Load Carrying Capacity of Precast RC Driven Piles in Tropical Sri Lankan Terrain

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ABSTRACT: Until the implementation of the first ever expressway project in Sri Lanka, the adoption of driven piled foundation systems had been rare. Such systems with 400 mm square precast reinforced concrete piles were proposed for the bridge structures of the Expressway project. Tender designs had envisaged load carrying a capacity in the order of 600 kN for piles driven to specified set, while that in other tropical countries higher capacities had been permitted. A comprehensive study was thus carried out to establish the load carrying capacity of individual piles. Estimates of carrying capacity were first made by static method, dynamic formulae, and wave equation analyses. Accordingly, static pile load tests were performed on 4 test piles. Results indicated that the load carrying capacity of individual piles could be enhanced up to 1000 kN to 1200 kN, depending on length of piles under given subsurface conditions.

1 INTRODUCTION

Structural requirements and subsurface conditions along with economic considerations generally dictate the foundation type. Deep foundations are required where shallow foundations do not provide adequate support. Piles are long slender structural elements used as deep foundations and are generally classified by their material and/or by method of installation. Preformed piles are of timber, concrete, steel or a combination thereof and usually are forced into ground using pile driving hammers. Precast concrete piles are still widely used in foundation systems.

In Sri Lanka, evidence on experience and literature on precast concrete driven piles used as deep foundation elements in buildings and in other infrastructure development projects were quite rare until the implementation of the Southern Expressway Project. Tender designs of the Southern Expressway Project recommended the use of driven pile foundation systems for proposed bridge structures.

However, partly due to reasons stated above, conservative design loads of the order of 600 kN for individual piles of 400 mm square, were recommended where piles were driven to a specific set. On the contrary, under similar subsurface conditions encountered in tropical countries such as Singapore and Malaysia, similar individual driven piles had been attributed with higher load carrying capacities.

A study was therefore undertaken to establish the load carrying capacity of individual driven piles under local conditions. This paper presents the methodology adopted in establishing the carrying capacity of 400 mm square driven piles.

2 SOUTHERN EXPRESSWAY PROJECT

The Southern Expressway is the first expressway ever constructed in Sri Lanka, running along the southern coastal belt of the Island. It traverses from Kottawa to Godagama (Matara) (126 km) and is a dual expressway with provisions of additional two lanes. A future extension of the Southern Expressway is planned from Matara to Hambantota to link Mattala Airport and Hambantota Harbour to Colombo.

The Central Engineering Consultancy Bureau (CECB) carried out the detailed design of bridge structures (B1 to B23) of the expressway, for the stretch Kurundugahahetekma to Godagama. These consist of 23 bridges; 6 river crossings and 17 road crossings, which are underpasses to the expressway. The spans vary from 18 m to 40 m. Superstructures of these bridges consist of 200 mm thick reinforced concrete decks supported on post-tensioned bridge girders (standard AASHTO type III–VI) and a majority of substructures founded on 400 mm x 400 mm square pre-cast pile foundations. The total length of the bridges is approximately 1km.

Within the scope of the project, 4 ultimate pile load tests were proposed to establish load carrying capacities of foundation systems at 58 locations.

2.1 *Sub Surface Conditions at Bridges*

Sites for bridges had been investigated by the direct method of boring at every foundation location with standard penetration tests (SPT) carried out at one metre intervals starting from the existing ground level (EGL). Study of available borehole logs indicated that a wide range of materials, namely alluvial deposits, peat and organic clays, and lateritic formations had been encountered at bridge sites.

Alluvial deposits underlying the valley floors generally composed of loose clayey, silty sand and sandy silt with or without organic matter overlying lateritic formations or/and bedrock. Lateritic formations had been found on hillsides. Borings at hillsides had revealed that the weathering profiles encountered were similar to those derived from siliceous rocks. Lateritic overburden on such weathering profiles vary in thickness from about 6m to more than 36 m at some locations.

3 SELECTION OF TEST PILE LOCATIONS

Based on site investigations carried out, it was clear that the material strata were highly variable for different bridge locations. Existence of the bearing stratum appeared to be shallower at some locations while deeper at others affecting pile lengths to carry the required working load.

After a careful study of subsurface conditions pertaining to all foundation locations, 4 locations B1-A2, B3–P5, B18–A6, and B21–A2 were selected from available borehole logs representing driving conditions along the proposed stretch. Letters A and P identifies abutment and pier locations, respectively. Locations selected for test piles and a brief of profile variation and pile length are given in Table 1.

Soft soils at location B21-A2 is assumed to be replaced by a granular material with an effective angle of internal friction 30°.

4 LOAD BEARING CAPACITY ESTIMATION

Estimation of the load carrying capacities of driven test piles were carried out using Static Formula, Dynamic Formula and Wave Equation Analysis.

