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## Set-up and limitations of small-scaled verification load tests on hand-dug caisson pile: A Malaysian contractor's experience

Mise en place et limites des essais de charge de vérification à petite échelle sur les pieux caissons étirés à la main: L'expérience d'un entrepreneur malaisien

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**ABSTRACT:** This paper presents the review on set-up design of small-scaled load tests namely shaft load test and plate bearing load test, based on local construction practice. Several design set-ups implemented in the Authors' past projects will be discussed and the set-up limitations such as hydraulic jack capacity, structural capacity of test lining will be highlighted. As the small-scaled verification load tests are typically carried out right after the completion of manual excavation, the caisson pile design parameters can be verified with much shorter waiting time in contrast to conventional full-scaled static load test. This paper also depicts the improvement introduced on the load test set-ups in different past projects without compromising the load test ultimate objective and technical requirement. The load test results from several projects are compiled and discussed. Besides, correlation and calibration between the small-scaled load test results and full-scaled static load test for certain projects are studied. The design set-up for small-scaled verification load tests of hand-dug caisson is neither typical nor standard provided the load test objectives are met. Factors such as pile diameter, test load, testing level and ground condition shall be considered before deciding the appropriate load test set-up.

**RÉSUMÉ :** Cet article présente l'examen de la conception de la mise en place d'essais de charge à petite échelle, à savoir l'essai de charge de l'arbre et l'essai de charge de la plaque de support, basé sur la pratique de construction locale. Plusieurs montages mis en œuvre dans les projets antérieurs des auteurs seront discutés et les limites du montage, telles que la capacité du vérin hydraulique et la capacité structurelle du revêtement d'essai, seront soulignées. Comme les essais de charge de vérification à petite échelle sont généralement effectués juste après la fin de l'excavation manuelle, les paramètres de conception des caissons peuvent être vérifiés avec un temps d'attente beaucoup plus court par rapport aux essais de charge statique à grande échelle. Cet article décrit également l'amélioration introduite dans les installations d'essai de charge dans différents projets passés sans compromettre l'objectif final de l'essai de charge et les exigences techniques. Les résultats des essais de charge de plusieurs projets sont compilés et discutés. En outre, la corrélation et la calibration entre les résultats des tests de charge à petite échelle et les tests de charge statique à grande échelle pour certains projets sont étudiés. La conception des essais de charge de vérification à petite échelle des caissons creusés à la main n'est ni typique ni standard, à condition que les objectifs des essais de charge soient atteints. Des facteurs tels que le diamètre du pieu, la charge d'essai, le niveau d'essai et l'état du sol doivent être pris en compte avant de décider du montage d'essai de charge approprié.

**KEYWORDS:** hand-dug caisson, caisson shaft load test, plate bearing load test, local construction practice, full-scaled static load test

### 1 INTRODUCTION

Hand-dug caissons are structural elements typically adopted as foundation or earth retaining system and are excavated using hand tools in stages with depths of up to 1 meter, depending on the competency of the ground. Caisson pile construction involves digging or dredging of materials from the opened hole in stages which accompanied with formation of cast in-situ circular concrete linings (refer to Fig. 1). In local foundation industry, hand-dug caissons are commonly adopted at sites with steeply sloping terrain, difficult access or insufficient working platform.

Full-scaled static load test using dead weight or anchored reaction frame system is frequently executed at field to verify the performance of installed foundation pile. Owing to large load-carrying capacity of caisson pile, intense load test set-up using kentledge blocks or reaction steel beams (refer to Fig. 2 & 3) may not be practical in terms of site safety, execution cost and time required to complete the set-up. Considering the mentioned factors, small-scaled load tests namely shaft load test and plate bearing load test are preferably used to verify the geotechnical performance of caisson pile.

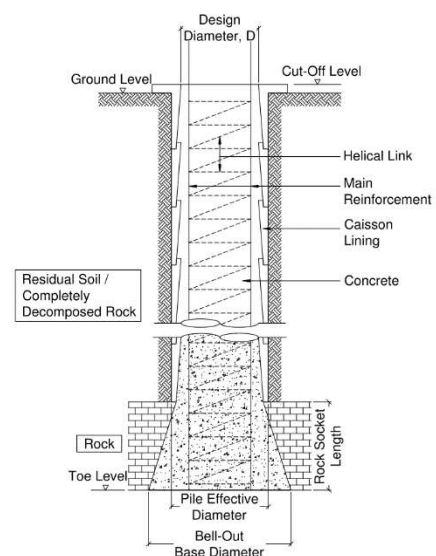


Figure 1. Typical caisson pile section



Figure 2. Static load test set-up system with kentledge blocks



Figure 3. Reaction frame system for a 6000-tonne static load test

## 2 DESIGN OF CAISSON PILE

The working capacity of hand-dug caisson pile shall be calculated using allowable concrete stress not exceeding the permissible value of  $0.25f_{cu}$ , as stipulated in BS8004 (1986). The geotechnical capacity of caisson pile is primarily derived from the shaft and base resistances of the founding materials, which may be soil or rock.

