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”Pent Up” Load and Its Effect on Load Test Evaluation

by

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"PENT UP" LOAD AND ITS EFFECT ON LOAD TEST EVALUATION

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ABSTRACT

"Pent up" load is the load versus depth that remains in a pile or anchor after unloading. This affects the evaluation of pile or anchor testing in terms of net settlement/residual movement and the resulting "apparent effective length". The theory and actual measurements of these effects are presented. Evaluation of load tests of piles or anchors must consider the effects of this "pent up" load.

INTRODUCTION

"Pent up" loads are loads/stresses that remain in the pile or anchor during unloading. This topic is rarely discussed in the literature; however, the author has routinely discussed this topic at ADSC and DFI Micropile Seminars. This paper presents:

- the terms used
- the theory of pent up loads
- actual strain gauge measurements confirming the existence of "pent up" load
- impact of pent up load on load test evaluation

For readability , the term "pile" throughout the paper should be understood to mean "pile or anchor", except in the "Clarification of Terms" section. The same concept also applies to drilled shafts.

THEORY/CONCEPT OF PENT UP LOAD

Figure 1 shows a typical load versus depth curve for a pile during testing. When the pile is unloaded and tries to rebound, friction develops and does not allow complete rebound. This friction (or bond) does not allow the load along the length of the pile to reduce to the load at the top of the pile. The resulting "pent up" load versus depth after unloading is conceptually shown in Figure 2. Pent up load is similar to negative friction or drag load (Fellenius, 2003) in the relative movement of the pile and soil.

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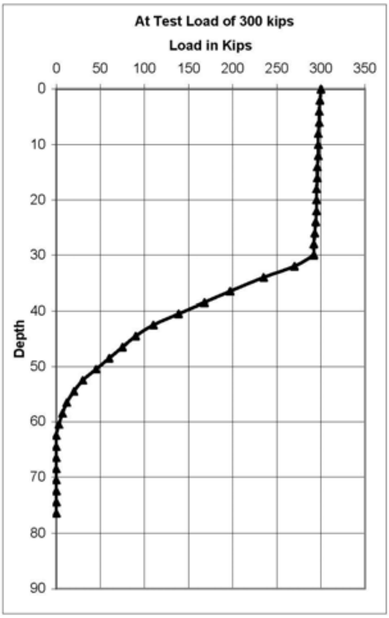

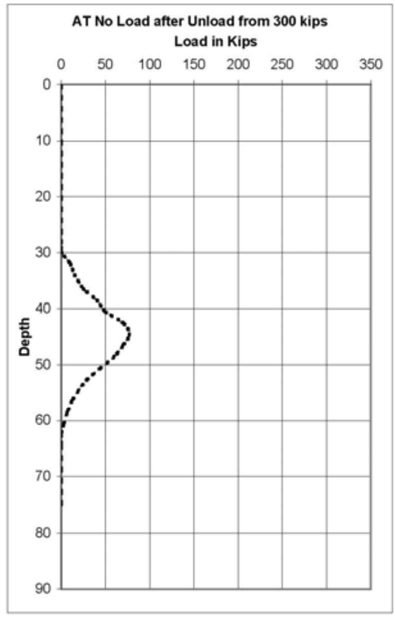

Figure 1. Typical Load versus Depth in a Pile or Anchor during Loading

Figure 2. Typical Load versus Depth in a Pile or Anchor after Unloading = Pent up Load

CLARIFICATION OF TERMS

Pent up Load This is defined in the previous paragraph and Introduction.

Residual Movement (Anchors)
Residual movement is a term used in anchor testing and is described in the Post-Tensioning Institute's Recommendations for Soil and Rock Anchors, PTI (1996 and 2004). It is the measured movement at the head of an anchor after the load has been removed, as shown in Figure 3.

Net Settlement
Net settlement is a pile load testing term and is the pile load test acceptance criterion in many US building codes. It is the measured movement of a pile after the load has been removed and therefore is essentially the same as "residual movement".