Table 1. Locations of Test Piles and Brief of Subsurface profiles

Location / Test Pile Length	Subsurface Condition		
	Layer	Depth (m)	Avg. SPT N
B1 A2 / 8m	Lateritic fill	0.0-2.0	07
	Very loose to loose silty sand	2.0-8.0	02~07
	Fresh charnokiticgneiss	>8.0	
B3 P5 / 18m	Firm ~ medium organic clay	0.0-10.3	04~07
	Medium dense silty sand with peat	10.3-16.0	12
	Very dense silty sand	16.0-17.0	>50
	Highly~slightly weathered rock	17.0-36.0	
B18A6 / 18m	Firm ~ stiff sandy silty clay	0.0-7.0	04~15
	Very stiff to hard sandy silt	7.0-16.0	20~45
	Hard sandy silt	16.0-33.0	>50
	Highly ~ slightly weathered rock	33.0-38.0	
B21A2 / 12.5m	Very loose clayey sand	0.0-2.0	00~02
	Loose clayey sand	2.0-12.0	05~08
	Very dense clayey sand	12.0-12.5	>50
	Fresh hornblende biotite gneiss	>12.5	

4.1 *Static Method*

The ultimate load capacity of a pile, P_u is given by;

$P_u = P_{pu} + P_{su}$ Where,

P_{pu} is the ultimate pile tip capacity; P_{su} is the ultimate skin resistance capacity

Depending on the availability of data obtained from direct method of boring and SPT, P_{pu} and P_{su} are estimated using the following correlations by Meyerhof (1956, 1976).

4.1.1 *Estimation of P_{pu}*

$$P_{pu} = A_p(40N_p)\frac{L_b}{B} \leq A_p(380N_p)$$

Where,

A_p is the net sectional area of toe; L_b is the pile penetration depth into point-bearing stratum; B is the width of the pile; N_p is the statistical average of standard penetration test numbers in the zone of about 8B above to 3B below the pile point.

For piles driven into non-plastic silts, in the above formula, an upper limit of $380N_p$ is taken as appropriate.

Having chosen B=0.4 m, for L_b> 4 m the upper limit was applicable as P_{pu}

P_{pu}= A_p (380N_p)

4.1.2 *Estimation of* P_{su}

P_{su}= A_s (2N_s)

Where,

A_s is the gross surface area of pile shaft; N_s is the average standard penetration test number over the pile length.
Hence,

P_u= A_p (380N_p) +A_s (2N_s)

Allowable load carrying capacity, P_a is obtained by adopting a factor of safety of 3.

P_a= P_u/3

4.2 *Dynamic Formula*

The ultimate pile capacity of the 400mm x 400mm square piles was determined using the Pile Driving formula which is a modified form of Gates (1957) formula,

$$R_u = 7E^{1/2}\log(10N) - 550 : E = Wh$$

Where,
W is the weight of ram (N); h is the Stroke (m); N is the number of hammer blows per 25 mm at final penetration.

This is a widely adopted method mainly because of its simplicity. However, it suffers from the crude assumptions based on which it had been formulated, such as
i. Wave propagation through the pile is completely neglected and it is assumed that the pile is a rigid body
ii. Dynamic capacity during driving is assumed to be equal to the static capacity under service conditions, completely neglecting the damping resistance during driving
iii. Change in the soil strength with after driving is not taken into account.

4.3 *Wave Equation Method*

The wave equation method considers the wave propagation through a pile due to the applied hammer blow. In this project, estimation of ultimate load capacity using the dynamic approach is in association with the K35 open end diesel pile hammer and implemented in the MICROWAVE computer program developed by the Texas A&M University (1993).

This computer solution is used to estimate the driving stresses induced in the pile and to determine the resulting motion of the pile during the impact and the resistance to penetration afforded by the soil at the time of driving. This is based on idealizing the actual pile driving system as a series of concentrated weights and springs. In this analysis, the pile is divided into number of elements and the mass of each element connected by pile springs is lumped at nodal points.

In idealizing the behavior of the cap block and cushion, properties of canvas/plastic based material and Rubber wood, respectively, were used in order to comply with the specification. Element numbers 1, 2, and 3 in the analysis, are assigned to specify the hammer, anvil, and helmet, respectively. The first pile element in all the cases would be the 4th element.

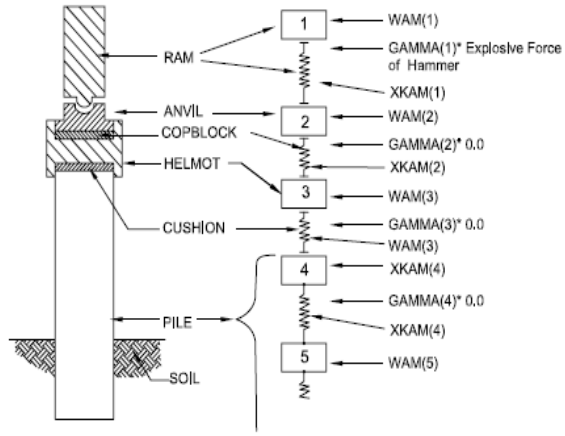

Fig.1 Pile Idealization for Wave Equation Analysis

The ram and helmet are assumed to be rigid concentrated masses between which a spring is inserted to represent the elasticity of the cushion. The pile is idealized as a similar series of concentrated weights and weightless springs. The idealization includes a simulation of the soil medium as well as the pile driver and pile. The pile hammer and pile idealized as a system of concentrated weights connected by weightless springs. The springs represent the stiffness of the pile, cushion and in some cases, the pile driver's ram. The soil medium is assumed to be weightless, i.e., the pile moves through the soil and does not move the adjacent soil mass, and is simulated by a spring and damper (dashpot) on each pile segment whose real counterpart is embedded in the soil.