For caisson pile embedded in soils, the ultimate unit shaft and base resistances are correlated to Standard Penetration Test (SPT-N) values using the following semi-empirical formulas (refer to Eq. 1 & 2):

$$\text{Ultimate unit shaft resistance, } f_{su} = K_s \times \text{SPT-N} \quad (1)$$

$$\text{Ultimate unit base resistance, } f_{bu} = K_b \times \text{SPT-N} \quad (2)$$

where  $K_s$  = shaft resistance factor  
 $K_b$  = base resistance factor

For a caisson pile with rock socket, the ultimate unit rock shaft resistance is estimated using design approach by Williams & Pells (1981) with consideration of the respective strength of intact rock and rock mass effect in association with the inherent discontinuities (refer to Eq. 3).

$$\text{Ultimate unit shaft resistance, } f_{su} = \alpha \times \beta \times q_{uc} \quad (3)$$

where  $\alpha$  = reduction factor w.r.t.  $q_{uc}$   
 $\beta$  = reduction factor w.r.t. rock mass effect  
 $q_{uc}$  = unconfined compressive strength of intact rock

The allowable rock base resistance is derived from the empirical formula recommended by Canadian Foundation Engineering Manual (1992) as shown in Eq. 4.

$$\text{Allowable unit base resistance, } f_{ba} = K_{sp} \times q_{uc} \quad (4)$$

where  $K_{sp}$  = coefficient based on spacing of discontinuities  
 $q_{uc}$  = unconfined compressive strength of intact rock

The design parameters derived from the design approaches above are adopted directly in hand-dug caisson pile without further downgrading factor due to the following:

- caisson shaft in rock socket formed by pneumatic tools is generally rougher and irregular (refer to Fig. 4)
- satisfactory base cleaning can be achieved in dry hole condition (refer to Fig. 5)
- proper inspection of rock socket condition can be carried out before concreting process



Figure 4. Typical caisson shaft surface in rock socket



Figure 5. Caisson pile base condition after proper cleaning

## 3 CAISSON SHAFT LOAD TEST

The typical caisson shaft load test set-up generally involves construction of a test segment/ lining and concrete bedding at caisson base, placement of hydraulic jacks in between, followed by positioning of displacement transducer(s) which secured to the caisson linings on top (refer to Fig. 6). Alternatively, the hydraulic jacks can be placed in between test segment and caisson lining, provided the shaft resistance is adequate in providing the reaction to conduct the load test.

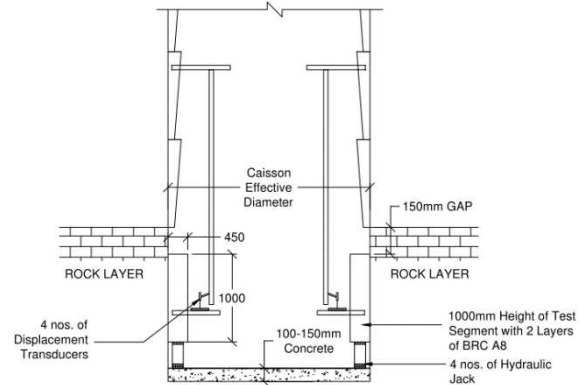


Figure 6. Typical set-up of caisson shaft load test

The number of hydraulic jacks (refer to Fig. 7) relies on the maximum test load, which relates to outer diameter and height of test segment as well as ultimate unit shaft resistance. The maximum test load of caisson shaft load test is determined using Eq. 5.

$$\text{Maximum test load} = \pi \times D \times H \times f_{su} \quad (5)$$

where  $D$  = effective diameter of test segment  
 $H$  = height of test segment  
 $f_{su}$  = ultimate unit shaft resistance



Figure 7. Caisson shaft load test set-up with 10 nos. of hydraulic jack

Due to concentrated load acting from hydraulic jack, the test segment shall be properly designed and where appropriate, to be enhanced with steel reinforcement or higher grade of concrete. Lower test segment height is occasionally opted to reduce the maximum test load especially for large diameter caissons but may adversely affect the flexural stiffness of test segment which will be in ring-shape. Fig. 8 illustrates structural failure (i.e. cracking) of a test segment with 800mm height during caisson shaft load test.



