Field tests on the lateral capacity of poles embedded in Auckland residual clay

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ABSTRACT

The purpose of this paper is to present results of field testing to evaluate the lateral capacity of timber poles embedded in Auckland residual clay. The work was undertaken because the commonly used relation by Broms seems to predict lateral capacities for embedded poles used in construction of pole retaining walls that are too conservative. The reason for this is the discounting of the lateral resistance contribution from the soil over then initial 1.5 embedment diameters. In all 16 poles were installed in residual clay at a site in Albany, thirteen of them concreted into bored holes with an embedment diameter of 0.45m and three of them driven. A total of 14 poles were tested. The conclusion from interpretation of the results is that a very good match is achieved between measured and predicted capacity if a modified version of the pole capacity equation is used which is based on lateral reaction present over the full embedded depth of the pole of $3s_u$. The paper describes the test method, the interpretation of the results, and verifies that a modified lateral capacity equation gives very good matching of the measured results.

1 INTRODUCTION

In the design of pole retaining walls and similar structures in NZ, with poles embedded in clay, frequent us is made of the approach proposed by Broms (Broms (1964)). Broms' paper refers to rather more substantial applications than simple pole retaining walls. He proposed an elegant idealisation of a rather complex problem. At ultimate lateral capacity he assumed the clay could exert a lateral pressure of 9 times the undrained shear strength ($9s_u$), but that for a depth of 1.5 times the embedment diameter there is no lateral reaction. The depth of ground offering no lateral resistance is rather expensive in terms of the moment capacity demanded of the pole shaft. Visual inspection of existing pole walls suggests that the soil near the ground surface provides lateral resistance.

To check on the actual capacity field tests were done in Auckland residual clay at a site in Fairview Avenue in Albany. The top half metre or so of topsoil was scalped and a level working platform prepared. A total of 16 poles were installed. Thirteen of these were 0.25 m SED and concreted into pre-bored holes with an embedment diameter of 0.45 m. Three 0.25 m machined poles were driven into the soil. The embedment depths varied as did the height above the ground surface at which the lateral load was applied. A view of the layout of the site is given in Fig. 1. A large reaction pole was embedded at the centre of the site and the 16 poles around the periphery. The poles were loaded with a hydraulic jack reacting against the central anchor pole.

Figure 1: Layout of the site and test arrangement showing the centre reaction pole and the test poles around the periphery.

Table 1: Field vane undrained shear strength results

Pole number	**Vane shear strength, s_u** (kPa) (Geonor H-60) at depth (metres)					
	0.1	0.4	0.7	1.0	1.3	1.6
1	74.4	89.3	65.5	71.5	84.4	79.4
2	79.4	93.3	81.4	83.4	-	-
3	79.4	86.3	83.4	83.4	-	-
4	83.4	73.4	79.4	87.3	-	-
5	89.3	81.4	83.4	156.8	67.5	69.5
6	78.4	87.3	87.3	97.3	101.2	87.3
7	78.4	97.3	97.3	101.2	95.3	69.5
8	87.3	83.4	97.3	113.1	99.2	79.4
9	97.3	91.3	79.4	107.2	97.3	101.2
10	83.4	93.3	75.4	nr	75.4	77.4
11	79.4	85.4	99.2	103.2	85.4	-
12	61.5	87.3	91.3	101.2	81.4	-
13	89.3	154.8	119.1	nr	154.8	-
14	81.4	103.2	94.3	91.3	146.9	83.4
15	79.4	83.4	84.4	71.5	96.3	81.4
16	69.5	82.4	84.4	79.4	85.4	83.4

2 SITE CONDITIONS

At the location of each pole a hand vane shear strength profile was obtained with a Geonor H-60 hand vane; the measured vane shear strengths are given in Table 1. The soil profile consisted of about 2 m of clay with reasonably consistent vane shear strengths. At greater depths the material

Figure 2: Pole under lateral load showing the instrumentation attached.

becomes more silty. The testing was done in the spring so there was not too much of a problem from drying out of the clay. After the concreting of the poles and before testing started (a few weeks) the ground around the poles was protected with a covering of plastic sheeting.

