Suggestions to improve method of installation of cast-in-situ driven and bored concrete piles

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Construction of pile foundations requires a careful choice of piling system depending upon the sub-soil conditions, the load characteristics of a structure and the limitations of total settlement, differential settlement and any other special requirement of a project. The installation of piles demands careful control on position, alignment and depth and involves specialized skill and experience [1& 2] In this Paper suggestions on improvements in method of installation of only bored and driven cast-in-situ piles have been included. However, stipulations of relevant IS Codes i.e. IS 2911 (Part 1/ Sec 1)- 2010[1] and IS 2911 (Part 1/Sec 2)-2010[2] should be followed for 'Design and construction of cast-in-situ driven piles' and for 'Design and construction of cast-in-situ bored piles' respectively.

A) GENERAL

1. Sub-soil Investigations

Detailed sub-soil investigations should be conducted with trial borings, standard penetration tests(SPT), location of ground water table, chloride and sulphate content in soil and ground water etc for a depth at least 10m below proposed founding level, particularly in a major project site to check variations in strata, existence of any cavern, old well etc.

In order to protect green pile concrete with reinforcements from action of high chloride and sulphate content in soils and adjoining ground water, stipulations of Table 4 of IS 456:2000 [3] should be strictly followed. If chloride content in ground water is too high (i.e above 25, 000 ppm) then expert advice shall be taken for remedial measures and /or use of alternative solution.

The author encountered at a project site chloride content 130, 000 ppm in ground water in a creek land filled with dredged material from Arabian sea where on the basis of expert advice precast concrete piles were driven under a multi-storeyed building. By use of precast piles concrete strength was fully attained before driving and the effect of chloride content on such concrete would be inconsequent.

It has been established in a recent research at CSIR-SERC , Chennai [4] that the chloride ion penetrability (tested through RCPT) of Portland Pozzolona cement was nearly one-third of corresponding OPC concrete and the RCPT value of concrete with Calcium Nitrite Inhibitor (CNI) was found to be significantly more than that of other concretes without CNI. Thus before using Corrosion Inhibitor, properties of the particular Inhibitor shall be thoroughly checked through relevant tests.

2. Survey

a) Survey of pile positions should be done using precision survey instruments handled by experienced Surveyor and not in a casual manner. Additional and special care shall be taken in survey particularly for location of single and two-pile groups as large static eccentricities of load due to pile being out of position would induce moments in piles for which they are not normally designed.

b) Pile Nos should be indicated on piling plan and the same should invariably be mentioned in all records maintained.

3. Sequence of installation of piles

a) In an isolated building installation of piles should be started from centre fanning outwards. Again in a large pile group similar trend should be followed i.e start from centre and proceed towards outer edges.

b) Disturbance of freshly laid concrete in a driven/bored pile shall be avoided by not installing the adjacent pile in the same group. Rather, principle of staggering should be followed and piling rig should be rolled/shifted by a suitable distance to start next pile in a large pile group before return again to first pile location. By this heaving of soil between piles in the same group also can be avoided. If pile groups are small , installation of pile(s) in two such groups at a distance should be taken up simultaneously.

4. Location of bore well at piling site

No bore well for withdrawal of ground water for various uses at site shall be installed under or near the edges of the building with pile foundation within influence zone of drawdown curve of the bore well to avoid settlement of building foundation.

The Author had a bitter experience of working in construction of a six storeyed warehouse building of flat slab construction resting on cast-in-situ driven piles in dock area in Kolkata where a few bore wells were installed in restricted building area itself for drawing ground water for gravel wash, mixing concrete etc . The level of bottom of piles 20 m long and of the strainer of borewells was more or less the same. By the time the roof of the structure (approx 150 m x 55m) with two expansion joints was cast with gradual progress in brickwork, flooring etc, at lower floors cracks were noticed at various locations in the structure alongwith uneven settlement at expansion joints. Also along length and width of the building settlement was noticed in a saucer shape after checking levels of top of pile caps which were initially maintained at datum. Maximum settlement at middle of length and width of the building was 18 cm in spite of the building resting on piles installed by a reputed Co.

As a remedial measure to save the building and for its future use , drawing water from the bore wells had to be immediately stopped and after detailed investigations a short dummy basement floor was introduced connected to the pile caps and tie beams.

5. Monitoring of settlement of pile foundation

It is advisable to record settlement of pile foundation particularly under high rise buildings and major structures during construction and for some time thereafter till full live load is applied to ascertain that total/differential settlement is within the allowable settlement for the particular structure. Normally such levels are measured on top of pile caps or at a fixed height on basement/ground floor columns/piers.

Group effect with long term settlement in tall buildings should be considered in deciding pile capacity particularly when resting on silty/clayey soil with high water table. If the entire foundation area of a building is occupied by piles in mixed type of soil, due to bulb effect the whole foundation as a unit may produce settlement in the structure more than permissible limit for the particular type of cladding and finishes used in the building even before load capacity of individual pile based on pile load test is reached.

The Author has the knowledge of reducing height of Tata Centre building in Kolkata , one of the tallest buildings in those days(1965-66), by three floors when due to bulb effect settlement monitored for the building resting on maximum No of cast-in-situ driven piles at minimum spacing for the whole building area was about to exceed the permissible limit.