Figure 8. Structural failure of test segment during load test

Amongst the limitations of typical caisson shaft load test set-up are many small capacity hydraulic jacks are required, a test segment needs to be constructed in advance and load test to be carried out inside confined space. Considering the factors mentioned, a modified top-loaded Caisson shaft load test was proposed by the Author at a project site with shallow bedrock formation (refer to Fig 9). A 1000mm diameter caisson pile segment of 1m embedded length was formed by portable breaker and a 300mm thick polyfoam was inserted at pile base to simulate zero base resistance condition. Vibrating-wire strain gauges (VWSG) were imbedded into the polyfoam to verify the effectiveness of the simulated pile base soft toe condition. The logged maximum change in strain of VWSG was only  $0.5 \times 10^{-6}$ , equivalent to 0.017% of strain value before load test. This had proven that there was no load transferred to the pile base and the load test set-up is feasible to serve the load test objective.

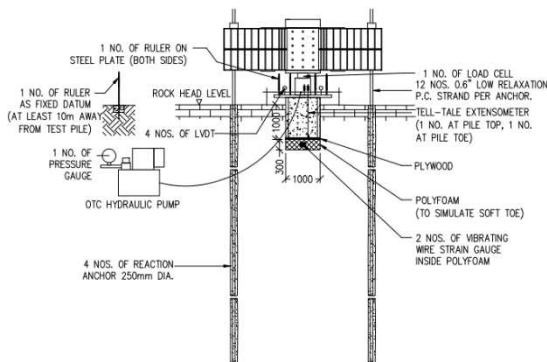


Figure 9. Modified top-loaded shaft load test set-up

Some of the caisson shaft load test results at several project sites are compiled and summarized by the Authors in Table 1.

Table 1. Summary of caisson shaft load test results

Test Pile Ref.	Project Location	Test Material <sup>(1)</sup>	$D$ <sup>(2)</sup> (mm)	$\delta$ <sup>(3)</sup> (mm)	$\delta/D$ (%)
G065-CP55	Bukit Tunku, Kuala Lumpur	Soil	1500	6.45	0.43
G274-CPN6	Bukit Jalil, Kuala Lumpur	Soil	2300	0.33	0.01
G405-CP13	Nusajaya, Johor	Soil	2500	2.33	0.09
G405-CP23	Nusajaya, Johor	Soil	2900	0.95	0.03
G405-CP1	Nusajaya, Johor	Rock (SD)	2500	1.69	0.07
G405-CP21	Nusajaya, Johor	Soil	2900	0.57	0.02
G405-CP36	Nusajaya, Johor	Soil	2500	0.52	0.02
G415-P13	Cheras, Kuala Lumpur	Rock (GN)	2000	6.53	0.33
G445-CP48	Wangsa Maju, Kuala Lumpur	Soil	3350	16.48	0.49
G481-CP17	Kuchai Lama, Kuala Lumpur	Soil	1300	0.65	0.05
G493-PCS1 <sup>(4)</sup>	Cheras, Kuala Lumpur	Rock (LM)	1000	0.63	0.06
G500-CP17	Genting Highlands, Pahang	Rock (GN)	2900	11.63	0.40
G500-CP30	Genting Highlands, Pahang	Rock (GN)	3100	7.97	0.26
G500-CP35	Genting Highlands, Pahang	Rock (GN)	3300	7.42	0.22
G500-CP49	Genting Highlands, Pahang	Rock (GN)	2900	2.20	0.08
G549-CP99	Genting Highlands, Pahang	Rock (GN)	3300	3.29	0.10

Notes: -

<sup>(1)</sup> SD = Sandstone, GN = Granite, LM = Limestone.

<sup>(2)</sup>  $D$  denotes as diameter of caisson test segment.

<sup>(3)</sup>  $\delta$  denotes as maximum movement of test segment at maximum test load.

<sup>(4)</sup> Modified top-loaded set-up was adopted for G493-PCS1.