3 TEST PROCEDURES

The load was applied with a hand operated hydraulic jack. The load was measured with a load cell, lateral displacements of the piles with displacement transducers at 2 levels, the measurements being with reference to a steel beam anchored away from the poles, the rotation of the pole near the ground surface was measured with a pair of accelerometers. The data was recorded through an analogue to digital converter (12 bit) and then stored on the hard disk of a small computer. Most of the instrumentation used is visible in Figs. 1 and 2.

Each loading took about half an hour, with the load being applied in steps and then held constant for a few minutes before the next load step was applied. Figure 3 shows the load history of one of the tests. As expected there is an initial stiff response and then a gradual softening as the load deformation curve tends towards a limiting lateral load. Subsequent processing of the data involved fitting an hyperbola to the data, the asymptote to this was taken as the ultimate lateral capacity of the pole. The results of all the tests are given in Table 2, from which it is apparent that there are a range of embedment depths and a distances above the ground surface at which the load was applied. Figure 4 shows the load deformation curves for tests 2, 3 and 4, which indicate reasonable consistency of the results.

4 INTERPRETATION OF TEST RESULTS

The main interpretation focussed on lateral capacity in relation to that of the Broms short pole capacity, given by:

$$H_{u\_Broms} = 9 s_u D_s \left\{ \sqrt{\left(L + 2f + 1.5D_s\right)^2 + \left(L - f\right)^2} - 2\left(L + 2f + 1.5D_s\right) \right\} \quad (1)$$

where: s_u is the vane shear strength of the soil, D_s is the diameter of the embedment, L is the depth of the embedment and f is the distance above the ground surface at which the lateral force is applied.

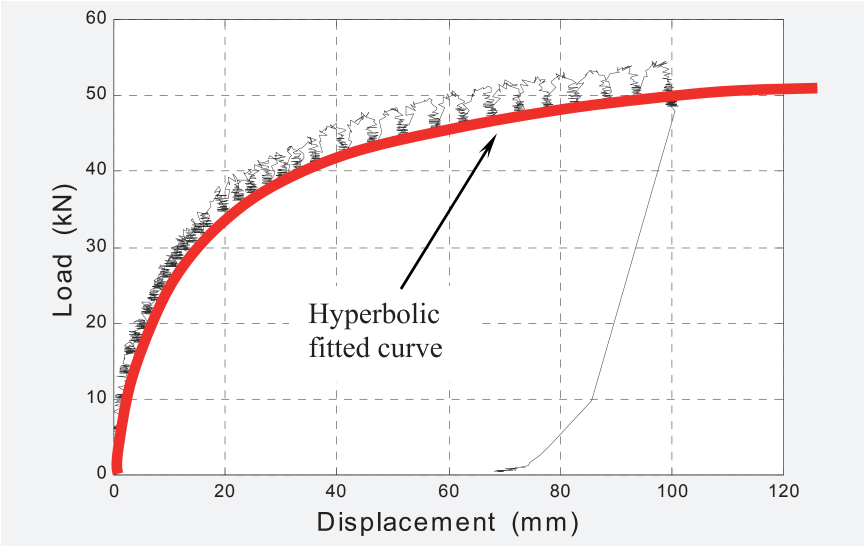

Figure 3: Test result for pole 13.

