Continuous Flight Auger (CFA) Piles

Economical Foundation Solution for Infrastructure Projects in India

Deep Foundations Institute of India, 2020

July 2020

Documents related to DFI India CFA Pile Trial Project

Deep Foundations Institute of India with the technical help from its parent body DFI USA, executed a CFA Piles trial project spanning from November 2017 to November 2019. The programme was successful with the help of several industry partners directly involved in the foundation construction industry.

The detailed documentation of this important project is available in the following guideline manual and the supplementary reports namely,

1. Document No.: DFII/CFA/G/4/R0 – April 2020,
   Guidelines for Design and Construction of Continuous Flight Augered Concrete Pile
2. Document No.: DFII/CFA/D&C/1/R3 – 15 January 2019,
   Document for Pile Design & Construction by Continuous Flight Auger (CFA) –
   A Technology Initiative by DFI of India
3. Document No.: DFII/CFA/PIR/2/R0 – 30 May 2019,
   Continuous Flight Auger (CFA) Trial Pile Installation Report at NPCIL Site, Gorakhpur,
   Haryana, Date of Trials: 27 – 30 MAY 2019
4. Document No.: DFII/CFA/LTR/3/R0 -November 2019,
   Compendium of Load Test Reports on Continuous Flight Auger (CFA) Trial Piles - Location:
   Gorakhpur, Haryana

The guidelines manual provides, in detail, the design process involved for both cohesive and cohesionless soils. As an added benefit to the user, a step-by-step design example is also provided in one of the Annexures. Specifications for materials of construction, viz., concrete, grout, reinforcement are provided in fluent engineering details. The equipment and accessories required for the construction of a CFA pile and the procedures of pile installation and quality control are comprehensively covered. Quality assurance such as load testing, integrity testing and pile instrumentation are also covered. CFA piling is one type of a cast-in-situ concrete pile that all other aspects, viz., integrity and load testing are very similar to that of bored cast-in-situ piles. The manual provides references to the various codes and other standard publications for load and integrity testing, materials and relevant influencing factors.

The supplementary documents provide in-depth details of every aspect of the design, implementation and testing of CFA piles as experienced in the trial project.

For copies (digital) of the above documents and for more details contact

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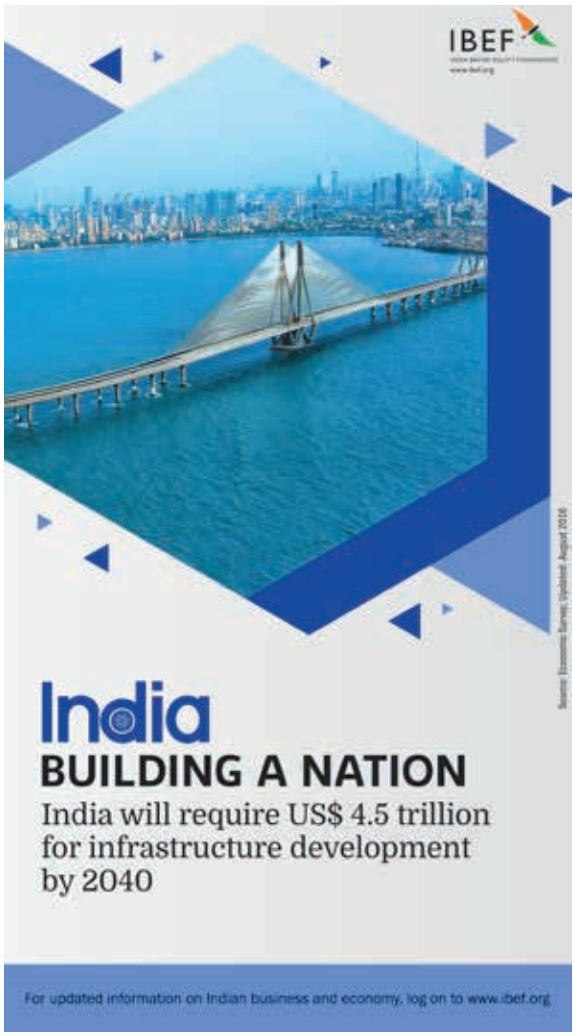
Infrastructure Growth in India

India has now set its sight on becoming a 5 Trillion US Dollar economy, and towards accomplishing this milestone, the government of India has announced plans to invest around INR 10 million crores in infrastructure projects in the next five years. Most of the infrastructure development involves the creation of the physical infrastructure, which means a great scope for the Civil Engineering and Construction industry.