Again, it is reported that Urbana Towers in Kolkata (45 storeyed) on pile foundation (55 m deep) recorded a settlement of 1 mm during Nepal earthquake (7.8 in Richter scale)in April, 2015 while still under construction.

6. Pile Concrete

a) Grade of concrete in piles should not be less than M25 and cement content not less than 400 kg/cum of concrete when ground water table is met.

b) Slump of concrete at the time of placing shall be between 150 and 180 mm whether in dry bore or below ground water table.

7. Record of installation of piles

Record of installation of piles shall be maintained as per format in IS code for cast-in-situ driven piles [1]and as per format in IS code for cast-in-situ bored piles [2].

8. Pile Integrity Test (PIT)

i) In major projects now-a-days 100 p.c piles are subject to low intensity PIT and such test is included as a schedule item in contract for which cost is not very high and many agencies in India can conduct this test.

ii) Even if not included as a regular item in Bill of Quantities in contract, in case of abnormality and/or doubt in quality of pile noticed from installation data in record i.e driving/boring record, quantity of concrete consumed, disruption in pouring of concrete, dislocation of pile shoe, honeycombing, cross-sectional changes, dis-continuity etc, low intensity pile integrity test should be conducted on all such piles before proceeding with construction of pile caps. If result of such test is not satisfactory, load test may have to be conducted on such pile or else pile may have to be rejected as per decision of the Engineer.

B) DRIVEN CAST-IN-SITU CONCRETE PILES

1. Pile driving formula

Any established dynamic pile driving formula may be adopted for driving of piles at site giving due consideration to limitations of various formulae. Minimum grade of concrete to be used in pile foundation is M25 [1].

2. Choice of pile type

a) This type of piles is widely used where at a particular site variations in soils strata is too much and length of pile cannot be easily ascertained in advance from sub-soil investigation results. At such sites wide variation of length of piles is normally noticed.

b) If piles are to be driven close to adjoining buildings not supported on pile foundations, proper precautions shall be taken to avoid any damage to the building structure. In such situations installation of bored piles would be a better option.

c) Due to limitation in capacity of pile driving rigs available in India, maximum dia of cast-in-situ driven piles is limited to 600 mm. Thus there is limitation of use of driven piles where load per pile is very high.

3. Pile Shoe

Cast iron conical pile shoes were mostly in use for driven cast-in-situ concrete piles to start with. But due to inconsistency in quality of casting of such shoes a large percentage of shoes started breaking and got damaged during driving. Remedial measures involved additional work by way of extraction of the tube, refilling of pile hole by soil /sand and re-installation of pile causing wastage of time and money apart from embarrassment to the Co.

As a solution now-a-days mild steel pile shoes of flat type are commonly used as shown in Figure 1 (with hexagonal and round base plate). However fabrication of shoes should be done carefully to avoid too much play in space between inner and outer ring. This may cause slanting of pile shoe during driving which may allow entry of adjoining soil. Also design of pile shoe should be done properly with adequate factor of safety to avoid damage during hard driving, if any.

4. Dolly

Timber dolly had been in use in India since inception of driven piles for placing on top of drive cap for transmission of load from hammer to pile tube. Depending on quality of timber used in dolly, hammer weight and height of fall, one timber dolly, normally 20 cm thick may be used in installation of one or more piles. Replacement of worn-out dolly during pile driving is time consuming.

For economy, alternative material e.g masonite board 10cm thick is in use in India now-a-days with which 20-25 piles may be installed even using pneumatic/ hydraulic hammer of higher capacity.

The Author used imported cushion 12 cm thick with 7 t hydraulic hammer in installation of driven piles in a project at Bhavnagar(in 1997) and it was possible to drive upto 400 Nos piles (40cm dia x 20 m long)in marine clay layers with one cushion.

5. Pile Tube

a) No of joints in pile tube of required length should be as minimum as possible. Seamless pipes, each of large length, say 8 m and above should preferably be used to minimize No of joints. Welding in joints where used

Figure 1. Mild steel pile shoe with hexagonal and round base plate.

shall be done with V-cuts by engaging skilled welders to maintain a straight line avoiding any protrusion of weld inside the tube. Again, cooling of joints after welding shall be done without development of any crack. Shifting and /or lifting of pile tube after welding should be done only after the joints are properly cooled to ambient temperature. Conventional A-frame driven piling rig is shown in Figure 2.

b)At a site where the length of pile tube falls short of length of pile to be installed, piling contractor tends to use 'Follower Tube' to make up the deficit length retaining the height of piling rig already mobilized at site. However, such proposal should not be encouraged as some amount of energy gets dissipated at junction between main pile tube and follower tube resulting in total length of pile installed with follower falling short of length required to sustain design load.

If on the basis of sub-soil investigation the depth of pile is decided and piling rig and pile tube are mobilized at site and subsequently during initial load test it is ascertained that length of pile required would be more, in that case either the length of rig should be extended at site , if possible , or else a taller rig should be mobilized along with lengthening of pile tube.