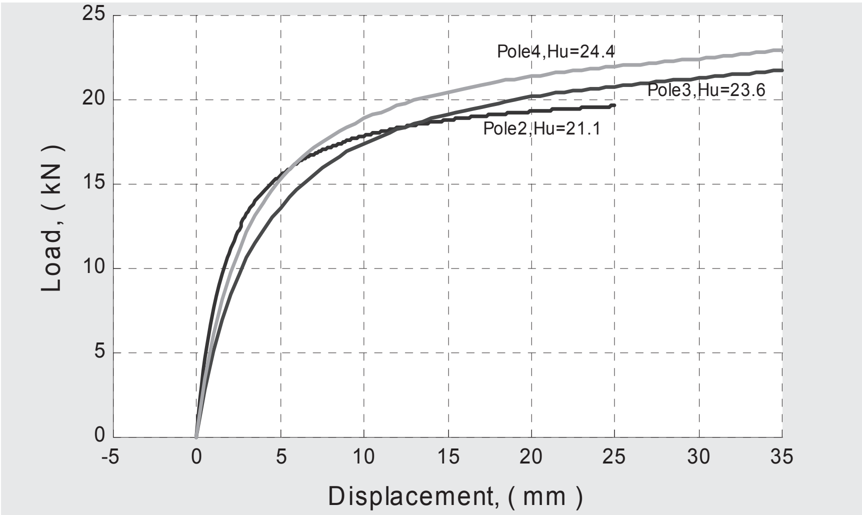

Figure 4: load displacement curves for poles 2, 3 and 4 which indicate the consistency of the results.

Figure 5 compares the measured capacities with those calculated from the above equation, from which it is apparent that the Broms capacity is less than the measured capacity for the poles with smaller embedments, but when the embedment is greater than about 1.7 m (say 4 times the embedment diameter) the Broms capacity matches the measured value quite well. As an alternative to the Broms model calculations were done with a linear increase in undrained shear strength with depth, starting at a finite value at the ground surface. We were somewhat surprised at the result as the best fit was obtained with an ultimate lateral pressure distribution constant with depth from the ground surface at $3s_u$, so the short term lateral capacity of a pole embedded in clay can be obtained from:

$$H_u = 3s_u D_s \left\{ \sqrt{L^2 + 4\left(f + \frac{L}{2}\right)^2} - 2\left(f + \frac{L}{2}\right) \right\} \tag{2}$$

It is also evident from Fig. 5 that the Broms expression, equation (1), gives an accurate result

Table 2: Pole details and measured and predicted capacities

Pole number	Embedment (L) (m)	Height of load (f) (m)	Measured H_u (kN)	Broms capacity (kN)	Equation 2 capacity (kN)
1	1.54	not tested			
2	0.95	0.50	21.1	2.8	22.3
3	0.98	0.50	23.6	3.9	23.5
4	0.95	0.50	24.4	4.7	23.9
5	1.86	1.00	53.5	56.3	52.4
6	1.96	0.80	65.4	64.0	58.5
7	1.80	0.80	59.2	63.1	58.1
8	1.66	1.00	45.6	43.2	46.0
9	1.57	1.00	43.6	35.4	42.1
10	1.67	1.00	37.0	35.7	38.9
11	1.35	not tested			
12	1.46	0.60	44.7	34.0	44.3
13	1.34	0.60	51.2	28.4	53.1
14	1.72*	0.65	36.3	10.6	31.1
15	1.71*	0.65	45.9	11.9	28.0
16	1.52*	0.65	37.6	12.8	23.2

* Driven piles

when the embedment depth is greater than about 4 embedment diameters. Also of note is the fact that for none of the tests was the moment capacity of the pole reached.

Figure 6 shows how this gives a very good match between the measured and predicted lateral capacities. Also evident is the greater capacity of the driven poles, presumably because the driving process increases the shear strength of the soil surrounding the pole.

Additionally we looked at the slope of the initial parts of the load deformation curves and found that these indicate an apparent Young's modulus value for the soil of about 30 MPa.

5 CONCLUSIONS

Results of lateral load testing on timber poles embedded in Auckland residual clay lead to the following conclusions:

- the Broms short pole equation gives a reasonable match between measured and predicted capacities only when the embedment depth is more than about 4 embedment diameters,
- for shallow embedment depths we found better matching between measured and predicted results if a constant lateral pressure from the ground surface of 3 times the vane shear strength was used (this capacity is given by equation 2),
- the lateral capacity of driven poles is greater than would be calculated using the measured vane shear strengths for the soil,
- the initial parts of the load deformation curves indicated a Young's modulus for the soil of about 30 MPa.

