

PRECISION INSTALLATION OF TOWER STRUCTURE ON CONCRETE FOUNDATION

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Abstract: *Accurate installation of precisely machined structures on civil foundations maintaining all the required accuracies is an intricate task. In the present case, the interface of the structures is through four numbers of bearing plates and clamping bolts. To keep this bearing plate in position within required alignment is a challenge due to compaction required during concrete casting and drying shrinkage thereafter. Levels of the individual bearing plates can be maintained within 4-5mm at the time of casting the foundation. Due to difficulties in maintaining level and relative position of the bearing plates with clamping bolts, the interface holes of the structure may not match. These inaccuracies in position of clamping bolts and level of bearing plates will lead to deviation in mission critical alignment of structure. A precise method is developed at R&DE(Engrs) for installation of precisely machined structures demanding accurate installation on concrete foundation. The paper elaborates this innovative procedure adopted for installation of such structure with its RCC counterpart to achieve essential stringent alignment accuracy of 5 minutes in azimuth.*

Key words: *Pile foundation, RCC, Lattice structure, Flatness Co-centricity, Alignment, Verticality, Jig, Jig Transit*

1. INTRODUCTION

A large transient dynamic load was required to be supported at height of about 11m from ground on alluvial soil. On investigation, it was realized that very deep pile foundation can support this kind of a structure. A novel idea of making use of some part of foundation as main structure, which was any way to be constructed, & thereby reducing the overall height requirement gained momentum. Finally it was decided to construct half of the structure as foundation in RCC at site & remaining half to be fabricated & precisely machined in an industry. Both the structures are to be aligned accurately at site to obtain required level, alignment & azimuth accuracies. This scheme has marked advantages like a) Reduction in overall height of the structure from ground level which will reduce moment to be transferred to the foundation & susceptibility to the wind load being in cyclonic zone thereby eliminating requirement of batter piles to support heavy lateral loads, b) Compressed time schedule, c) Elimination of difficulties in machining, handling & transportation of otherwise a huge structure, & d) Saving in concrete requirement. However, there was a challenge of aligning of both the parts, one of which is cast in situ in RCC at site conditions on an alluvial soil & the other precisely machined on most accurate machines.

A lattice steel tower structure having approximate 2.4m x 2.4m cross section and 6 m height is required to be installed on and aligned with its 5.5 m deep concrete counterpart, having similar cross section & constructed integrally with 23m deep friction pile foundation. Peculiar characteristics of this structure are a) Heavy transient dynamic load in longitudinal direction at the tip of the structure along with considerable lateral component, b) Partly steel & partly RCC Construction, c) Requirement of co-centric central hole through out the steel & concrete portion, d) Founded on alluvial soil, & e) Stringent bore alignment & structural azimuth requirements.

The interface for mounting of the structure with the concrete foundation is through bearing plates and anchor bolts at ground level. There are two more interfaces which shall be aligned & be co-centric with the bore on the top of the tower structure. The bore at the top of the structure is at 5.5 m above ground level and other two independent precisely bored components are to be integrated at ground level (with steel structure) and a bout 5 m below ground level (with concrete structure).

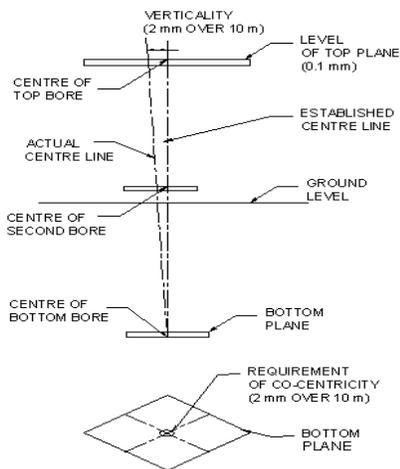


FIG. 1. REQUIREMENT OF ACCURACIES

Normal installation accuracies on concrete structures are fairly coarse. In this case, installation tolerance of 2 mm verticality, 2mm concentricity of three bores of about 1000mm dia. over 10 m and 0.1 mm level of the top structure with azimuth orientation within 5' was to be achieved for this partly steel (precisely manufactured in factory) & partly RCC (cast at site with greatest possible care) structure, as shown in Fig.1. Construction of this tower structure posed a challenge due to its unique heterogeneous construction, precision required, site conditions and severe transient dynamic loads (axial and lateral) to be supported at the top of the tower structure.

