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CPT based estimation of driven timber pile capacities

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ABSTRACT: Driven timber piles are a common pile type used in New Zealand. Established direct design methods from CPT, such as the LCPC method (Bustamante and Gianeselli, 1982), do not include driven timber piles as a specific pile type in those methods. In this study, direct pile design using the LCPC method has been compared to PDA testing and full scale pile load tests on two driven timber piles at a site in Auckland, New Zealand. The results suggest that the LCPC method provides a reasonable estimate of ultimate pile capacity of the driven timber piles at this site. Further research is required to confirm the widespread applicability of this method for driven timber piles in general. This future work may lead to adjustments in the LCPC coefficients for pile end bearing and side friction specifically for a driven timber pile type.

Keywords: driven timber piles; CPT; direct design; LCPC

1. Introduction

Driven timber piles are a popular pile type in New Zealand (NZ) due to the availability of timber and ease of handling, transporting and installation. The common species of tree that is grown and used for timber in NZ is Pinus Radiata; a fast-growing pine that is receptive to preservative treatment. The treated timber used for piles has an expected life of greater than 100 years. This timber is an environmentally sustainable product and has the benefit of permanently locking carbon absorbed from the atmosphere via the tree into the ground as foundation piles. Timber is a huge industry in NZ, with 1.3 million hectares of commercial forests and is a large export product for the country.

The advantages of timber, in particular, the environmental benefits, are likely to increase the popularity of driven timber piles throughout the world.

Driven timber piles are usually designed in a conventional manner; applying bearing capacity and skin friction values derived from estimated soil parameters. The piles are 'verified' by pile driving formulae when installed. This results in some uncertainty in the actual pile capacity.

The use of pile driving analysis (PDA) methods have increased and is a positive step over reliance on pile driving formulae. However, the wave propagation speed through a timber pile is dependent on the density, water content and elasticity of the timber at the time of driving, which can vary. Therefore, assumptions need to be made in order to estimate pile capacities using PDA, which will introduce some error in the method.

CPT based direct design methods have been found to provide good estimates for pile capacities. One such method by Bustamante and Gianeselli [1], also known as the LCPC method, was based on the analysis of pile load tests with a wide range of pile and soil types. Although this method includes a range of driven pile types, driven timber piles is not specifically covered.

The author is not aware of any other published methods of direct design from CPT for driven timber piles.

In this study, two driven timber test piles were installed at a site of a proposed multistorey residential building in Auckland, New Zealand. CPT tests were conducted at each pile location prior to the pile installations. PDA tests and full scale static pile load tests were carried out on the test piles. The results of the PDA and pile load tests were compared to CPT direct design estimates obtained using the LCPC method.

2. Ground conditions

Several boreholes and CPTs were conducted at the site to determine the ground profile. The ground conditions are summarized in Table 1 below.

Table 1. Summary of ground conditions

Depth BGL (m)	Ground conditions	Approx. CPT q_c (MPa)
0 - 5	Firm silts and clays and organic soils	<1
5 – 6.5	Dense silty fine sand	20 - 30
6.5 – 7.5	Firm clay	<1
7.5 – 9.0	Dense silt/sand layered with stiff silt/clay	5
9.0 – 12.5	Dense silty fine sand	20 - 40
12.5 - 20	Stiff clays	2 - 4
20+	Weak sandstone rock	>20

The soils at this site down to 20 m depth are alluvial soils of the Puketoka Formation of Pleistocene age. These overlie weak sandstone rock of the East Coast Bays Formation.

There are two dense sand layers; at approximately 5 m depth; and at approximately 9 m depth. These dense sand layers vary in thickness across the site and the upper sand layer is not present in some places. For this study the two test piles were driven to 10 m depth at the top of the lower dense sand layer.

Groundwater was found to be at about 2 m depth.

3. Test pile Installations

The test piles comprised 450 mm diameter timber poles. These poles were stripped of bark, but otherwise unmachined; displaying the irregular sides and the natural taper of the original tree trunk. These unmachined poles are referred to as 'uglies'. The ends of the piles are of different diameter due to the taper in the piles. The small end diameter (SED) of the poles is 450 mm, whereas the large end diameter (LED) is 550 mm (at 10 m length).

In order to install the piles, it was first necessary to pre-drill with an auger. The purpose of this was to allow the pile to stand in the hole to a height which the pile could then be driven. This was drilled to 2 m depth with a 500 mm auger. At test pile 1, it was also necessary to pre-drill through the upper dense sand layer, that otherwise would not be possible to drive through. A 400 mm diameter auger was used for this purpose.

