Retrofitting of N–W Corner of Kolkata High Court Heritage Building Through Micropiles and Grouting

Satyendra Mittal and G. L. Sivakumar Babu

Abstract Monumental buildings keep experiencing the distresses due to weathering effects or other reasons. Micropiling had been found very useful for retrofitting works (Srivastava et al. in stability analyses of 18 m deep excavation using micropiles. IGC, N, Delhi, 2016). Kolkata High Court building is a beautiful, majestic building, built in 1872, over a large area, along Hooghly River. The North–West (N–W) corner of the building had experienced some settlement in the year 2014–2015. Authors had inspected the building in December 2015 and again in February 2016. The site visit report indicated that there was differential settlement of shallow foundation of building in its N–W corner. Ingress of Hooghly River water up to foundation was one of the possibilities of distress in foundation. The micropiling followed by grouting was found the most appropriate solution for the site. The site solutions shall be instrumented also over a period of 10 years or so, to periodically monitor the settlement, if any, of building after the treatment.

Keywords Micropile · Ground improvement · Retrofitting · Grouting
Monumental building

1 Introduction

Kolkata High Court building is one of the monumental buildings of Kolkata and is founded on soft soils. Its construction work was completed in 1872. In the year 2014, the building experienced distress in the form of cracks in the super structure at different locations, due to settlement of the foundations.

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Authors of this paper visited the site in the months of December 2015 and May 2016 to probe into the reasons of settlement of building. It was decided to get the soil investigation done at this site. The PWD authorities confirmed that there was no event like earthquake, etc., at this site. However, ingress of water into foundation from Hooghly River could not be ruled out as it was flowing hardly 300 m away from the N to W corner of the high court building. Based on the detailed soil investigation report and the site visits, micropiling and grouting were found the most appropriate solutions for this site. It was informed by site officials that the stresses due to vertical loads were in the range of 22–24 t/m^2. During the site visit, it was noted that differential settlements were in the range of 8 mm or so. The damages are shown in Figs. 1, 2, 3 and 4.

Fig. 1 A view of cracks in wall (outer view of N–W wall)

Fig. 2 Damage seen on the wall

Fig. 3 Distinct cracks seen on wall (N–W) side

Fig. 4 Differential settlement in floor

2 Subsoil Conditions

The soil investigations were performed by Civil Engineering Department of Jadavpur University Kolkata. Information from six number of boreholes, including field testing using SPT and laboratory tests, has been used to understand the type of soils, location of water table, etc. Results in general show that the soil profile is variable in nature and the groundwater table is at around 2.3 m level (during non-monsoon period) and around 1.5 m (during monsoon period). Typical foundation has width of 2.13 m and is resting on filled up compacted soil varying from 1.5 to 5 m. It is followed by soft clay of undrained strength varying in the range of