Interfacing & precise installation of structures with concrete foundations has always been a convoluted task. The bearing plates and anchor bolts are placed and held in position with respect to the formwork. The green concrete needs compaction to achieve desired density. During compaction of concrete, these bearing plates get dislocated. To worsen the situation, the forms themselves swell during placing and compaction. Shrinkage of the concrete worsens the task & the problem is further aggravated as the foundation is to be constructed on marine, highly plastic, alluvial soil. These dislocations and misalignment pose great problems during interfacing of structures requiring accurate alignment.

A template having foot prints of foundation bolts is primarily utilized in construction sector, which is barely sufficient to hold the foundation bolts in place, but is insufficient to keep the bearing plates in required level.

To avoid hassles with matching of anchor bolts, a pipe is embedded around the anchor bolt and open space is kept for adjustments which are subsequently filled with polymers. Much longer anchor bolt is

required in this case to accommodate the free length for adjustments, which calls for additional depth of foundation concrete. This method also does not ensure levelled base plates.

Expansions bolts are also used for installation of light structures where loads are less. In the present case, expansion bolts were not suitable because of heavy structure and higher dynamic loads.

To overcome all these difficulties, an innovative procedure is evolved at R&DE (Engrs) Pune, to install heavy load bearing structures, having stringent requirements of level, verticality and co-centricity of the central bores of the structure, at installation site.

2. CONCEPT

To arrive at the required azimuth which is a prime requirement, the same is to be transferred from the permanent references available at the finalised location & permanently marked on grouted machined steel plates at ground level using optical instruments. Both the axes shall be pre-marked on the ground before excavation starts in similar way. The bearing plates are to be embedded in foundation concrete while casting the concrete. Locations of these foundation plates are to be fixed with reference to the pre-marked axes.

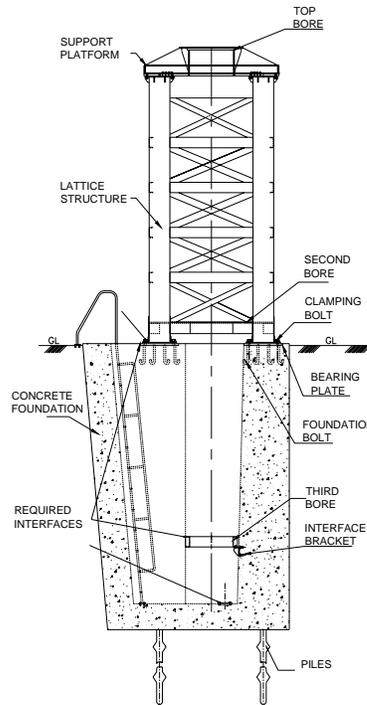


FIG.2 TOWER STRUCTURE WITH CONCRETE FOUNDATION

The individual level of the bearing plates shall be maintained within spirit level accuracies and relative

level between various bearing plates shall be maintained with help of water level. Features for mounting of bottom (third) bore shall be marked on the form work & cast in concrete when the work reaches at that depth & location. The forms are to be made stonger to reduce bulging & thereby dislocations. The concreting is carried out as per standard practice.

On completion of the concreting & curing for required time, relative level of the four plates is to be measured. The individual plates are to be levelled by differential scraping.