The global experience suggests that the construction projects that do not complete the foundations on schedule end up in major cost escalations and time delays. Key factors, namely, technologies, modern equipment, and skilled workforce in foundation construction, play a significant role in the faster and safer completion of a project. India needs to travel further to instil these key factors in the infrastructure projects to embrace the expected goals of its development.

A speedy and safe foundation construction needs advanced technologies and modern equipment other than those being now practised or used in India. Often, economical foundation systems being practised outside India using modern equipment and technologies are not encouraged here for want of a specified design and construction practice suiting to India. Continuous Flight Auger (CFA) Pile Technology is one of such foundation systems that has a great potential to improve the speed of foundation construction in India. The construction procedure of CFA piles being different from bored cast-in-situ piles and driven piles, the existing Indian Standard codes in their current edition do not cover CFA piles.

For historical reasons, bored cast-in-situ piles are the most common deep foundation type in India. As a result, most of the modern foundation equipment in India belong to this category. CFA piles can also be installed using similar modern bored piling equipment but with minor modifications/ changes of accessories. The use of CFA piles would result in significantly increased pile installation productivity compared to that of bored piles.



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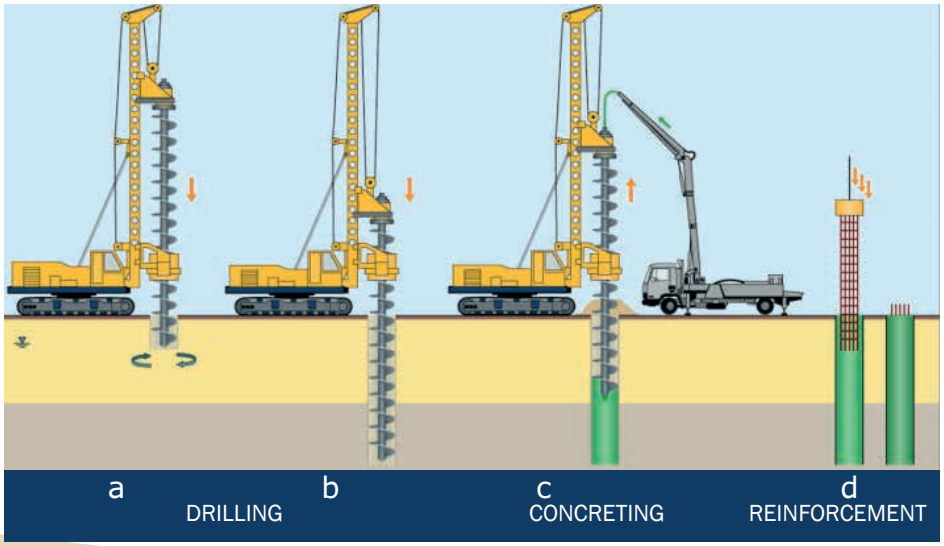
https://www.ibef.org

What is Continuous Flight Auger (CFA) Pile?

Continuous Flight Augers (CFA) piles are cast-in-situ piles, where a hollow-stem continuous flight auger is rotated and pushed into the ground at a controlled speed to the specified pile depth. Concrete or grout is then continuously pumped under positive pressure through the hollow stem of the auger to fill the borehole as the auger is withdrawn. Once the auger is completely extracted from the borehole, the reinforcing cage is lowered into the fresh concrete or grout to the designed depth. Normally the reinforcement cage moves down through the concrete or grout by its self-weight provided the consistency of the concrete or grout is designed appropriately.

