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Unsatisfactory Behavior of Bored Cast In-situ Piles During Testing – Ignorance or Negligence!

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Abstract. A large diameter bored cast in-situ pile did not perform satisfactorily during the initial vertical load test conducted recently at a turnkey project site in the northern India. Geotechnical investigation, design of piles and installation of piles were in the scope of the contractor, even then the test pile settled more than the permissible limit. Such incidents raise a question, whether that behavior was due to negligence of the piling team or ignorance on their part. A pile may fail during load testing due to one or more reasons. However, workmanship and supervision are of prime importance, because, even theoretically very well designed pile may not perform satisfactorily if the construction/ workmanship is of poor quality.

The paper presents problems faced in construction of bored cast in-situ piles at a project site, its probable causes and how the issues were resolved. It deliberates on the various steps of installation of a bored cast in-situ pile and what may go wrong at each step. Practical solutions implemented, guidelines issued for good workmanship and proper supervision in installation and testing of piles, have also been discussed. It may give some insight to novice academicians as well as practicing engineers.

Keywords: Bored Cast In-situ Pile; Capacity, Testing; Satisfactory; Workmanship; Installation, Rig, Slurry, Initial Load Test.

1 Introduction

A successful pile load test provides assurance of satisfactory behavior of untested job piles on safer side. Initial pile load test is performed for one or more of the purposes, such as, to prove the suitability of the piling methodology, quality of workmanship of the execution team, to confirm the design parameters inferred from the geotechnical investigation, to determine ultimate load carrying capacity and to find out relative magnitudes of shaft and end bearing resistance in case of cyclic initial vertical load test. Generally, the test pile shall represent the working pile to be installed, in all respect, because even a small variation in construction procedure and workmanship may lead to inconsistent effects on the behavior of the pile.

Recently, the authors came to know about unsatisfactory behavior of a large diameter bored cast in-situ pile during initial vertical load test conducted at a project site in the northern India. Site investigation, design of piles and off course construction of both test piles and working piles are a part of the scope of the contractor. Thus, obtaining all the information including geotechnical investigation data, necessary for the construction of pile foundation; are in the scope of the contractor. However, it is learnt that the initial vertical load test pile settled more than the permissible limit during testing; raising the question, whether such a behavior of pile was due to negligence that is, failure in selecting proper design parameters, pile installation technique, or was it due to ignorance that is lack of knowledge/ information regarding soil characteristics, proper workmanship?

A pile may not perform satisfactorily (may fail) during load testing due to one or more reasons. Geotechnical investigation data may not be accurate or may be erroneous, incorrect design calculation of load carrying capacity of pile, poor workmanship during installation of pile, bad quality of construction and very remotely there may be a chance of vested interest in failing of the test pile. As the installed pile can rarely be inspected later on for any defects, it requires considerable experience in design, in choosing correct soil parameters and specialized skills of piling team and reliable workmanship in construction of pile foundation. Behavior of piles in the ground and subjected to loading is dependent not only on the physical properties of the soil and the pile but also on type of pile and the method of installation of pile. In case of failure, the design team may blame the construction team and vice versa. However, workmanship and supervision are of prime importance, because, even theoretically very well designed pile may not perform satisfactorily if the construction/ workmanship is of poor quality.

2 Case Study of a Project Site

Sub-surface soil condition met with at a thermal power project site located in the Indo-Gangetic Plain in the state of Uttar Pradesh; essentially consists of silty sand followed by silt with occasional clay content, generally in a dense state having SPT 'N' value greater than 30 beyond 15m depth below ground level. Ground water table was met with at about 2m below ground level at the time of investigation. Installation of bored cast in-situ piles using crawler mounted rotary hydraulic drilling rig was adopted because large diameter bored piles have higher capacity, resulting in less number of piles. As per contract, length of 760mm diameter pile below cut-off level (COL) and corresponding safe vertical capacity were 27m and 250MT respectively. However, as per the result of the first Initial Vertical Load Test on 760mm diameter, 27m long pile, safe vertical load capacity achieved was about 150MT as against the rated capacity of 250MT (Fig. 1, 'Initial LT 760(27m)'). Pending successful completion of test pile, the contractor had proceeded for installation of working pile at his own risk and cost. In view of shortfall in the capacity of above initial vertical test pile, a routine vertical load test on job pile was conducted and the observed load settlement data of routine load test is shown in Fig. 1 (‘Routine’), which gave only about 140MT safe capacity as against design capacity of 250MT.