A drilling jig shall be manufactured, with which drilling & tapping shall be done on the bearing plates on foundation & corrsponding drilling of holes on the base plates of the tower structure for having accurate interfacing. Reference of the axes marked on ground shall be taken for referencing the drilling jig for drilling holes on foundation & reference of machined marked axes shall be taken for drilling on the tower base plates. This will ensure exact matching of all holes on both structures. Jig axes shall be matched with foundation / structure axes optically to ensure adequate accuracy. After optically aligned with axes, jig shall be clamped and holes shall be drilled. The necessary azimuth alignment is ensured by matching the machined markings with that of transferred axes on grouted plates. The same shall be measured and reported. Fig.2 Shows the tower structure assembly mounted on foundation.

Both surfaces of the tower structure viz. Top & base plates at bottom interface of structure shall be precisely machined to ensure parallelity. The structure shall be accurately leveled using suitable shims or scraping of bearing plates during its mounting on the foundation. Level shall be checked at the top of the structure using optical level. The verticality of the structure shall be checked using two Jig Transits (Optical instrument). The machine marked centerlines on sides of the tower structure & on grouted steel plates (before excavation) for foundation are used during verticality measurements. Required torque shall be applied to the clamping bolts.

The final configuration of the installed structure is to have three co-centric bores of which top one is a part of machined structure while other two are independently machined components to be installed accurately at 5m & 10m distance from the top bore. The second bore to be installed is near ground level while third bore is at 5m deep in side the foundation. The installation of these bores shall be carried out with the help of alignment telescope fixed at the centre of the top bore with the required accuracy of ± 0.2 mm.

After installation, the composite structure (steel structure and concrete foundation) shall be subjected to proof load test in longitudinal & lateral direction corresponding to operational loads. After the tests, the alignments are to be re-confirmed for their stability.

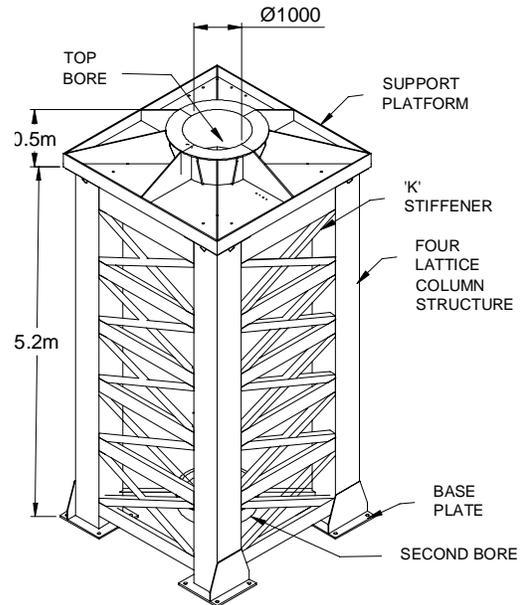


FIG.3 TOWER STRUCTURE

3. DESCRIPTION

Fig. 3 shows the tower structure. It weighs about 10 tonnes & is 5.5m high and needs to be aligned and installed on its concrete counterpart which is 5 m deep. Tower structure is made by bolting of Support platform with four lattice column structure. Support platform has machined top & bottom surfaces and has an accurate bored hole of required diameter with specified geometrical tolerance. The lattice column structure is also having machined surfaces at top and bottom with centre lines marked on machine on all four sides.

The foundation has to be constructed in marine plastic alluvial clay soil in coastal area. Twelve number of friction piles of 28 m deep having two bulbs are bored & cast in situ. On curing of the piles, a foundation pit of 7.5m depth is dug & the piles are cut at this depth. A pile cap of unusual size & shape is constructed over these piles. The pile cap has columnar structure on all four corners & a central pit of 5.5m depth. The pit is made waterproof since the water table is almost at the ground level. A bearing plate is cast alongwith foundation on top of each column at the top of the pile cap at ground level. The foundation is designed to transfer 400t of compressive load.

Installation accuracies required for the tower structure are: level of top face of support platform shall within 0.1 mm, verticality of tower structure within $\varnothing 2$ mm and concentricity of two bores on steel structure & one on foundation shall be within 2 mm over 10 m with azimuth orientation within 5'. The process followed for achieving these accuracies is enumerated under.