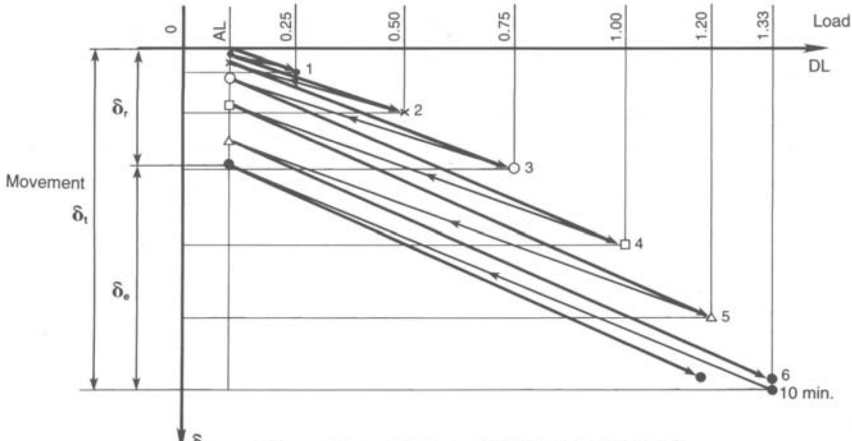

Figure 8.1a Plotting of Performance Test Data

Figure 3. Residual Movement (δr) from PTI (2004)

Residual Stress

Typically residual stress refers to the stress in an element after it is made or installed. In foundations, residual stress is typically considered to be the stress remaining in a pile after pile driving. This is similar to pent up load where the load is created from the driving equipment and process instead of the testing procedure.

FIELD MEASUREMENTS SHOWING PENT UP LOAD

Figures 4 and 5 show load versus depth calculated from strain measurements using vibrating wire strain gauges (Deschamps and Richards, 2005) from two pile load tests at different sites. Figure 4 was a pile bonded in soil and Figure 5 was a pile bonded in rock. In both Figures, the pent up load is shown as dashed lines with the same symbols as the previous maximum loads.

In Figure 4, the pile was loaded to 280 kips at the top of pile resulting in a load versus depth curve show as a solid line with squares. Then the pile was unloaded to an alignment load of 24 kips resulting in the load versus depth curve shown as dashed lines with squares. A final cycle of loading was performed to 555 kips resulting in the solid line with triangles. Then unloading to 24 kips resulted in the dashed line with triangles.

Figure 5 was loaded and unloaded similarly. Again dashed lines represent readings after unloading the pile in this case to zero top of pile load. C in the legend indicates compression and T represents tension. Tension is shown as a negative load.

