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Application of bored pile instrumentation for better understanding on its load-transfer behaviour under compression load

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ABSTRACT

Introduction. Deep foundations are widely used as common foundations for construction work in Indonesia. The axial compression capacity of deep foundations or simply we called it pile, consist of friction and end-bearing.

Materials and methods. Many formulas used to predict the capacity, and yet the behavior better achieved from instrumented static compression test pile.

Results. This paper shown a load transfer behavior for bored pile with diameter of 120-cm with effective length of 30-m constructed in very soft to stiff clay soil with its toe seated in very dense sand.

Conclusions. Result showed that long piles capacity in soft to medium clay dominantly resist by its friction under small displacement (<0.7 % diameter), while the end-bearing fully mobilized under higher displacement (>10 % diameter).

KEYWORDS: deep foundation, instrumented test pile, friction, end-bearing, load transfer, *t–z*

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Применение измерительных устройств для изучения передачи нагрузки буронабивными сваями под нагрузкой на сжатие

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АННОТАЦИЯ

Введение. Глубокие фундаменты широко используются при строительстве зданий в Индонезии. Прочность глубокого или свайного фундамента на осевое сжатие состоит из трения и концевой несущей способности сваи.

Материалы и методы. Для прогнозирования несущей способности используется множество формул, однако можно оптимально изучить работу свай посредством инструментальных статических испытаний на сжатие.

Результаты. Показано влияние нагрузки, передаваемой на буронабивную сваю диаметром 120 см и рабочей длиной 30 м, установленную в глинистый грунт высокой и низкой жесткости с опиранием основания на плотный песок.

Выводы. Определено, что длинные сваи в мягкой глине и в глине средней жесткости сопротивляются путем трения при малых перемещениях (<0,7 % от диаметра), в то время как при более высоком перемещении (>10 % от диаметра) полностью задействуется концевая несущая способность сваи.

КЛЮЧЕВЫЕ СЛОВА: глубокий фундамент, пробная свая, трение, концевая несущая способность сваи, передача нагрузки, *t–z*

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INTRODUCTION

Bored pile as one of deep foundation commonly use all over the world known to have some advantages like its ability to resist significant load (Omarov et al., 2016; Zhussupbekov et al., 2017) [1–11]. This load will resist by the soil and its interaction to pile toe resistance and pile shaft resistance. The goal for optimizing the shaft and toe resistance already become a major concern by studying theoretical and experimental soil-pile interaction. This relation could understand better by having some instrumentation installed in pile while doing a static load test. The more behavior we got from instrumented test pile, the more cost efficient to the future design process.

This paper presents the result of a bored pile behavior during static compression load test by using vibrating wire strain gages.

RESEARCH METHODOLOGY

Soil information

The soil data below ground surface show s fill material with 4 m thickness follow with very soft silty clay with average SPT value of about 1. Below this layer, 7 m thick stiff silty clay found, followed with very stiff clayey silt with 4m thickness and cemented silty sand until the end of drilling exploratory. Fig. 1 (left) shows this soil condition in graphical.

Pile information

A 120 cm diameter bored pile with 30-m effective length constructed with rotary drill machine using bentonite slurry as its drilling fluid to stabilized the shaft during the construction process. Bentonite slurry with volume weight 10.5–11.0 kN/m^3, filtrate loss less than 20 cm^3 and filter cake less than 1 mm during construction choose to anticipate collapsing of shaft at sand layer. The pile concrete strength design with f'c 30 MPa with slump of 18 ± 2 cm.

Instrumentation information

Test pile instrumented with (21) vibrating wire strain gages (VWSG) distributed along its total depth at (7) elevation as shown in Fig. 1 (right). The VWSG (Fig. 2) basically measuring the strain based on its natural frequency. It was tied to rebar and signal transmitted to top pile through cables.