3.1 Transfer of references

A permanent true north reference is available near the site. This reference was transferred to the required location with the help of 1" theodolite on two numbers of grouted steel plates. The necessary co-ordinate frame with required azimuth with respect to true north was then generated using two 1" theodolites on eight numbers of grouted steel plates on the ground near the proposed location. The machine marks on these corresponding to the axes and azimuth is oriented with help of theodolite & the plates are fixed in ground. Fig 4. shows the markings made on ground.

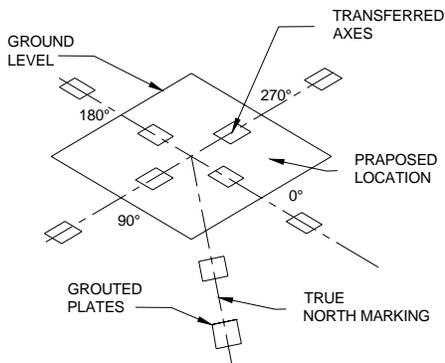


FIG. 4 TRANSFER OF TRUE NORTH

3.2 Positioning of bearing plates

Bearing plates with foundation bolts are manufactured separately. The base of each column of structure is 660mm x 660mm. Accordingly, bearing plate of 850mm x 850mm is used. Foundation bolts are designed to cater for moments on the tower structure and are welded to bearing plates. Pre-marked reference axes on the ground are used to align these bearing plates during foundation. The foundation bolts are placed within the reinforcement bars of foundation, levelled with help of spirit level and are tack welded to avoid any dislodgment during concreting & compacting. After complete curing, level of all bearing plates was checked again. The individual level of the plates was found to be within 1.6 mm and relative level among all plates was within 4.5 mm.

3.3 Interfaces below ground level

For mounting of bottom plate having the third bore at 10 m from top surface, two channels at 90 & 270 degree faces were cast in concrete, as shown in

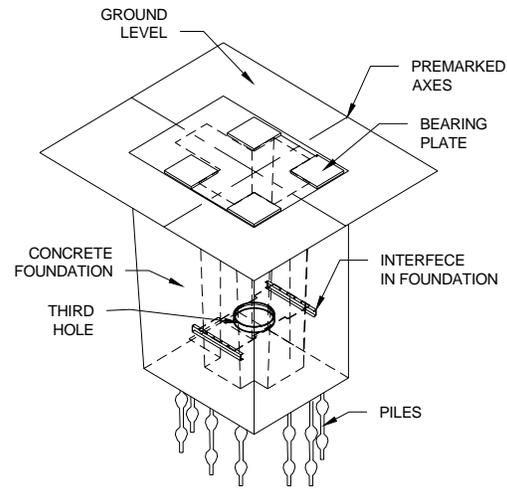


FIG.5 CONCRETE FOUNDATION

fig. 5.

These features were aligned & oriented with reference to the axes marked on the ground & fixed in the steel formwork used for supporting green concrete.

3.4 Manufacturing of Drilling Jig

To match the clamping bolts on foundation with the holes on structure base plates, a drill jig was conceptualised, as shown in fig.6. Here, the machine co-ordinates for generating the holes on structural base plates were fed to the CNC Floor borer. The same machine with similar machining set up as that for the structure was employed and same CNC program used to generate matching interface bores for the transfer Drill Jig. In the same set up the machine markings on the drill jig were made for referencing it with pre-marked foundation for drilling and tapping for clamping bolts. This also ensures the necessary

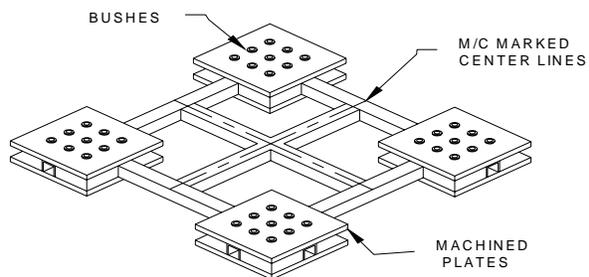


FIG.6 DRILLING JIG

azimuth of the structure during installation.

