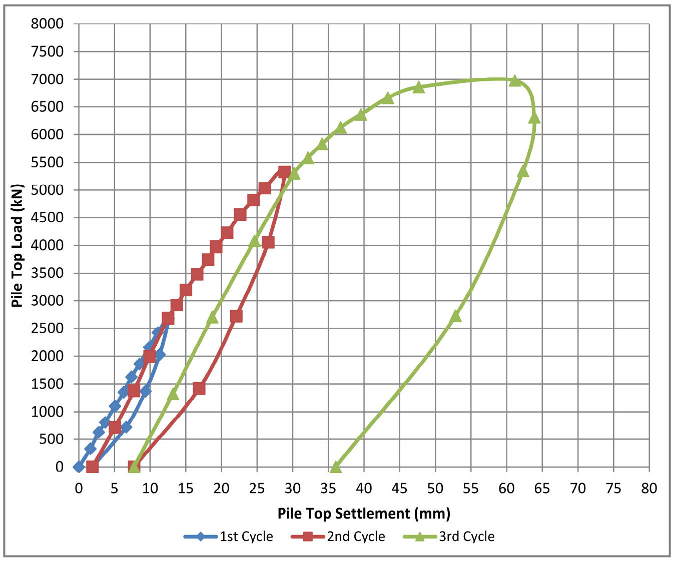

Figure 7 Load-Settlement Graph of Test Pile

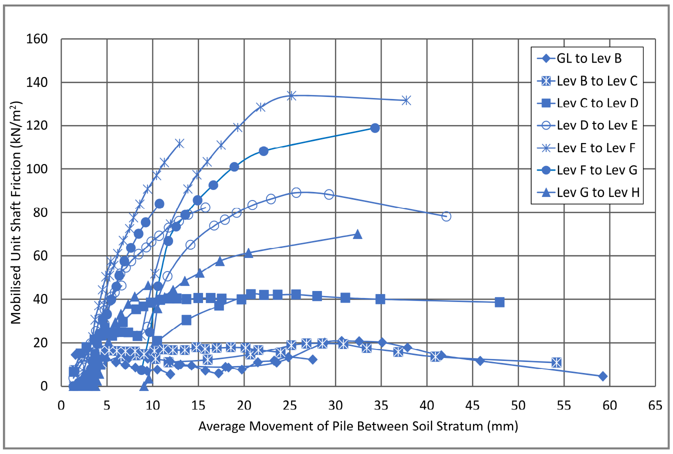

Figure 8 Interpreted Mobilised Shaft Friction of the Respective Debonded Pile Segments

Table 1 Maximum Mobilised Shaft Friction and Corresponding Debonding Material

Segment	Debonding Material	Average SPT-N	Max Mobilised Shaft Friction, fs (kPa)	fs /SPT-N
C	Grease	7	19.7	2.8
D	Bitumen	15	42.2	2.8
E	Bitumen + Primer	22	89.0	4.0
F	Primer	20	133.8	6.7
G	Bonded	15	118.8	7.9

The effectiveness of the debonding materials was quantified based on the percentage of reduction in pile shaft friction between the actual measured mobilised pile shaft friction with debonding and the estimated pile shaft friction without debonding. The estimated pile shaft friction for Segments C to F assuming no debonding (fully bonded) is tabulated in Table 2 together with the resulting reduction in shaft friction. We can conclude that the most effective debonding material are heavy-duty mechanical grease and bitumen coating (64.4% reduction for both), followed by bitumen with primer coat (48.8% reduction) and lastly primer coat only (15.3% reduction).

Table 2 Shaft Friction Reduction and Corresponding Debonding Material

Segment	Debonding Material	Est. Shaft Friction without Debonding (kPa)	Reduction in Shaft Friction by Debonding (%)
C	Grease	55.3	64.4
D	Bitumen	118.5	64.4
E	Bitumen + Primer	173.8	48.8
F	Primer	158.0	15.3
G	Bonded	118.8	0

4. DISCUSSIONS

Some discussions on the evaluation of efficiency of debonding effect can be as follows:

i. The skin friction factor, f_s/SPT-N for pile capacity is originally adopted from Meyerhof (1976). This factor can vary with respect to the SPT-N values. In general, f_s/SPT-N decreases with increasing SPT-N value.

ii. In addition to the above, the skin friction factor, f_s/SPT-N might also reduce with increasing distance of the location of friction from the pile toe. It is understood that the radial stress on the pile shaft reduces after some distance from the action of soil displacement at the pile toe with bearing failure from pile toe advancement. Hence the pile skin friction capacity shall reduce accordingly.

iii. The degree of mobilisation of skin friction can be restrained by the relative pile shaft interface movement with respect to the supporting soils especially in end bearing condition whereby the toe will have limited displacement.

5. CONCLUSION

Debonding materials was successfully applied in-situ onto the surface of a 600mm diameter prestressed spun pile and installed via static injection method with the use of steel collars and bentonite in-fill to protect the debonding layers. Based on the instrumented test pile results, grease and bitumen shows largest reduction in shaft resistance (64.4% reduction) followed by bitumen with primer coating (48.8% reduction) and finally primer coating only (15.3% reduction).

As bitumen and grease debonding materials achieve the same desired effect, the efficiency of grease application is considered more superior in terms of practicality. The key reasons of conventional bitumen solution include longer time required to heat up bitumen compound, brushing of hot-viscous bitumen onto pile body and cooling time of the bitumen layer, all of which are not necessary when applying grease at normal ambient temperature; however, the long-term durability of grease was not assessed in this study.

6. REFERENCES

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