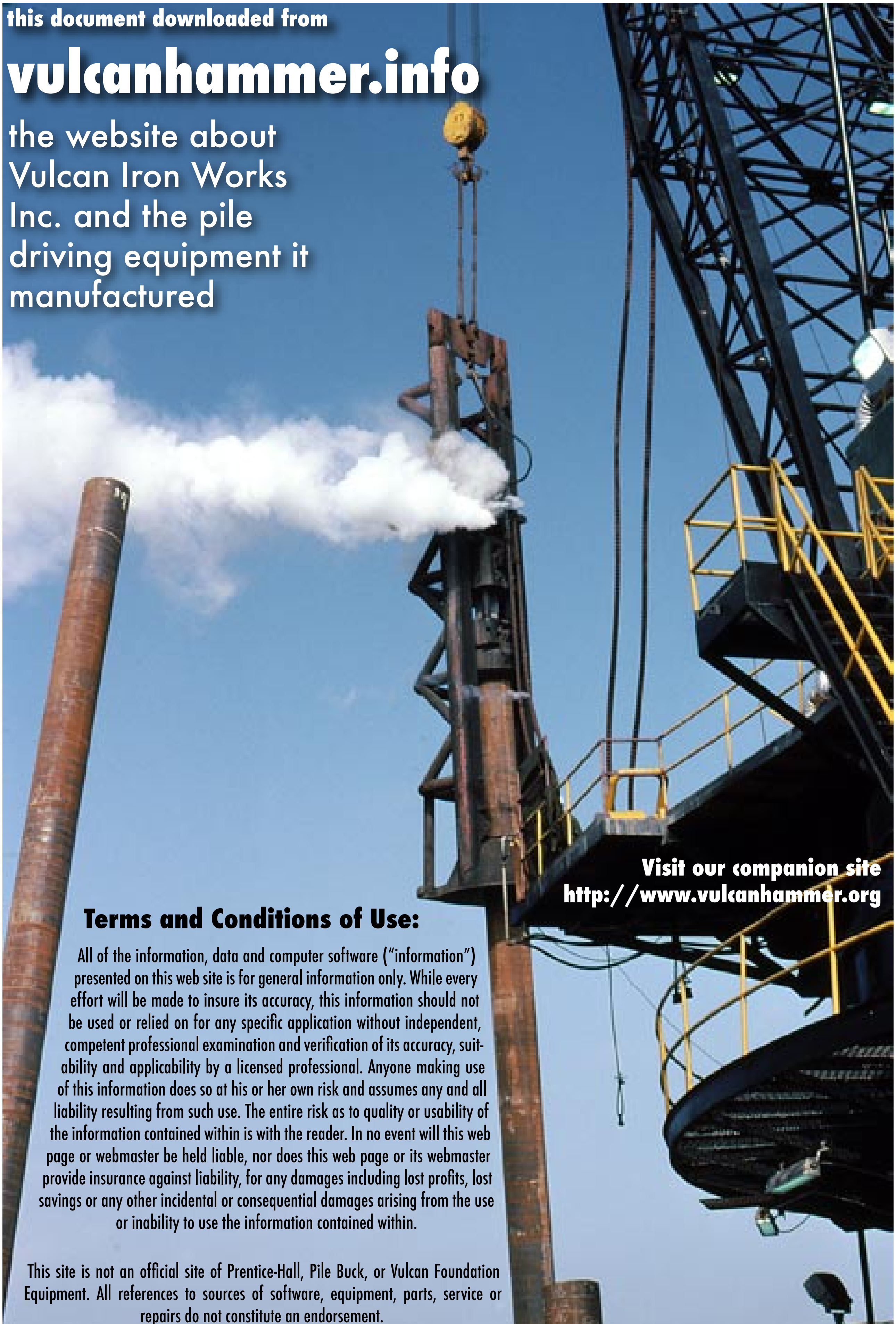

WAVE EQUATION ANALYSIS AND PILE DRIVING ANALYZER FOR DRIVEN PILES: 18TH FLOOR OFFICE BUILDING JAKARTA CASE

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ABSTRACT: In many cases, the actual capacity of piles can be gained from static and dynamic pile tests. And this case is using dynamic pile test such as Pile Driving Analyzer (PDA) for driven piles. In other hand, beside the bearing capacity of pile, the type of hammer with its weight, its drop, and soil stratification give responds. The responds vary and also give the information of pile's displacement, pile's tension forces, or pile's tensile forces. This information is useful in pile's performance and pile's integrity. This paper examines the case of 18th floor office building in Jakarta. In this paper, both the effects of driving and the wave propagation in piles are analyzed based on the kentledge system loading test (static test) and PDA. From the wave equation analysis which is proposed by Smith (1960), the geotechnical engineers can determine the dynamic capacity of pile and compare to the results of static test and PDA. The main problem is the spun pile had cracks along the pile from the head when conducting the static test in the certain degree of design load. Initially, the pile has a good result from Pile Integrity Testing (PIT). With combination of static test and PDA, bearing capacity graph for spun pile (P182) is generated. It is shown that final set is 0.3 mm and this value is close enough to driving record (0.2 mm). The cracks of the pile head during static load test may be caused by overstress after pile driving. It is modeled by wave equation analysis and shown that the damage of pile is mainly governed by compression force. The ultimate capacity of pile is 401.0 ton from static test. The wave equation analysis gives a conservative ultimate capacity value as 350.0 ton.

KEYWORDS: wave equation analysis, pile driving, driven pile, diesel hammer, static test

1. INTRODUCTION

In many cases, the actual capacity of piles can be gained from static and dynamic pile test. And this case is using dynamic pile test such as Pile Driving Analyzer (PDA) for driven piles. In other hand, beside the bearing capacity of pile, the type of hammer with its weight, its drop, and soil stratification give responds. The responds vary and also give the information of pile's displacement, pile's tension forces, or pile's tensile forces. This information is useful in pile's performance and pile's integrity.