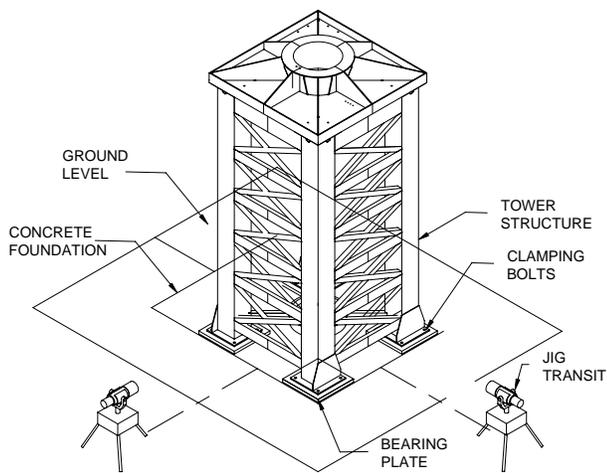


FIG. 9 MOUNTING OF TOWER STRUCTURE

Both the butting faces of the jig are machined surfaces for matching with tower base plates & foundation plates and adequate strength to avoid deflection during machining & its use. Centre lines & azimuth orientation are marked on the faces of the jig with fine machine mark. With reference to centre point and recorded locations during structure machining, holes were drilled on resting plates of jig. Bushes of required drill size were manufactured to insert into jig holes and to provide guide while drilling holes on bearing plates. The marked centre lines on jig are used to align jig with pre marked centre lines on foundation with help of Jig transit & it is levelled with help of precision optical level. Jig was clamped with foundation after alignment and drilling is carried out by portable drilling machine. The jig was stress relieved after welding & before machining to avoid any distortion due to locked up stresses.

3.5 Manufacturing of Tower Structure

Tower structure is a lattice structure consisting of Support platform and four columns laced together by

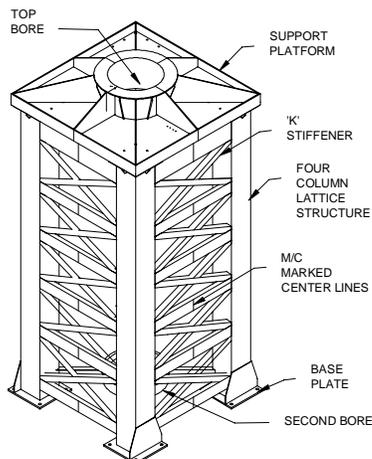


FIG. 7 MACHINED TOWER STRUCTURE

stiffeners & tie beams, as shown in fig. 7. The loads are transferred at the Support platform which is the topmost part of the structures. The column structure further transfers the load to the RCCS structure & is a

connecting member between the support platform and concrete foundation.

The support platform is a built up structure of size 2.6 m x 2.6 m. The parallelism between top and bottom face of support platform was maintained within 0.05mm on CNC Floor borer. The holes for clamping with column structure were bored in same setting. The top central hole was machined with its top face on vertical turret lathe & bore diameter was maintained with in 0.1 with perpendicularity within 0.05mm with the face. Centre lines were marked on top surface and sides on machine itself.

The column structure has four 400mm x 400mm columns laced & braced with 'K' stiffeners and tie beams. Reference pads on two sides were welded to the columns. Initially machining on these pads was done to establish the references. With these references machining of base plates on either side of the column was done in one plane. Parallelism between these base plates was maintained within 0.05 mm by machining on both the ends in two machining setups by rotating the structure by 180 degrees. Axes were marked on sides during machining. Holes were bored on bottom with specified coordinates for jig and on top with specified coordinates for support platform.

