Strengthening of Equipment Foundations on Loose Soils of a Power Plant in Eastern Uttar Pradesh

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Abstract. Small equipment foundations of a power plant placed on a 5-6-m thick poorly compacted fill underlain by rock experienced excessive settlements. Strengthening measures adopted included installing micro-piles extending to the top of rock and filling large voids in the fill with a thick grout of cement and sand. This highlights the importance of proper compaction as well as the need to test the bearing strata adequately before constructing foundations on fill.

Keywords: Excessive Settlement, Goeotechnical Investigations, Foundation Strengthening, Micro-piles, Cement-grouting.

1 Introduction

At a major thermal power plant in eastern Uttar Pradesh some small equipment foundations were placed on backfilled soils adjoining the turbo-generator (TG) foundation. The TG foundations were seated on the rock at about 8 m depth. The equipments were installed on foundations cast on the backfilled soils.

The filling extended to about 4-6 m depth underlain by rock. These foundations, generally ranging in width from 1 to 2 m bearing just below the floor level were designed for a low bearing pressure of about 4 T/m^2. The premise was that compacted fill can withstand this low bearing pressure safely.

However, the compaction of the backfilled soil was inadequate. This resulted in excessive settlement of several foundations even before the equipments were made operational. The failure was triggered by the seepage of rainwater into the loose soils. The measured settlement of various foundations ranged from 16 mm to over 180 mm.

Foundation settlements were higher towards the TG side where the backfilling depth is high as compared to the opposite side. Due to foundation settlement, few cracks in the nearby area paving slab was also observed.

Some equipments that had experienced excessive settlement are listed in Table 1.

Table 1. Measured Settlement of Equipment Foundations on Loose Fill.

Equipment	Measured Settlement, mm
Seal Oil	40-180
Stator Cooling water skid	60 to 193
WO & LO coolers of MDBFP-A	40 to 110
CPU service vessels	16 to 60
Vacuum Pumps	30 to 60
EHC foundation	35 to 60
ST forced cooling air foundation	35 to 60

All these foundations were less than 2 m wide and were designed for a net bearing pressure of 4 T/m^2. Selected photographs of the settled foundations are presented on Fig 1 and 2.

Fig.1. Cracks in the seal oil foundation

Fig.2. Tilted foundation due to settlement

Since foundations which are placed over inadequately compacted backfilled soil has settled even before the full load was applied on them, therefore the possibility of these foundations to settle further cannot be ruled out as the extent of compaction in the backfilled soil was not uniform.

The possibility of settlement of other foundations which are not settled yet was suspected. Preventive action was required to be taken around all the foundations which are placed over insufficiently compacted backfilled soil in the main power house area especially all around the TG foundation where the depth of back filling is more.

2 Soil Conditions

To investigate the soil conditions, boreholes were drilled to the top of the rock. Also, dynamic cone penetration tests were performed and terminated upon meeting refusal on the underlying rock. Fig. 3 presents typical borehole data.

The borehole data indicated that below the 0.5 m thick floor (150 mm thick RCC, 50 mm thick PCC, 200 mm thick stone soling), the natural soils consist of loose sandy silt/ clayey sit of low to medium plasticity. The liquid limit ranges from 22-46% while the plasticity index is in the range 8-26%. The shrinkage limit is in the range of 13.9-14.8%. The fill extends to 4-6 m depth below which, rock is met.

The field SPT-N values [1] generally range from 1 to 4 indicating the soils are very loose / very soft to soft in consistency. Refusal (N>100) was met at the soil-rock interface at about 4 m depth.

Dynamic cone penetration tests (DCPT) were performed in accordance with IS: 4968 (Part 2)-1976 RA 2007 [2]. DCPT blow-counts (N_{DCPT}) generally range from 0 to 4 to about 3.5 m depth. Refusal was met at the soil-rock interface. Fig. 4 presents results of plots of N_{DCPT} versus depth.

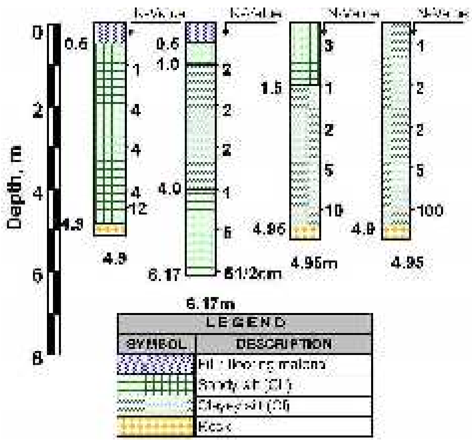

Fig.3. Typical borehole data.

