

## **Pile Dynamic Analyzer (PDA) Test: An Overview of the Pile Integrity Evaluation Technique**

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**Abstract:** A case study was done on the pile dynamic analyzer (PDA) test. PDA test also known as dynamic pile testing (DPT), which serves as an alternative to conventional load test for installed piles. PDA comes with the advantages of being more time-saving, cost-saving as well as environmental-friendly, where the pile test method omits the need for heavy haulage and mobilisation of the dead weights on site. PDA is primarily carried out to monitor and evaluate the driven pile condition, both in terms of structural and geotechnical performance. The geotechnical ultimate capacity as well as installation driving stresses, structural integrity and hammer energy transferred to the pile, supporting soil strength and deformation properties, pile-soil interaction characteristics, and the nature and magnitude of the applied load can be determined from the PDA test. Dynamic pile testing (DPT) and instrumentation will be conducted using Pile Dynamic Analyser (PDA) with further analysis using the Case Pile Wave Analysis Program (CAPWAP). In short, testing using PDA has gained popularity in recent years because it is relatively cost-efficient, time saving, and easy to perform.

**Keywords:** Pile Dynamic Analyzer, CAWAP, Foundation

### **1. Introduction**

Pile Driving Analyzer (PDA) or known as dynamic pile testing (DPT) is a type of dynamic test. In the construction of building, foundation neither shallow nor deep foundation is the “core structure” as it plays its important part in providing safe, stable and adequate strength to support the whole structure. In order to ensure the safe and stable high performance of the building structure, the selection of foundation has to be precise based on the consideration of structural requirements, subsurface condition, site characteristic and economics. The ultimate strength of a deep foundation must satisfy both structural

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and geotechnical limits for the foundation to perform as desired [1]. Figure 1 shows the PDA testing conducted at site. The dynamic testing was conducted using a hydraulic hammer in order to provide an impact on the pile top and measuring the force and velocity signals generated. Subsequently, the CAPWAP software was used to analyse the pile-soil model to determine the activated pile capacity.



**Figure 1: PDA at site**

There are several integrity tests that performed to determine and evaluate the piles condition. For driven piles, it can be evaluated by dynamic testing for geotechnical ultimate capacity as well as installation driving stresses, structural integrity and hammer energy transferred to the pile, supporting soil strength and deformation properties, pile-soil interaction characteristics, and the nature and magnitude of the applied load [2]. In short, the main objectives of dynamic pile testing are evaluation of pile driving resistance and static capacity, determination of driving stresses, assessment of pile structural integrity and investigation of hammer and driving system performance.

### 1.1 Brief description of Pile Dynamic Analyzer (PDA)

Dynamic pile testing (DPT) and instrumentation will be conducted using Pile Dynamic Analyzer (PDA) with further analysis using the Case Pile Wave Analysis Program (CAPWAP). Case Pile Wave Analysis Program (CAPWAP) software was used for the analysis of data from PDA field tests; through CAPWAP, the pile mobilized capacity, skin friction, end bearing, and settlement data at working and test loads were obtained. Pile capacity obtained from the CAPWAP analysis on the PDA test results is considered to be fully mobilized if only the net set of 3 mm is achieved at the time of testing. During the analysis, adjustments and reasonable judgments had to be made for certain parameters, such as the soil resistance distribution, quake, and damping factors. Pile force and pile velocity are usually measured near the pile top. The PDA is as shown in Figure 2. The data are acquired from the strain and acceleration transducers which provide signal conditioning, calibration and processing those measured signal, integrates the acceleration to velocity and displays the measurement for PDA operator evaluation. The PDA is connected directly to a laptop running the Windows PDA Program to provide full-onsite PDA processing capability.