3.6 Drilling with Jig on RCC structure

A foundation with bearing plates and interfaces below ground level were fully cured and ready for installation. The pre-marked axes with respect to true north were available on the ground. These axes were transferred to bottom of central pit in the foundation with the help of theodolite. The Jig was positioned on the bearing plates, optically aligned with the marked axes and clamped, as shown in fig. 8.

Total 32 numbers of holes were drilled with portable drilling machine. After this jig was removed and tapping was done by the machine itself. Thus the foundation was made ready for installation of tower structure.

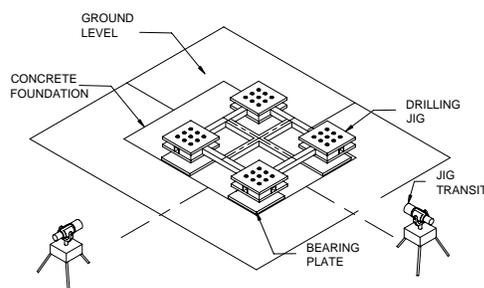


FIG. 8 MOUNTING OF DRILLING JIG

3.7 Installation of tower structure

Tower structure was positioned on the bearing plate in vertical condition approximately at the desired location. Since the structure is heavy & bulky, it was difficult to shift or rotate it precisely to align with the marked axes. To overcome this difficulty, tangent screw arrangement was made to push the structure in required direction and distance. Two theodolites were positioned on two axes & the machined marks on the tower were sighted & aligned with the marking on the ground. The structure was clamped with foundation plates by clamping bolts after alignment with the axes, as shown in fig.9.

3.8 Level, Verticality & Alignment Checks

The top surface of the structure where the loads are transferred is a critical location as far as the alignments are concerned. The level of support platform is a factor of prime importance with defined verticality. The level was monitored using optical level mounted on the support platform itself, as shown in fig.10. Error observed after initial reading was corrected by adding machined shims ranging from 0.01 to 0.05mm thickness. Level of top surface of 0.06mm was achieved against minimum specified in 0.1 mm. Required torque was applied to clamping bolts and level was cross checked.

For checking verticality of tower structure two jig transits were mounted on two perpendicular axes with reference of the markings made on the ground. The instruments (Jig Transits) were set along 0° and 270° respectively, as shown in fig.11, so that always two adjacent sides can be sighted. The jig transit reads shift of the axis with respect to the reference. All the four sides of the tower structure were checked and the verticality achieved was 0.09 mm against specified value of 2mm.

The three bores, two on the steel portion & remaining one in the RCC counterpart were to be aligned. The top bore on the support platform is accurately machined after welding & stress relieving.

Machined axes marks are made on flange for reference. At other two holes independently machined rings having similar axes marked were fixed with the structure after alignment with the top. An optical

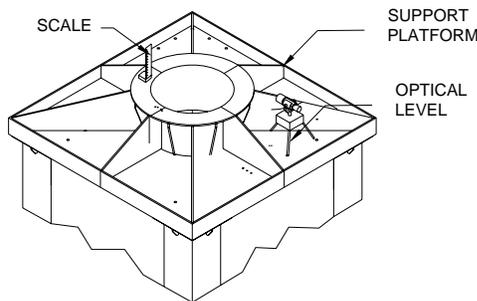


FIG. 10 LEVELLING OF PLATFORM

alignment telescope was fixed along the centre of top

bore of support platform using a fixture. Since the support platform is already levelled, the instrument will generate required axis perpendicular to it, as shown in fig.12 & fig.13.