From the tabulated caisson shaft load test results, it is observed that the maximum movement of test segment is in the range of 0.5mm to 16.5mm. This is translated to 0.01% to 0.49% of test segment diameter. The upper bound of test segment displacement is noticed for shaft load test in soil scenario, namely G065-CP55 and G445-CP48. All the test results are deemed satisfactory as all are within 1% pile diameter, which is the recommended pile-soil relative displacement for fully mobilized shaft resistance of replacement piles, as reported in Geo Publication No.1 (2006).

#### 4 CAISSON PLATE BEARING LOAD TEST

Small-scaled caisson plate bearing load test is generally conducted at the design founding depth to verify the bearing capacity of soil/ rock using bearing plate of certain sizes which can be square or circular. The reaction system required to exert test load onto the pile base is provided by the shaft resistance of caisson linings via steel I-beam(s). A typical caisson plate bearing load test set-up is shown in Fig. 10. The maximum test load of caisson plate bearing load test is determined using Eq. 6.

$$\text{Maximum test load} = A \times f_{bu} \quad (6)$$

where  $A$  = base area of bearing plate

$f_{bu}$  = ultimate unit base resistance

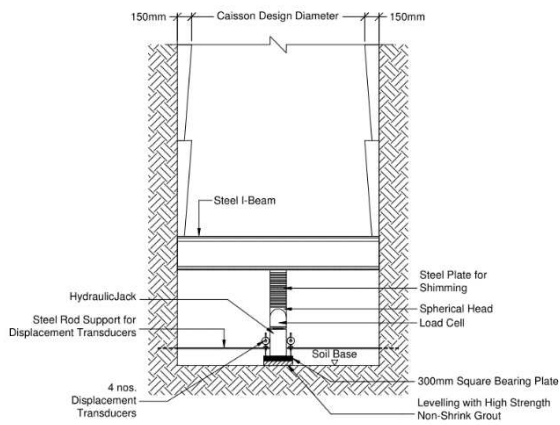


Figure 10. Typical set-up of caisson plate bearing load test

The steel I-beam for reaction system is designed as simply-support structure with a concentrated point load at middle of span. To optimize the beam design by reducing the effective span or due to limitation of beam length, a sacrificial reinforced concrete lining of certain thickness and height may be constructed (refer to Fig 11). The shortcoming of this modified set-up is the extra effort on removal of the sacrificial lining upon load test completion.

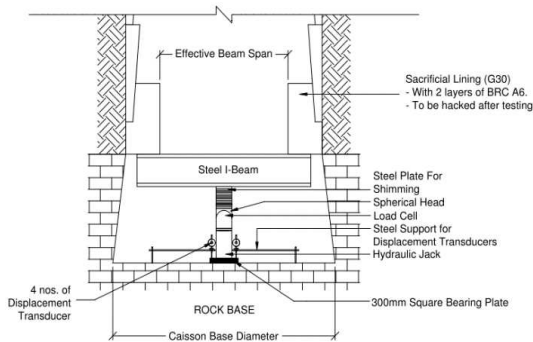


Figure 11. Modified caisson plate bearing load test set-up with sacrificial concrete lining

For hand-dug caisson pile with short pile length, the upper shaft resistance may be insufficient in providing reaction for the load test set-up. For this reason, the Authors had proposed an alternative load test set-up with reaction anchor using high tensile strength reinforcement bar (i.e. Freyssibar of Freyssinet, steel grade 1030MPa). The reinforcement bars were designed to anchor into bedrock through predrilled hole with suitable bonding agents or adhesives (refer to Fig. 12). To complete entire reaction system (Fig. 13a), the reinforcement bars were connected to the secondary I-beam using flat nut and washer of equivalent strength (refer to Fig. 13b).

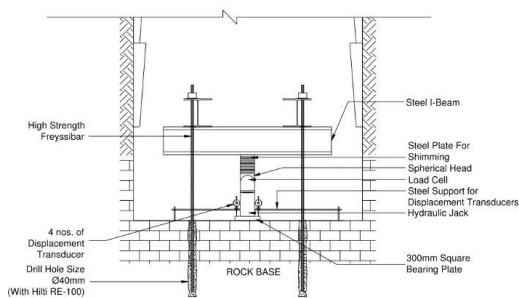


Figure 12. Modified caisson plate bearing load test set-up with reaction anchor



Figure 13a. Load test set-up inside hand-dug caisson



Figure 13b. Connection of reinforcement bar

The Authors summarize the caisson plate bearing load test results at several project sites, as shown in Table 2.

