ASSESSMENT OF EXISTING FOUNDATIONS FOR BUILDING UPGRADE PROJECTS

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1 ABSTRACT

Building owners are often faced with the question of whether to demolish and rebuild to gain extra floor space, or to assess if existing buildings can support additional levels. Aside from the adequacy of the superstructure, consideration must be given to the capacity of the existing foundation system to cater for the increased loading. Douglas Partners (DP) has employed a range of portable equipment for use in often congested basements and poor access areas, to investigate and develop a geotechnical model for such sites.

Where no records exist, or where the assessment of the existing pile foundation is required for QA purposes, low-strain pile testing techniques may be used to determine pile lengths. The geotechnical model and existing foundation details are subsequently combined to assess the capacity and expected settlement performance of the existing foundation system. In most cases, increased confidence in parameters and advances in foundation analysis and design methods has permitted extra floors to be added, thus realising a large capital benefit for the owner of the building.

2 INTRODUCTION

Substantial increases in property values over the last 20-30 years in beachside suburbs and key commercial areas of Sydney have resulted in owners looking to increase floor space. Similarly, increased traffic congestion and reduced street parking has also driven owners to consider incorporating off-street parking to existing buildings. In some Council areas where existing buildings exceed current height restrictions, it is a commercial imperative to retain the building superstructure. This situation has resulted in major refurbishments and the conversion of many buildings from commercial to residential structures, often with an increased or modified configuration of loading.

Douglas Partners (DP) has recently undertaken a number of investigations to assess whether the existing foundation system is adequate to cater for the load increases associated with additional floors or a reduced pile length, in cases where a new basement is constructed below an existing building.

DP has adapted drilling and cone penetration testing (CPT) equipment to operate in tight-access and low-headroom conditions. This paper will focus on the use of portable CPT equipment to assess the capacity and settlement of existing pile foundations subject to additional loads. A photograph of a portable CPT rig operating is shown in Figure 1.

Figure 1: Portable CPT rig in operation for a building upgrade project.

Aside from investigating the founding conditions for existing piles, the consultant is often faced with the problem of having little or no information on the piles themselves. Non-destructive test methods such as sonic integrity testing (SIT) or various geophysical techniques have been employed to determine the length and diameter of the existing piles.

Once the soil profile and geometrical details of the piles are established, traditional static analyses are performed to assess the piles in the context of the current piling code (AS2159-1995), for the proposed load increases. The ultimate geotechnical strength is estimated using an in-house computer program based on a range of empirical correlations between CPT results and pile base/shaft stresses. The increased confidence in pile capacity and settlement estimates that are achieved with CPT data usually indicates that extra load can be safely supported by the existing foundation system, with relatively minor additional settlement.

3 BACKGROUND

The first step in any existing foundation assessment is to gather all historic data including as-built drawings including piling records showing pile types, lengths and diameters and other construction details (e.g. lengths of temporary casing, pile driving records). Also, subsurface data is reviewed and in many cases there is only historic borehole data with little detail and often no reduced levels. A preliminary assessment of the existing pile capacity and expected (new) settlement under the increased loading is performed on the basis of available information.

It is the authors’ experience that building upgrade projects usually require the close interaction of the structural engineer, architect and geotechnical consultant. The preliminary foundation assessment plus changes to the building layout and the estimated increases in loading generally dictate the extent of investigation and pile testing required.

The essence of the “forensic” foundation assessment method is the use of low-strain pile testing methods, in conjunction with portable CPT adjacent to the subject piles. The following sections describe the application of the various investigation and testing techniques.

4 PILE LENGTH ASSESSMENT

4.1 SONIC INTEGRITY TESTING

Sonic integrity testing (SIT) is a low-strain technique that is mostly used for checking the structural integrity or continuity of newly constructed pile shafts for quality control purposes in piling contracts. This paper refers to use of the sonic echo test, or sonic impact test, as it is referred to in AS 2159 – 1995, the Australian piling “code”.

The sonic impact test involves inducing a compressive stress wave to a pile via a hand-held hammer blow. The stress wave travels down the pile shaft as a wave front and is reflected back towards the pile head, either wholly or in part, by changes of impedance within the pile. The sensor, which is normally a piezo-electric accelerometer, records the reflected stress wave. The pile toe and other significant sectional discontinuities (e.g. inclusions, cracks) cause changes of impedance. The velocity of the wave front or wave speed (C) is determined by the mechanical properties of the pile material.