The piles were driven SED down with a 3.6 tonne drop hammer at various drop heights. The piles were installed at locations where CPTs were previously carried out.

Once installed to the target depth (10 m BGL), the piles were left to rest before PDA testing.

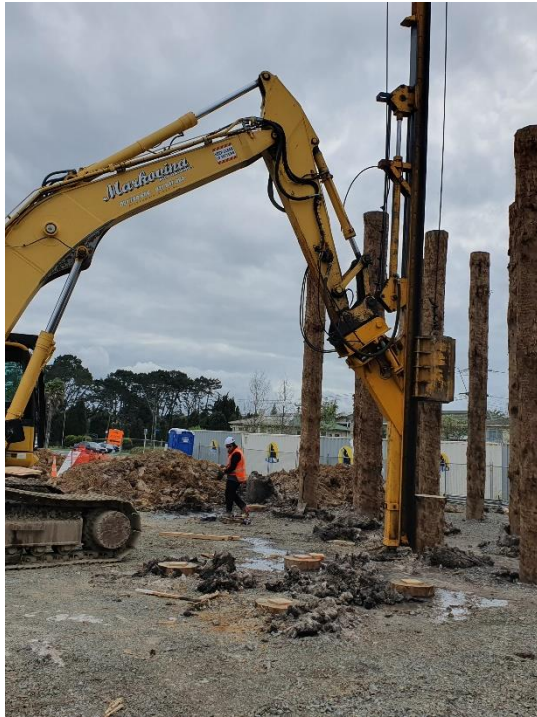Fig. 1 below shows timber piles being driven at the site.

Figure 1. Timber piles 'uglies' being driven with 3.6 tonne drop hammer

4. PDA Testing

PDA testing was carried out 4 days after installation of the test piles. The PDA tests were carried out using the same 3.6 tonne drop hammer for redriving the piles.

The ultimate axial capacities were estimated using CAPWAP analysis along with end bearing and skin friction predictions. An assumption was made on the wave speed propogation through the timber piles. The results of the PDA testing are given in Table 2 below.

The accuracy of the total axial capcity of the piles is reported to be within +/- 10% of the given CAPWAP value.

Table 2. Summary of PDA/CAPWAP results

	Test Pile 1	Test Pile 2
Total axial capacity (kN)	2,250	1,960
Skin friction (kN)	1,150	1,000
End bearing capacity (kN)	1,100	960
Deflection at 550 kN (mm)	3 - 4	3 - 4

5. Pile load testing

Full scale static pile load tests were conducted 5 days after installation for test pile 1 and 7 days after installation for test pile 2. The test frame comprised a load beam with four screw piles as reaction piles. The test frame set up is shown on Fig. 2 below. .

Figure 2. Static load test frame and jack

The load was applied using a hydraulic jack and the load measured from a calibrated digital hydraulic pressure gauge. Deflection was measured by precise levelling to nearest 0.5 mm. The tests were carried out in general accordance with ASTM 1143/D 1143M-07 [2] using the quick test procedure.

Two loading and unloading cycles were applied. The first loading cycle was applied in 120 kN increments to the working load of 600 kN and then unloaded. The second loading cycle went to failure or the maximumm load capacity of the jack (2,400 kN) in 200 kN increments over 600 kN and then unloaded in 400 kN increments.

The results of the pile load tests are shown graphically on Figs. 3 and 4 for test piles 1 and 2, repectively. A Chin-Kondner [3] extraplotion was carried out for the load test data and these are also shown on the plots in Figs. 3 and 4.
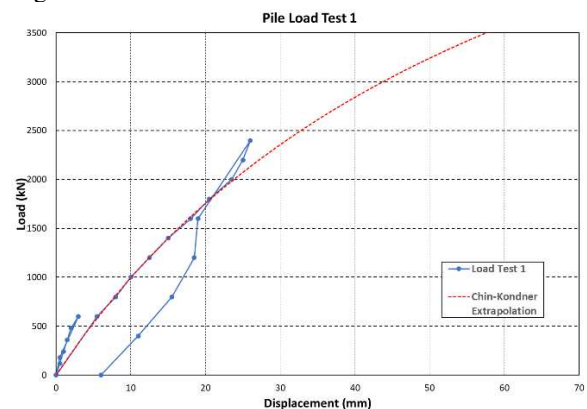