This paper examines the case of 18th floor office building in Jakarta. Both the effects of driving and the wave propagation in piles are analyzed based on the kentledge system loading test (static test) and Pile Driving Analyzer (PDA). From the wave equation analysis which is proposed by Smith (1960), the geotechnical engineers can determine the dynamic capacity of pile and compare to the results of static test and PDA. When conducting the static test in the certain degree of design load, the main problem occurs when the spun pile had cracks all along the pile, starts from the head. Initially, the pile has a good result from Pile Integrity Testing (PIT). So, the aim of this paper is to simulate and find the source of the pile cracks with wave equation analysis.

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2. WAVE EQUATION ANALYSIS

Wave equation models a pile as a series of masses connected by springs and a hammer blow as a compressive stress wave which travels trough the pile (Figure 1). General form of wave equation analysis is:

$$\frac{\delta^2 u}{\delta t^2} - \frac{E}{\rho}\frac{\delta^2 u}{\delta x^2} + R_d = 0 \quad (1)$$

where u is longitudinal displacement of a point, E is modulus of elasticity, ρ is density, t is time, x is longitudinal direction, and R_d is soil resistance.

Wave equation analysis programs are utilized more reliable pile driving result. In this paper, the MICROWAVE is conducted. The wave equation analysis will provide driving system of pile-hammer combination suitability, driving stresses, as well as pile drivability or adequacy of the driving system to achieve required bearing capacity.

The wave equation is usually used to investigate bearing capacity graph which is a plot of ultimate soil resistance versus set. Another is to give information about equipment compatibility-solutions for determining the type of hammer. A pile-hammer system is a set of discrete element which can be solved by using of springs and dampers. Smith (1960) proposed five basic equations for wave equation analysis:

$$D_{m,t} = D_{m,t-1} + V_{m,t-1}.\Delta t \quad (2)$$
$$C_{m,t} = D_{m,t} - D_{m+1,t} \quad (3)$$
$$F_{m,t} = K_m.C_{m,t} \quad (4)$$
$$R_{m,t} = F_{m-1,t} - F_{m,t} + R' \quad (5)$$
$$V_{m,t} = V_{m,t-1} + (R_{m,t}.\ \Delta t.g)/W_m \quad (6)$$

where: $D_{m,t}$ = displacement of element m when $t = t$
$D_{m,t-1}$ = displacement of element m when $t = t-1$
$C_{m,t}$ = spring compression of element m when t = t
K_m = pile's spring constant include cap, capblock, and cushion
$F_{m,t}$ = spring force of element m
R' = soil resistance, include damping effect
$R_{m,t}$ = final force resultant
$V_{m,t}$ = velocity of element m when t = t
W_m = weight of element m
g = gravitation
Δt = time interval