1. CFA piling consists of a continuous process of boring to a final depth using a single and full-length auger (a). While boring, the auger flights are filled up with soil, and lateral support is provided to the hole (b).
2. The concrete/ grout is pumped into the hole through the hollow auger stem to the base of the auger while withdrawing the auger from the hole, (c). Pile bore stability is provided by concrete at the bottom and soil-filled auger above. The auger is either rotated in the same direction as during the drilling process or extracted without rotations. Under no circumstances, the auger should be rotated in the opposite direction than during penetration during the extraction process. The grout/concrete level shall be maintained below the bottom of the auger during withdrawal to maintain consistent grout/concrete filling.
3. Concrete pressure shall be monitored and shall never be negative. The latter could indicate that the auger tip was lifted out of the concrete which might cause hole collapses. If the auger is lifted out of the fresh concrete, concrete placement must be suspended, and the pile has to be re-drilled.
4. Concrete must be poured to working platform level to ensure borehole stability. Maximum of 300mm of fresh concrete can be scooped out prior to cage installation.
5. The reinforcement cage is lowered into wet concrete/grout filled hole immediately after withdrawal of the auger (d).

The diameter of CFA piles generally varies from 0.4m to 0.9m with lengths up to 25m. Modern rigs can have diameters up to 1.5m and reach depth up to 30-50m (but hose are special cases)



Schematic of the
CFA Pile installation sequence
Courtesy: Keller

Productivity and Application of CFA Pile

The high production rate of CFA piling can make the method very economical. The installation is vibration free, and careful construction reduces the lateral stress relief associated with bored piles. The most significant distinction to conventional bored piles using Kelly bars is that the CFA pile does not create an open excavation. Compared to the conventional bored cast-in-situ piles, the depth and diameters of CFA piles are limited. The construction of CFA piles in water-saturated or unstable soils is possible without any additional measures like casings or drilling fluid to keep the excavation stable. The installation parameters need to be monitored and controlled correctly so that over-excavation is avoided.

Close control of the installation process is essential to ensure the highest quality CFA pile construction. Instrumentation that monitors all aspects of CFA piling, including pile depth, auger rotation, penetration rate, concreting pressure, concrete volume, extraction rate and concrete consumption is essential for the economical and safe construction of CFA piles.

The CFA piles can be used in most applications, including earth retention works. Large diameter CFA piles are now being constructed in different parts of the world. The immediate application in India for moderate to heavy load conditions is possible because, in India moderate to large size piling rigs such as Bauer BG25, 28, 30, etc., and Soilmec SR60, 70, 100 are readily available.

- ◊ CFA piles are effective in providing structural support for a range of structures.
- ◊ Prevention of landslides or protection of existing buildings using CFA piles combined with other techniques such as ground anchors or soil nails has been successful.
- ◊ Contiguous piles or secant pile walls can be constructed using CFA piles.
- ◊ Other infrastructure projects such as tunnelling, road or bridge construction as well as flood protection could also utilize CFA piling solutions.
- ◊ CFA piles have been used successfully in the implementation of pile assisted rafts.

CFA Piles (secant pile wall) for earth retention application and guide wall for CFA piles, Ref: Martin D. Larisch

The production rate of CFA piles can be significantly higher than for rotary bored piles installed with temporary casings or under drilling support fluids. It has been reported that production rates could be 3 to 4 times higher, subject to project specific details and limitations and should be assessed for each project individually. The time saving is attributed to the absence of the following

i. temporary casing,
ii. frequent disposal of the spoils
iii. stabilising mud application and
iv. washing and tremie operations.

