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INFLUENCE OF PILE DRIVING HAMMER PERFORMANCE ON DRIVING CRITERIA

P.C. Lim* and B.B. Broms*

SYNOPSIS

In traditional piling practice, the set(s) is often used to define refusal. However, the set depends on the energy transferred to the piles and thus on the performance of hammers. Depending on the operating mechanism of various hammers, the performance of hammers could be very different. Findings based on stress-wave measurements have shown that the efficiency of diesel hammers or the transfer ratio can be as low as 20%. In this paper, the transfer ratio of hammers based on actual field measurements of diesel hammers, hydraulic hammers and drop hammers, as well as the implication of the hammer energy on the required set of the piles is discussed.

INTRODUCTION

During the seventies to eighties, diesel hammers were widely used in Singapore for the installation of driven piles. Considerable experience has been gained over the years for diesel hammers with respect to the set, for the quality control of driven piles. With the prohibition of diesel hammers since April 1, 1988, other types of pile driving hammers such as the hydraulic hammers are also used.

The experience in Singapore with the quieter hydraulic hammers is limited and most of the piles are still being driven to the same 'set' as that required for diesel hammers. Damage to piles and hydraulic hammers due to overdriving has been reported. The question is, can the set criteria for piles driven by diesel hammers be applicable to hydraulic hammers?

The fundamental concept in the derivation of most pile dynamic formulae is based on an energy balance between the input energy of the hammer to the work done by the pile as the pile tip penetrates a distance (s) against a resistance (R). The formulation also takes into consideration losses of energy associated with the capblock and the cushion assembly. It is self-explanatory that the energy that causes the pile to do positive work is in effect the energy that is transferred to the pile. For a given resistance, the set is therefore dependent on the energy transferred to the pile.

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*Nanyang Technological Institute, School of Civil & Structaral Engineering, SINGAPORE 2263

COMPARISON OF HAMMER EFFICIENCY

The actual energy transferred to the pile is usually much lower than the energy delivered by the hammer because of friction losses, elastic compression of the cushions and the acceleration of the helmet. In most cases, the pile cushion generally consists of several layers of plywood. Changes in the elastic properties of the capblock during the driving affects the axial force transmitted to the pile. For diesel hammers, energy losses can also be due to pre-ignition, wrong type or insufficient fuel supply, blockage of exhaust ports or leakage due to worn piston rings.

$$E(t) = \int_{o}^{t} F(t)\, V_p\, (t)\, dt \qquad (1)$$

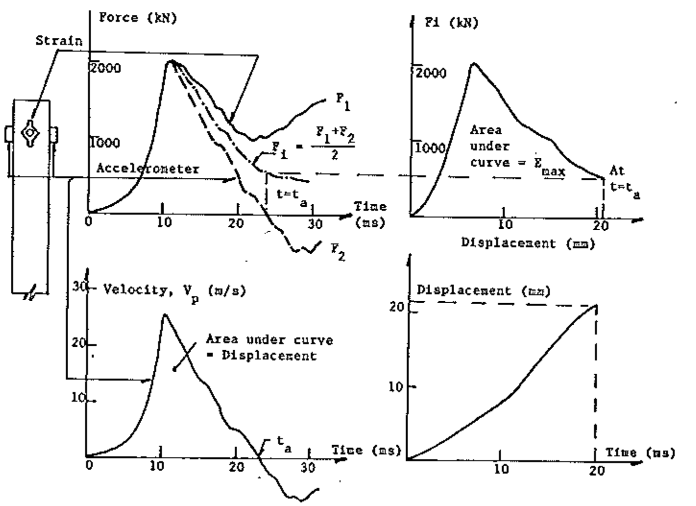

Fig. 1 Evaluation of maximum transferred energy to the pile (E_{max})

The energy delivered by the hammer depends mainly upon the mass of the hammer and the velocity of the hammer at impact which is difficult to measure on site. The energy that is transferred to the pile from the hammer depends on the transfer ratio, defined as the ratio of the actual energy transferred to the pile and the theoretical energy which is the product of the mass of the hammer (W) and the stroke (H). The actual energy transferred to the pile can be obtained from

stress-wave measurements using equation 1 as given by Rausche & Goble (1972). The method for the evaluation of transferred energy to the pile adopted in this paper is based on that given by Broms and Lim (1988) and can be explained by a relatively simple model as illustrated in Fig. 1.