6. Problems normally faced during installation and their solutions

i) Where ground water table is high or artesian condition persists, during driving of pile tube the bottom of tube may get filled with ground water for some depth. After final set of pile tube, inside of it should be checked for presence of accumulation of ground water. If depth of such water is more than 30 cm the tube should be extracted, pile bore refilled with selected soil and re-driving of pile tube should be done.

However, if such water accumulation is frequent and of routine nature, caulking/sealing of groove in pile shoe where the tube rests during driving, should be done with raw jute and bitumen to prevent entry of ground water during driving.

The Author has the knowledge of two piling projects in Kolkata in which due to not checking such water accumulation of water at bottom of pile tube on completion of driving , the piles failed during load test as the bottom concrete was of sub-standard quality. Since it was not possible to extract such piles, load carrying capacity had to be reduced, redesign of pile groups done and additional piles installed by the contractor at his own cost resulting in cost and time overrun.

ii) a)Particularly when driving is very hard, due to excessive pull during extraction of pile tube with concrete and pile cage inside, sometimes snapping of wire rope or breakage of pulley block/sheave etc may take place. In such a situation it is a common practice to reduce friction by punching one or more empty bores and scoop out soil around the pile tube for its easy extraction . The earlier it is done, the better. Subsequently extracted tube is cut into pieces of suitable length preferably at welded joints where feasible, break and remove concrete and reinforcements and then re-weld carefully maintaining straight length for the tube and leaving no protrusions inside the tube.

To avoid such a situation, regular maintenance of piling engine and winch should be done alongwith increasing No of sheaves in pulley block and replacement of wire rope whenever first sign of wear is noticed.

b)The pile bore and punched holes after removal of jammed pile tube shall be filled with soil/sand as specified and left for sometime before re-driving pile at the old location.

iii) If on a rare occasion pile tube during extraction is lifted with pile cage and concrete inside since green concrete is still to set the tube should be removed outside pile location and by hammering on top of the tube it should be emptied. The empty pile bore should then be filled up and further procedure followed as in (ii) (b) above.

Figure 2. Conventional A-frame rig moving on roller over timbers.

iv) If pile cage alone is extracted during extraction of pile tube leaving behind concrete inside the bore, again on a rare occasion, due to protrusion of weld inside tube/ breakage of cover blocks resulting in touching of cage on side of pile tube etc , such pile shall be rejected, pile group to be redesigned and additional pile(s) as required would be installed.

v) Sometimes stiff clay or dense sand layer of relatively small thickness 1 to 1.5 m exists followed by soft layers before reaching founding stratum . It may cause very hard driving with available equipment mobilised at site being unable to puncture this stiff layer. In such cases attempt shall be made to extend the pile to required depth by mobilizing hammer of heavier weight , increasing height of fall of hammer and using heavier pulley block for extraction etc.

The Author has the knowledge of foundation of multi-storeyed Terminal building at Kolkata airport where cast-in-situ driven piles were installed by one piling contractor (in 1963-64) using steam hammer when with the system and equipment available with the Co, a stiff clay layer about 1.5 m thick at approx 18m depth could not be punctured and piles were terminated somewhere in that layer. During load test, however, the piles failed to carry the design load. Subsequently, additional piles had to be installed on the basis of re-design of pile groups and pile caps at contractor's own cost.

During execution of second phase of the project, with detailed sub-soil information available, the selected contractor installed driven piles to required length and capacity using higher capacity of drop hammer and increased height of fall of hammer successfully puncturing the stiff clay layer and pile lengths were between 22 to 24 m.

7. Concrete compaction and consumption in piles

a) Tamping of pile tube during extraction after concreting is a standard practice which should be rigorously followed for artificial compaction of pile concrete in the bore apart from gravity compaction under weight of concrete mass with high slump.

b)In normal mixed soil condition volume of concrete consumed in driven cast-in-situ pile does not exceed theoretical volume of pile for the driven length.

However, the Author came across a piling site at Bhavnagar near sea coast where thick marine clay deposits existed. During installation of driven piles when pile tube was extracted, marine clay of about 5 cm thick used to get stuck to the outer periphery of the tube. As a result, actual volume of concrete consumed in 40 cm dia pile was between 20-25 p.c. more than theoretical volume of pile. After extraction of tube it used to take some time to get the clay layer dried up in prevalent windy condition at site when cracks appeared in clay deposit on tube surface which was then removed fast by hammering before shifting the tube to new pile position.

8. Sophistication in pile driving and quality control of pile concrete

i)The Author used crawler mounted Pile Driver(imported), Hydraulic Hammer (7 t and 10 t), Vibrator cum Extractor, concrete batching plant and transit mixer in installation of driven piles 40 cm and 45 cm dia upto 22m length in marine clay deposit for a plant at Bhavnagar, Gujarat . refer Figures 3 and 4. Standard practice followed by piling contractors in India is transporting concrete from 10/7 or 14/10 mixer by chute cart and placing into pile tube with help of winch and wire rope. However, at Bhavnagar site concrete from automatic batching plant was transported by transit mixer and directly poured into pile tube.

By this record No of piles could be installed in a day by one Pile Driver i.e 40 Nos 40 cm dia 20-22 m long, achieving 36 minutes cycle time.