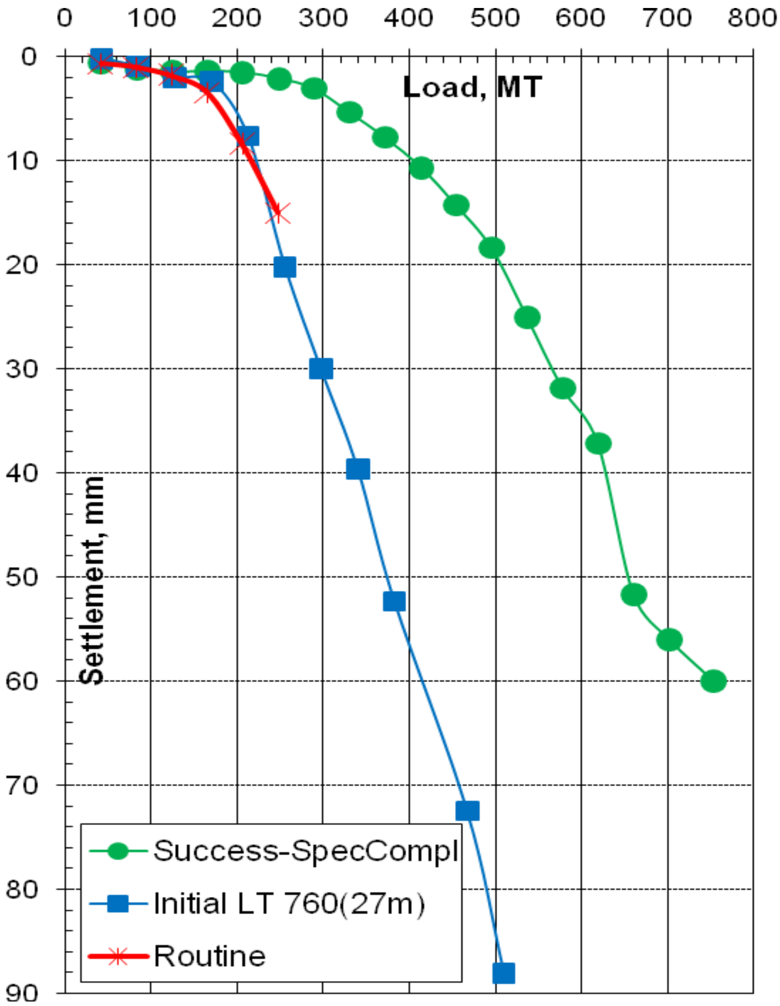

Fig. 1. Load-settlement graph of initial/ routine vertical load tests on 760mm dia. pile

So the very first initial vertical load test on 760mm diameter pile did not give the desired capacity. Scrutiny of the pile installation record revealed that it had not met following requirements of the technical specification,

(a) Time gap between end of boring and start of placing of concrete exceeded specified 6 hours and took 13 hours for start of concreting and 5 hours 50 minutes for completion of concreting.

(b) SPT at termination level of pile (27m below COL) was not done, however, at 23m depth in one of the nearby group of piles was done and it was recorded as 27. Thus, SPT 'N' value greater than 50 at termination level, as required by the specification, was probably not available.

(c) Flushing of pile bore with airlift technique to remove loose muck was not carried out after lowering of reinforcement cage, i.e., two stage flushing was not done.

Subsequently, the complete methodology of pile installation was witnessed to assess the experience and workmanship of the piling team engaged so as to find out the probable reasons of unsatisfactory performance of above test pile and following deficiencies were observed,

(a) Continuous circulation of bentonite slurry was not maintained.

(b) When Kelly of piling rig was withdrawn, the level of slurry in the pile bore, used to get dropped, although specification required that the slurry level shall be 1.5m above the ground water level or up to the top of casing pipe, whichever is higher during the boring operations.

(c) Presence of very thick slurry (density = 16 kN/m^3) at bottom of bore.

(d) Lowering and withdrawal of bucket rapidly without rotation of Kelly, leading to suction effect in the pile bore while withdrawing the bucket.

(e) Considerable time gap between end of boring and start of concreting (13 hours), resulting in loosening of soil on the surface of pile bore due to stress release.

(f) Airlift flushing operation was not effective due to inadequate capacity of compressor deployed and that too only single stage, leading to accumulation of muck, debris at bottom of pile bore.

Another test pile of 760mm diameter, 27m length was installed meeting the specification requirement in the nearby area. The SPT 'N' value observed at the termination level was 104 (more than 50), two stage flushing of the pile bore with air lift technique was carried out after lowering the reinforcement cage and second just before start of concreting. The time gap between completion of pile boring and start of concreting was less than 6 hours including conducting SPT at termination level in pile bore. Concreting was completed in one hour ten minutes. Density of fresh bentonite slurry was 10.6 kN/m^3 and that of contaminated slurry was 11.5 kN/m^3. The initial vertical load test on this pile gave a safe vertical capacity of 280MT. Load settlement graph for this test is also shown in Fig. 1 ('Success-SpecCompl') to compare with the first Initial Vertical Load Test and Routine Vertical Load Test results.