**Figure 2: PDA equipment**

## **2. General Test Method**

The equipments and its method are described as the followings:

- 3 nos. of 6 mm diameter holes are drilled on two opposite sides of the pile for attachment of gauges at 1.5 times pile diameters below the pile top.
- Two pairs of strain and accelerometer gauges are bolted onto the opposite sides pile using wall plugs. These gauges are connected to a PDA for recording the dynamic signals and field evaluation of data quality, soil resistance and pile integrity as shown in Figure 3.
- During testing, piling hammer with specified weight is positioned and dropped onto the pile to induce a driving force.
- Dynamic measurement of force and velocity will be collected by gauges attached to the pile.
- The transducers and accelerometers will be dismantled at the end of the testing. PDA data will be transferred and stored in a disk for subsequent report and analysis.
- This data will be processed by the PDA to give immediate visual and permanent record onsite. The key indicators for these results are Max. Resistance (RMX), Pile Integrity (BTA), Max Force (FMX), Max Stress (CXS) and Energy at Pile Top (EMX).

For the field results, the PDA interprets the measured dynamic data according to the Case Method equations. A CAPWAP procedure is an analytical method to predict the static pile capacity, soil resistance distribution, soil damping and stiffness value, pile-load movement and pile-soil interaction. Figure 4 presents the CAPWAP method description.

FIELD SHEET FOR DYNAMIC PILE TESTING

Project Location: 1121 77 1/2 St, W2, Langkat  
Date of Test: 11/1/2014

PILE AND HAMMER DETAILS (See Information Provided)

Pile Ref:	HT	53	23	125	58
Pile Location:	SAKID 5	158M 0.1	147M 14.1	148M 11	121M 12.11
Pile Type:	SC	SC	SC	SC	SC
Pile Material:	CONCRETE	CONCRETE	CONCRETE	CONCRETE	CONCRETE
Ultimate Strength (kN):	SC	SC	SC	SC	SC
Pile Area (cm <sup>2</sup> ):	200,450	200,450	200,450	200,450	111,410
Pile Area (in <sup>2</sup> ):	309	309	309	309	170
Total Pile Length (m):	21.0	21.0	21.0	21.0	21.0
Length Below Cap (m):	21.0	21.0	21.0	21.0	21.0
Pile Penetration (m):	21.0	15.5	11.0	25.0	21.0
Pile Make-Up (m):	0.1 (1.0)	0.1 (1.0)	0.1 (1.0)	0.1 (1.0)	0.1 (1.0)
Pile Working Load (kN):	38	38	38	38	22
Pile Test Load (kN):	76	76	76	76	44
Hammer Type:	SC	SC	SC	SC	SC
Hammer Weight (kN):	2.5	2.5	2.5	2.5	2.5
Drop Height (m):	0.5	0.5	0.5	0.5	0.5
Pile Drive Rate:	110 (200)				
Type of Pile:	Standard				
Load of Drive Monitoring:					
Time (ms)	0.00	1.00	2.00	3.00	4.00
Force (kN)	0.00	0.00	0.00	0.00	0.00
Velocity (m/s)	0.00	0.00	0.00	0.00	0.00
Time (ms)	0.00	1.00	2.00	3.00	4.00
Force (kN)	0.00	0.00	0.00	0.00	0.00
Velocity (m/s)	0.00	0.00	0.00	0.00	0.00