The time lapse (t) between the hammer impact and arrival of the returning reflected wave from the pile toe, or other interface, will therefore be given by:

(1) $$t = 2L / C$$

where L = distance to the reflecting surface

C = wave speed (m/s)

The wave speed “C” for a concrete pile is dependent upon concrete quality and consistency as follows:

(2) $$C = (E/\rho)^{1/2}$$

E = Young’s Modulus (N/m^2)

ρ = density (kg/m^3)

For example, in sound concrete the propagation or C is generally between 3500 m/s to 4300 m/s. The usual range of C is about 3700 – 4000 m/s for fresh concrete of 32 – 40 MPa strength that is only seven days old, increasing to 4000 – 4300 m/s for fully cured concrete of 60 MPa strength that is over three months old.

For the newly constructed piles, the operator is able to adjust C until the pile length as indicated from the piling records and toe reflection corresponds. In this way both the general consistency of the pile material is indirectly indicated (via C), together with the depth below the pile head to the various reflecting interfaces.

For forensic pile investigations however, where no piling records are available, the operator must adopt the appropriate C value, on the basis of laboratory testing of concrete core samples or experience. The adopted value of C is critical in determining the pile length as it is the travel time between the hammer impact and the excitation of the pile head caused by the reflected stress wave that indicates the pile length.

4.2 FORENSIC SIT METHOD

Ideally SIT is carried out by imparting a hammer blow to the pile head and measuring the reflection response of the pile. This is the case where SIT is used for routine QA control of newly installed piles, where the pile length is known and documented in the contractors records or digitally via a pile installation recorder (PIR)™, or equivalent device. For forensic SIT projects however, the existing piles support the superstructure of the subject building and therefore often cannot be readily accessed. It is sometimes possible to access the existing piles where partial demolition of the building allows some piles to be exposed. For example in situations where the internal layout of the building is to be modified. In some other cases, the piles extend to the surface and are isolated from the slab-on-ground floor or pavement. If the columns are smaller than the piles upon which they are founded, there is often sufficient access around the perimeter of the pile head to carry out SIT.

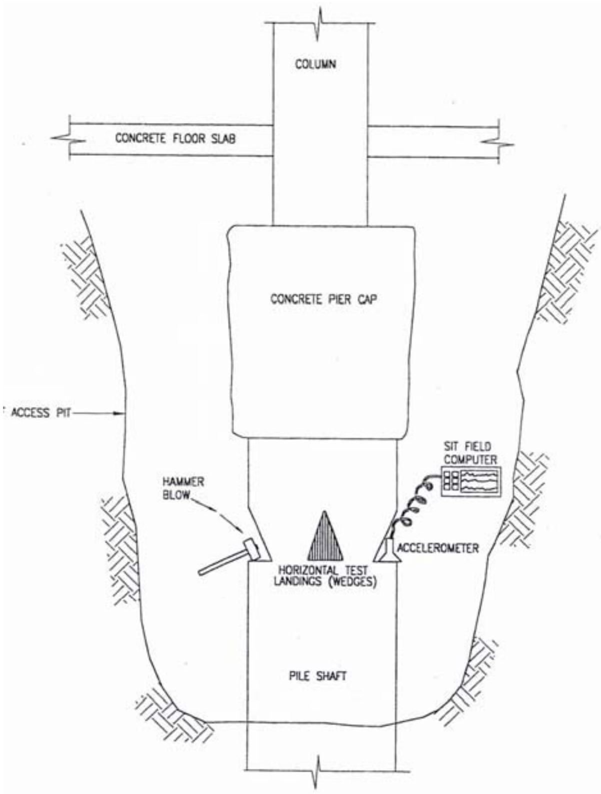

Figure 2: Typical pile preparation and testing arrangement for non-accessible pile head.

In cases where the pile head is not accessible, it is necessary to excavate a pit large enough to expose the upper pile shaft and allow safe entry by the testing engineer. This usually involves sawing through the floor slab and then removing the material around the pile cap and upper section of the pile shaft. Two wedges are then cut into the side of the shaft to create horizontal landings to place the accelerometer and for the hammer blow, as shown in Figure 2.

SIT signals are displayed in terms of velocity (or impedance) versus pile depth and are referred to as "reflectograms". On the basis of the above, it is the shape of the reflectogram that provides a qualitative indication of the presence of pile discontinuities and the location for the pile toe. The operator normally adopts a range of trial pile lengths based on the adopted C value and available borehole or CPT data, until a clear toe reflection is observed at a consistent and plausible pile length. For longer piles, or where a higher degree of accuracy is required, the C value for the concrete pile is determined by coring a sample of about 500 mm length and then conducting a 'Sonic Velocity' laboratory test.