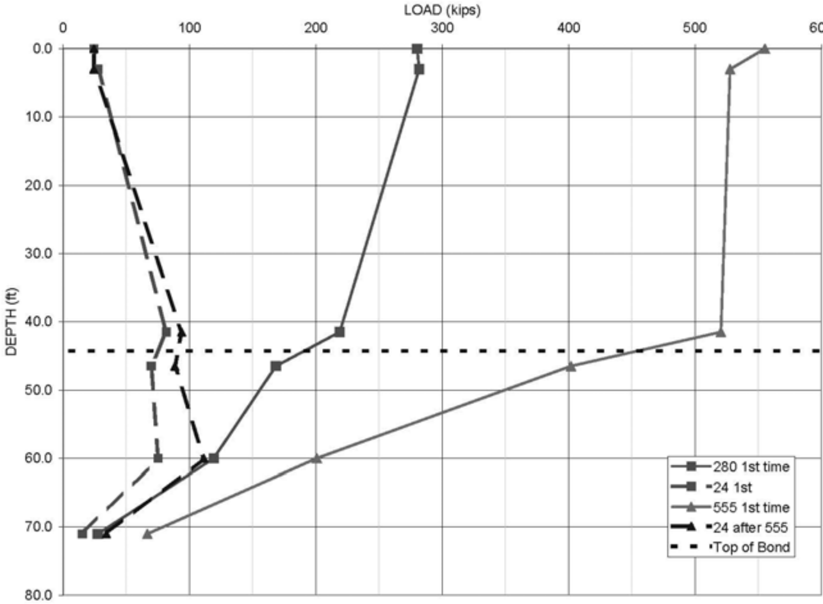

Figure 4. Load versus Depth for a Micropile in Soil

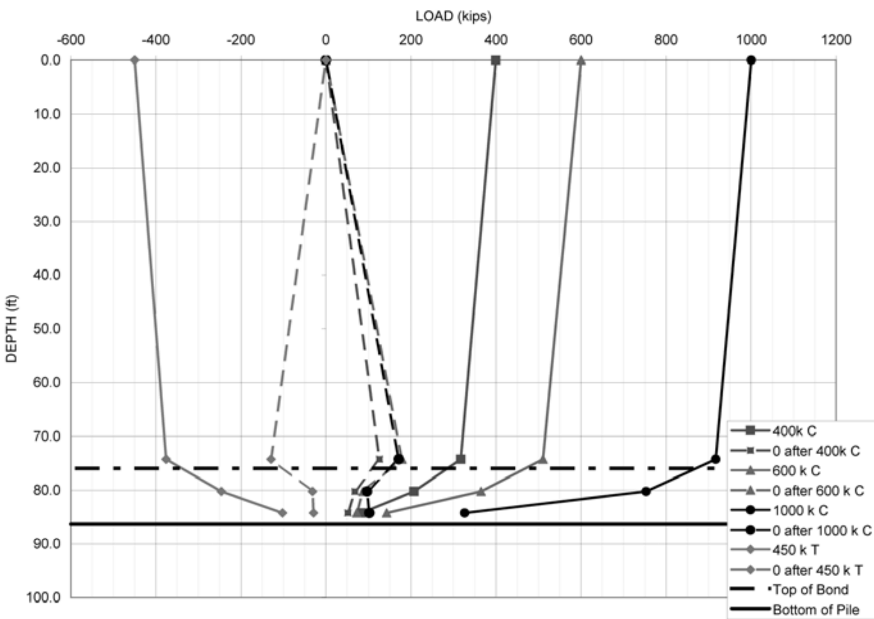

Figure 5. Load versus Depth for a Micropile in Rock

In both Figures, the pent up load (shown as dashed lines with the same symbols as the previous maximum loads) is significant magnitude ranging from 75 kips to 175 kips. This phenomena has been seen in several other load tests. Gomez et al (2003) reported similar load in the pile after unloading which they termed locked in load.

The magnitude of pent up load in a pile or anchor will be affected by geology, design, structural materials, and construction methods.

EFFECTS ON MEASUREMENTS DURING PILE OR ANCHOR TESTS

From basic mechanics of materials,

$$\varepsilon = \frac{\delta}{L} \quad \text{or} \quad \delta = \varepsilon * L \qquad \text{Eq. 1}$$

where δ is deflection
ε is axial strain, and
L is length.

If a pile or anchor is divided up into increments, then

$$\delta = \sum_{0}^{L} \varepsilon(z) * \Delta l \qquad \text{Eq. 2}$$

where $\varepsilon(z)$ is strain variation with depth and
Δl is the length of the increments.

Therefore, deflections are the area under the strain versus depth curve. Since strain is most often measured on the structural elements (casing, strand, bar, or grout), this deflection is the elastic deflection of the pile or anchor.

From basic mechanics of materials,

$$\sigma = \varepsilon * E \qquad \text{Eq. 3}$$

and $$\sigma = P / A \qquad \text{Eq. 4}$$

where: E is modulus of elasticity,
P is load, and
A is cross section area.

Combining Eqs 2, 3, and 4 and considering load and area as a function of depth,

$$\delta = \sum_{0}^{L} \frac{P(z)}{A(z) * E} * \Delta l \qquad \text{Eq. 5}$$

The area under the strain versus depth curve after unloading is the elastic deflection from the pentup load. This area and thus unrecovered elastic deflection are included in the measured net settlement or residual movement.

Figure 6 shows how “apparent elastic length” relates to load versus depth (strain versus depth). This figure is conceptual; however, the figures above confirm that pent up load exists to a significant magnitude.

Figure 6.A shows the load versus depth at a test load of 300 kips. Figure 6.B shows the pent up load after unloading to zero.

The dotted line in Figure 6.C is Figure 6.A curve minus 6.B curve.

Figure 6.C also shows the “apparent elastic length”. Apparent elastic length is often calculated in the literature as:

$$Lapparent = \frac{\delta e * A * E}{\Delta P} \quad \text{Eq. 6}$$

Where:

- δe is measured elastic movement = measured total deflection – measured residual movement (see Figure 3)
  = total deflection – measure net settlement (for piles)
- A is cross sectional area of pile or anchor
- E is modulus of elasticity
- ΔP is the change in load = maximum from previous load cycle minus alignment load

In PTI (1996 and 2004), this “apparent elastic length” is referred to as the “apparent free tendon length” when applied to anchors.