The performance of diesel hammers, hydraulic hammers and drop hammers has been investigated for driven piles at several sites in Singapore. The results are as shown in Fig. 2.

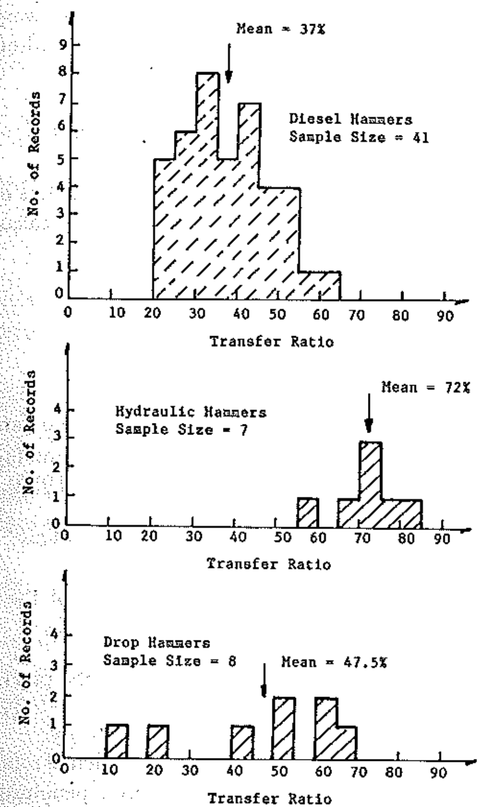

Fig. 2 Transfer Ratio of Hammers

For the diesel hammers, the transfer ratio ranged from 20% to 61% with an average of 37%. The data on hydraulic hammers are limited but the results do reflect a consistently higher efficiency. The efficiency of the hydraulic hammers ranged from 58% to 82% and the average is 72.0%. It is interesting to note that average efficiency of the hydraulic hammers is approximately 1.9 times that of the diesel hammers. In the case of drop hammers, the transfer ratio ranged from 11% to 68%, the average is 48%.

The operation of the hydraulic hammers and the drop hammers is similar in principle. However the performance of the hydraulic hammer was much better as compared to the drop hammer. The transfer ratio for both hydraulic hammers and drop hammers was higher than the diesel hammers.

DRIVING CRITERIA FOR DRIVEN PILES

Pile driving is interrupted when the required pile capacity has been reached. The following simplified Hiley's equation can be used to calculate the pile capacity or penetration resistance R.

$$R = \frac{E_{max}}{s + 1/2\,(k_2 + k_3)} \qquad (2)$$

Where E_{max} is the actual energy transferred to the pile by the hammer, s is the set (permanent displacement of the pile per hammer blow) and $(k_2 + k_3)$ is the elastic compression of the pile and the soil (Broms & Lim, 1988).

The assumptions on which equation 2 is based are as follow:

(1) The load distribution is constant along the pile.

(2) The elastic compression of the pile (k_2) and of the soil (k_3) increase linearly with the penetration resistance

The values of E_{max}, s, k_2 and k_3 can be measured as the pile is being driven to refusal.

In traditional piling practice, the set is often used to define refusal. However, equation 2 shows that the set for a given required penetration resistance increases with the energy. Hence, unless the energy delivered by the hammer is constant the set should not be used as the sole criteria in defining the performance of the pile, as illustrated by the following example.

EXAMPLE

Consider a pile driven to a set(s) of 1.00mm/blow by a K25 diesel hammer and by a HH5 hydraulic hammer with a ram stroke of 2.0 metre and 0.7 metre respectively. The temporary elastic compression of the pile and the soil is assumed to be 12mm. The average efficiency of the diesel and hydraulic hammers is taken as 37% and 72% respectively. The operation speed for both diesel and hydraulic hammer is 40 blows per minute.