Plant and Machinery for the Construction of CFA Pile

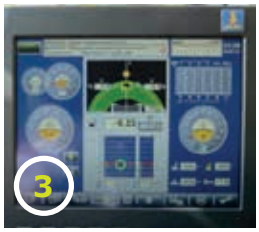
Conventional hydraulic rotary rig modified to house continuous flight auger

CFA piles can be installed using similar modern bored piling equipment used in the construction of bored cast in-situ piles, but with certain modifications/change of accessories. The presence of reputed international piling rig manufacturers in India makes its implementation easier. Soilmec, Bauer, Mait and Casagrande are some of the manufacturers who have a strong presence in India. The rig specific CFA equipment and the relevant accessories namely the instrumented control unit and the CFA kit can easily be procured and the available rigs modified to enable the construction of CFA piles.

The typical other plant and machinery required for the construction of CFA piles are

i. Long boom crane,
ii. RMC plant, Concrete/ grout pumps,
iii. Excavators,
iv. Reinforcement cage fabrication unit, and
v. Ring vibrator (optional)
vi. Monitoring unit

Special attention should be applied to the calibration of the concrete pumps to ensure the correct amount of concrete being delivered into the pile. The construction of suitable working platforms and access ways is important to ensure safe piling operations.



1) RMC truck and concrete, 2) grout / concrete pumping unit, 3) Automated Monitoring Unit installed within rig panel
4) grout / concrete hose, 5) Piling with hydraulic rotary rig mounted continuous flight auger and long boom crane

Soil Conditions Suitable for CFA Pile

A wide range of geotechnical profiles are suitable for the construction of CFA piles. The exemptions are profiles with large stones and boulders, dry sand deposits and heavily layered soil with intermediate soft clay layers. Table 1 lists different soil profiles and their suitability for adopting CFA pile.

Table 1: Soil Profiles and CFA Pile Applications

Type of Profile	Applicability	Explanation
Alluvial deposits	Most applicable	Uniform profile facilitates ease of drilling control
Sedimentary deposits with a smaller number of layers	Most applicable	Fairly uniform profile
Sedimentary deposits with weak clay deposits	Fairly applicable	Intermediate weak clay deposits may get dragged by the auger
Sedimentary deposits with several weak clay deposits	Not applicable / need extra care	Excavation of soft material is difficult. Excessive concrete over-consumption possible
Residual formations without cobbles & boulders	Applicable	Can be excavated using the auger but should not exceed 200-300mm in diameter
Residual formations with medium size cobbles	Somewhat applicable	Difficulties in advancing the auger
Residual formations with large size cobbles or boulders	Not applicable	Auger advancement not possible
Highly weathered soft rock deposits	Fairly applicable	Heavy-duty augers can excavate the borehole. Steady & slow penetration rates should be achieved to avoid over-excavation and side loading of the auger
Thick layers of weak soil followed by bearing stratum	Not applicable	Large length and difficulty in lowering the reinforcement for the full length
Weak clay immediately followed by moderate to strong rock	Not applicable	No skin friction and no adequate penetration for end bearing. Excessive concrete over-consumption
Dry sand deposits and collapsible soils	Not applicable	Loss of water from the concrete/ grout resulting in poor pile material and difficulty in reinforcement lowering. Risk of over-excavation and loss of skin friction and end bearing.
Thick overlying dry clay layer with shrinkage cracks	May not be applicable	Loss of water from the concrete/ grout resulting in poor pile quality and potential difficulty in reinforcement installation.

Quality Control & Quality Assurance for CFA Pile Construction

The quality control of CFA Piles mainly depends on three factors namely,

1. The rate of auger advancement and withdrawal of the same with simultaneous concreting / grouting
2. The appropriate mix design for the concrete/grout
3. The design of the steel reinforcement cage for its sturdiness

The monitoring device for recording and maintaining the auger speed in rotation, torque, and the penetration rate is one of the key factors in achieving the best out of the construction. This monitoring device measures the concrete/grout pressure and volume at every stage of the concreting process providing valuable data on the constructed pile diameter. Modern piling rigs are fitted with electronic and mechanical sensors and measurement devices to monitor construction parameters during the execution of CFA piles.