The measured elastic rebound δe is equal to the area under the load versus depth curve shown in Figure 6.C divided by A*E. Therefore, the “apparent elastic length” is the equivalent rectangle with the same area, which is also shown in Figure 6.C. This is also presented in PTI 2004, page 74.

Figure 6.D shows the “apparent elastic length” compared to the load versus depth. “Apparent elastic length” is substantially less than the depth that the load reached and not even the depth where half of the load is transferred. This must be recognized when evaluating load tests and when studying previous literature discussing the “apparent elastic length”.

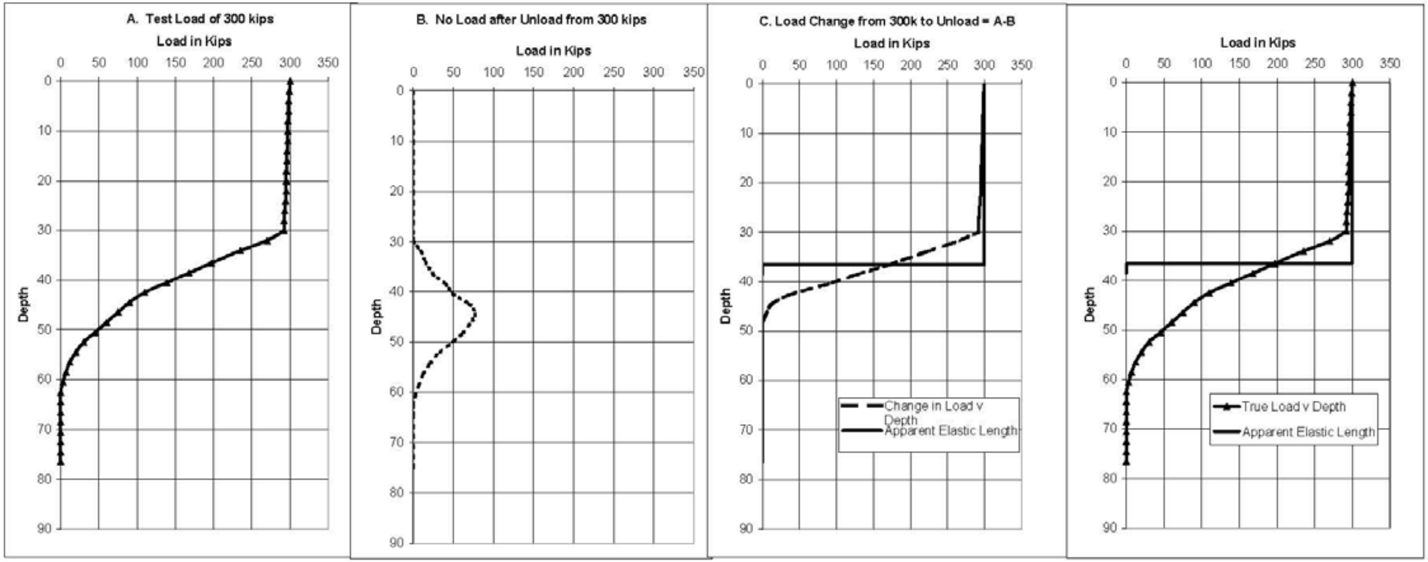

Figure 6. Load versus Depth and “Apparent Elastic Length”

CONCLUSIONS

Pent up loads occur during unloading of a foundation element during testing and affect the interpretation of test results as follows:

1. Net settlement or residual movement each include some amount of deflection from the pent up load and thus overestimate the movement of the bottom of the pile or anchor.
2. This causes elastic movement or rebound to be an underestimate of true elastic elongation.
3. Due to 1 and 2, apparent elastic length underestimates the depth of load transfer.

Therefore, the acceptability of pile load tests using net settlement should consider the effects of pent up load. This is especially true for relatively flexible micropiles with higher strength steels and high strength grout.

The magnitude of pent up load in a pile or anchor will be affected by geology, design, structural materials, and construction methods.

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