From equation 2 the penetration resistance at a set(s) of 1mm/blow is as follows:

Diesel Hammer:

$$R = \left(\frac{0.37 \times 2.5 \times 2000}{1.0 + (12/2)}\right) = 264\text{t or } 2.64\text{MN}$$

Hydraulic Hammer:

$$R = \left(\frac{0.72 \times 5.0 \times 700}{1.0 + (12/2) \cdot R/264}\right) = 321\text{t or } 3.12\text{MN}$$

The required set(s) for a pile driven by hydraulic hammer to attain a penetration resistance of 2.64MN is:

$$264 = \left(\frac{0.72 \times 5.0 \times 700}{s + (12/2)}\right)$$

$$s = 3.5 \text{ mm/blow}$$

The required driving time for a penetration of 1.0 metre at an operating speed of 40 blows per minute is:

Diesel Hammer:

$$\text{Time} = \frac{(1000/1.0)}{40} = 25 \text{ mins}$$

Hydraulic Hammer:

$$\text{Time} = \frac{(1000/3.5)}{40} = 7 \text{ mins}$$

Although the theoretical energy delivered by the diesel hammer is higher than by the hydraulic hammer, the actual energy transferred to the pile is considerably higher for the hydraulic hammer because of the higher transfer ratio. Thus piles driven by a hydraulic hammer will have greater bearing capacity for a given set than piles driven by a diesel hammer as shown in the calculation. The resulting penetration of the piles will also be much higher for a hydraulic hammer.

A reduction of 72% in the driving time can be achieved using a hydraulic hammer for a given penetration resistance, since the required final set for piles driven by a hydraulic hammer is much higher. At 20 blows per minute, the time required to drive a pile by a hydraulic hammer is 14 minutes. The driving time is reduced by 43%.

At a set of 2mm/blow for the diesel hammer which corresponds to a penetration resistance of 231t (2.31MN), the time required to drive 1 metre length of pile is 12.5 minutes at 40 blows/minute. For a hydraulic hammer, the set is 4.9 mm/blow. The time required to drive the pile 1m into the same material is 5 minutes at 40 blows/minute, a reduction by 60%.

Further improvements in the efficiency of the hydraulic hammers are possible by using a thinner cushion and by reducing the mass of the helmet. The average efficiency of a hydraulic hammer could thereby be increased to 85% and the final set from 3.5mm/blow to 5.3mm/blow for a penetration resistance of 264t (2.64MN). The driving time could then be further reduced by 30% or more.

The difference in the time required for the pile driving between a diesel and a hydraulic hammer will increase with increasing elastic compression of the pile and of the soil. For end bearing piles, the difference will increase with increasing pile length. The difference is usually small for friction piles.

CONCLUSIONS

The transfer ratio is generally much higher for hydrulic hammers than for diesel hammers as well as the actual energy transferred to the pile. The required set would therefore be higher for piles driven to the same penetration resistance by a hydraulic hammer than that for piles driven by a diesel hammer. Correspondingly, the bearing capacity and the length of pile driven by hydraulic hammer for a given set would be greater than that of pile driven by diesel hammer. The driving time for piles driven by hydraulic hammer will also be shorter. A saving in construction time is thus possible although the hammer speed is dependent on the soil resistance, the elastic properties of the soil, pile

stiffness and the pile length. Therefore, the set established for diesel hammers cannot be used for piles driven by hydraulic hammer because the piles would be overdriven and the bearing capacity will be higher resistance.

REFERENCES

RAUSCHE, F. and GOBLE, G.G. 1972. "Performance of pile driving hammers". *Journal of the Construction Division, ASCE,* Vol.98, No C02, pp 201–217.

BROMS, B.B. and LIM, P.C. 1988. "A simple pile driving formula based on stress-wave measurements." *Proc. 3rd Int. Conf. on the Application of Stress-Wave Theory to piles,* Ottawa, Canada.