Figure 3. Pile Driver with Hydraulic Hammer and Vibrator-cum-Extractor on crane.

ii) For fast completion of installation of large No of piles in the project, a few conventional driving pile rigs were mobilized. Even for pouring concrete directly into the pile tube at an elevated position after part extraction of the tube, special arrangement was made as shown in Figure 5.

iii) Because of existence of soft soil strata at top, adjacent piles could not be installed in sequence in the same group and the pile driver had to be shifted to next group (s) and later return to the first group after allowing enough time for concrete to set. Since the Pile Driver was crawler mounted its movement was very fast as against conventional piling rigs moving on rollers over timbers .

iv) At bottom level of pile cap pile concrete should be of sound quality (ref Figure 6). If not, dismantling shall be done upto the level of sound concrete and then pile is rebuilt with design mix concrete.

9. Piles in rake (Raker piles)

In high seismic zones to cater to high horizontal forces, it may be economic to provide piles in rake under tall structures, bridges and heavy machineries etc. Such piles would be able to resist large horizontal forces apart from

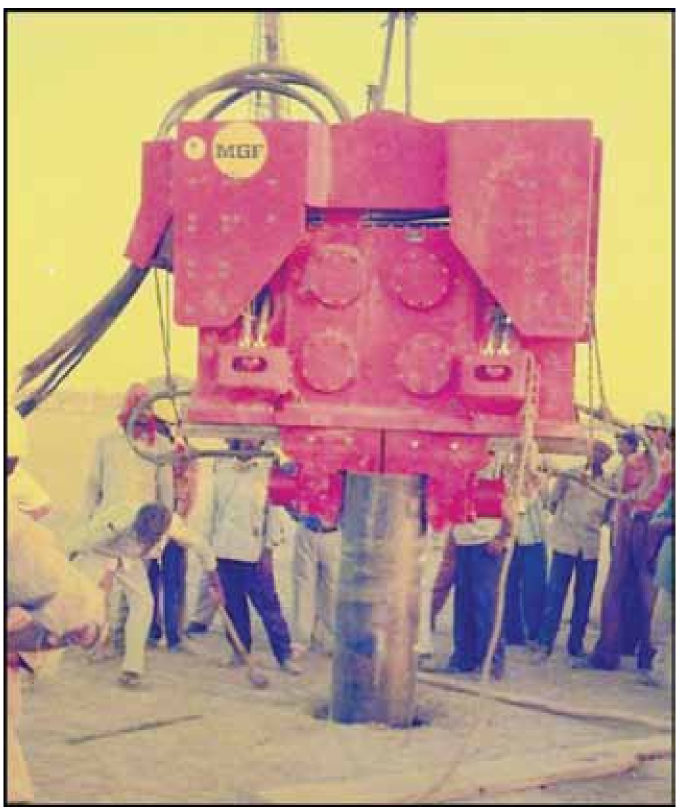

Figure 4. Vibrator- cum- Extractor in grip of pile tube for extraction

Figure 5. Set-up for pumping concrete from Transit Mixer to pile tube at a height.

vertical load. There are some special requirements for installing these piles as stated below:

i) Vertical conventional piling rig is normally converted into a raker pile rig attaching one trapezoidal piece of pile frame at bottom of a vertical rig. Precautions shall be taken in fabrication of the components for matching and accurate assembly so that the hammer moves through inclined guide frame smoothly without getting detached which may cause serious accident. Also close inspection of the hammer and guides shall be done to check wear and tear of hammer and guides.

ii) Checking of rake in pile tube shall be done frequently during driving, particularly when stiff resistance is encountered in driving through hard soil strata.

iii) Rake should not normally be flatter than 1H in 6V and preferably be limited to 1H in 7V as beyond this slope,

Figure 6. Sound pile concrete at pile cut-off level.

compaction of concrete and the quality of pile may be doubtful.

C) BORED CAST-IN-SITU CONCRETE PILES

1. Dry bore with no ground water table

At some sites where water table is not encountered upto termination level of pile and the bore can stand on its own, there is a tendency to install the pile without the aid of bentonite mud. In such cases it is to be checked against collapse of soil, if any, till time of concreting including when pile reinforcement cage is lowered inside the bore. If any appreciable soil deposit is noticed at pile bottom due to above which can cause settlement of pile under load, flushing of bore with water or bentonite should be done for its removal.

2. Use of M.S. Liner

a) It is a common practice to use Mild Steel (M.S) liner for top 2.0- 2.5 m length of pile where sub-soil water table is high and top soil is soft. Thickness of liner plate should be such that round shape of the pile is retained. Depending on contract condition such liner may be retained or extracted after pile concreting.

b) If length of temporary liner used in any project exceeds 3 m such additional length should be provided through threaded joints with pieces 1.5 to 2 m in case of Hydraulic rigs (refer Figure 7) for easy and faster installation as well as extraction on completion of concreting in pile.

Figure 7. Bored piles under installation by Hydraulic Rig.

Figure 8. Marine bored piles in open sea condition

c) As per standard practice pushing of liner should precede boring and not that after boring, the liner should be pushed in the hole.

d) For special use of large diameter bored cast-in-situ piles in marine structures reference is drawn to Annex E of IS 2911(Part 1/Sec 2)[2] and refer Figure 8.