The concrete/grout mix design is an important aspect of the best CFA pile construction practice. The selection of proper coarse and fine aggregates, binding materials like cement, fly ash and additives, and water is of great importance. The concrete or grout used in CFA pile construction shall have good workability and resistance against segregation. The coarse and fine aggregate in the concrete shall remain suspended after placement, allowing the smooth lowering of reinforcement cage. The slump shall be minimum 200mm ± 25mm when tested following IS 1199. Slump Flow value, employing the use of inverted Abrams standard concrete slump cone as per IS 1199, shall be typically in the range of 760 to 890mm. It is not difficult to maintain the workability for about four hours using 400 to 450 kg/m^3 cementitious material, 10 mm coarse aggregate and a retarder.

In most of the projects, full-length reinforcement is a requirement. Sturdy reinforcement cage provided with freely rotating cover rings can achieve this requirement. The right concrete/grout mix ensures the easy penetration of the reinforcement cage. Welding of spiral stirrups and spacers to the equally distributed main bars enhances the quality of the reinforcement cage. The use of long boom crane for lifting and lowering of the cage shall be a norm.

Quality Control & Quality Assurance for CFA Pile Construction

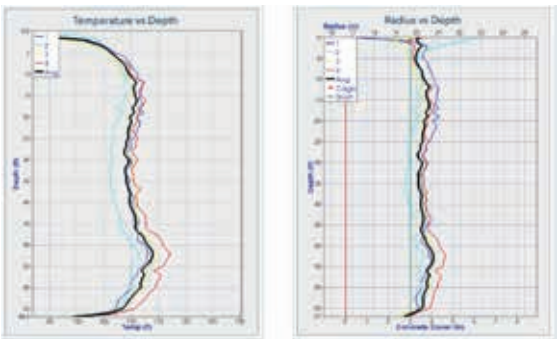
Thermal Integrity Profiler (TIP) can evaluate the full cross-section for the entire length of the deep foundation element measuring heat generated by curing cement. The diameter of foundation elements like, drilled shafts/bored piles, augered cast in place (ACIP)/CFA piles, drilled displacement piles, slurry walls, barrettes, soil nails, and jet grouted columns can be assessed by this procedure. TIP together with the observations through the monitoring device can identify the potential problems with respect to the amount of concrete cover quickly in order to avoid identical issues for the remaining piles on site.

Pile Integrity Test (PIT), or low strain impact integrity testing of deep foundation is a widely used non-destructive test method for the evaluation of pile quality, and integrity. In the low strain impact integrity testing, the response of the pile to an impact on the head of the pile shaft is determined by a high precision transducer mounted on the pile head. The transducer can either be an accelerator, or a velocity sensor. PIT is an established procedure in India. The test procedure is standardized as per ASTM D5882.

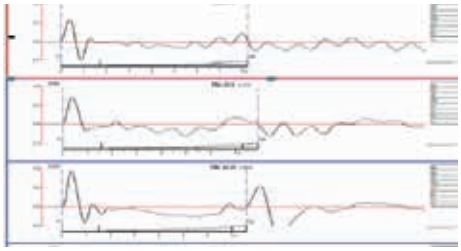
Loading tests of test piles for vertical compression, pull out and lateral loading are standard quality control procedures that can be adopted for CFA piles also. These procedures are available in IS 2911 Part 4.

High Strain Dynamic testing can be used to evaluate pile capacity. The test procedure is standardized as per ASTM D4945-2000 and also forms part of various specifications and codal provisions worldwide. The method is convenient, reliable and helps evaluate pile capacity and integrity in quick time and one or more piles can be tested per day. The testing is conducted for obtaining the records of force and velocity under drop weight impacts. The field results are further analyzed with an appropriate signal matching technique to refine the soil parameter assumptions.

