AN IMPROVED EFFICIENY OF DROP WEIGHT SYSTEM IN HIGH STRAIN DYNAMIC LOAD TEST

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ABSTRACT

High strain dynamic load test (HSDLT) is commonly used in testing for displacement piles. Recently, it has also increasingly used as an economy method to evaluate the capacity and integrity of cast-in-situ foundation system. To get a reliable pile analysis, a good quality stress-wave signal in HSDLT is utmost important. Secondly, an adequate stresses mobilization along the pile shaft and the toe is also very critical for the capacity determination. A proper selection of drop weight system for HSDLT on drilled shaft is one of the key components so as a uniform and sufficiently large impulse can be impacted on the pile head to sufficiently mobilize the pile-soil interaction behaviour. The typical conventional drop weight system in HSDLT engages a free-fall ram with a rigid guide frame. However, several studies reported a large variation of energy transfer efficiency (ETR) from the free-fall ram onto the drilled shaft. The ETR can be ranged from 3%-98% due to varies reasons. An uneven ram impact could be one of the possible reasons that causes a low ETR even with the best practice to align the verticality of the rigid guide frame with the pile head. Paikowsky (2004) conducted a series of numerical simulation to study the effect of a tilted ram impact, at very small angle of 1^o, onto the pile capacity determination. The study suggested that the induced stress-wave can only become uniform after a distance of 2 to 3 times of pile diameter (D) below the pile top. This paper presents a new drop weight system for HSDLT that was innovatively designed with a hydraulic-lifted modular ram built on four independent automatic self-adjusted outrigger system. It enables the almost perfect vertical alignment of the ram to the axial direction of the pile head. Based on the compiled case histories, the conventional drop weight system registers an averaged ETR of 39% associated with a standard deviation of 19.9%. As a comparison, this new drop weight system shows a remarkable y improved ETR of 56% associated with standard deviation of 8.2% after minimizing the effect of uneven ram impact.

Keywords: Drop Weight System, Uneven ram impact, Energy transfer efficiency, Verticality of ram-pile alignment

1 INTRODUCTION

High strain dynamic load test (HSDLT) is commonly used in testing for displacement piles. Recently, it has also increasingly used as an economy method to evaluate the capacity and integrity of cast-in-situ foundation system. Some of the possible difficulties in the dynamic measurement and analysis using HSDLT include but are not limited to non-uniform cross-section of drilled shaft, uneven pile top surface, poor quality concrete especially at the exterior portion of shaft, uneven ram impact, and small section area of ram versus shaft section area etc.

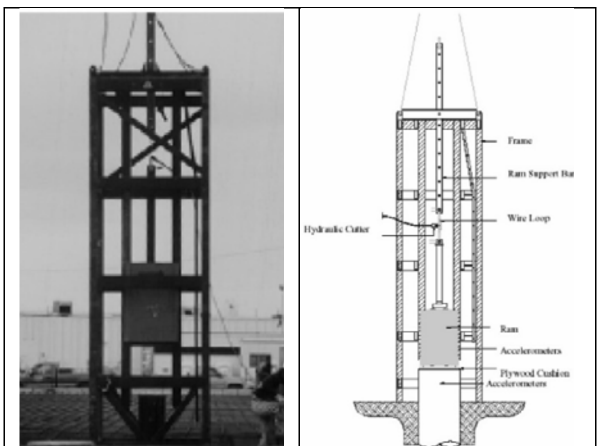
To get a reliable pile analysis, a good quality stress-wave signal in HSDLT is utmost important. Secondly, an adequate stresses mobilization along the pile shaft and the toe is also very critical for the capacity determination. A proper selection of drop weight system for HSDLT on drilled shaft is one of the key components so as a uniform and sufficiently large impulse can be impacted on the pile head to sufficiently mobilize the pile-soil interaction behaviour.

1.1 The Typical Drop Weight System in HSDLT

Typically, HSDLT on a drilled shaft uses a free-fall ram with a rigid guide frame. The free-fall ram in HSDLT involves a simple mechanism of lifting and dropping a designated heavy ram (being about 1% to 2% of test capacity) on the pile head. Paikowsky (2004) has discussed extensively on varies drop weight system for HSDLT on drilled shaft. Fig. 1 shows a typical conventional drop weight system in HSDLT.