When liner is provided as sacrificial in case of piles in standing water or for marine structures for part or full length as applicable, thickness of liner plate should be sufficient as required for handling and driving/pushing the fabricated liner of required length, retaining its circular shape for the particular dia of pile. Again, all precautions shall be taken for safety of mobile gantry, piling rigs mounted on the same and stability of piles during high floods with velocity and current in water, while constructing river front structures. Suitable M.S bracings are to be provided to connect liners/piles under temporary condition for such stability till permanent connection to pile heads is provided, refer Figure 9. Attempt shall be made to extend piles to safe depth below maximum scour level.

Construction of pile muffs with steel plates is a standard practice adopted for support of precast beams where used for deck structure.

3. Checking of alignment

i) Alignment of piles, vertical or in rake, where provided, should be checked during installation of pile at depth intervals of 2 m, unless any closer interval is mentioned in contract document.

ii) During installation of raker piles through Hydraulic Rotary Rig inclination as required shall be provided in the mast and piling should proceed. Once in a month or earlier in case of doubt mast inclination shall be checked.

iii) If tripod rig (refer Figure 10) is used with bailer / chisel for installation of raker piles in marine condition in particular where liner of large length is exposed and standing above bed and if the rake is flatter than 1 Hor. on 6 Vert. then thickness of permanent liner shall be suitably increased to compensate for the loss of liner thickness due to friction developed during movement of bailer / chisel along inside face of liner in inclined position. If thin liner plate is used it may result in formation of pockets due to wear and tear of liner plate and loss of mortar / concrete through such pockets resulting in formation of poor quality of pile.

The Author has seen in one marine job formation of big openings in 6 mm. liner when pile was installed in rake 1 Hor : 2.5 Vert and lot of cement mortar and concrete leaked through the openings with compromise in quality of such permanent piles.

4. Maintenance of records during boring

i) Details of sub-soil strata as encountered during boring operation should be recorded with change of strata along with special information, if any as boring is advanced upto founding level. For any major and very important project with large No of piles, an experienced Geologist should be deployed for ascertaining correctly the types of strata as encountered.

ii) Standard Penetration Tests (SPT) should be conducted to determine founding level of pile suitable for carrying design load with required factor of safety.

Figure 9. Mobile piling gantry.

Figure 10. Bored piling using tripod rig

5. Collapse during pile boring operations

i) During pile boring collapse of soil in borehole results in increase of dia of pile causing irregular increase of clear cover over reinforcement bars which would affect quality of pile apart from increasing cost due to increase in quantity of concrete consumed.

ii) On completion of pile boring after withdrawal of DMC / RMC pipes and lowering of reinforcement cage flushing of pile bottom is done generally using tremie pipes. After such flushing if concreting is not started soon and the bore is allowed to remain unattended for long, collapse of bore hole is very likely to take place affecting quality of pile adversely due to deposition of loose soil at pile bottom. Under load soft deposits would get compressed and settlement of pile would take place. In such conditions flushing of bore shall be repeated before commencing concreting in pile.

iii) In case of boring done with rotary hydraulic rig, cleaning bucket shall be attached to the Kelly when founding level is reached, for cleaning the base of each pile. Airlift technique may be used as an alternative method for cleaning of borehole.

6. Reasons for collapse of soil in pile bore

These mainly depend on type of soil i.e. whether cohesive or non-cohesive, its density, location of water table and pore water pressure, vibration effects, height of unsupported vertical face of wall and liquid inside borehole.

Presence of liquid inside a borehole increases the stability of the vertical cut earth surface of the borehole. When soil collapses total active pressure becomes more than cumulative passive pressure. Presence of liquid inside the borehole exerts counter pressure to resist the active pressure on the soil and facilitates the stability of the soil. Quantum of pressure exerted by the liquid on the vertical cut surface of the hole depends on the density of the liquid.

7. Density requirement for Bentonite mud

a) Specification for Bentonite powder is covered in IS 6186 – 1986 (reaffirmed 1997) which is a characteristic type of fine grained clay being an alteration of volcanic ash containing not less than 85 p.c. mineral montmorillonite. It is used for various purposes other than stabilisation of pile bore. When used in bored piling work its property requirement satisfying IS 2911 (Part 1/ Sec. 2)[2] as stated in paragraph 7 (b) & (c) below shall be satisfied.

b) In cases other than mentioned in para B- 1 above borehole is generally stabilized by use of bentonite mud. For fresh bentonite suspension density should be between 1.03 and 1.10 g/ml. depending on pile diameter and type of soil encountered. Density of bentonite after contamination with drilled material in the bore may rise upto 1.25 g/ml. which shall be brought down to at least 1.12 g/ml. by flushing with fresh bentonite before concreting.

c) Also other recommended tests for bentonite mud in IS 2911 (Part 1) Sec. 2 – 2010 [2] are :

i) Liquid limit of bentonite shall be 400 p.c. or more when tested as per IS 2720 (Part 5).

ii) Marsh viscosity of bentonite suspension when tested by a standard Marsh Cone shall be between 30 to 60 sec. In special cases it may be allowed upto 90 sec.

iii) The pH value of bentonite suspension shall be between 9 and 11.5.