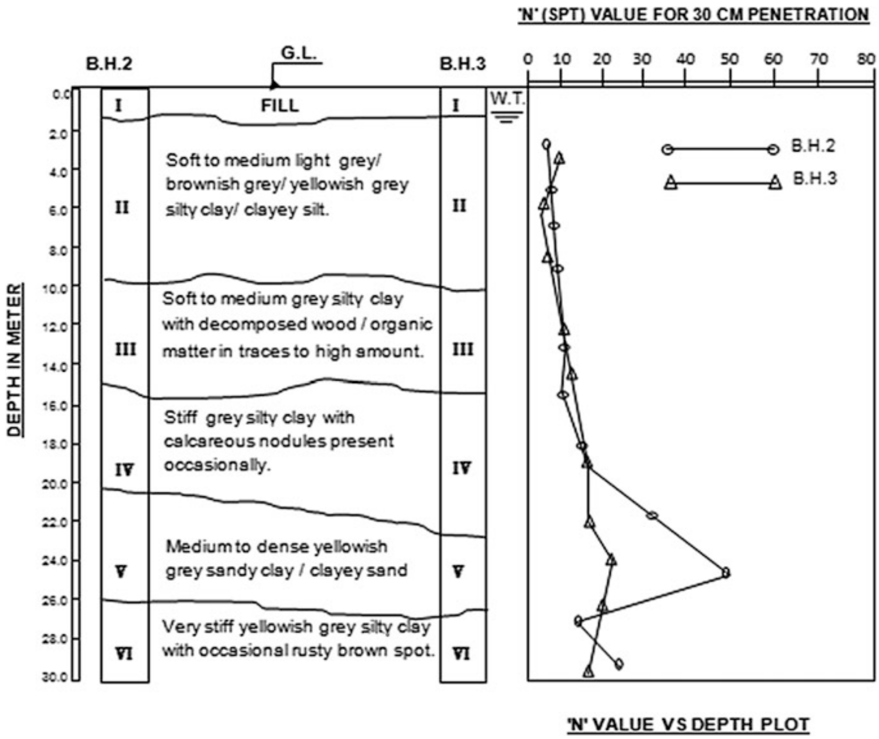


Fig. 5 Soil profile log at Kolkata High Court site

3.6 t/sqm. Typical soil has stiffness of about 8–10 MPa (evaluated from consolidation tests) and is considered to be low to medium and is expected to lead to settlements when there is increase in loads (Mittal and Shukla 2014). The representative bore log of site is shown in Fig. 5.

3 Possible Solutions for the Site

It was informed by site officials during the site visit that the stresses due to vertical loads were in the range of 22–24 t/m^2. During the field visit, it was noted that differential settlements were in the range of 8 mm (at three locations, the settlements were in the range of 6, 7 and 8 mm, respectively) over a period of about six months and are the clear indication of excessive distresses noted. Hence, immediate ground improvement of the foundation soil was necessary. It was proposed that in addition to the micropiles suggested, grouting should also be used to improve the ground below the foundations. For the purpose of analysis, properties of micropiles given in Table 1 have been proposed to be used. Figure 6 shows the configuration

Table 1 Properties of the in situ soil and improved soil

	In situ properties	Improved properties
Properties layer 1 (0–3 m)		
Unit weight (kN/m^3)	18	18
Young's modulus (kPa)	20,000	40,000
Poisson's ratio	0.2	0.2
Cohesion (kPa)	10	40
Friction angle (°)	20	30
Properties layer 2 (3–6 m)		
Unit weight (kN/m^2)	18	18
Young's modulus (kPa)	15,000	35,000
Poisson's ratio	0.35	0.35
Cohesion (kPa)	36	60
Friction angle (°)	1	25
Properties layer 3 (6–17 m)		
Unit weight (kN/m^2)	17	17
Young's modulus (kPa)	10,000	25,000
Poisson's ratio	0.35	0.35
Cohesion (kPa)	20	40
Friction angle (°)	1	25

of micropiles. Hollow steel pipes of 125 mm diameter and 3 mm thick at 250 mm spacing (c/c) for 9 m length are suggested as micropiles. In addition, four bars of 20 mm diameter (or 12 mm diameter) made of Fe 500 steel with proper centralizer to keep them at the centre and filling the annular space with M 20 concrete are suggested. The grouting of the foundation soil has also been suggested. As the material is clay, grouting using resins/cement has been suggested. Literature shows that cement/resin grouting improves the strength and stiffness of the soft soils (Mittal 2016). For considering the effect of grouting, the properties of the original ground are assumed to be increased. The improved properties in terms of stiffness, strength, cohesion and friction angle are given in Table 1.

For the sake of analysis (conducted through Plaxis 2010 software), two cases were considered in the current study, one is without ground improvement and other with ground improvement with micropiles. Mohr–Coulomb soil model was provided for all the soil layers. Table 1 shows the properties of soil used for the analysis and also the improved properties of the soil after the ground improvement. As there was excessive mesh deformation when the footing was provided below the surface, the soil above the footing was provided as a surcharge loading. This provided the results slightly on the conservative side. A surcharge loading of 38 kN/m^2 was provided as the surcharge loading corresponding to 1.9 m overburden soil. Groundwater table was considered to be 3 m depth. A loading of 400 kN/m^2 was applied as the footing stress, and the loading was provided in increments.

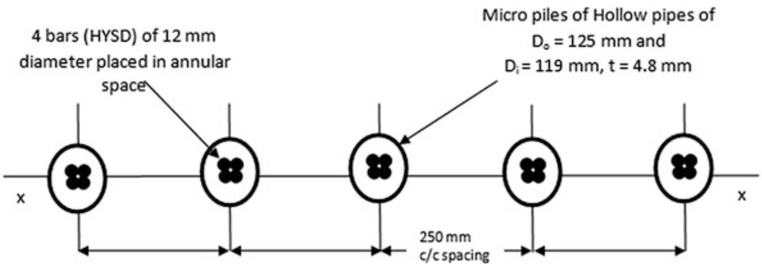


Fig. 6 Scheme for micropiles

Figure 6 shows the scheme for layout of piles. Figure 7 shows the mesh generated for the initial condition without ground improvement, and Fig. 8 shows the model with ground improvement and micropiles. Micropiles were provided at 0.4 m away from the edge of footing. Micropiling is suggested from analysis, up to a depth of 9 m below the footing load. Figures 7 and 8 show the deformed meshes for both the cases. Figure 9 shows the load—displacement curve for both the cases. Boundaries of the mesh have been provided at adequate distance away from the loading point.