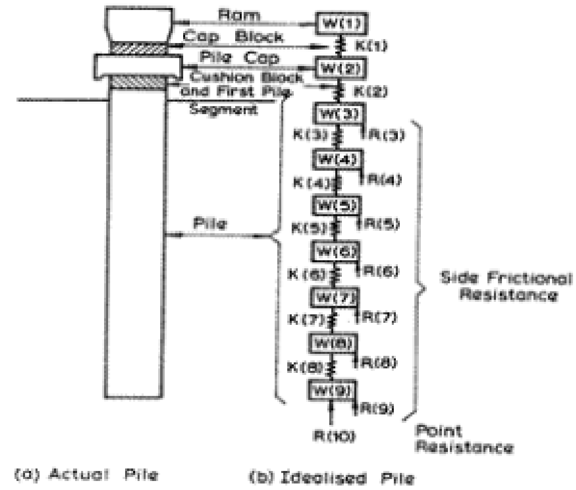

Figure 1. Smith's rheology model (Poulos & Davis, 1980)

3. SOIL PARAMETERS

The soil investigation was conducted two times by PT Tarumanegara Bumiyasa (April 1997) and PT Duta Rekayasa (October 1997). In general, for 15.0 m first of upper layer, the clay and silt layers are dominant based on the result of eight boreholes and combined with three dutch cone penetration test (DCPT). Water table is found in 8.0 – 8.5 m below the ground surface. The soil stratification is shown in Figure 2.

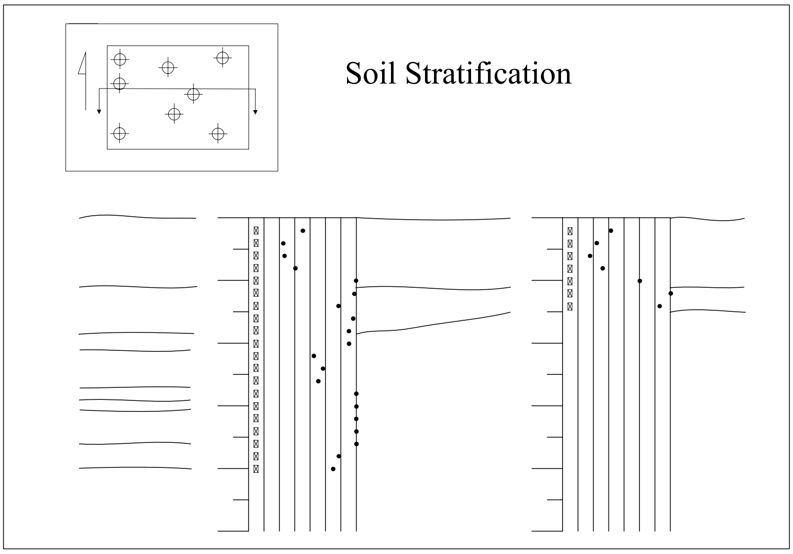

Figure 2. Simplified soil stratification

4. CASE STUDY

4.1 PILE'S DATA

This case uses A 50 cm diameter with 9 cm thickness and 15.0 m length spun pile. The hammer type is K-45 with 2.3 m hammer drop. Final set is 0.2 mm. This pile, named P182, was driven in November 1997 but was not used due to the project is abandoned by monetary crisis in Indonesia.

4.2 CRACK ON TEST PILE

In December 2005, this pile was planned as a part of pile group to give an adequate bearing capacity for upper structure. Loading tests such as kentledge system of full-scale loading test (static test), Pile Driving Analyzer (PDA), and Pile Integrity Testing (PIT) were conducted on the site.

Before applying static test, PIT was first done and the result shown that the pile had good connections between segmental piles and good structural integrity. But, when applying static test in 175% design load (210 ton) from total 200% of working load, the pile's head visually had hairy crack along as the pile axes. The crack was about in 1.5 – 2.0 m length. Usually, spun piles do not have cracks to achieve the design load because of their high concrete strength. Figure 3 shows the crack on the pile during static test.