The diameter of the pile can normally be measured where the pile head, or alternatively the upper pile shaft are exposed. In the case of enlarged-based piles, or where substantial oversupply of concrete has occurred, it may be useful to infer the geometry of the entire pile length. Modelling software is available for interpreting and analysing SIT signals, such as PROFILE™, which is a computer program within the software package PIT-W™, developed by Pile Dynamics Inc. of the USA. Pile PROFILE™ analysis of selected records allows the engineer to generate a "most likely pile impedance verse depth plot" (PDI, 2001). The program works by estimating and then removing the velocity effects of soil resistance to establish a "reference line". The pile geometry or profile is then calculated by integrating the difference between measured velocity and the 'reference line'. An example of the output from a PROFILE™ analysis carried out for an grout-injected (CFA) pile for a building upgrade project in Sydney's eastern suburbs is presented in Figure 3. It is noted that significant enlargement of the upper shaft, was also apparent for the piles on this project.

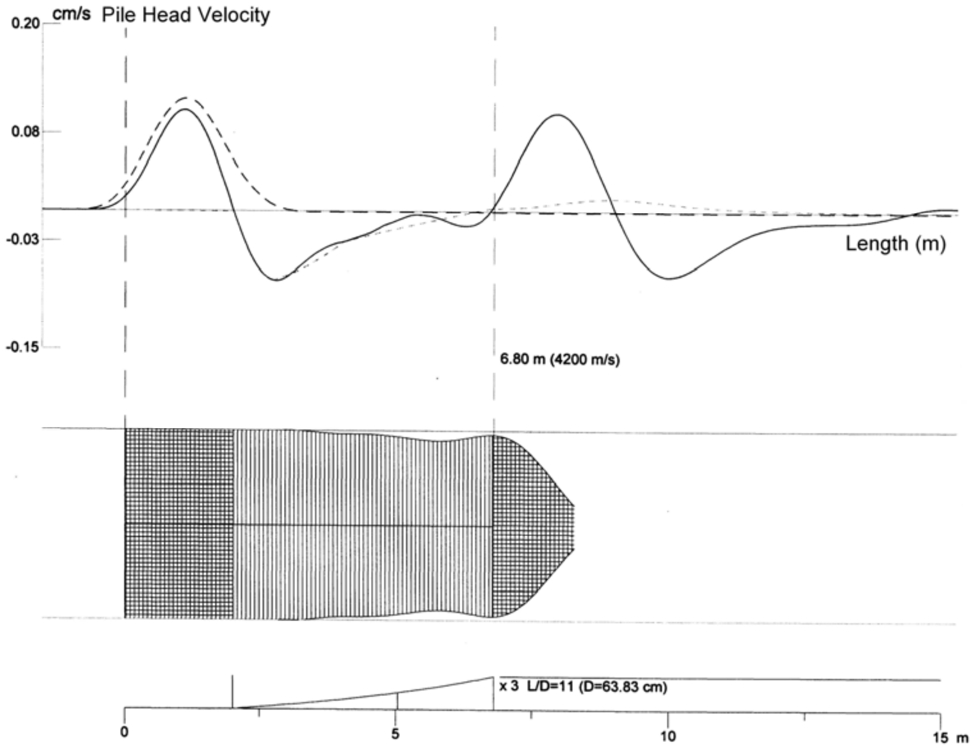

Figure 3: Example of output from PROFILE™ analysis for a grout-injected CFA pile.

5 PORTABLE CONE PENETRATION TESTING

Cone penetration testing (CPT), also referred to as 'Dutch Cone' or electric friction cone (EFC) testing, involves the continuous pushing of a rod with an instrumented tip and shaft that can measure and electronically relay end and shaft resistances to a computer at the surface. The measured tip and shaft resistances are stored digitally and can be sent to the office via modem for immediate review or analysis.

Pushing of the rods is usually via a purpose-built truck with up to 21 tonnes thrust force. In difficult access situations however, as is often the case for building upgrade projects, a portable hydraulic ram system is used to push the cone rods with a thrust force of up to 5 tonnes. The frame for the ram is usually bolted to the existing floor slab or alternatively, tanks of water can be used to provide sufficient reaction force to push the rods. The equipment can be disassembled and taken down stairwells and into confined areas and can be set up with only 2.6 m of headroom.