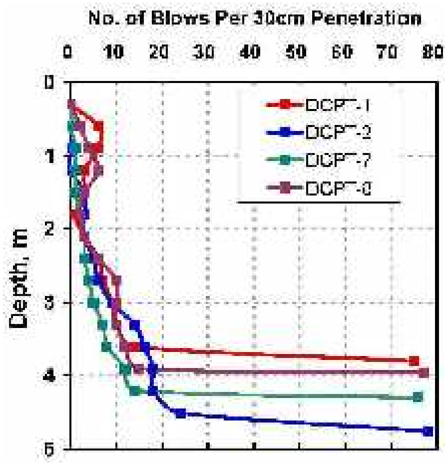

Fig.4. Typical DCPT plots

In-situ density tests conducted below the floor slab suggested that field density of 75-90% of the maximum dry density values (standard Proctor [3]) as against the specified minimum of 95%. It is likely that the deeper soils may be looser with percentage compaction of 50 to 75%.

3 Engineering Solution

Due to site constraints, it was not feasible to dismantle the equipments, excavate the loose soils and place back in layers with proper compaction. To arrest the settlement and ensure safe foundations, various methods were explored considering site conditions.

The engineering solution was aimed at restricting further settlement of the loose soils and to transfer the loads safely to the underlying rock.

3.1 Trial Grouting

Initially, trial cement grouting was done all around the foundation to the top of the rock so to form a grout curtain. This shall provide lateral confinement to the soils and restrict further settlement. The grout was prepared by mixing 1 bag of cement with 100 litres of water and pumping into the grout hole until refusal to further grout intake was met under a steady pressure of 1.5-2 kg/cm^2 (Sanjay Gupta, et al. 1997 [4]). The intake of cement grout was 60 to 950 litres of grout (0.5 to 9 bags of cement) per grout hole. Typical photograph of the grouting in progress is illustrated on Fig. 5.

Fig.5. Trial grouting in progress

At places, due to presence of large voids, adequate pressure did not build up even after pumping large quantities of grout. At such locations, soil investigation after grouting did not show much improvement in soil conditions suggesting that the voids were interconnecting and the grout was flowing in an uncontrolled manner.

Considering the uncertainties in grouting in very loose soils, likelihood of high cement consumption and uncontrolled flow direction of grout, grouting adjacent to the foundations was not considered as a preferred sure-shot option.

3.2 Micro-Piles

3.2.1 Installation Scheme

Micro-piles of 150 mm diameter with casing extending to the top of the underlying rock were installed below and adjacent to the equipment and structurally connected with existing foundation. Prior to piling, the concrete floor slab was cored using a diamond cutter. Boring was done to top of rock and the reinforcement was lowered into the hole. PVC pipe of 150 mm diameter was inserted into the hole to the top of rock. Concreting was done using coarse aggregate of 10-12 mm size to allow flow of concrete into the pile bore. The reinforcement at top was bent and welded to the existing reinforcement of the foundations.

3.2.2 Design Concept

The skin friction of the loose soils was ignored for the purpose of analysis. Since the pies were planned to be seated on refusal stratum / rock, the end bearing component was considered in the design. The refusal stratum was treated as a dense sand for purpose of analysis with an angle of internal friction of at least 35 degrees. The vertical compression capacity of the pile was computed as per IS: 2911 Part 1 Section 2 – 2010 [5].

Conservatively, each pile was designed for a safe vertical load carrying capacity of 1.5 tonnes in end bearing for a factor of safety of 2.5. A total of 511 piles of 2 to 4 m length (depending on the depth to rock) were installed in the area adjoining the TG foundation.

3.2.3 Installation Sequence and Guidelines

The micro-piles were installed as per the section drawing illustrated on Fig. 6. The micro piles were resting on rocky stratum below.

Initially, a hole was drilled in the paving slab for micro piles. Through these holes cement sand slurry (1:4) in pump-able consistency was pumped below the slab to fill up the void space between slab and filling underneath. Drilling into the soil for micro piling was started after 24 hours of slurry pumping to allow slurry to settle and consolidate. The hole drilled in paving slab was roughed before start of concreting for adequate bonding.

The maximum spacing guidelines, followed for micro-pile execution is shown on Fig. 7. The first row of micro-piles is installed as close as possible from the edge of foundation or end of floor slab. The spacing between the micro-piles is 1.75 m centre-to-centre. The second row of micro-piles is placed at 1.5 m distance away from the first row. All the further rows of micro piles are installed at 1.75 m spacing.