Table 2. Summary of caisson shaft load test results

Test Pile Ref.	Project Location	Test Material <sup>(1)</sup>	$D$ <sup>(2)</sup> (mm)	$\delta_M$ <sup>(3)</sup> (mm)	$\delta_c$ (mm)
G415-P13	Cheras, Kuala Lumpur	Rock (LM)	2300	2.22	6.75
G445-CP116	Wangsa Maju, Kuala Lumpur	Rock (SCH)	1300	24.53	61.77
G445-CP134	Wangsa Maju, Kuala Lumpur	Rock (SCH)	1800	1.96	5.55
G447-N89	Bdr Sri D'sara, Selangor	Rock (GN)	2300	0.25	0.76
G481-CP17	Kuchai Lama, Kuala Lumpur	Soil	1300	15.72	39.58
G500-CP11	Genting Highlands, Pahang	Rock (GN)	3300	1.25	4.11
G500-CP30	Genting Highlands, Pahang	Rock (GN)	3100	0.40	1.30
G500-CP35	Genting Highlands, Pahang	Rock (GN)	3300	0.56	1.84
G500-CP49	Genting Highlands, Pahang	Rock (GN)	2900	9.31	29.86
G500-CP50	Genting Highlands, Pahang	Rock (GN)	2900	0.50	1.60
G500-CP63	Genting Highlands, Pahang	Rock (GN)	3100	0.41	1.33
G501-CP2	Mont' Kiara, Kuala Lumpur	Rock (GN)	2500	0.70	2.17
G535-CP287	Ampang Permai, Selangor	Rock (GN)	2100	0.99	2.94
G542-CP6 <sup>(5)</sup>	Ctr Park D'sara, Selangor	Rock (GN)	2500	2.12	6.58
G543-CP1 <sup>(6)</sup>	Ctr Park D'sara, Selangor	Rock (GN)	2300	0.49	1.49
G549-CP97	Genting Highlands, Pahang	Rock (GN)	3900	1.64	5.55

Notes: -

<sup>(1)</sup> SCH = Schist, GN = Granite, LM = Limestone.

<sup>(2)</sup>  $D$  denotes as caisson pile base diameter.

<sup>(3)</sup>  $\delta_M$  denotes as measured maximum plate settlement at maximum test load.

<sup>(4)</sup>  $\delta_c$  denotes as calculated caisson pile settlement using Eq. 7.

<sup>(5)</sup> Modified set-up with reaction anchor adopted for G542-CP1 & G543-CP1.

<sup>(6)</sup> Square bearing plate of 300mm was adopted for all the tests above

The measured plate settlement from small-scaled plate bearing plate test is typically correlated to the estimated settlement for actual pile size using the empirical formula proposed by Terzaghi and Peck (1948), as indicated in Eq. 7.

$$\rho_f = \rho_B \times \left( \frac{2\beta_f}{\beta_f + \beta_B} \right)^2 \quad (7)$$

where  $\rho_f$  = settlement of foundation  
 $\rho_B$  = settlement of bearing plate  
 $\beta_f$  = foundation size  
 $\beta_B$  = bearing plate size

From the tabulated caisson plate bearing load test results, it is observed that the maximum plate settlement is in the range of 0.25mm to 24.53mm. Upon size correction using Eq. 7, the estimated caisson pile base settlement varies from 0.76mm to 61.77mm. All the test results are acceptable as all are well within 10% pile diameter, which is typical movement to mobilize base resistance of replacement piles (Geo Publication No.1, 2006). Higher base movement of more than 3% pile diameter is observed for G445-CP116 or G481-CP17, which are cases with soil or weak rock (i.e. Schist).

## 5 LIMITATIONS AND RECOMMENDATIONS

It is understood that the results obtained from small-scaled caisson verification load test such as shaft load test and plate bearing load test are not fully comparative to conventional full-scaled static load test in terms of behavior of testing element, mechanism of load test and the corresponding measurement. For these reasons, Eq. 7 is typically used to convert the measured readings from caisson plate bearing load test to a more realistic pile base settlement under the equivalent test load. Based on the Author's knowledge, there is no empirical formula to correlate the measured displacement from caisson shaft load test to actual pile behavior and further study in this subject is recommended. On the other hand, the Author suggests to adopt minimum four (4) numbers of hydraulic jack for 1.2m to 2m diameter of test lining and minimum six (6) numbers of hydraulic jack for larger than 2m diameter to ensure that the applied load to be distributed evenly around the test segment.

