- A high level of QA/QC is mandatory in jet grouting. This includes not only reviewing the jetting parameters and grout quality, but also understanding the drilling conditions and composition of the spoil.
- Experience matters, more so in jet grouting than other grouting technologies, as the field crew can significantly impact the process.

PREDICTIONS AND SUMMARY

These project summaries demonstrate a few of the newer innovative possibilities for jet grouting, but further applications will develop over time. Jet grouting project numbers in the US easily exceed 750 in the last 30 years. Recognized now in North America as a mature product, it will see consideration where it was not previously. In doing so, we must be cautious in its application and understand where success is achievable, for a competitive price and a suitable schedule, without accepting uncompensated risk.

CONCLUSION

Technological advancements in equipment and innovative design approaches have been instrumental in expanding the use and applications for jet grouting. As seen in the above project examples, this technology has proven to be a versatile, flexible, and cost effective means for ground improvement across a variety of markets, ranging from the tunneling industry to commercial building and public works. By heeding the lessons learned and building on past successes, experienced contractors and designers will continue to drive innovative uses for jet grouting.

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Use of Jet Grouting in Retrofitting of a RMG Factory Building in Chittagong, Bangladesh

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Abstract

In April 2013, a deadly collapse of a ready-made garment (RMG) building occurred in Bangladesh which caused instant death of 1,134 and injury to more than 2500 people. RMG in Bangladesh faces challenges to ensure workplace safety for the millions of garment workers. The recent structural assessment of the existing 3,500 RMG factory buildings identified that approximately 700 factories needed to be urgently retrofitted. In this paper, the methodology to retrofit a 4-storied RMG building in Chittagong was described in detail. The existing foundation of the building was inadequate, jet grouting together with bored piles were used to improve the foundation condition. The paper also describes the design, construction and performance of the jet grouting process. Soil modeling, settlement of the mat foundation under super structural loads and static pile load test for JGC (jet grouted column) is discussed. The choice of jet grouting as a soil and foundation improvement solution and its advantages are pointed out. In application of jet grouting, type of treatment, application procedure and operational parameters are also discussed.

INTRODUCTION

The retrofit process is a general term that consists of a variety of treatments, including: preservation, rehabilitation, restoration and reconstruction (Kelley, 1996). When an existing building found potential for severe damage due to lack of capacity against various possible loading, is considered for retrofitting. Most of the structures built prior to 2000s in Bangladesh were typically not designed with proper details to perform adequately during earthquakes. While Details Engineering Assessment (DEA) conducted in several buildings, most of them have been found vulnerable against seismic load. Recent events like collapse of Rana Plaza in Bangladesh have increased the awareness among building owners as well as building users for various purposes. The seismic retrofitting design and construction have recently been initiated in Bangladesh for vulnerable buildings. In retrofitting, strengthening of all structural elements has been considered as per requirements and relevant deficiencies.

Jet grouting columns are frequently adopted in foundation engineering as an alternative to piles with the aim of strengthening weak subsoil and transferring loads to deeper and more competent strata (Modoni et al, 2010). Jet grouting, among all kind of soil improvement, has certainly acquired a special place due to its widespread use in all kind of soil and capability of giving convenient solutions to most geotechnical problems. Jet grouting technology can give practical and cost-effective solutions to a number of difficult situations, such as for excavation support, ground-water barrier, bottom sealing to prevent pollutants from entering excavations, protection of bridges against scour, stabilization of slopes and underpinning of existing foundations in commercial and industrial settings (Croce et al., 2014). It is commonly recognized that jet grout was first applied to soils by the Japanese in 1960's (Nakanishi 1974).The experience on the use of high-speed jets in late 1960s for cutting rock and rock-like materials (Farmer and Attewell, 1965) inspired a group of Japanese specialists to investigate their use as a ground improvement tool. They developed an idea of injecting fluid binders within previously drilled boreholes to erode and mix in place the soil. Chemical binders were used in the first patented version, known as the Chemical Churning Pile (CCP) (Miki 1973; Nakanishi 1974), but these products were soon replaced by water-cement grouts. In the subsequent decades, the technique has developed significantly and is now being widely used around the world. The CCP and Jet Grout methods came to the attention of European companies in general and Italian companies in particular on the occasion of the international competition on the methods for the stabilization of the Pisa Tower in the early 1970s (Croce et al., 2014).Currently, jet grouting is used all over the world (Ryjeski et al. 2009).