6 APPROACH TO EXISTING PILE ASSESSMENT

6.1 GENERAL

By combining the estimated length of the pile with the subsurface profile (CPT data), an assessment of the pile capacity and settlement can be determined for the subject pile. A certain amount of pile data such as the pile diameter, construction material and pile type is required to effectively asses an existing pile.

A Limit State approach to pile assessment in accordance with AS 2159-1995 is normally adopted. The new design action effect (S*) and Serviceability loads are provided by the structural engineer. A choice of geotechnical strength reduction factor (ϕ_g) commensurate with the level of site investigation data and pile load test data is chosen by the geotechnical engineer assessing the pile. Where portable CPT has been performed directly adjacent to the subject pile a ϕ_g value of up to 0.65 can be justified. This reflects the increased level of confidence in the continuous profile of soil strength provided by CPT, as compared to historic borehole logs which often only include intermittent Standard Penetration Test (SPT) results.

Aside from capacity and settlement considerations, it is important to assess the continuity and structural integrity of the existing piles, where they will be re-used for an upgraded building. Where SIT has been performed and the pile toe is clearly visible, the integrity of existing piles can usually be assessed.

6.2 PILE CAPACITY

The ultimate geotechnical strength (R_{ug}) or capacity of existing piles is estimated using the inferred pile geometry in conjunction with CPT data and relevant empirical correlations. There are numerous published empirical correlations between CPT cone resistance (q_c) and the ultimate base (or end) bearing pressure (f_b). Different correlations are appropriate for various pile types, installation methods and soil materials.

For example, the "Dutch Method" (DeRuiter and Beringer, 1979) is suitable for displacement pile types such as driven precast concrete piles, auger-screwed concrete piles (e.g. Atlas) or driven cast-in-situ piles such as the enlarged-base (Franki) pile. This Method involves a complex smoothing and averaging procedure taking into account q_c values from eight pile diameters above the pile toe level and up to four diameters below, to determine the average or "smoothed" cone resistance (q_{cs}). The calculated value of q_{cs} is then adopted to estimate f_b, with an upper limit of 15 MPa applied. Other empirical correlations based on either q_c or the CPT sleeve friction (f_s) are used to estimate the ultimate shaft friction.

DP uses an in-house computer program, ConePile, for preliminary assessment of R_{ug}. ConePile uses the q_c and f_s results directly from the processed CPT data files to provide an instant graphical presentation of the following pile parameters versus depth:

- Ultimate End Bearing Pressure (f_b), superimposed over cone resistance (q_c) profile (in MPa);
- Ultimate Shaft Friction, superimposed over sleeve friction (f_s) profile (in kPa);
- Ultimate Shaft Capacity (in kN), cumulative with depth;
- Ultimate Geotechnical Strength, R_{ug} (in kN), cumulative with depth; and
- Design Geotechnical Strength, R* (in kN), cumulative with depth.

ConePile allows the engineer to select the appropriate pile type, size and shape for analysis from a series of drop-down menus, together with the adopted $Ø_g$ value. Also, there are a number of empirical correlations aside from the 'Dutch Method' to estimate the above pile parameters, including the 'LCPC Method' (Laboratoire Central des Ponts et Chaussées, 1982). An example ConePile result for a building upgrade project in Bondi is shown in Figure 5, with the pile geometry, as estimated from forensic SIT methods (and PROFILE^{TM} analysis) superimposed on the plot.