To verify the shape correction factor proposed by Terzaghi and Peck (1948), a comparison study was carried out between small-scaled plate bearing load test and full-scaled instrumented static load test using bi-directional load test system at project G542. Bi-directional static load test was conducted on a working test pile G542-CP7 with design pile diameter of 1800mm. As the sacrificial hydraulic jacks were placed directly on the caisson pile base, the resulting base settlement relative to the applied load was measured with certainty (refer to Fig. 14). Table 3 summarizes the applied test pressure and the corresponding pile base settlement for G542-CP7 as well as the estimated pile settlement of G542-CP6 using Eq. 7.

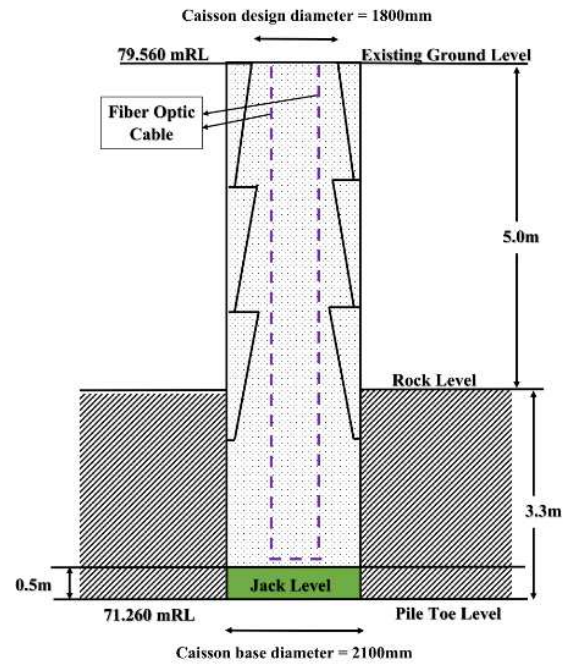


Figure 14. Test pile set-up for G542-CP7

Table 3. Summary of comparison study for G542-CP6 & G542-CP7

Applied Test Pressure (kPa)	Test Pile G542-CP7		Test Pile G542-CP6		Variance of $\delta_C/\delta_{BDLT}$ (%)
	$D^{(1)}$ (mm)	$\delta_{BDLT}^{(2)}$ (mm)	$\delta_P^{(3)}$ (mm)	$\delta_C^{(4)}$ (mm)	
5290	2100	1.25	0.48	1.42	+13.9%
6387		1.52	0.56	1.66	+9.6%
7483		2.23	0.63	1.87	-16.0%

Notes: -

(1)  $D$  denotes as caisson pile base diameter.

(2)  $\delta_{BDLT}$  denotes as caisson pile base settlement for bi-directional load test.

(3)  $\delta_P$  denotes as measured plate settlement for caisson plate bearing load test.

(4)  $\delta_C$  denotes as calculated pile settlement using Eq. 7.

(5) Pile base rock quality of G542-CP6 and G542-CP7 are assumed to be consistent

From the study above, it is discovered that the discrepancies between measured caisson pile base settlement from full scaled load test and calculated pile settlement from small-scaled load test are generally within 20%, with an average of less than 5%. This implies that the Eq. 7 is reasonable for derivation of estimated pile base settlement, based on the case study of this specific project.

The modified caisson plate bearing load test with reaction anchor(s) is only applicable for load test on competent rock base, typically Grade II rock or better. This is because there may be certain degrees of disturbance on the ground of soils or weak rocks (i.e. Sandstone, Schist) near to reaction anchor during load test. To verify the minimum ground disturbance for competent rock base, the Authors recommend to include additional displacement transducers in between the bearing plate and reaction anchors. The measured bearing plate settlement shall be corrected should there be any significant ground heave during load test.

## 6 CONCLUSIONS

Small-scaled caisson load test such as caisson shaft load test and plate bearing load test are alternative to replace the conventional static load test for pile performance verification due to several considerations namely steeply sloping terrain, difficult access or insufficient working platform.

The design set-up for small-scaled verification load tests of hand-dug caisson is neither typical nor standard provided the load test objectives are met. The Authors had introduced modification and improvement to the small-scaled load test set-ups after considering factors such as pile diameter, test load, testing level and ground condition.

The Authors acknowledge the limitations of small-scaled verification load tests in terms of behavior of testing element, mechanism of load test and the corresponding measurement, in comparison to conventional full-scaled static load test. The empirical formula Eq. 7 proposed by Terzaghi and Peck (1948) had been verified by the Author based on a project case study. The Authors suggest recommendation on improvement of existing load test set-up and further study on the caisson shaft load test results.

## 7 ACKNOWLEDGEMENTS

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