8. Bentonite types and how bentonite suspension helps in stabilization of bore

i) Normally two types of bentonite are available i.e. Sodium based and Calcium based. Bentonite is mostly available as calcium based in nature but as per requirement it is altered to sodium based to acquire requisite properties for specific purpose of stabilisation of vertical cut soil surface. It is not possible to distinguish between calcium based and sodium based bentonite only by mere visual inspection. For this pH value and swelling index of the two have to be tested.

ii) Sodium based bentonite has got higher liquid limit than other clay minerals and even much more than calcium based bentonite. Due to thixotropic properties the sodium based bentonite solutions form a gel and in turn due to osmosis effect the gel is transferred to cake. Sodium based bentonite normally takes 12 hours to get the maturity.

iii) Action of bentonite in stabilizing the sides of boreholes is primarily due to thixotropic property of bentonite. This property permits the material to have the consistency of a fluid when introduced into a trench or hole. When left undisturbed it forms a jelly like membrane on the borehole wall and when agitated it becomes a fluid again.

iv) In case of granular soil bentonite suspension penetrates into sides under positive pressure and after sometime it forms a jelly. The suspension then gets deposited on the sides of the hole and makes the surface impervious and imparts a plastering effect.

In case of existence of impervious clay in the bore however the bentonite does not penetrate into the soil but deposits only as thin film on the surface of the borehole. Under such condition stability is derived from hydrostatic head of the suspension [5]. It is thus recommended to have top level of bentonite suspension in a borehole at least 1.5 m. above ground water table.

9. Concentration of bentonite suspension[5]

To achieve requisite density of the bentonite solution the concentration of bentonite (as p.c. of bentonite powder by wt. to be mixed with potable water) is calculated as under

$\gamma_s = 1 + 0.006 \times C_s$ Where γ_s = Density and C_s is concentration of bentonite by wt.

Example : To achieve density 1.05 g/ml. of bentonite suspension,

$1.05 = 1 + 0.006 \times C_s$ or $C_s = 0.05 \div 0.006 = 8.33$ p.c.

i.e. in 1 m^3 (1000 litres) of water 83.3 kg. bentonite powder will have to be added to get density of 1.05 g/ml. of bentonite suspension.

10. Flow of bentonite mud

For economy in use of bentonite mud the overflowed bentonite solution from the pile bore during boring is collected by gravity flow through a temporary channel normally made on ground by clayey material and stored in a tank called 'Contaminated Bentonite Tank'. The bored muck mixed with bentonite suspension is collected in this tank and after a lapse of time the bored muck is precipitated and the rejuvenated bentonite solution is calmly overflowed and collected in another adjacent tank called 'Rejuvenated Bentonite Tank'. To maintain required density of this rejuvenated bentonite solution and to continue boring with this solution either matured bentonite jelly or fresh bentonite solution will be mixed time-to-time with this rejuvenated bentonite solution, agitated or recirculated for homogeneity.[5]

To eliminate calcium ions generated from cement slurry and accumulated in the rejuvenated tank, special additives e.g. Phosphates and 'Sodium Hydroxide' may be used. Again when sand content in contaminated bentonite is high particularly in case of piles in sandy strata bentonite solution is passed through De-sander where most of the sand particles are separated out and bentonite solution coming out of De-sander is circulated in the system after checking density requirement.

The Author has noticed at several bored piling sites use of only one bentonite tank for mixing and storage of used bentonite which is against standard practice.

11. Grouting of pile base/sides

a)In order to limit settlement of bored pile particularly where differential settlement between consecutive pile groups in continuous spans is critical, even in case of piles resting on rock cement grouting of pile base is sometimes adopted in important structures.

At Sirsi circle flyover in Bengaluru such cement grouting has been adopted to seal fissures in rock and improve bearing capacity.

c) Even cement grouting of sides and bottom of bored pile leaving MS Pipes at certain depth below cut-off level is done to increase side friction and ultimate skin friction resistance of pile in some projects in mixed soil condition.

At a gas based power plant at Kawas, Gujarat , this practice has been followed at a pressure 50 kg/sq.cm.

12. Bored Piles in rock

i) Mechanical Rotary rigs are suitable for installation of bored pile in normal soils and not at all suitable for rock strata where Hydraulic Rotary Rigs are to be deployed.

Figure 11. Rock Auger fitted to Hydraulic Rig

ii) Socketing of pile with low capacity Hydraulic Rotary rigs and ordinary rock cutting tools is difficult beyond 15 to 20 cm depth in hard rock strata of strength above 200 kg/sq cm. Specially designed rock cutting tools i.e rock auger with high capacity of rigs is essential to extend socketing between D and 1.25 D (where D = dia of pile) normally recommended in such rocks , ref Figure 11.

iii) Weight of chisel and capacity of operating winch shall be commensurate with diameter of pile, ultimate crushing strength(UCS) of rock, depth of socketing required in rock etc.