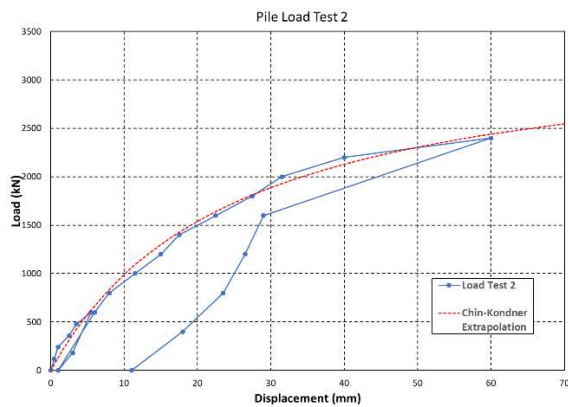**Figure 3.** Pile load test results for test pile 1

Figure 4. Pile load test results for test pile 2

6. CPT Direct design by LCPC method

The results of the CPTs undertaken at the two test pile locations have been analysed using the LCPC method (Bustamante and Gianeselli [1]). The computer program CPeT-IT by Geologismiki [4] was used to undertaken the calculations. The following assumptions were made:

i. The toe of the pile is 450 mm diameter
ii. The diameter of the shaft is 500 mm diameter (being the average diameter along the length of the pile)
iii. The pile is assumed to be equivalent to a driven precast pile (Group II and Category IIA)
iv. Careful construction practices

The unit pile side friction, f_b, has upper limit restrictions in the LCPC method. These were not applied for this study.

The results of the LCPC analysis for each of the two CPTs is shown in Figs. 5 and 6 below as plots of pile capacity with depth. It should be noted that the plots show ultimate capacity, not allowable capacity, as the factor of safety was set to 1. The plots also show the cone resistance values and soil behavior types.
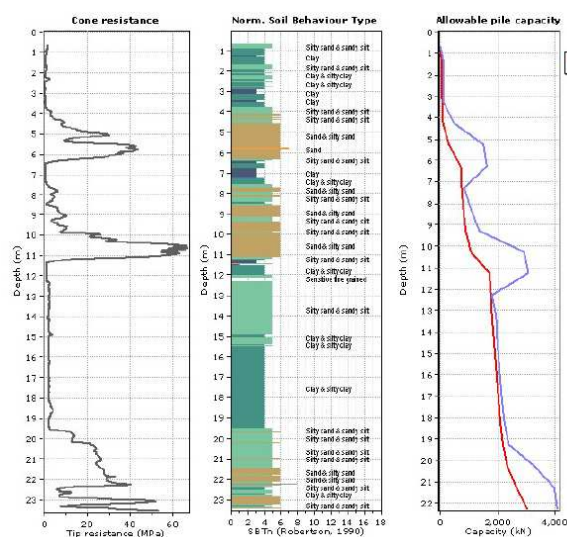

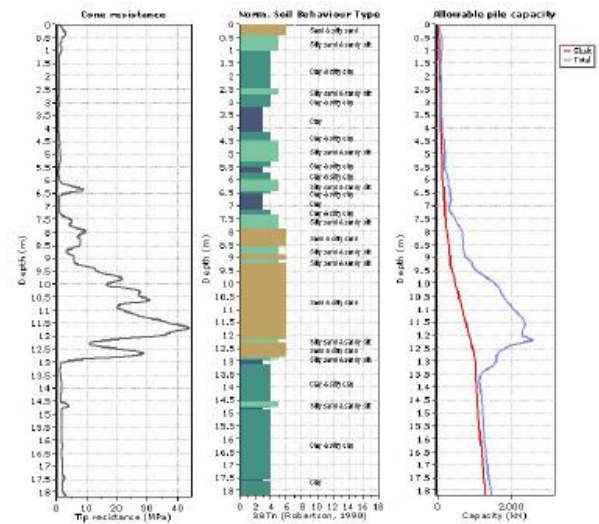**Figure 5.** LCPC direct pile design analysis at test pile 1

Figure 6. LCPC direct pile design analysis of test pile 2

7. Comparison of results

The results of the LCPC analysis for piles embedded to 10 m depth are compared to the capacities determined from the PDA tests and the static load tests. These are summarised in tables 3 and 4 below. In the case of the static load tests, the load at 10% of the pile diameter is taken to be the ultimate pile capacity. For test pile 1 where the load test did not reach failure or 10% of the pile diameter, the ultimate capacity was taken from the Chin-Kondner extrapolation at 10% of the pile diameter.