This paper presents the first ever use of Jet Grout in Bangladesh for retrofitting of an existing foundation of a four storied RMG building, situated in Chittagong Export Processing Zone, Bangladesh. Figure 1 shows the building before and after retrofitting. The building is a RC beam-column structural frame system and the structural configuration is regular in pattern. This building has been constructed in 2001. A DEA has recently been carried out by EIMS to ensure the serviceability of the building. After completion of the DEA, the building has been found structurally inadequate due to highly stressed conditions of several columns and existing mat foundation considering existing gravity and lateral loads as per Bangladesh National Building Code (HBRI, 1993).The report suggested preparing retrofitting design and construction of the building to sustain lateral load as per BNBC. When it comes to retrofitting design, preparing a constructible design is the main challenge for structural engineers due to its existing condition. Considering all difficulties of construction, column jacketing and concrete shear wall scheme have been proposed to give the super structure an overall stability against all kind of possible loading. To overcome the foundation inadequacy deep beams have been inserted in two opposite side of the mat resting on Jet Grout Columns (JGC). While constructing the JGCs, there are several obstacles due to existing condition. The sizes of the JGCs have been adjusted as per field condition. Full control of jet grouting application has been maintained by monitoring all jet grouting phases carefully. The diameter of the pile has been checked by digging up to a depth of several feet for most cases. The core sample has been collected from grout piles and compressive strength has been evaluated. Subsoil investigation and Static Pile load test have also been carried out.

In this paper methodology of retrofitting design for both super and sub-structure is discussed along with the changes that have been made due to field condition. Construction process, impediments and relevant changes are also included. In addition, type of treatment, application procedure and operational parameters for jet grouting are discussed.

(a) (b)

Figure 1: Building (a) before and (b) after retrofitting

BUILDING INFORMATION AND DEFICIENCES

The evaluated building is a four-storied concrete moment resisting frame. The structural configuration of this building is regular in pattern. All of the interior columns are circular having 650mm in diameter and all edge and corner columns are square in shape having 500mm x 500mm in size. Typical floor beams are 250mmx700mm in size along both principle directions of the building. Crushed stone chips have been used as coarse aggregate for concrete and steel deformed bars have used as reinforcement. The ground floor height is 5.55m and other typical floor height is 3.6m. The existing floor system is a two way edge beam supported floor having 160 mm thickness. The plan dimension of the building is 21.4mx21.4m. The existing foundation is mat foundation having a thickness of 500mm. The ground floor is a structural floor with proper reinforcement and thickness is 200mm. The evaluated concrete strength as per ACI 562

(2013) is 18.4MPa and the yield strength of deformed bar is 420MPa. The main use of the building is to supply electricity to others buildings. There are several high voltage generators and other machineries related to electrical connections and supply in the ground floor. The other floors are used for office purposes and the top floor for garments product.

Based on DEA, several structural deficiencies have been identified. Most of the columns are inadequate in capacity due to earthquake forces. The reinforcements of mat foundation along both principle directions is inadequate for bending moments due to upward soil pressure caused by the action of gravity loads. The underneath soil of the existing mat foundation is found to be compacted. The estimated settlement is acceptable.

SEISMIC RETROFITTING DESIGN AND CONSTRUCTION

Since the structural elements are mainly inadequate due to lateral forces and the access for strengthening the interior columns are not possible due to existing condition, additional concrete shear walls are attached to the exterior columns at front and rear sides of the building. From numerical analysis, it has been observed that shear wall increased overall lateral stiffness of the building, also the inter-storey drift of the first floor remains within tolerable limit. Along with shear wall, two columns are also strengthened as per conventional column jacketing procedure using high strength concrete. Concrete shear wall required deep foundation to resist the uplift force action due to lateral forces. For this purpose cast-in-situ piles in addition have been considered below the foundation of the shear walls.