The Author has seen at a few project sites use of chisel of wt between 1.5 t and 2 t with winch capacity 3.5 t to install 1200 mm dia pile in hard rock with UCS 300 kg/sq cm and based on penetration of 2cm per hour the pile has been terminated even before achieving 1 D penetration in rock which is not a sound practice. One such chisel is shown in Figure 12. In such cases at least 3.5 t chisel, refer Figure 13 operated by 7.5 t winch should have been used for a satisfactory job.

iii) In hard rocks where Standard Penetration Test (SPT) cannot be conducted beyond N value greater than 200, the capacity of pile socketed in rock should be based on strength of rock as per design guidelines.

iv) When rock strata is reached and Hydraulic Rotary Rig is unable to drill through the same sometimes after one hour of drilling with negligible progress the pile is terminated at that level which is not a fair practice.

Such pile should be tested for load capacity and fulfillment of other criteria as per design requirement.

v) If rock socketing to a particular depth is mandatorily required and the Hydraulic Rig is not able to drill through the same with rock cutting tools available with the contractor it is a common practice to use tripod rig with heavy duty chisel of suitable weight. After drilling through overburden using Hydraulic rig the same is shifted and chiseling through rock is started with tripod rig.

However, risk with use of free fall type chisel in drilling in rock is that if rock strata is very hard and strength above 200 kg/sq cm control of alignment of chisel without a proper guide is extremely difficult. As a result a proposed vertical pile may be installed in rake.

The Author has experience in a marine project in basalt rock in Mumbai when some such vertical piles installed with tripod rig and chisel had to be exposed during adjoining excavation and rake measured was to the extent of 1 H in 5 V, ref Figure 14.

Figure 12. Rock cutting chisel of sub-standard quality in use.

Figure 13. Heavy duty rock cutting chisel

Figure 14. Vertical bored piles installed in hard rock as raker pile (rake 1 H in 5 V)

To avoid such a situation, where Hydraulic rig is used, depending on crushing strength of rock , cutting tool i.e rock auger should be purchased on advice from machine suppliers or suitable equipment i.e Reverse Circulation Drill should be mobilized under expert advice.

13. In case of Hydraulic Rotary Rig length of total telescopic Kelly mobilised with the particular rig should be sufficient to install bored pile upto the specified founding level. Also condition of joint between Kelly pieces and between Kelly and bottom tool should be checked periodically so that during boring / drilling operation neither any Kelly piece nor the tool gets detached and is lost in the borehole.

It is extremely risky to send a diver in bentonite suspension in a pile borehole to salvage a Kelly bar or tool detached from the Kelly of the rig.

14. In case while boring in silty / sandy strata with Hydraulic rig using drilling bucket a hard strata of soft clay or similar is encountered it is always advisable in such a situation to withdraw the bucket and fit drilling Auger to drill through this stiff layer as otherwise there is a possibility of damage of the bucket and detachment from the Kelly end. The bucket may be lost in the bore which may have to be abandoned and redesign of pile group with installation of additional piles etc. may be involved which is a very costly and time consuming process.

15. i) Bentonite pump mobilised for circulation and flushing of borehole in order to clean pile base to satisfaction shall be of adequate capacity for the dia and depth of piles under installation. As a guide, for installing 1200 mm dia pile of 20 m length, minimum capacity of bentonite pump for flushing and cleaning of pile base is 40 H.P.

The Author has seen use of only 15 H.P pump in such cases which is grossly inadequate for cleaning of pile base.

ii) Bentonite pump shall be located as near the pile bore as possible so that frictional loss in transport pipeline for bentonite upto the borehole location is minimum for maximum efficiency of the pump in cleaning of pile base.

16. Pile reinforcements

a) Where length of bored pile is large and dia is more than 600 mm it becomes difficult to handle, lift the pile reinforcement cage in one length and place the same inside bore. In such case stiffener reinforcement in cage should be closely spaced and suitable spreader beam(s) may be used. If after all these it is not possible to place the cage in single length inside pile bore the same would be divided in two or more pieces and joints welded after hanging the lower piece of cage inside pile bore by steel bar of suitable capacity placed on top of temporary liner.

b) Clear cover to pile reinforcements, laterals as links or spirals and stiffener rings shall be provided as per Para 6.11.4 of IS 2911 (Part 1/Sec 2) [2]. Cover blocks shall be strong and provided in enough Nos so that the cage retains verticality and does not get tilted.

17. Actual quantity of concrete consumed in a bored pile of certain nominal dia and length should be compared with its theoretical volume and average for about 20 Nos. piles should be calculated to ascertain increase in quantity over theoretical quantity as 'over break' p.c. This should normally be between 5 and 8 p.c. If increase is beyond 8 p.c. reason should be investigated. Also if in any bored pile actual volume of concrete consumed is even less than theoretical volume it is considered unusual and reasons should be ascertained through Integrity Test if no other apparent reason is established.

18. Recent advances in technology for installation of bored piles in India as noted by the Author

i)As an alternative to well foundation which has been considered as a tricky and time consuming process for construction of bridges in wide and deep waterway, large diameter bored piles are being installed using hydraulic rigs mounted on mobile piling gantry or jack-up platform/ spudded pontoon by contractors in India. One such arrangement has been shown in Figure 15.

ii) Bentonite being available in abundance in India and also being cheap is mostly used for stabilization of bore during installation of bored piles. However, bentonite having potential of polluting water is not allowed to be discharged in river or aquifer/water source from where drinking water is supplied. In some states in Europe use of bentonite is banned for stabilization of boreholes for piles, diaphragm walls etc.