The properties of the micropiles were calculated as per Srivastava and Babu (2016). The EI value was taken as 2×10^6 kN-m^2/m, and EA value taken was 1743 kN/m.

From Fig. 9, it is clear that for in situ condition, the soil fails well below the applied load of 400 kN/m^2. For the improved ground, the ultimate load is reached when the displacement reaches a value of 36 mm. The existing stress being in the range of 240 kN/m^2; the corresponding displacements are less and will take care of further loading as well.

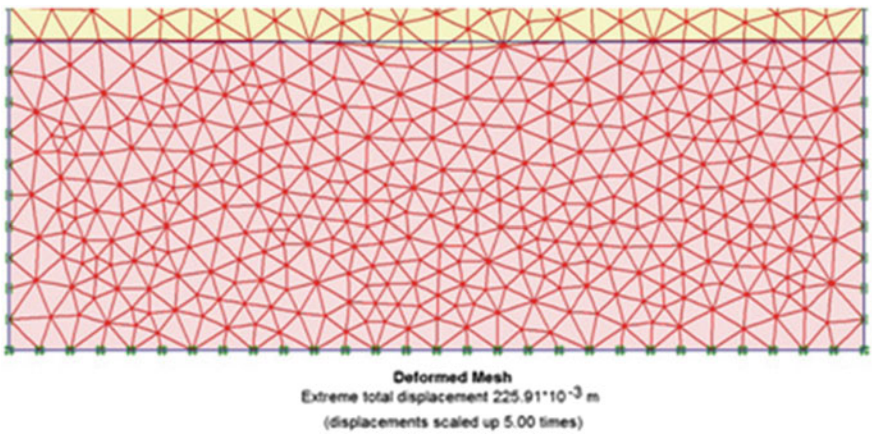


Fig. 7 Deformed mesh after loading (sample fails below ultimate load) in the in situ case without ground improvement

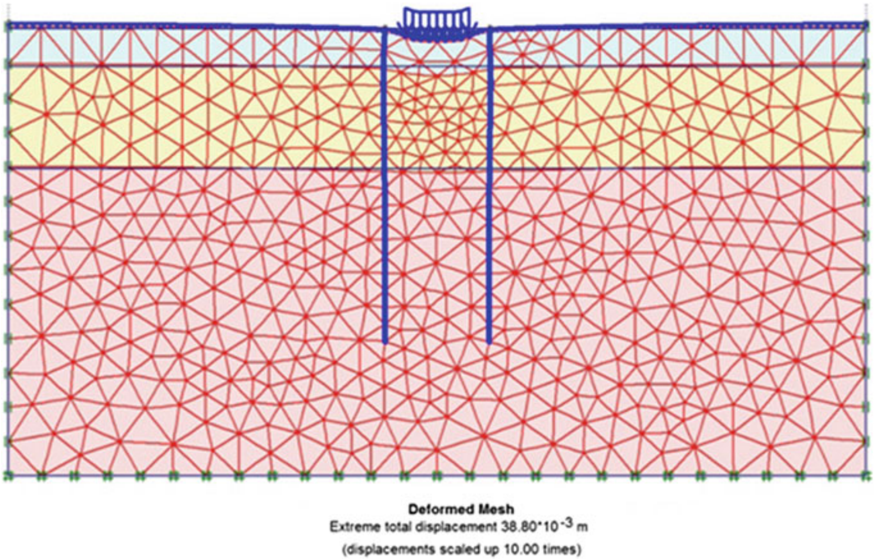


Fig. 8 Deformed mesh after loading for case with ground improvement and micropiling