A good practice of HSDLT usually includes several impacts of free-fall ram at varies heights to check the functionality of sensors, to evaluate the distribution of stresses at the allowable limit, and to attain an adequate mobilization of pile capacity. Depending on the platform preparation and the alignment of guide frame after each drop, the drop weight system sometimes needs to reset to ensure adequate verticality of the ram. It may need to unload the entire test setup, dissemble the system, moving the loading device, releveling the platform and resemble the system again. This process of resetting a drop weight system is cumbersome and time consuming.

Even the best practice of platform preparation may not produce the best result especially in energy transfer from the ram onto the drilled shaft. Hussein et al. (1992) reports a relatively low energy transfer efficiency of only 14% in HSDLT on drilled shaft. This is probably because of friction loss in the cushion and the winch hoisting system of the drop weight system.



(a) (b)

Fig. 1. Typical drop weight system in HSDLT: (a) Typical setup at site (b) Schematic diagram. (After Hussein et al., 2004)

1.2 The Effect of Uneven Impact in HSDLT

Paikowsky (2004) highlighted the inability or difficulties of ram alignment in the drop weight system. This will result in an uneven impact and thus uneven stress distribution across the pile head. The numerical simulation to study the effect of uneven impact (with a relatively small tilt in the ram of about 1^{o} from vertical) onto the pile capacity determination. It was shown that this small tilt will produce a significantly uneven stress distribution across the pile head. Fig. 2 shows the simulation result at 3 m below pile top at various time steps, which revealed that uneven stresses still exist after a distance of 3-times of pile diameter (D) from the impact surface. It suggests that the measuring sensors shall be installed at a further distance than the minimum 1.5D from pile top, as recommended by ASTM D4945. However, this requirement will post difficulty for the case with large diameter drilled shaft, which will then require much deeper excavation to install the measuring sensors.

1.3 An Innovative Drop Weight System with Perfect Ram-Pile Verticality Alignment

The conventional free-fall ram with rigid guide frame is always limited by its flexibility in terms of verticality adjustment. Therefore, a drop weight system with a better control of verticality is required to produce a uniform impact at pile head. This is to mobilize the desired pile-soil capacity at the utmost efficient of energy transfer from the drop weight. This paper presents a HSDLT system consisting a drop weight system incorporating an innovative hydraulic lifting feature built upon four numbers of independent automatic self-adjusting outrigger system. This system is able to position the ram at a near perfect verticality with the axial direction of the pile head. Fig. 3 and Fig. 4 illustrate the schematic diagram and the field setup of this drop weight system. In addition, this paper aims to evaluate the efficiency of energy transfer between this new drop weight system that equipped with verticality adjustment, and the conventional rigid guide frame drop weight system. Several local case histories compiled by the author will also be presented to illustrate the advantage and effectiveness of this new stet-up.

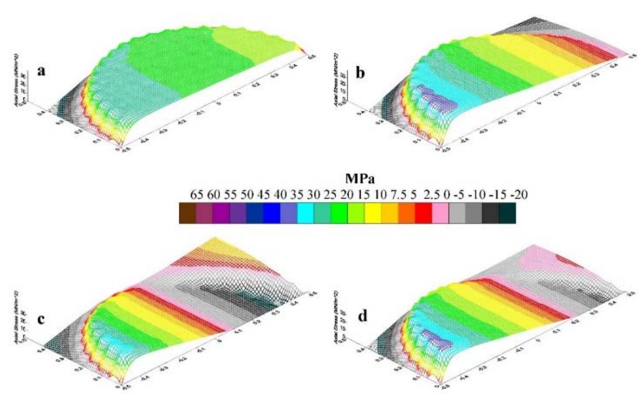


Fig. 2. The calculated normal stress at 3m below the pile head with tilt angle of 1^{o} for time equal to (a) 6 ms, (b) 7 ms, (c) 8 ms, (d) 9 ms. Pile diameter = 1m. (After Paikwosky, 2004)