Pile test information

Test pile conducted using kentledge method following ASTM D1143-07 with kentledge load under cyclic procedure. The test performed using (2) 1,000 Tons capacity hydraulic jack complete with (2) VW load cell on pile head. Concrete blocks, primary and secondary steel beams were use as its reaction system. Four dial gages use to measure vertical deformation and (2) dial gages place to measure any lateral deformation under specific test load. The arrangement of static load test presented in Fig. 3.

The test pile was designed for a working load of 480 Tons. Loading schedule designed in (5) cycles with maximum applied load for each cycle was 240, 480, 720, 960 and 1,200 Tons.

RESULTS OF THE RESEARCH

The test performed up to (5) cycle with maximum load of 1,080 Tons only and unload to 0 % since the settlement already passed 10 % of its diameter. Total settlement measured at pile head under 240, 480, 720, 960 and 1,080 Tons were approximately 3.00, 6.26, 9.96, 57 and 110.71 mm; respectively. Upon unloading of the test load, the recorded settlement was about 110.71 mm the recovery of test pile was about 18 % and this implies that under maximum test load of 1,080 Tons, pile was borne by both shaft and end-bearing resistance. Summary of load-settlement result shown in Table and Fig. 4 presented the load settlement curve.

Instrumentation by VWSG gave results of load transfer and unit resistance as presented in Fig. 5 and 6; respectively. The main idea from measurement of strain (in micro strain) is to calculate the load at each elevation by assuming the shaft area and concrete modulus is constant. Even the modulus assumed to be constant, it still needs to calculate to the actual condition to get a more realistic load transfer (Lim et al., 2013). Fig. 5 shows the fully mobilized resistance which can be seen from the parallel line from each loading schedule. It is clearly shown that the very soft clay layer (GL to Elev. –15.0 m) gave a small resistance with unit skin friction range from 1–3 T/m^2 while the cemented silty sand (Elev –24.5 to –28.5 m) gave a higher unit friction up to 24 T/m^2 as shown in Fig. 6.

The mobilized unit skin friction and mobilized end bearing later plot to pile section shortening to get the *t–z* and *q–z* curves (Reese et al., 1989) and presented in Fig. 7 and 8; respectively. The *t–z* shows that only a very small displacement, i.e. <8 mm or equal to 0.7 % of pile diameter needs to fully mobilized the unit skin friction at each soil layer as shown in Fig. 7. In contrary, Fig. 8 shows that a very high displacement, like >130 mm or more than 10 % of pile diameter needs to fully mobilized the unit end-bearing.