Installation and testing of second vertical load test pile was witnessed by the design team not only to ensure compliance of various provisions of the technical specification but also to elicit the best effort from the piling gang and the quality team. Sucessful performance of the second test pile made the authors to believe that earlier tested piles did not perform satisfactorily due to negligence of the piling team in not circulating the bentonite slurry continuously resulting in presence of thick slurry at the pile bottom, keeping considerably high time gap than permissible in the specification between end of boring and start of concreting, taking longer time in concreting and flushing the pile bore only once. On the other hand, ignorance was evident in the way air flushing was carried out and the way in which cutting tool/ bucket was withdrawn. The GI pipe used for air inlet (for flushing bentonite slurry) was simply lowered straight inside the tremie pipe, which might be resting on the pile bore bottom and loosening the bottom of pile bore by air jet action. During installation of second test pile, the air flushing arrangement was got modified. The air pipe was kept as close as possible to bottom of pile bore (about 400mm above) and connected at right angle (a ‘J’ type metal pipe welded with the bottom segment of tremie pipe) to tremie pipe at bottom from outside the tremie pipe. Flushing took place due to the jetting action of air in the upward direction through the tremie pipe. The compressed air flushed the relatively thick slurry column upwards, creating suction at pile bottom, which resulted in rushing of fresh bentonite slurry from top. Operation was continued for about 20 minutes until desired density of slurry was achieved. The rig operator was advised to rotate and withdraw slowly the cutting tool/ bucket to prevent suction due to piston action.

2.1 Interpretation of Load-Settlement Curves

When the test pile is loaded, initially the pile-soil system behaves elastically and a straight-line relationship between load and settlement is observed up to a certain point on the curve. As can be seen, curve of successful test, relatively flattens (mild slope) with increase in load and separates from other two test curves. With further increase in load, yielding at pile-soil interface takes place; full skin friction is mobilized and the curve bends downwards (steep slope). As the load on pile increases, contribution of skin friction and end bearing in resisting the load also increase. Initially, major portion of the applied load is resisted by the skin friction mobilized (generally flat portion of the curve) and end bearing just picks up. Once, almost full skin friction has been realized, contribution of end bearing increases. However, in case of first initial load test, as soon as the increased load reached towards tip of pile, the anticipated resistance by end bearing did not materialize and hence very less resistance to the pile tip movement. As the end bearing is not being actualized to the expected level due to low tip resistance, there is a large settlement of pile tip, simulating something like plunging of pile, which may be due to presence of soft muck/ debris at the base.

The above issue of unsatisfactory behavior of test pile was discussed with the piling experts, both practitioners and academicians with reference to soil condition, type of pile adopted, methodology of construction, workmanship, bentonite slurry properties and theoretical estimate of load carrying capacity of pile. Learnings have been formulated in comprehensive Dos & Don’ts, not only for piling work but also for pile testing. Knowledge/ experience thus gained have been shared at subsequent projects, highlighting the importance of workmanship, which plays an important role in realizing the safe load carrying capacity of pile apart from expertise/ experience of personnel involved.

3 Problems Likely to be Faced and Troubleshooting

Bored cast in-situ piles have several advantages over other types of pile and hence most prevalent in India. Due to its high capacity, large diameter, long length, care is necessary at all stages of design and construction, particularly, in workmanship and supervision. With the use of rotary hydraulic piling rigs, piles are generally installed at a faster pace and as accurately vertical as possible. However, deviation with respect to position and alignment shall be within the permissible limits specified in IS 2911. For deviation in position more than the permissible limit, design of pile groups shall be revisited to check adequacy of the group. The guide casing may get tilted during boring/ drilling due to hitting of bottom of casing by bucket/ cutting tool while withdrawing. This requires careful withdrawal of the tool and also a gap of about 75mm between outer surface of the tool/ bucket and inner surface of the guide casing to be maintained. As the boring operation progresses through soil deposits, the sides of the pile bore may collapse/ cave-in causing necking in pile shaft. In some cases there may be over breaking leading to bulging of pile shaft. If these problems occur at shallower depths then it can be overcome by using temporary guide casing of adequate length. However, in case of medium to loose cohesionless soil and if it requires to be bored below ground water level; then temporary liner for the full depth of such deposit would be required and such liner needs to be driven by a vibro hammer.