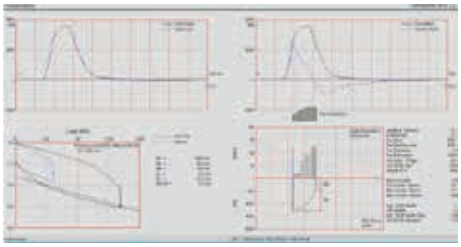
Courtesy: https://aatechscientific.com/pile-testing/
https://www.fprimec.com/pile-integrity-test/



Thermal Profiling - GEO Instruments



Pile Integrity Test - PDI



Wave Analyser - PDI

Vertical Compression - DFII

Lateral Loading Test - DFII

Vertical Tension - DFII

Worldwide Use of CFA Pile

Courtesy; Keller: 760mm to 910mm x 55m (Special case) - HJ Foundation - World Record

Several countries like USA, Canada, UK, Germany, France, Italy and Australia have been using CFA piles with great success for more several decades. In some countries, CFA piles are known under the name Auger cast-in-place piles (ACIP).

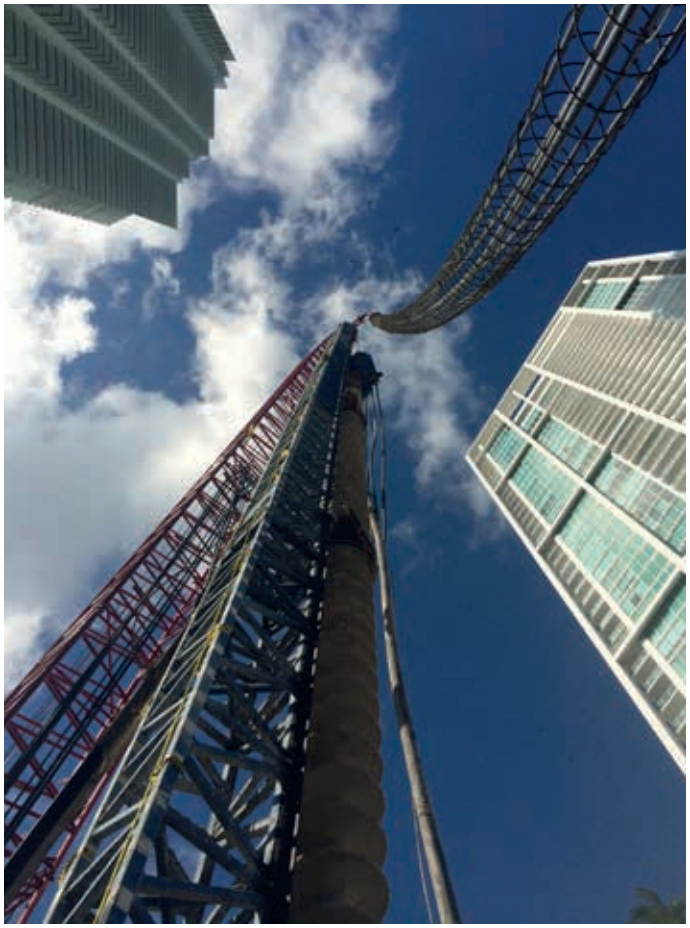
Globally, the share of large-diameter bored cast-in-situ piles, CFA piles and pre-cast driven piles is about 25%, 23% and 21% respectively. More than 60% of the pile foundations in India use medium to large diameter bored cast-in-situ piles. Driven cast-in-situ pile also has a large application in Indian piling jobs.

Pile lengths over 40m have been constructed successfully in Australia using CFA piles. Typically, these piles range from 600mm to 1,200mm in diameter. Pile diameters of 1500mm for pile depth close to 30m are also common in Australia.

Type	Soilmec SR50	Mait HR160	MaitHR420	Enteco E25MD	Fundex F3500	Bauer BG40
Rotary Drive Torque	180 kNm	163 kNm	420 kNm	530 kNm	450 kNm	400 kNm
Operational weight	50 T	52 T	130 T	130 T	120 T	120 T
Pile diameter	900 mm	1,000 mm	1,500 mm	1,500 mm	1,500 mm	1,200 mm
Maximum drill depth	21 m	19.5 m	35 m	38 m	45 m	26.5 m

Selection of typical CFA piling rigs in Australia. Courtesy: Martin D. Larisch

Worldwide Use of CFA Pile



Courtesy; Keller: 760mm x 54m - ACIP-HJ Foundation - Full Length Reinforcing - One Thousand Museum in Miami.