6 ACKNOWLEDGEMENTS

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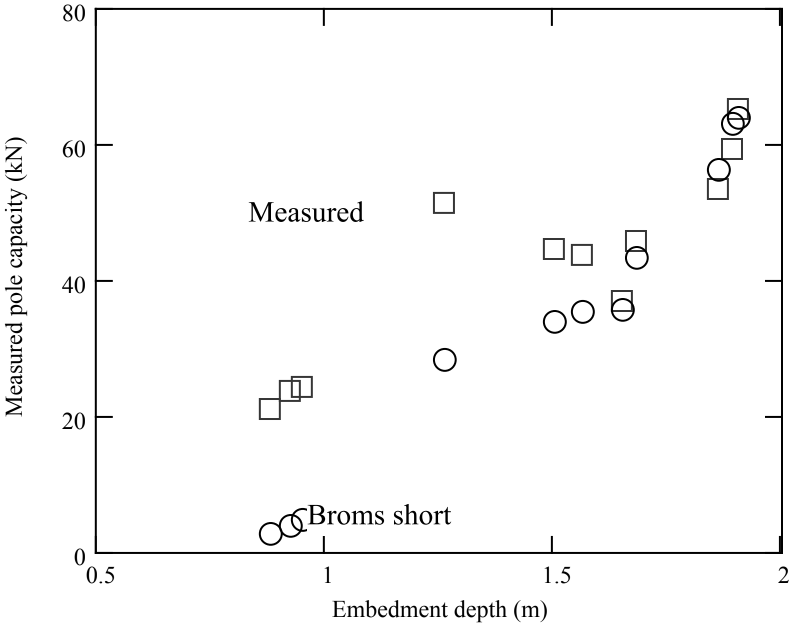

Figure 5: Measured lateral capacities compared with the Broms short capacity.

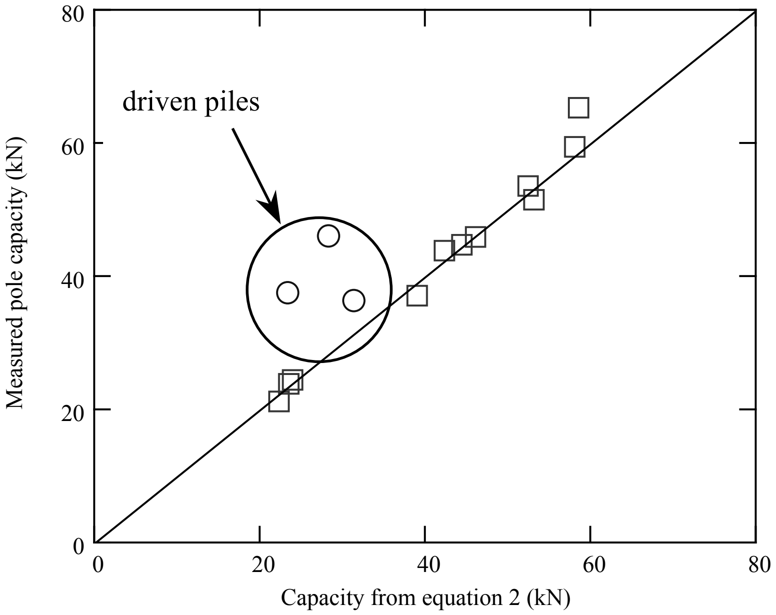

Figure 6: Measured lateral capacities compared with those predicted using equation 2.

Mr. Phillip Chapman of Foundation Engineering Ltd., who obtained access to the site and advised on the origins of the soils present; and Jim Hammond, Chris Dron, Mark Liew and Jeff Melster who assisted with the testing.

7 REFERENCES

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