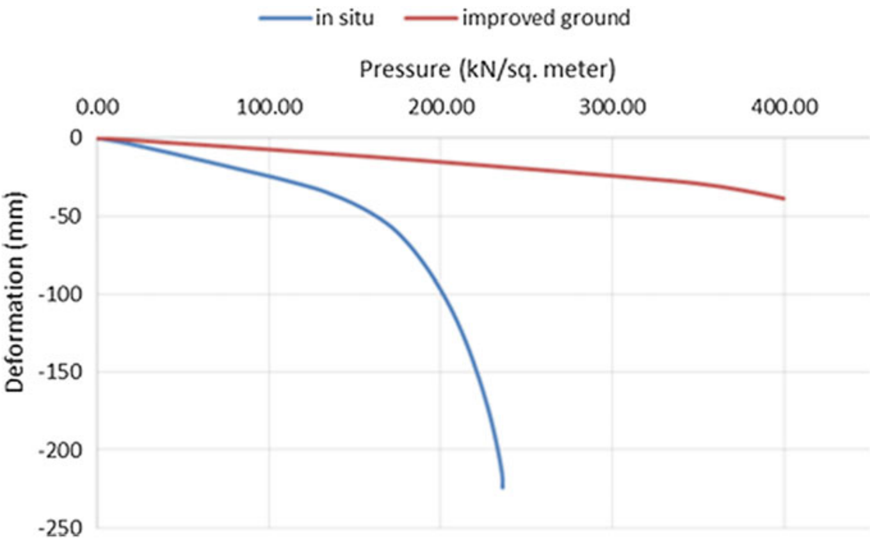


Fig. 9 Load versus displacement curve for in situ soil and improved ground

4 Grouting Technology

At the high court site, the water table is at around 2.3 m depth or so. The River Hooghly is also towards North–West side and is hardly at a crow distance of 250–300 m from high court building. Hence, regular seepage of river water towards high court building cannot be ruled out. Further, in N–W corner only, library of HIGH COURT is situated, where very high loads of periodicals and journals were also noted during site visit of authors. Hence, it has been strongly recommended to do grouting around foundation and up to minimum of 3 m depth below the foundation. The grouting shall be done after construction of micropiles. Since it is steel micropile, it will be very quick to install. The concreting shall also be done (poured) within pipe itself.

5 Construction Methodology

5.1 Construction of Micropiles

The micropiles shall be made of hollow pipes with O.D as 125 mm and ID as 119 mm (Mittal 2016). In the pipe, 4 bars of 20 diameter each (or 12 diameter each) shall be placed duly tied up with GI wire and then M 20 concrete slurry shall be poured in the annular space left there. The c/c spacing of vertical micro plies shall be 250 mm as shown in Fig. 6. The distance of micropile shall be 3 times of diameter of micropile (i.e. 375 mm, say 400) from outer edge of foundation as shown below (Fig. 10). The micropile shall have a pointed shoe at the bottom for ease in driving. It is worth mentioning here that micropiling shall be done only outside the building (i.e. on the external side only) and pipe will be left into ground permanently. Thus, it will be sacrificial pipe.

It has also been suggested to protrude micropile 250 mm outside existing floor level of building on its outside, and these protruded portions of all micropiles shall be tied up with a RCC beam or jointed by a channel section of suitable size. This capping beam shall provide additional and composite rigidity.

6 Grouting Process

Grouting shall be done after the micropiling is done. Here, grouting has been proposed with resins (instead of cement slurry). “DRUCSTONE” grout material is one such material and is popular in international market. It is difficult for the authors of this report to provide generic names of grouting material. It is recommended that grouting be done with a very high grout pressure under the supervision of a very competent geotechnical engineer. Grouting shall be done within at least 3 m depth