Worldwide Use of CFA Pile

Courtesy Malcom Deep Foundation;

CLIENT
Owner: Occidental of Elk Hills, Inc.
General Contractor: CB&I Inc.
SERVICES
CFA Piles
225 EA – 380mm Diameter
822 EA – 600mm Diameter
464 Pile Integrity Tests (PIT)

CFA piles can be installed very efficiently with modern high-torque hydraulic drilling rigs up to a depth of 38m and up to 1200mm in diameter. Crane mounted lead systems extend the installation range beyond 52 metres, however, pile diameters are reduced with depth. Malcolm's method for installing with the crane mounted lead system is called "CFA Mega Piles."

References

Augered cast-in-place Pile Manual (Model Specification with Commentary), Augered Cast-in-place Pile Committee of Deep Foundations Institute, Third Edition, First printing-2016 ,
Geotechnical Engineering Circular (GEC) No:8 (2007), Design and Construction of Continuous Flight Auger Piles, FHWA-HIF-07-03, Section 5.3.2, pp 72-74
(1) Larisch, M, Poskitt, N, Netterville, H and Dredge, S 2013, 'Advanced quality assurance for piling works for the WICET project in Gladstone',AGS journal, Volume 48, 1 September 2013, pp.99-112
(2) Larisch, M., D., 2018, 'Current practice of CFA piling in Australia and New Zealand', Proceedings on the International conference on Deep Foundations and Ground Improvement, June 2018, Rome, Italy

The CFA Pile Trial Project by DFI of India

Deep Foundations Institute of India with the technical help from its parent body DFI USA, invested in a project of design, construct, and test of CFA piles in India. This trial project involved design and planning, geotechnical investigations, pile execution works, and load tests over three years with the help of several foundation construction industry partners.

Methodologies and experiences during this trial initiative are well documented and are expected to provide confidence to the construction industry in India to adopt CFA Pile technology on a regular basis across the country. The implementation of CFA piling technology would benefit all stakeholders- the owners of projects (early project completion), the main contractors (early project completion) and the piling contractors (higher efficiencies and profitability), and ultimately our country (faster infrastructure development).

The CFA Pile Trial Project executed by DFI of India comprised

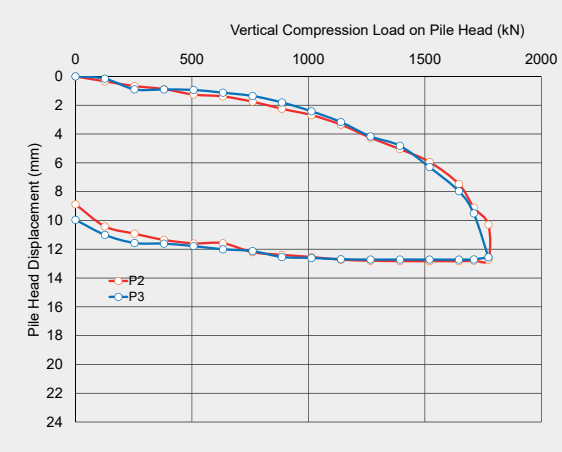
1. Selection of site 30m x 40m
2. Geotechnical characterisation of the site
3. Geotechnical and structural design of the CFA piles
4. Installation of two probe CFA piles
5. Installation of six trial CFA piles
6. Instrumentation of two trial piles, and
7. Load testing and performance analysis of six trial piles,
   i. 2 Nos of Vertical compression,
   ii. 2 Nos of lateral and
   iii. 2 Nos of pull out