4.3 STATIC LOADING TEST

Static loading test with kentledge system was conducted in this study on September 2005. The design load was two times of working load (120 ton). From the load settlement curve, the ultimate capacities are obtained from Chin's (1971), Mazuekiwich's (1972), and de Court's (1999) interpretation methods. The result showed that the ranges of ultimate capacities are between 347 ton and 422.0 ton (Figure 4). In this case, the capacity of 401.0 ton in average was used.

Figure 3. Loading test on progress (left) Cracks on pile during loading test (right)

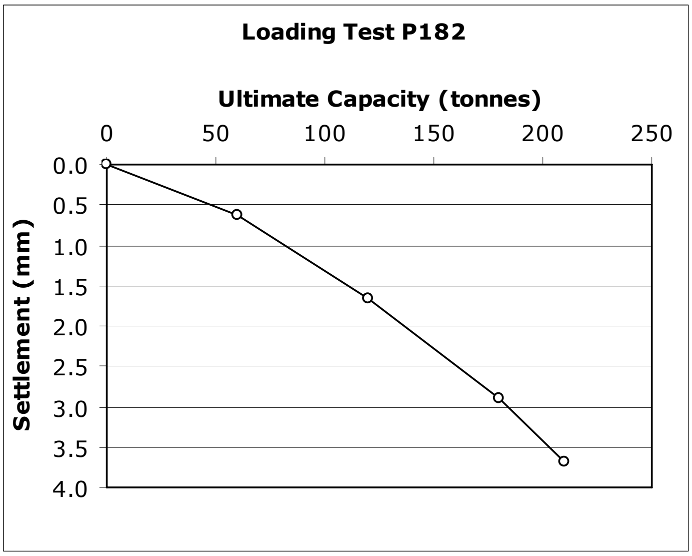

Figure 4. Result of static loading test

4.4 PILE DRIVING ANALYZER (PDA)

In this case, PDA was applied in the closest pile to this spun pile which has similar pile's data (pile P184). With applying CAPWAP analysis, final set is 0.5 mm with 20.07 blows/cm. Unfortunately, the ultimate capacity was not closed to the static test even the value is lower about two times than static test. The prediction of PDA is 190.0 ton (Figure 5). However, from this data, the load portion of friction and end bearing could be known.

4.5 BACK ANALYSIS WITH WAVE EQUATION ANALYSIS

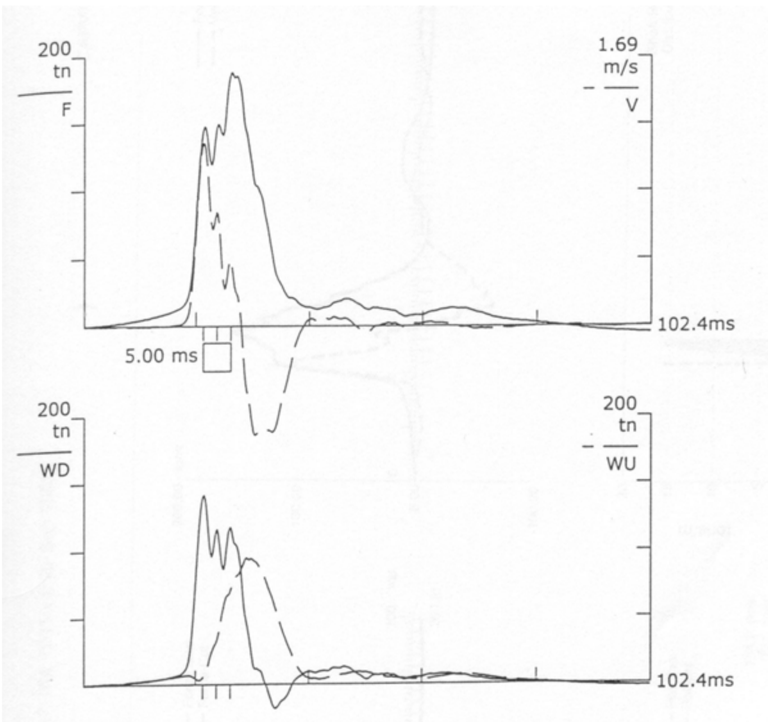

Figure 5. PDA's result for pile number p182

As a reference, to avoid the pile's cracks during driving, Code of Practice (ACI 543) recommended to design a pile so it can transfer the load in process of pile driving preparation. The recommended safety factor is 3 to restrict the pile working stress.