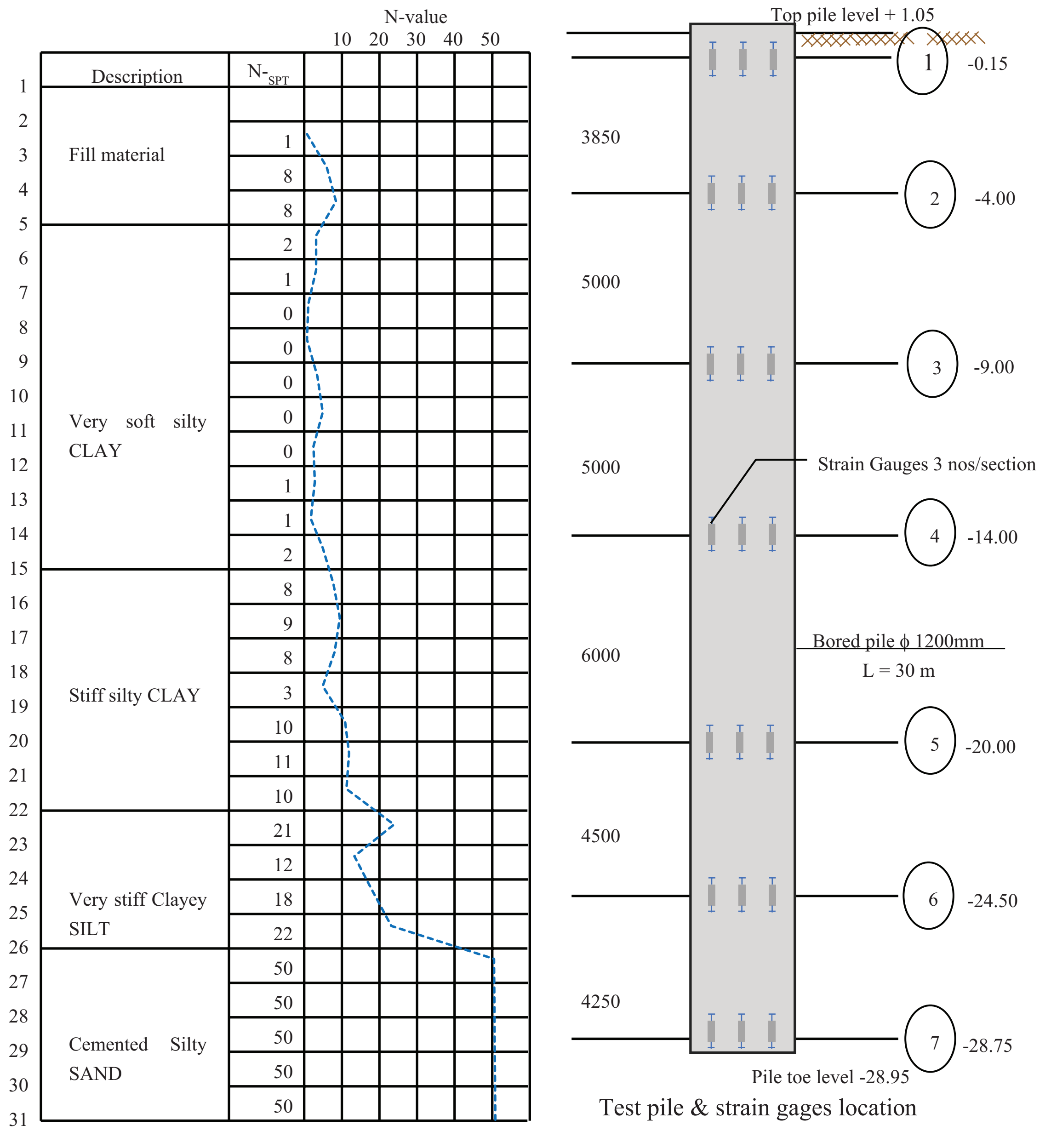

Fig. 1. Soil condition and test pile details

Рис. 1. Состояние грунта и характеристики пробных свай

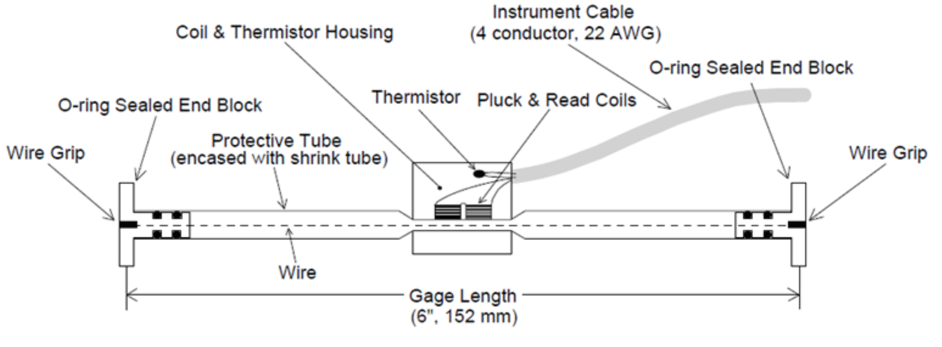

Fig. 2. Schematic of Vibrating Wire Strain Gage (Source: GEOKON, Inc.)

Рис. 2. Схема вибрационного тензодатчика (Источник: GEOKON, Inc.)