Figure 3: An example of field sheet

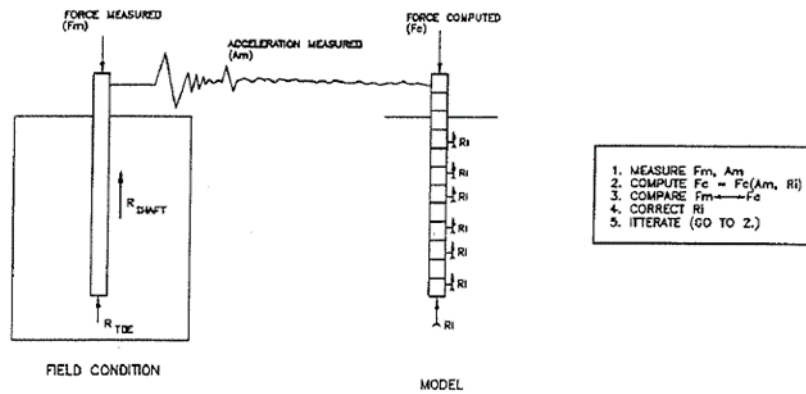


Figure 4: CAPWAP method

The results of CAPWAP analysis for dynamic pile testing data were found to be very reliable in the determination of ultimate capacity of both cast-in-situ and driven piles [3]. From the CAPWAP analysis, the results generated are presented in Figure 5. An example of plots generated from CAPWAP analysis result are shown in Figure 6. The plots of the force and velocity measurements, the match between measured and calculated impact force, soil resistance distribution at ultimate load, and pile-top and toe load-movement relationships under a simulated load test were included in the results.

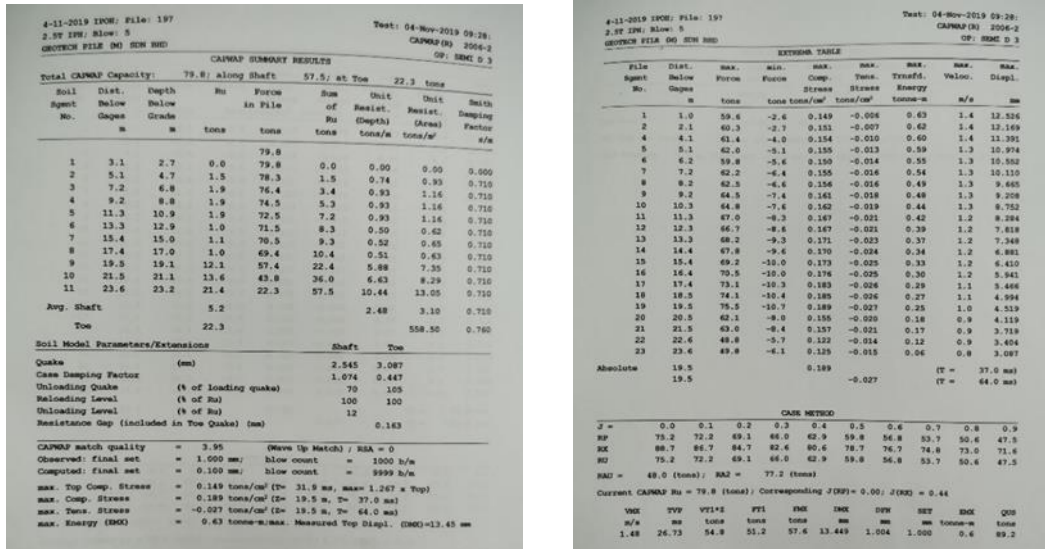


Figure 5: CAPWAP summary results

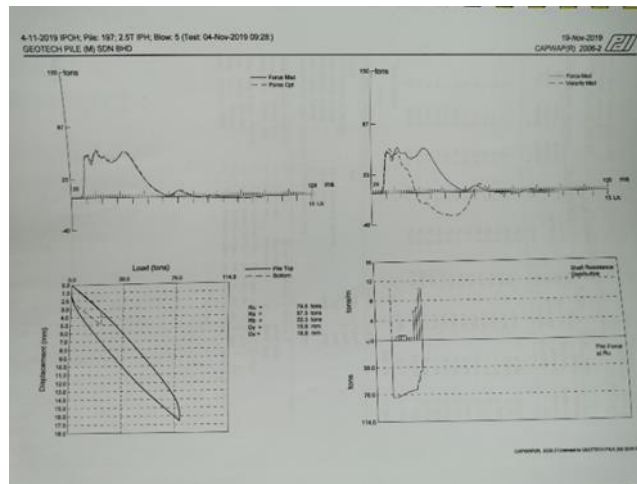


Figure 6: Plots generated from CAPWAP

### 3. Discussion

Testing using PDA has gained popularity in recent years because it is relatively cost-efficient, time saving, and easy to perform and it is supported by [3]. The cost of dynamic testing is significantly smaller than the costs of static tests. However, as the testing loads increase, dynamic testing becomes increasingly cost effective.