In India, alternative material is available. It is highly concentrated dry synthetic polymer designed specifically for chemical interactions with diverse types of soil profiles. It has been successfully used in pile foundation and diaphragm wall construction in a number of private high rise building projects and metro construction where specified in contract. This polymer is bio-degradable and degrades in contact with concrete, non-toxic during all stages of use and after use as well. It is costlier than bentonite but where pollution of water source is involved, use of this polymer gets a preference in any case.

iii) In Sea-Link project in Mumbai, commissioned in Mumbai a few years back, bored piles upto 2 metres dia have been installed under pylon structures in cabled stayed spans in rock strata using Reverse Circulation Drills mounted on Jack-up barges. Socketing in rock has been extended upto 15 m depth in hard rock strata of strength upto 50 MPa. Also, special techniques have been adopted by erecting a steel tubular pile cofferdam for casting of a 6 metres thick pile cap resting on 52 Nos piles.

iv) In a Container Terminal at Kochi 1200 mm dia 75 metres long bored piles have been installed using Hydraulic Rig and 50 mm dia tor bars in 6m lengths using Dextra Bartec couplers.

v) In a No of high rise residential/ commercial building projects upto 63 storeys height on-going or recently completed, bored piles have been installed upto 1200mm dia and depth upto 62 metres below ground level.

D. LOAD TEST ON PILES (VERTICAL)

1. Static load test on piles shall be conducted as per IS 2911, Part 4 [6]

Figure 15. Hydraulic Rig mounted on mobile gantry

2. Initial load test on pile should be conducted in a fair way to finalise length of pile required for the particular dia to carry the design load with required factor of safety. On the basis of performance of test pile any revision in design should be done and also any improvement in construction practice, if necessary, may be adopted.

3. Following alternatives are normally followed for vertical load test on piles;

a) By erection of loading platform with concrete blocks, refer Figure 16 or with bags normally filled with stone chips or sand where sufficient space is available.

b) Where enough space is not available around test pile due to adjoining running road or obstructions etc normally 4 Nos Anchor/Tension piles with in-situ concrete are installed and suitable truss/girder arrangement is made to provide reaction. In such cases precaution shall be taken to provide length of anchor pile considerably less than test pile so that upward force mobilised through friction on sides of anchor piles does not have influence on vertical load capacity of test pile. Also spacing of anchor piles should not be too close to prevent free settlement of test pile and in any case, not less than 3 times dia of pile under test..

c) Soil anchors or rock anchors in rake may be used to provide reaction load for static load test where rock exists at or some depth below founding level of pile. Normally 4 or 8 Nos H.T.steel anchors of suitable capacity are used for the purpose. Figure 17 shows one such load testing arrangement using 8 Nos anchors for load test on pile in a river bridge project.

Figure 16. Pile load test using concrete blocks on loading platform

Figure 17. Pile load test using rock anchors

d) By taking help of adjacent piles at specified distance where available in a pile group with suitable arrangement for transfer of load in case of routine load test.

e) Where due to space constraints load test cannot be conducted by any of the above methods High strain type dynamic testing of piles for load capacity are in use in Indian projects now although these are conducted as per ASTM method and there is no BIS Code for such tests. There are some controversies in this regard and it is reported that static load test results on a pile in the same group where all piles were installed under identical condition varied widely being on the lower side compared to pile load capacity recommended on the basis of dynamic testing.

In view of above it is suggested that at least one static load test and one dynamic test be done on two piles preferably in the same group installed under identical conditions to compare the pile capacity determined by each method for comparison and to establish design load for pile before proceeding with further dynamic tests.

f) Before start of pile load test, finished level of top of test pile shall be recorded using precision leveling instrument and net settlement on completion of test as recorded through dial gauges used in load test shall be compared with level of top of pile measured through leveling instrument after rebound.

References

1. ______ *Driven cast-in-situ concrete piles*, IS 2911 (Part 1/Sec 1) : 2010, Bureau of Indian Standards, New Delhi.
2. ______*Bored cast-in-situ concrete piles*, IS 2911 (Part 1/Sec 2) :2010, Bureau of Indian Standards, New Delhi.
3. ______ *Code of practice for Plain and Reinforced concrete*, IS 456 : 2000, Bureau of Indian Standards, New Delhi.
4. Bhaskar Sangoju, Ravindra Gettu and B.H. Bharatkumar, Study of the parameters governing the chloride induced corrosion of reinforcement steel in cracked concrete, The Indian Concrete Journal, March, 2017, Vol. 91, No. 3, pp. 37-48.
5. 'Collapse of soil in pile borehole and its stabilization using bentonite suspension' by Mr D. Bhattacharyya (Indian Roads Congress- Vol 68-3, Oct, 2007).
6. ______ *Load Test on piles*, IS 2911 (Part 4) : 2013, Bureau of Indian Standards, New Delhi.

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