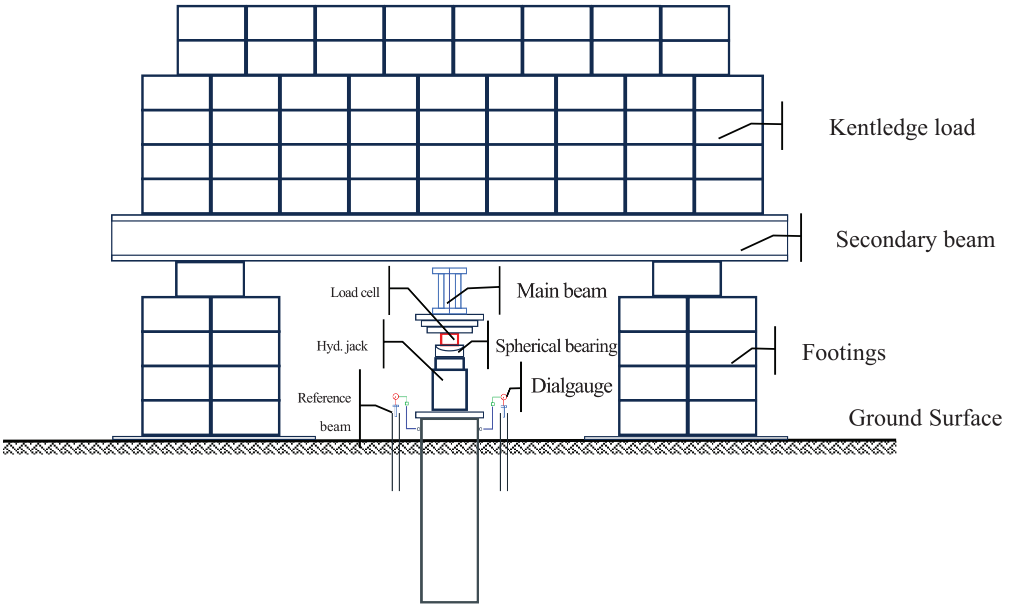

Fig. 3. Static load test arrangement

Рис. 3. Схема испытания статической нагрузкой

Load settlement summary

Сводка расчетов по нагрузке

Load, %	Applied load, ton	Top Settlement, mm
25	120	1.39
50	240	3.00
75	360	4.69
100	480	6.26
125	600	8.71
150	720	9.96
175	840	12.95
200	960	57.00
225	1,080	135.09