Pile capacity and the soil strength may alter with time after installation of the pile [1]. As the longer the time interval, the greater the shaft friction contribution is towards the pile capacity [3]. At the early period of pile installation, capacity is often lower due to pore pressure effects. As time increases, capacity then increases as pore pressure effects dissipate or as the normal earth pressures are restored [2]. This process of gaining capacity with the time is called as ‘soil setup’. Thus, it is then suggested by the [2] that the dynamic piling test should be tested at least one week after pile driving process. Moreover, dynamic test or PDA test requires specialized trained personnel to conduct the test. The training requirements are quite substantial and tests must be performed by an engineer.

For larger projects, the amount of static testing is generally reduced after the correlation of dynamically and statically tested piles is established, and then it is supplemented by additional dynamic tests to increase the total percentage of piles tested [2]. This improves the quality assurance as reducing



the costing of test. Test reports are prepared by the pile tester company for developer, consultant and piling contractor. Testing load applied to the pile top is twice times the working load of the pile. The working load depends on the type, material and sizes of piles of the piles. Figure 7 shows an example of summary of pile details that involved in the construction of 11 storey of apartment.

Item	Pile Numbers	Pile Type	Pile Material	Material Strength (MPa)	Pile Size (mm)	Total Length (m)	Length Below Gauges (m)	Penetration (m)	Pile Make-Up (m)	Working Load (tons)	Test Load (tons)
1	218	RC	Concrete	45	300 x 300	24.0	23.4	23.1	4 x 6m	100	200
2	243	RC	Concrete	45	300 x 300	12.0	11.1	10.8	2 x 6m	100	200
3	252	RC	Concrete	45	300 x 300	36.0+6Dolly	36.5	36.0	6 x 6m	100	200
4	164	RC	Concrete	45	300 x 300	36.0+6Dolly	36.5	36.0	6 x 6m	100	200
5	26	RC	Concrete	45	300 x 300	18.0	17.2	16.8	3 x 6m	100	200
6	107	RC	Concrete	45	300 x 300	18.0	14.5	14.1	3 x 6m	100	200
7	88	RC	Concrete	45	300 x 300	36.0+6Dolly	36.5	36.0	6 x 6m	100	200
8	57	RC	Concrete	45	300 x 300	36.0+6Dolly	36.5	36.0	6 x 6m	100	200
9	1	RC	Concrete	45	300 x 300	48.0+6Dolly	48.5	48.0	8 x 6m	100	200
10	185	RC	Concrete	45	300 x 300	36.0+6Dolly	36.5	36.0	6 x 6m	100	200

Figure 7: Pile details

Based on the project, the hammer ram weight was 7.5 tons and dropped at a height of 0.3 m. The method of testing was referred to [4]. From the field results obtained from PDA, the summary results of testing is as presented in Figure 8. The pile integrity can be evaluated, i.e. the pile integrity should have reached a minimum of 70.0 % and to be considered as an ‘acceptable integrity’.