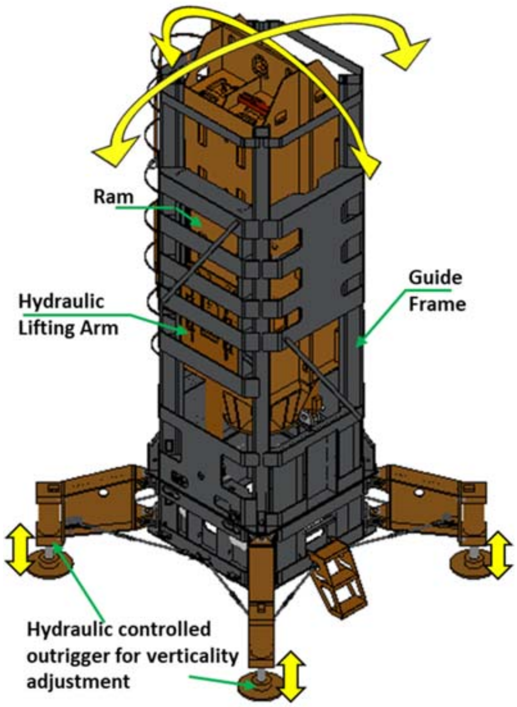


Fig. 3. The schematic diagram of the new drop weight with verticality alignment via outrigger system.

Fig. 4. The field setup of a new drop weight system for HSDLT on drilled shaft.

2 MEASUREMENTS & ANALYSIS METHODLOGY

The performance and consistency of the proposed new drop weight system are evaluated based on the energy transfer efficiency from the drop weight onto the pile shaft, and the standard deviation in the energy transfer respectively. The energy transfer efficiency (ETR) is defined as the percentage of maximum transferred energy measured at the sensor divided by the potential energy of the ram. The transferred energy measured is the integration on the product of averaged force and the averaged velocity (i.e. $Energy = \int F\ x\ V\ dt$), measured by the force transducers and accelerometers respectively; and the potential energy is given by the ram weight times the drop height. A good drop weight system shall register a high ETR value associated with a low standard deviation value.

This study compares the new drop weight system with ability in verticality alignment and the conventional rigid guide frame drop weight system. The ETR in the conventional drop weight system are available in several studies (Seidel and Rausche, 1984; Robinson et al., 2002 Rausche et al., 2006; and Paikwosky, 2004). The data for 24 cases of HSDLT on the large diameter drilled shaft using new drop weight system were compiled by the authors. The overall key parameters of these drop weight systems and cases are tabulated in Table 1.

Table 1. The key parameters of drop weight systems and the energy transfer efficiency in varies studies.

Studies	No. of Piles	Pile Diameter (m)	Ram Weight (tn)	Drop Height (m)
Seidel & Rausche (1984)	9	1.1m, 1.3m, 1.5m	20t	1.6m & 2.5m
Robinson et al. (2002)	24	0.46m, 0.9m	6.5t	0.2m to 1.2m
Rausche et al. (2006)	11	1.0m, 1.5m, 2.0m	20t & 40t	0.6m to 3.8m
Paikowsky (2004)	158	0.3m to 1.5m	-	-
The Authors (Conventional Drop Weight System)	11	1.5m, 1.8m, 2.2m	60t & 90t	1.4m & 2.1m
The Authors (New Drop Weight System)	24	1.5m, 2.0m, 2.5m, 3.2m	60t & 94t	1.0m to 2.4m

3 COMPARISON OF PERFORMANCE OF TWO DROP WEIGHT SYSTEMS

This section presents the performance of the conventional and the new drop weight system. It is noted that the adopted case histories/database of HSDLT in this study consists of different geometry of drilled shaft, different configuration of cushion system, and subjected to varies other factors during HSDLT (e.g. pile head conditions, ram stiffness, ram friction etc.), which may affect energy transfer efficiency other than the ram-pile alignment/verticality. However, these results of HSDLT are assumed to be conducted with the best practice in platform preparation and appropriate setup of drop weight system for HSDLT on drilled shaft.

3.1 The Conventional Drop Weight System

The conventional drop weight system usually consists of a rigid guide frame, heavy ram, and a mechanical lifting-and-release system. To evaluate the energy transfer efficiency of the conventional drop weight system, four (4) numbers of publication on case histories, plus and one numbers of database for HSDLT on drilled shaft compiled by the Authors are adopted in this study. Fig. 5 shows the maximum energy transfer at the pile head versus the potential energy of these case histories. The ETR and the standard deviation of ETR in these case histories are summarized in Table 2.