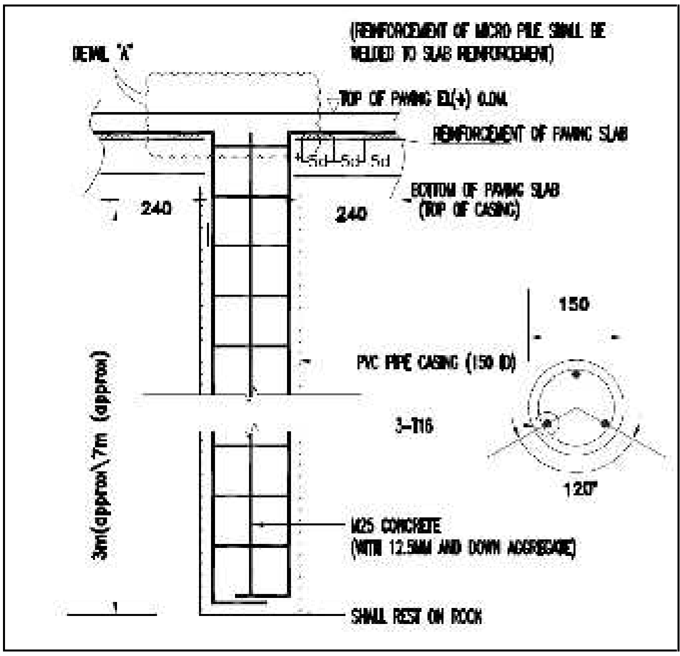

Fig.6. Typical section of micro-pile

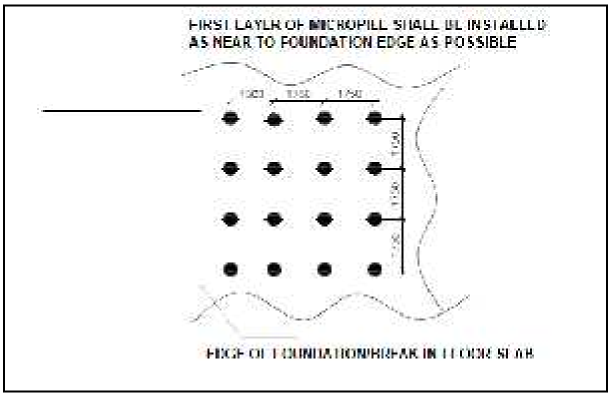

Fig.7. Spacing guideline for micro-pile

3.2.4 Interconnection with Existing Ground Floor Slab

The micro-piles will be effective only if the piles are suitably connected with the existing floor slab and the load transfer mechanism is taking place. The connection detail of slab with micro pile reinforcement is shown in Fig.8.

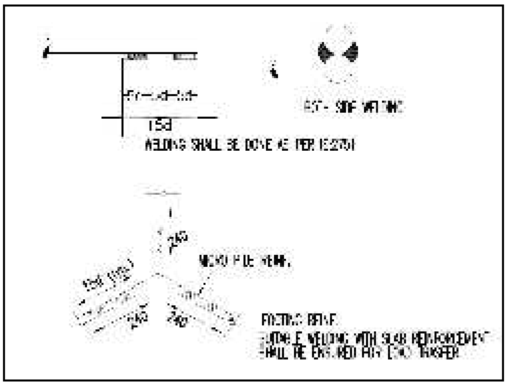

Fig.8. Interconnection details of micro-pile and floor slab

4 Grouting

In areas where large voids were observed beneath the floor slab (formed by settlement caused by seepage of rainwater through the loose soils), a thick grout of cement plus sand was pumped to fill the voids. Fig. 9 shows the concrete flooring between equipment cored for grouting purpose.

This was done as a preventive action around all the foundations and paving area which are placed over insufficiently compacted back filled soil in the main power house area especially all around the TG foundation where the depth of back filling is more. Improvement of soil using grouting was envisaged to avoid further possibility of settlement.

The purpose of injecting grout was to increase shear strength and to decrease compressibility and permeability. Displacement/compaction grouting consists of using cement slurry or cement-sand mixture which when forced into the soil under pressure displaces and compacts the surrounding material.

A 20-mm diameter conduit pipe was placed in the hole. A steel plate was attached to the conduit pipe at 0.5 m depth. A concrete plug was placed in the grout hole at 0.5-m depth below ground level to seal the hole and to ensure that the soil below the foundation level is strengthened. A typical section of the grout hole is illustrated on Fig. 10.

5 The Lessons Learnt

This case study demonstrates the importance of proper geotechnical investigation and ensuring thorough compaction of fill on which foundations will be supported, even if it is lightly loaded.

Even if foundations are lightly loaded, placing them on loose uncontrolled fill is fraught with serious risk. On major projects, timelines often dictate such decisions but should be assiduously avoided. Prior to construction, the extent of compaction of the fill should be independently verified to ensure adequate foundation behavior.

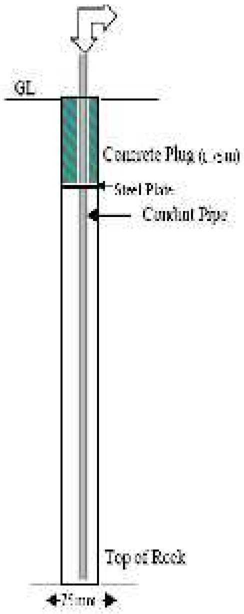

Fig.9. Holes cored in between equipment for grouting   Fig. 10. Schematic of grout hole

Micro-piles extending to the top of the underlying rock were effectively used to transfer the loads safely and bypassing the loose fill. Grouting in the open areas between the equipment was done as a precautionary measure to fill large voids.

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