Temporary stresses developed during driving are listed in the output of the computer program. During analyses, total stroke of the pile driver is increased in steps and the resulting compressive and tensile stresses induced by driving are compared with the maximum allowable resistance offered by pile material in compression and in tension as given by the following equations.

Maximum allowable compressive stress = $0.67\ f_{cu} + f_y A_{sc}/A_c$

Maximum allowable tensile stress = $f_y A_{sc}/A_c$

Where,

f_{cu} is the characteristic strength of concrete; f_y is the characteristic strength of concrete; A_c is the net cross-sectional area in a pile; A_{sc} is the area of vertical reinforcement.

The maximum adoptable total stroke obtained by the above process is then utilized to plot the load capacity versus set. The ultimate load capacity corresponding to a set of 1.67 mm (15 hammer blows per 25 mm) as given in project specification is then read off from the curve.

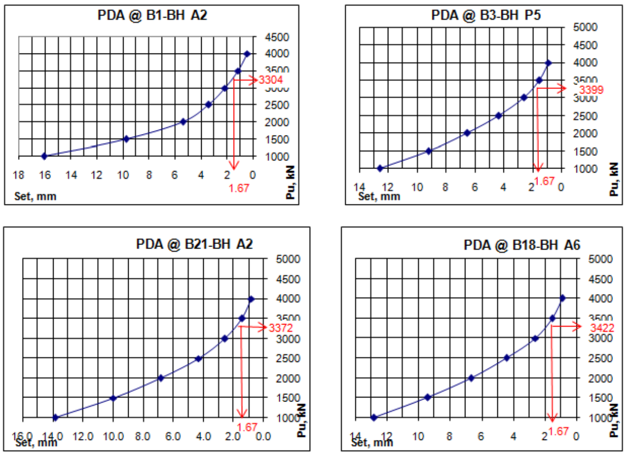

Fig. 2 Load capacity vs set graphs

Allowable load carrying capacities of individual piles obtained from the different approaches are summarized in Table 2.

Approach	Allow. Load Carrying Capacity (kN)
Static Method	1000~1500
Dynamic Formula	850
Wave Equation Method	1100~1150
Structural Capacity (Working stress concept ;$s_{cc}A_c + s_{sc}As_c$) ($s_{cc} = 0.25f_{cu}$; $s_{sc} = 0.42f_y$)	1700

Table 2. Allowable Load Carrying Capacities from Different Approaches

5 LOAD TESTING

As the most reliable means of assessing the load carrying capacity piles, Maintained Static Load Tests were carried out on piles driven at the 4 selected locations. The tests were carried out generally in accordance with ASTM D1143, Standard Test Method for Pile under Static Axial Compression with 3 or 4 load cycles as allowed. For all test piles, 1.0 the working load was adopted as 1200 kN based on the above estimations.

Individual pile capacities witnessed by the Static Load Test were in the range 1000 to 1500 kN for short to long piles as shown in Table 3.

Location	Allow. Load carrying Capacity (kN)
B1 A2	1200
B3 P5	1500
B18A6	1425
B21A2	1000

6 ESTIMATED VS TESTED CAPACITIES

The allowable loads as obtained from the dynamic formula are the lowest estimated. Compared to the static pile load test results these values are significantly low. The capacities estimated by static method though comparable with the static load test results for the piles driven at Bridges B1, B3, and B18 but over estimated the value for the pile at Bridge B21. Those estimated by Wave Equation Analysis varies in the range of 1100 to 1150 kN. Based on the above results, a load of 1000 kN was decided to be attributed for piles less than 15 m and 1200 kN for piles with lengths more than that reasonably.

7 CONCLUSIONS

Precast driven piles had been proposed for the bridge structures of Southern Expressway. Based on a comprehensive study, it was concluded that the carrying capacity of a 400 mm square pile driven to specified set could be enhanced up to 1000 kN to 1200 kN, depending on the length of pile, for a given subsurface condition.

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REFERENCES

Meyerhof, G. G. (1976), "Bearing Capacity and Settlement of Pile Foundations," JGED, ASCE, vol.102, GT 3, March, pp. 195-228 (Terzaghi Lecture).

Gates, M. (1957). "Empirical Formula for predicting pile bearing capacity." Civil Engineering, (27(3) 65-66.

Texas A&M University, Department of Civil Engineering (1993), Software Manual, “Pile Driving Analysis by the Wave Equation”.