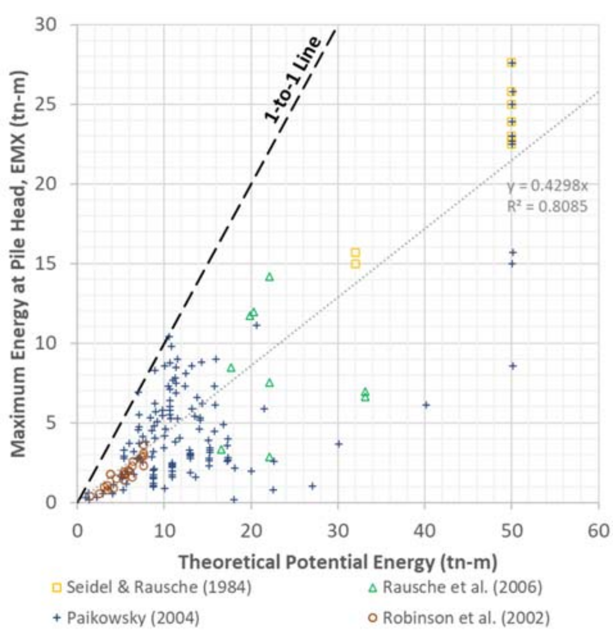


Fig. 5. The maximum energy register at pile head versus the potential energy in varies HSDLT case histories using conventional drop weight system.

Table 2. The ETR and standard deviation for conventional drop weight system in varies case studies.

Studies	Energy Transfer Efficiency (%)	Average of Maximum Energy Transfer Efficiency (%)	Standard deviation* (%)
Seidel and Rausche (1984)	45% to 52%	48.5%	3.3%
Robinson et al. (2002)	21% to 48%	33.8%	7.7%
Rausche et al. (2006)	9% to 64%	32.5%	21.2%
Paikowsky (2004)	3% to 98%	38.8%	22.0%
By the Authors (Conventional Drop Weight System)	31% to 58%	47.2%	18.2%

Standard deviation* is the standard deviation of the ETR post-analyzed by the authors.

Seidel & Rausche (1984) and Robinson et al. (2002) report averaged ETR of 48.5% and 33.8% respectively. A low standard deviation of 3.3% and 7.7% in ETR are found on the drop weight system in these studies. It is suggested that the test condition including the ram-pile alignment were rather good in the HSDLT. Conversely, Paikwosky (2004) reported a highly varied ETR with an average value of approximate 39% associated with a high standard deviation of 22%. Similarly, Rausche et al. (2006) reported ETR ranged from 9% to 64% with an average value of 32.5% associated with a high standard deviation of 21.2%. It is worth to note that the last studies statically showed almost identical large variation of ETR with a high standard deviation of 21-22%. Majority of these HSDLT test results were found to be limited to a relatively small diameter bored pile (D<1.5m) and maximum potential energy of less than 60 tn-m.

The authors also compiled a number of HSDLT by using conventional drop weight system, but with larger potential energy ranged from 60tn-m to 220tn-m. The maximum measured energy transfer versus the theoretical potential energy of these data are plotted in Fig. 6, together with the other case histories. A best line is fitted among these data and register a gradient of 0.40 (or 40%), which shows good agreement with the average ETR of 39% in HSDLT with conventional drop weight system.

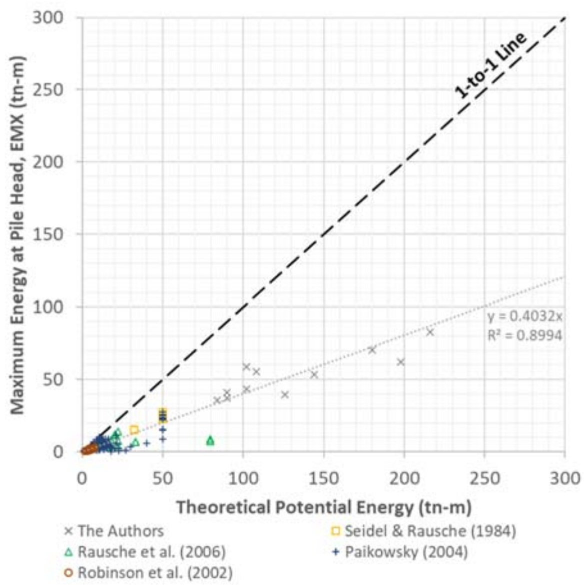


Fig. 6. The maximum energy register at pile head versus the potential energy in varies HSDLT on drilled shaft reported by the authors and other case histories.