Item	Pile Numbers & (Blow no.)	Pile size (mm)	Penetration Length (m)	Maximum Energy Transferred to Pile Head EMX (ton)	Maximum Measured Pile Top Force FMX (tons)	Maximum Compression Stress at Pile Top CSX (MPa)	Mobilized Capacity By Case Method Jc = 0.5 RMX (tons)	Pile Integrity Evaluation
1	218 (6)	300 x 300	23.1	2.10	169	18.4	207	Acceptable Integrity. BTA: 75%
2	243 (3)	300 x 300	10.8	1.33	209	22.8	218	Low Integrity. BTA: 53% @ 6.8m from top of pile.
3	252 (2)	300 x 300	36.0	1.12	100	10.9	101	Acceptable Integrity. BTA: 71%
4	164 (4)	300 x 300	36.0	1.75	211	23.0	206	Acceptable Integrity. BTA: 76%
5	26 (2)	300 x 300	16.8	1.47	194	21.1	203	Acceptable Integrity. BTA: 100%
6	107 (2)	300 x 300	14.1	1.43	203	22.2	204	Acceptable Integrity. BTA: 100%
7	88 (2)	300 x 300	36.0	2.43	171	18.7	117	Acceptable Integrity. BTA: 70%
8	57 (6)	300 x 300	36.0	2.12	175	19.1	172	Acceptable Integrity. BTA: 73%
9	1 (6)	300 x 300	48.0	3.65	201	21.8	211	Acceptable Integrity. BTA: 70%
10	185 (6)	300 x 300	36.0	1.65	176	19.2	188	Acceptable Integrity. BTA: 73%

Figure 8: Summary of dynamic testing field results

The field test results obtained will be further analysed with CAPWAP as shown in Figure 9. The total mobilized capacity of the piles had to be more than 200 tons (test load) in order to reach the set requirements. Based on the results obtained, the design of reinforced concrete structures such as slab either suspended or non-suspended slab, ground beam, pile cap and etc can be determined

SUMMARY OF CAPWAP ANALYSIS RESULTS										
Item	Pile Numbers & (Blow no.)	Pile Status	Pile size (mm) & Test Load	Penetration Length (m)	Mobilized Capacity			Pile Top Settlement		Remarks
					Total (tons)	Shaft (tons)	Toe (tons)	@ Working Load (mm)	@ Test Load (mm)	
1	218 (6)	Set	300mm x 300mm (200 tons)	23.1	218.1	123.3	94.8	6.4	16.5	Test Load Achieved
2	243 (3)	Set	300mm x 300mm (200 tons)	10.8	217.5	118.3	99.1	4.9	10.1	Test Load Achieved
3	252 (2)	Unset	300mm x 300mm (200 tons)	36.0	96.1	72.6	23.5	-	-	Test Load Not Achieved
4	164 (4)	Unset	300mm x 300mm (200 tons)	36.0	213.8	203.8	10.0	3.7	10.0	Test Load Achieved
5	26 (2)	Set	300mm x 300mm (200 tons)	16.8	204.7	137.9	66.8	5.9	12.9	Test Load Achieved
6	107 (2)	Set	300mm x 300mm (200 tons)	14.1	212.8	134.2	78.6	5.7	11.8	Test Load Achieved
7	88 (2)	Unset	300mm x 300mm (200 tons)	36.0	118.5	87.9	30.6	12.5	-	Test Load Not Achieved
8	57 (6)	Unset	300mm x 300mm (200 tons)	36.0	173.1	148.6	24.6	7.0	-	Test Load Not Achieved
9	1 (6)	Unset	300mm x 300mm (200 tons)	48.0	213.7	190.6	23.2	10.8	25.0	Test Load Achieved
10	185 (6)	Unset	300mm x 300mm (200 tons)	36.0	204.2	196.9	7.3	5.5	13.5	Test Load Achieved

Figure 9: Summary of CAPWAP analysis results

#### 4. Conclusion

In conclusion, PDA test contributes major in the sector of civil and structure. DPT or PDA test with CAPWAP analysis have been practiced widely for engineers and contractors. This method has been applied to driven piles to determine the pile integrity, pile capacity and pile-soil interaction. PDA method encourages the engineer to find a better foundation solution especially for the ‘design-build’ project. The work quality and professionalism of the personnel in setting up the field test and realize the importance of pile testing in foundation selection and design stage of building such that the design of pile cap in consulting stage play significant part. The test load applied during PDA test is always double the working load of the pile. However, the pile capacity is not mobilized if displacement during the hammer impact is insufficient.

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