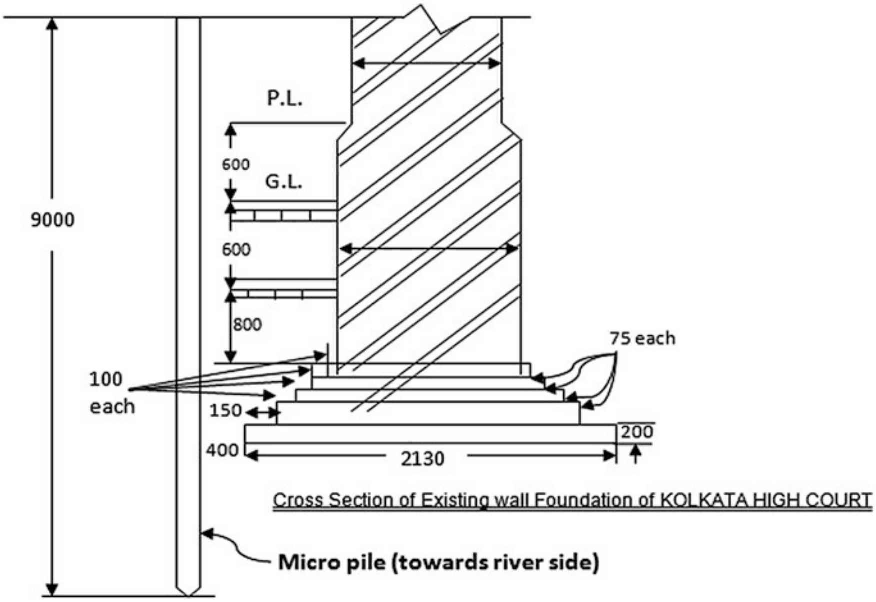
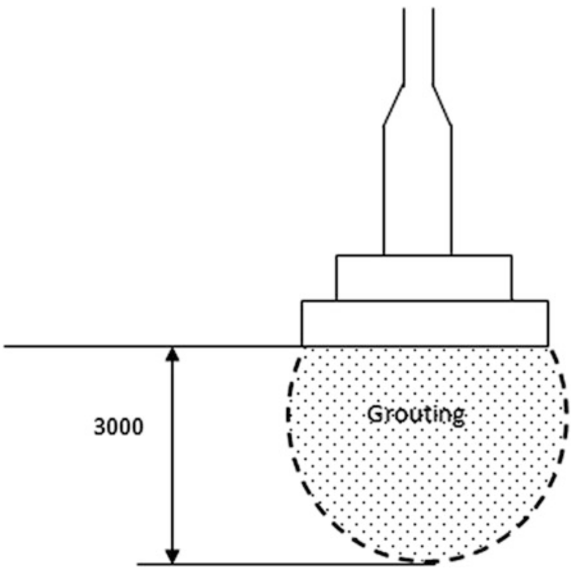


Fig. 10 Schematic of micropile

below the footing level (Fig. 11). The grouting fluid dose should be about 25–50% of wt. of soil present their at site (i.e. wt. of soil present from NGL up to minimum 3 m depth from there to be treated with grout). Thus, after calculating that area,

Fig. 11 Grouting area (grouting to be done on both sides of foundation)



the bulk volume of soil can be determined, and thereby weight of in situ soil should be determined. The grouting of in situ soil mass shall help in two ways, e.g.

(a) Reduction of permeability
(b) Increasing in situ bearing capacity of soil.

Grouting pressure shall be applied in two stages. In first stage, grout pressure should be minimum 1.5 bar, and at second stage, the pressure shall be around 5 bar. Gradual pressure increment shall be done within 30–40 s in second grade viscosity. Grouting shall be done through perforated pipe with valves and shall be strictly in accordance with ASTM C881 standards. The nozzle diameter of grout tube shall be commensurate with the pressure to be applied for grouting, as per standard practices.

Some pilot tests were conducted in IIT Roorkee Labs to see the effect of grouting on soil mass, and the results were encouraging.

7 Instrumentation

The combination of micropiling and grouting, as discussed above in the report, is believed to control the ingress of water into foundation, provide a confinement to the existing foundation and also increase the bearing capacity of existing foundation. It has been, however, also recommended to do some instrumentation to monitor the results from these proposed solutions. The instrumentation is proposed for following:

(a) To monitor further sinking of foundation, if any, using VW type settlement system.
(b) To monitor any possible tilt of building by using vibrating wire tilt meter.
(c) To monitor developments of new cracks, if any, after adopting all treatment measures, by installing VW crack meter.

8 Concluding Remarks

(a) For the present case, use of micro piling followed by grouting of the soft soil is suggested for improving the condition of the existing ground. It is quite possible that after the implementation of the ground improvement techniques, further deformations and movements are unlikely. However, to correct the profile of the ground, either the flooring needs to be redone or techniques that correct the profile without disturbing the set-up may be used.
(b) Before taking of retrofitting work, the excessive load of books in the library needs to be reduced. All the book racks kept in NW directions should be immediately shifted to opposite direction.

(c) The micropile pipes shall be left into the ground only and shall never be withdrawn from ground.
(d) The instrumentation shall help in monitoring the performance of foundation of high court building post construction.

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