3.2 The Performance of New Drop Weight System

A total 24 numbers of HSDLT performed with the new drop weight system were compiled and evaluated in this paper. This new drop weight system has a theoretical potential energy ranged from 60 tn-m to 280 tn-m with drop weight of 60t and 94t at varies drop heights. With the best alignment of ram-pile verticality in HSDLT, a range of ETR register at 44% to 77%.

Table 3 compares the ETR and its standard deviation for the new HSDLT system. The comparison between the old conventional system and the new drop weight system was also included in Table 3. The conventional drop weight system produced an average ETR of 39% with standard deviation of 19.9%. Conversely, a remarkable average ETR of 57.3% associated with standard deviation of 8.2% are found in the new drop weight system.

Table 3. The evaluation of the new drop weight system versus the conventional drop weight system.

Type of Drop Weight System	Energy Transfer Efficiency, ETR (%)	Average of Maximum Energy Transfer Efficiency (%)	Average Standard deviation (%)
Conventional Drop Weight System (Rigid Frame + Ram)	3% to 98%	39.0%	19.9%
New Drop Weight System with Verticality Adjustment	44% to 77%	57.3%	8.2%

Fig. 7 plots the maximum energy registered at pile head against the theoretical potential energy of these two systems. The best-fit line of the new drop weight system indicates a gradient of 0.56 (or 56%), which shows good agreement with the average ETR of 57.3% for that system. It is worth to note that some data points in the conventional drop weight system fall closed to the best-fit line of the new drop weight system. It suggests that the conventional drop weight system is able to obtain a high ETR if the verticality of the ram-pile is well aligned. Otherwise, the effect of uneven ram impact will dominate the conventional drop weight system. On the other hand, in the new system, the vertical alignment of the ram-pile system is automatically assured under normal operation condition.

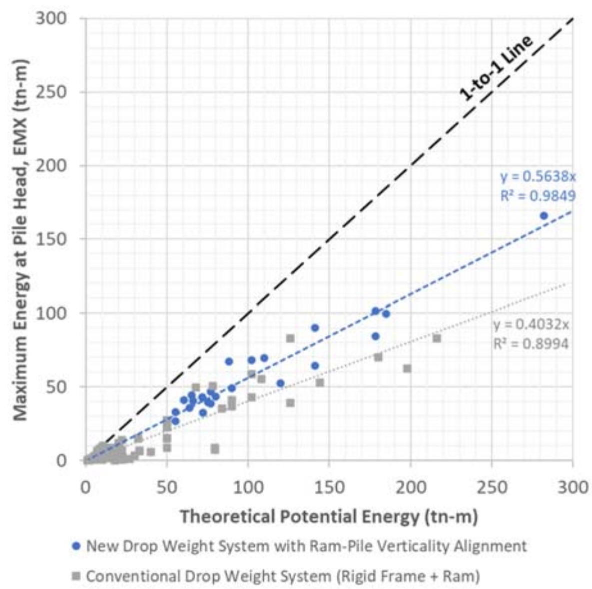


Fig. 7. The maximum energy register at pile head versus the potential energy in HSDLT system for a new drop weight system with alignment of pile-ram verticality in each impact.

4 CONCLUSIONS

This paper examined the effect of uneven ram impact in HSDLT that performed with conventional system and a new drop weight system. The new drop weight system with ability to align ram-pile verticality shows a remarkable high ETR with good consistency. An average ETR of 56% can be achieved for this new system, as compared to the conventional drop weight system of about 39%. This new system could help in the application of larger ram weight system aiming to maixumin the effective ram impact energy with maximum energy transfer efficiency to mobilize the required pile resistance, especially for the HSDLT on large diameter drilled shaft. This study is intended as a living document. As more field results and research are made available, the other effects that affect the ETR could be differentiated and further quantified.

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