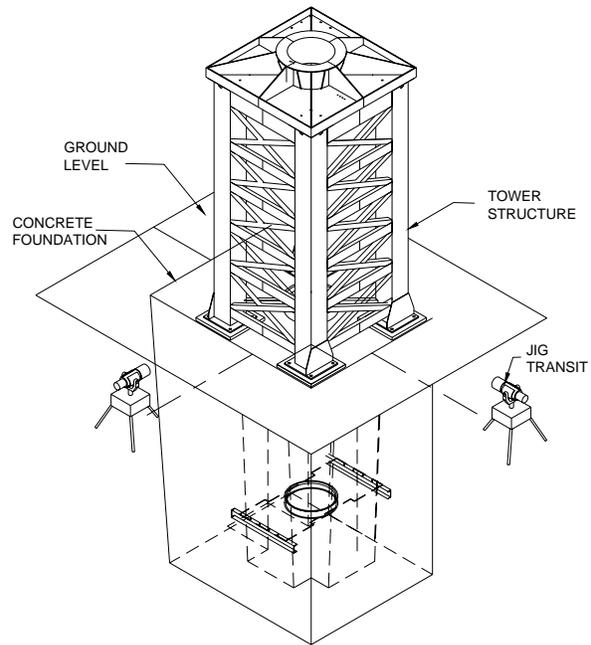


FIG. 11 VERTICALITY OF TOWER STRUCTURE

Since the bottom plate is farthest (at 10m), it was to be aligned first to minimise error in perpendicularity. An optical target was fixed in the bottom hole and was brought within the required alignment & dowelled. The middle plate having

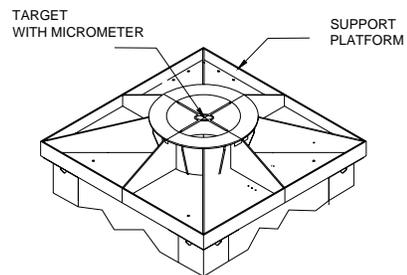


FIG. 12 ESTABLISHMENT OF TOP BORE CENTER

second bore was also aligned using same procedure. Co-centricity of 1.03 mm over 10 m was achieved against specified value of 2mm over 10 m.

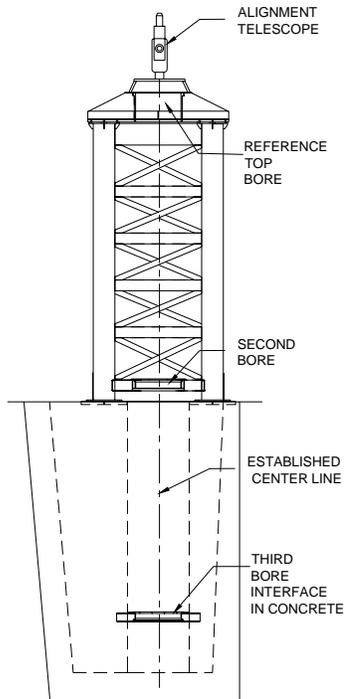


FIG. 13 ALIGNMENT TEST

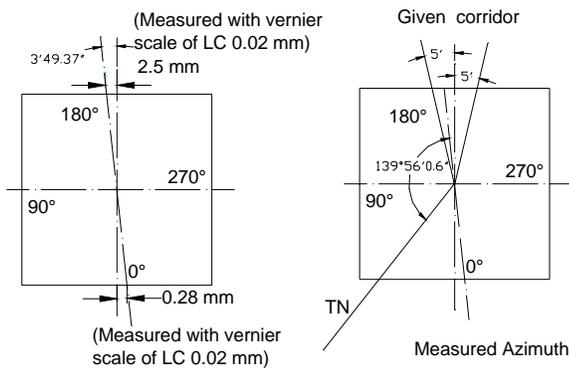


FIG.14 ORIENTATION WRT TRUE NORTH

4. ORIENTATION WRT TRUE NORTH

The readings of shift of centre lines of each side faces of the structure at top were recorded. Accordingly, new generated axes at top were found. From these, new generated rotation of top plane was drawn and the exact azimuth of the structure was found as shown in fig. 14

5. CONCLUSION

The requirement of precision installation of accurately machined structure on concrete foundation made in alluvial soil, was successfully achieved by using the above procedure. Thus the evolved method is well established and validated for further such kind of precision installations.

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