Table 3. Summary of comparison of pile capacity methods for test pile 1

Method	End bearing capacity (kN)	Skin friction capacity (kN)	Total capacity (kN)
PDA	1,100	1,150	2,250
Load test	-	-	3.050*
LCPC	1,620	1,220	2,840

*based on extrapolation of load-displacement curve at 10% of pile diameter

Table 4. Summary of comparison of pile capacity methods for test pile 2

Method	End bearing capacity (kN)	Skin friction capacity (kN)	Total capacity (kN)
PDA	960	1000	1960
Load test	-	-	2,225*
LCPC	1,480	760	2,240

*at displacement of 10% of pile diameter

The results are also shown on the plots of load vs displacement in Figs. 7 and 8. Here the PDA results are adjusted so that the displacement at 550 kN is between 3 and 4 mm, as provided by the PDA analysis. The ultimate capacity is aligned with 10% of the pile diameter (45 mm). In the case of the LCPC direct design, the load-displacement diagram is adjusted to match the pile load test curve, with the ultimate capacity again at 10% of the pile diameter. In doing so, the ultimate skin friction is estimated to occur at approximately 3% of the pile diameter (for test pile 2).
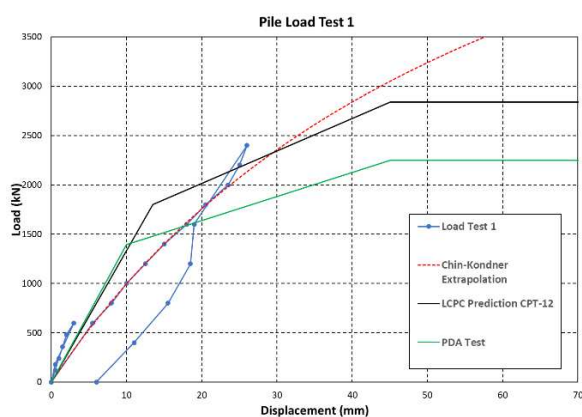
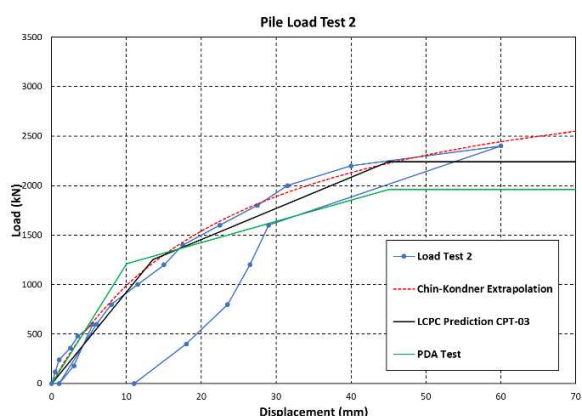**Figure 7.** Comparison of LCPC, PDA and pile load test for test pile 1

Figure 8. Comparison of LCPC, PDA and pile load test for test pile 2

There is a reasonable agreement between the measured load test capacity from the static load tests and those estimated from the LCPC analysis, particularly for test pile 2. The pile load test for test pile 1 did not reach failure or 10% of the pile diameter due to the maximum jack capacity being achieved at 2,400 kN. Consequently, the ultimate pile capacity is not known. The LCPC prediction (2,840 kN) is close to the Chin-Kondner extrapolation at 10% of the pile diameter (3,050 kN), although this cannot be relied on for an ultimate pile load.

Pile test 2, where failure of the pile was reached in the pile load test, is the better test for comparison purposes. For this test pile, the LCPC prediction matched the measured capacity from the pile load test. This assumes, however, that the load at 10% of pile diameter defines the ultimate capacity.

The PDA predicted capacities were lower than the measured pile load test capacities and the LCPC predictions. For pile test 2, however, the PDA prediction is within 10% of the pile load test capacity (at 10% of pile diameter), which is in line with the stated accuracy given in the PDA test results.

8. Conclusion

The LCPC direct design method from CPT provided a reasonable estimate of the load capacity for the driven timber piles at this site. The PDA tests also provided reasonable estimates of pile capacity, although they underpredicted the capacity measured in the pile load tests. Further studies undertaken in a similar manner are needed to demonstrate the suitability of this method for driven timber piles in different soil types. With a larger database of such information, it may be possible to adjust the coefficients used in the LCPC method to refine the results specifically for driven timber piles, if found appropriate. Future studies should also consider the effects of pre-drilling and the effects of the natural taper and irregularities of the pile sides.

Acknowledgement

References

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