This case has an aim to understand the behavior of driven pile based on the observation of the pile on the site. Then, this pile behavior is back calculated from the result of static test and PDA. The site evidence and analysis result show that the crack may be caused by over stressed during driving. During driving, the pile will experience compression and tensile forces. The number of blows during driving which had 1661 blows could be one of the causes which lead to pile's crack.

The tensile force and stress in the pile is 95.0 ton and 27 kg/cm^2 respectively. The tensile force is including using a safety factor of 3. An allowable tensile stress for temporary load is 78 kg/cm^2 (0.8f_c'). The pile itself has a pre stress minimal 45 kg/cm^2. It means that the total allowable tensile stress is 123 kg/cm^2.

However, at a certain time caused by driving, the compression force with wave equation analysis gives a value of 588 kg/cm^2 which is nearly closed to pile concrete strength. Based on PDA's result, before static test, it gave a good BTA value. So, the pile may not be strong enough to hold the inducted load from the staged design load when the pile is during static test. The pile got cracks when 175% of load is applied.

In Figure 6, it is shown that the ultimate capacity can reach 350.0 ton. It means that dynamic driving resistance is about 30.0 blows/cm or final set is about 0.3 mm. This result is close enough to the pile's driving record final set on the site which has a value of 0.2 mm.

To sum up, the source of structural damage may be caused by overstressing where the compression stress is about similar to concrete strength. The tensile stress can be well transferred by pile.

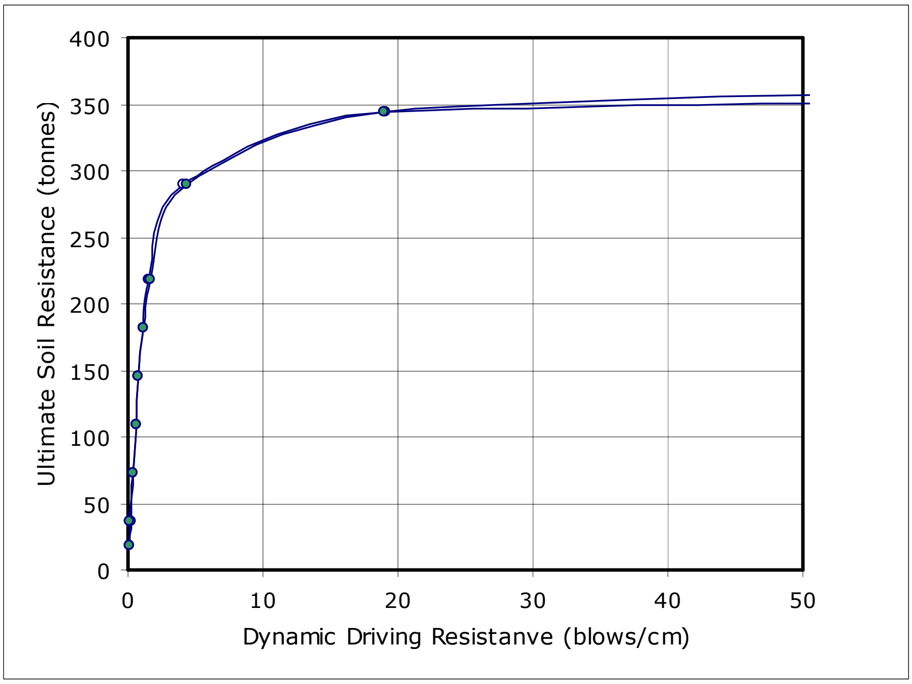

Figure 6. Bearing capacity graph for pile number P182

5. CONCLUSION

- With combination of static test and PDA and also PIT, bearing capacity graph for spun pile (P182) is generated. It is shown that final set is 0.3 mm and this value is close enough to driving record (0.2 mm).

- The cracks of the pile head during static load test may be caused by overstress after pile driving. It is modeled by wave equation analysis and shown that the damage of pile is mainly governed by compression force. The total number of blows of entire pile can also give a contribution of cracks.

- The ultimate capacity of pile is 401.0 ton from static test. The wave equation analysis gives a conservative ultimate capacity value as 350.0 ton.

- It is shown that a K-45 hammer is a good choice if the pile is not under overstressed condition.

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