Pile boring in progress using CFA

Pile boring in progress using CFA

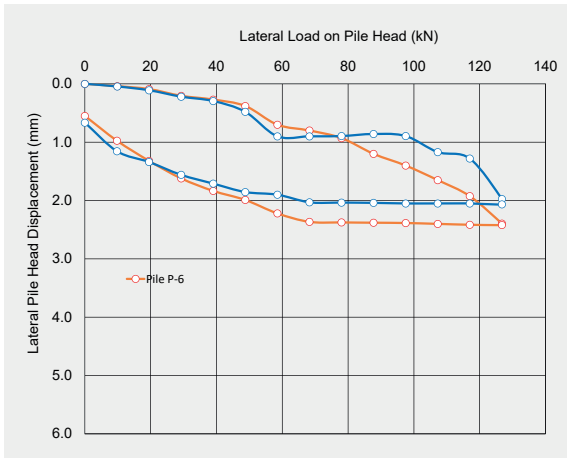
Muck removal around pile by Excavator

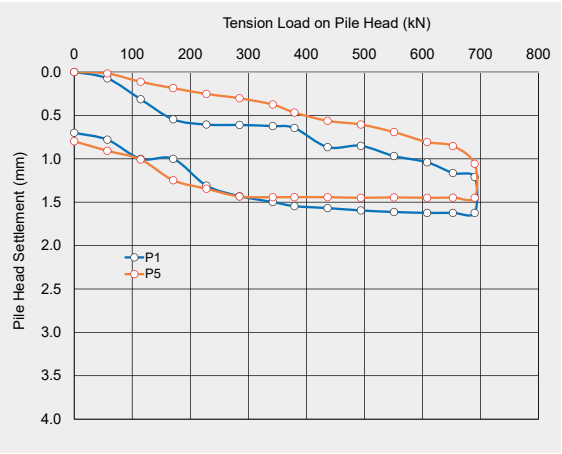
Performance of Trial CFA Piles



Vertical Compression
680mm dia CFA piles, 11.5m long

Lateral Loading Test
680mm dia CFA piles, 11.5m long





Pull out (Tension) Loading Test
680mm dia CFA piles, 11.5m long

DFII CFA Pile Technology Implementation Committee

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3. Mr Pranav Jha, Assistant Manager – Operations, DFII
4. Mr T. S. Mahendran, Manager – Admin & Accounts, DFII

DFII CFA Test Pile Project - Industry Support

In-Kind Contribution	Details
Nuclear Power Corporation of India Limited (NPCIL), Mumbai	Providing land for the conduct of CFA trial piles in their greenfield project at Haryana and provided quality control services.
ITD Cementation India Ltd., Mumbai	Providing resources, supervision, site infrastructure for concrete, reinforcement fabrication, and pile testing work.
Soilmec India, Mumbai	Providing CFA kit, assembling CFA kit including operators form Italy and India and test pile installation
Ultratech Cement	Supply of cement
Tata Projects Limied, Mumbai	Supply of electrical cables, load-carrying vehicles
SCHWING Stetter (INDIA) Pvt. Ltd	Supply and operation of concrete pump
Smart Structure (Radise Group) US	Instrumentation and related analyses for two piles
PDI, US / Geo Dynamics, Vadodara	Thermal integrity profiling of two piles and PIT on all piles
BASF Chemicals, Mumbai	Supply of admixture
Asahi Ropes, Delhi	Supply of wire ropes
Balaji Enterprises, Chennai	Supply of cover blocks

Financial Support	Details
L&T Construction, Chennai	1,000,000
Tata Projects Limited, Mumbai and Saritha Infra & Geo-Structures	1,000,000
Keller Ground Engineering India Pvt. Ltd., Chennai	500,000
IRB Infra, Mumbai	400,000
Afcons Infrastructure Ltd, Mumbai	250,000
Manjeera Constructions, Hyderabad	100,000
SKCL Developers, Chennai	100,000
Advance Construction Technologies, Chennai	100,000
Dr. K S Ramakrishna, DFI of India	100,000
Smart Structures (Radise Group), US	60,000
Mr. G Venkata Prasad, DFI of India	30,000