Mostly, bentonite based drilling mud is used for stabilizing the sides of pile bore. The bentonite slurry shall be maintained at least 1.5m above the ground water level or upto the top of guide casing pipe whichever is higher; during complete boring operations. The slurry shall be under constant circulation until start of concreting. Density of fresh and contaminated slurry shall be checked regularly. Excessive contamination of the slurry would make it more viscous and rapid withdrawal of bucket may create suction effect and local collapse of the pile bore may occur. Thus, check on the density/ viscosity of the slurry shall be enforced to avoid such problems and the drilling tool/ bucket shall be withdrawn slowly while rotating as well. Cleaning of the pile bore base shall be carried out effectively and final cleaning to be carried out shortly before concreting. Suitable capacity of compressor shall be deployed to carry out air flushing. Two stage flushing of slurry using airlift technique, after completion of boring and after placement of reinforcement cage; shall be carried out to ensure that the pile base is completely free from sludge/ debris/ bored material which may be fine sand and silt suspended in the slurry and gradually settled at the pile base. Some designers, factor the contribution of end bearing in the load carrying capacity of pile, particularly in granular soils wherein loosening of the base is almost impossible to avoid even when bentonite slurry is used as supporting measure. The reinforcement cage shall be lowered vertically in the pile bore by using two hooks to avoid tilting. Reinforcement cage if got tilted while lowering, then it will scratch the sides of the pile bore. Hanger bars shall be used/ welded with reinforcement cage of pile to maintain cut-off level. Bars of the cage shall be bent in ‘L’ shape at bottom; if the cage is congested then alternate bars may be bent to permit flow of concrete. Concreting of pile bore shall be a continuous process and completed without any break. A surge concrete of about 1.0 to 1.5 m^3 shall be done in the first pour so as to displace completely the sludge/ muck/ debris from the bottom of the pile bore. Tremie pipe shall always remain lowered into the green concrete during complete concreting process. Piles shall be concreted as soon after completion of boring as possible but concreting shall start within 6 hours of completion of boring. If concreting is delayed, then the sides of the pile bore may be softened, even if slurry is being circulated continuously. Softening of sides may result in lowering of skin friction and in some cases; the softened sides may slump in to the pile bore.

Primarily, the initial load test on pile is specified to ascertain the design capacity of the pile and hence to get assurance that the workmanship so adopted for construction of piles would meet the requirements of the specification. Lack of understanding and improper procedure of conducting a test may lead to various problems. Apart from safety aspects, Dos & Don'ts mainly focused on relative position of vertical, lateral and uplift initial test piles; valid calibration certificates of pressure gauge and LVDTs, adequate capacity and numbers of jacks, maximum test load, stability of kentleadge, testing at cut-off level or otherwise, load increment, waiting time at each step of loading, recording of readings, etc. In case, settlement of pile head increases and reaches to the upper range of the LVDT (Linear Variable Differential Transducer), then LVDTs need to be reset to zero by inserting steel plate on top of the pile head. Initial cyclic vertical load test if carried out as per the stipulations of IS 2911 (Part-4), then it takes more than 4 days to complete the test and hence supervision to be done on continuous basis. A successful pile load test may help in further improvement of the pile design and construction methodology.

4 Conclusions

Use of crawler mounted rotary hydraulic drilling rigs for installation of bored cast in-situ piles, has not only reduced the project construction time but also resulted in superior quality of piles installed. Behavior of a pile subjected to loading depends not only on the properties of the surrounding soil strata but also on the methodology of installation, workmanship and quality of construction.

Through case history presented here, authors are of the opinion that the unsatisfactory behavior of the pile was primarily due to failure of the piling team to exercise the standard practice and workmanship needed for installation of bored cast in-situ piles and also the piling team ignored compliance to some of the requirements of the technical specification. Experience of piling foreman, specialized skills of piling gang plays an important role in delivering projects faster, better and at optimized cost. At the most, we may allow mixed members in the gang, that is, more number of persons with experience in bored cast in-situ piling work and less number of persons with no or hardly any piling experience. When gang/team without any piling work experience is deployed, then it may be used as a testing ground and the owner may have to pay a heavy price for their training and also time will be lost resulting in delay in completion of the project.

Learnings/ findings from this project have been shared with the site engineers at various projects emphasizing the importance of experience, skills of the persons involved to achieve workmanship, quality checks to be carried out and overall strict compliance with the specification requirements to avoid recurrence of such type of problem. It is felt that the discussion in previous paragraphs regarding practical solutions implemented, guidelines issued for good workmanship and proper supervision in installation and testing of piles, may give some insight to novice academicians as well as practicing engineers.

Construction of piles is a specialized activity and demands very high level of skills and experience from the piling agency. Ignorance or negligence by the persons involved may result in various problems; affecting the quality, cost and time schedule of the project. Even with advancement in design engineering, piling installation techniques, machines, methods adopted and testing; skill, experience and judgment of individuals play important role in the successful behavior of a pile under loading.

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