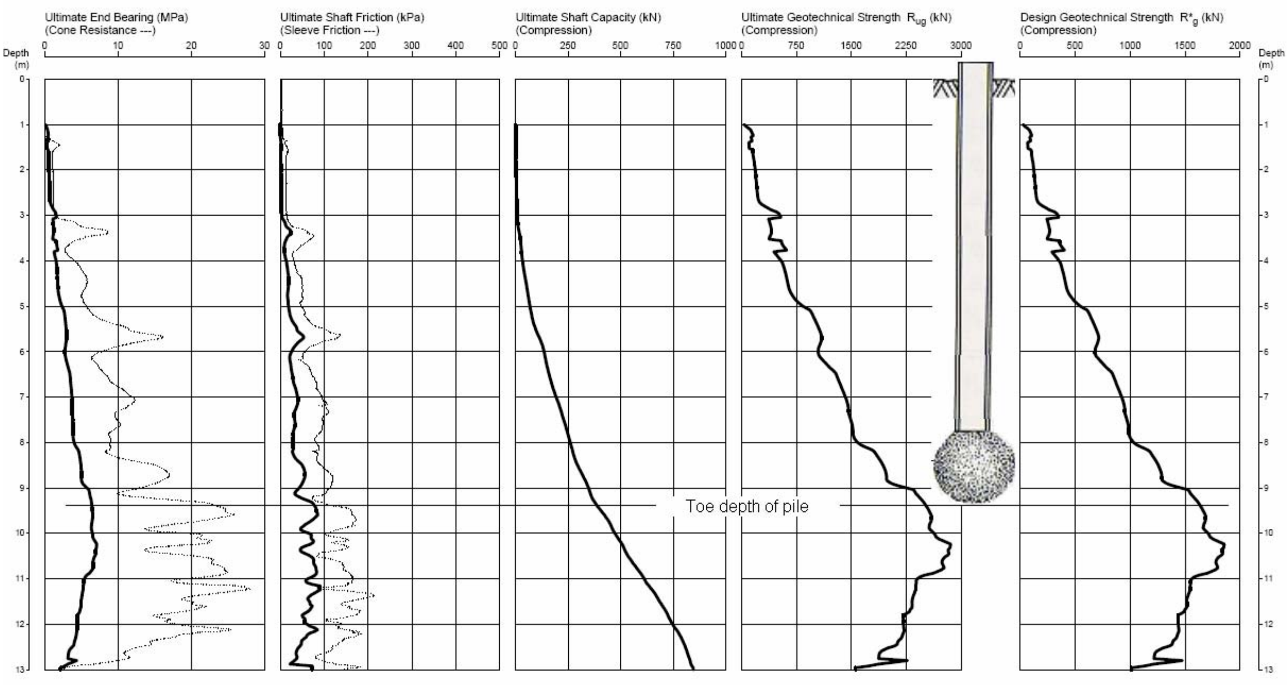

Figure 4: Example ConePile result with SIT shape analysis result overlay.

The benefits of the ConePile program relate to the speed with which the engineer can perform multiple analyses to understand the sensitivity of the pile capacity to various geometrical details of the pile or soil layer thicknesses.

ConePile is regularly calibrated with pile load test data obtained from in-house and with the assistance of a few major Australian piling contractors.

6.3 PILE SETTLEMENT

An elastic analysis method is usually adequate to estimate pile settlement for situations where the proposed increase in load is 30 to 40 % of the existing rated pile load. The computer program PISSAP (developed by Randolf, 1997) is one suitable application for this type of settlement analysis. The weighted average shear modulus of soils (G) indicated above and below the pile base is used in the calculation. The sensitivity of the settlement analysis can be assessed by varying G along the pile shaft and at the base of the pile. Other details such as pile diameter can be varied to assess the effect on the estimated settlement.

Where proposed load increases are in excess of 40 to 50% of the existing serviceability or working loads, a more rigorous, non-linear analysis is generally necessary to account for an increased proportion of plastic behaviour of the pile at the maximum load.

It is always recommended in building upgrade projects that the columns subject to load increases of greater than 15% are monitored with precise levelling of settlements to 0.5mm accuracy. Levelling points are established before any building work commences and regular readings are taken throughout construction and the addition of new loads. Although the magnitude of settlement that occurred for the original building construction can only be theoretically estimated, the rate at which the subject column settles under the increasing load provides a general indication of the overall performance of the pile foundation. Trigger levels of 3 to 5mm are usually set, at which point the builder is obliged to stop work and await the geotechnical and structural engineer's reviews.

7 CONCLUSION

Foundation design and in particular pile design, prior to about 1985, was necessarily conservative. Design was typically based on limited borehole information, with often unreliable or insufficient SPT results as the main indicator of soil strength.

With ever-increasing property prices in Sydney, building owners must consider the option of whether to demolish and redevelopment properties or, to better capitalise existing buildings by adding additional floors or undertaking major refurbishment.

DP have employed portable CPT equipment to test the soil profile directly adjacent to key pile locations for building upgrade projects. Where no piling records are available, forensic SIT methods have been used to determine pile lengths and in some cases, to infer the entire pile geometry using available modelling software (e.g. PROFILE™).

An in-house computer program, ConePile, is used in conjunction with commercially available settlement analysis software, to quickly and efficiently assess the capacity of existing piles to support increased loading. The authors have found that the graphical presentation of the analyses allows the geotechnical engineer to more easily communicate the results and sensitivity of the pile analysis to the client and structural engineer.

The increased confidence in soil parameters achieved with close-by CPT and advances in foundation analysis methods over the last 30 years usually allows the addition of new floors or increased loading from major building refurbishment. Therefore, the 'forensic' approach has the potential to add value to existing buildings without the need for additional piling or major underpinning works.

8 REFERENCES

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