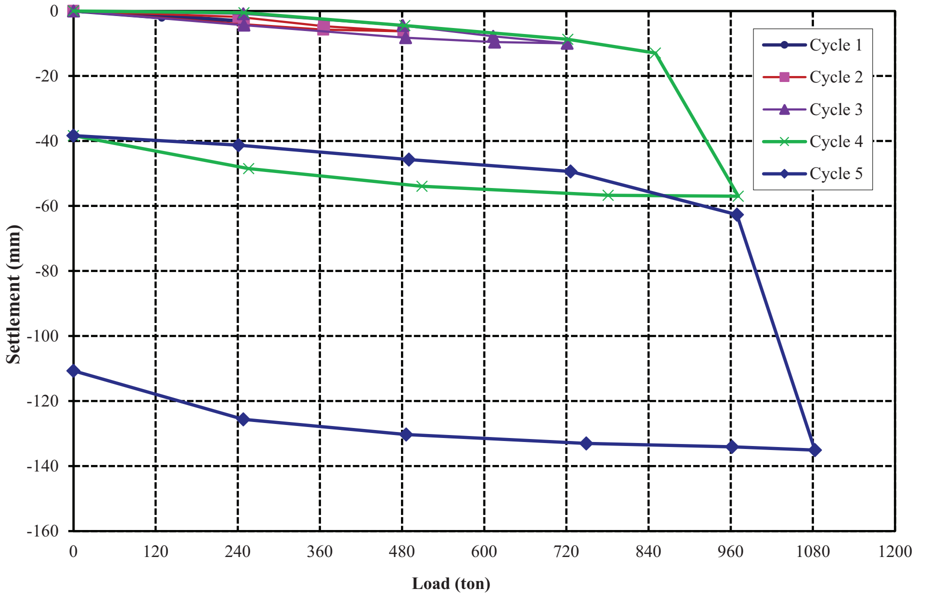

Fig. 4. Load-settlement curve

Рис. 4. Кривая распределения нагрузки

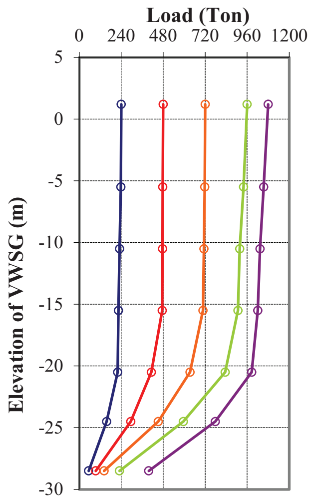

Fig. 5. Load transfer curve

Рис. 5. Кривая передачи нагрузки

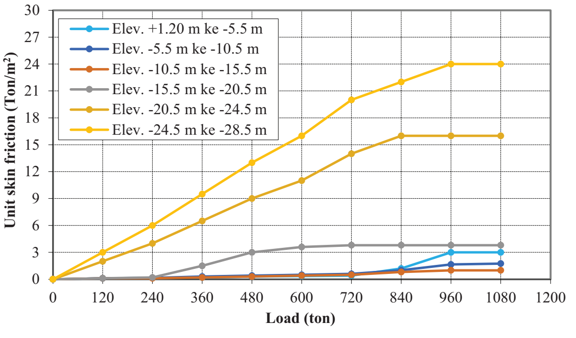

Fig. 6. Unit skin friction — load in various depth

Рис. 6. Удельное поверхностное трение и нагрузка на различной глубине

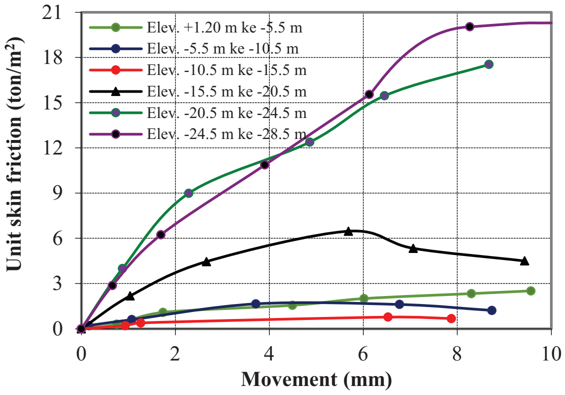

Fig. 7. *t–z* curves

Рис. 7. Кривые *t–z*

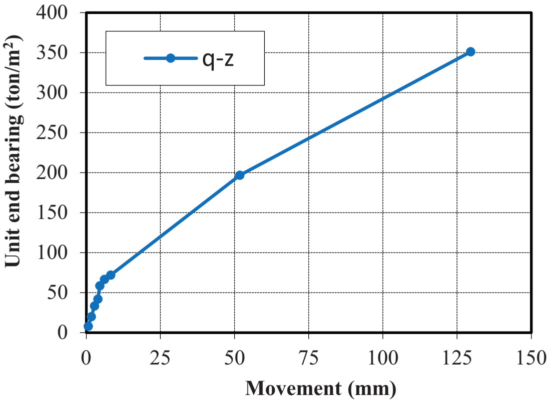

Fig. 8. *q–z* curve

Рис. 8. Кривая *q–z*

CONCLUSION AND DISCUSSION

It is clearly shown from the research how the friction behaves under compression load, it needs only small displacement to fully mobilized while the end-bearing needs higher displacement; means when displacement become a limit during design stage, increasing the friction capacity became a better option compared to increasing the end-bearing capacity. This understanding could result in better design and cost efficiency. Of course, further works need to be done for case where bored pile meet with rock at the pile toe.

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