Inadequacy of the foundation occurs due to upward soil pressure that reacts against the vertical loading of the building. To rectify this inadequacy reinforcement of top layer need to be increased in both principle directions. This is practically impossible due to the setup of electric generator at the ground floor and presence of active electric lines under the ground floor slab. The designer has proposed to let the mat distribute its load in such a way that it will reduce soil pressure on it. Mat connecting deep beams (thicker than the normal beam) have been proposed along the front and rear sides of the building. These two deep beams have been connected with the mat. The mat behaves like a two way edge supported slab and the moment due to upward pressure of underneath soil will be transferred by the deep beams. The compacted soil is not fully capable to support the beams. Therefore continuous cement grout columns (JGC) are considered. These JGCs will be able to reduce the deflection of deep beams. Figure 2 shows the location of JGCs.

The retrofitting construction has been completed within three months. Within this time period, forty six Jet Grout columns (JGC), sixteen bored piles, two 21m long mat connecting deep beams, eight pile caps, six mat beams, two column jacketing and eight shear walls have been constructed. Figure 3 shows construction of different new building elements for retrofitting purposes.

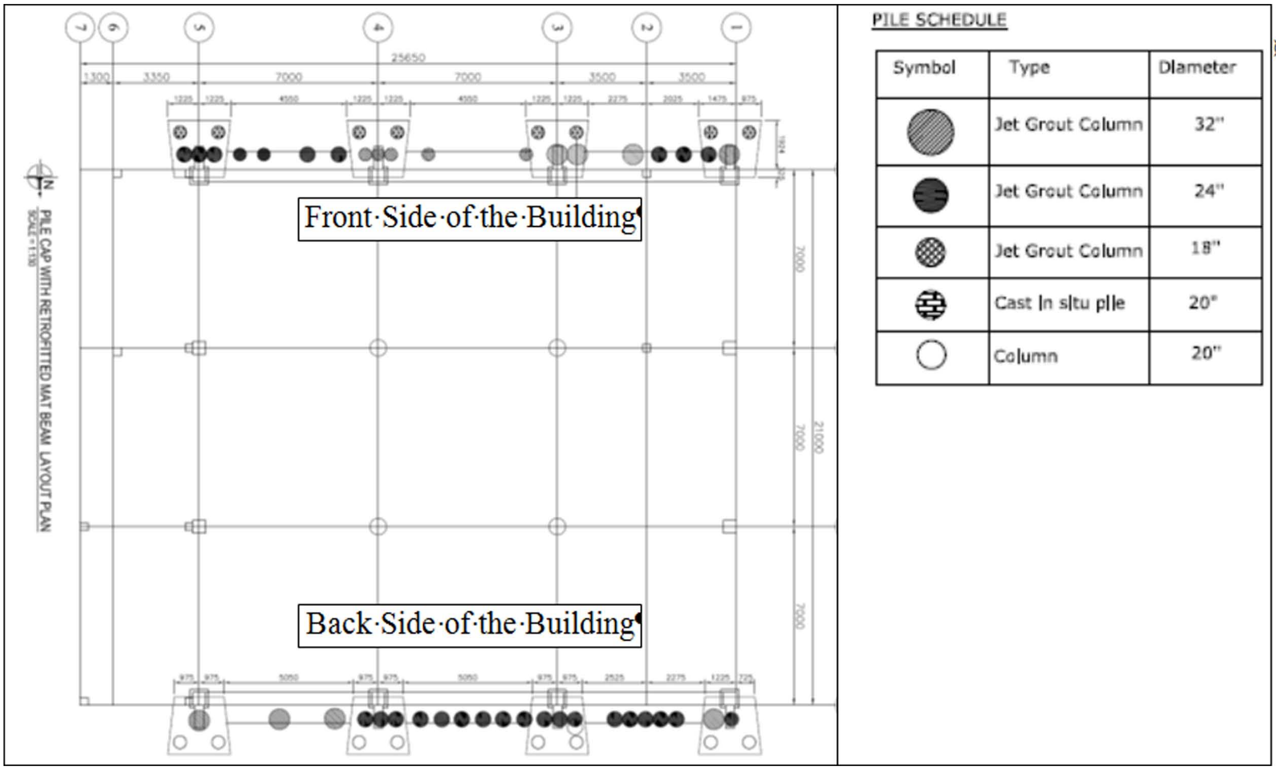
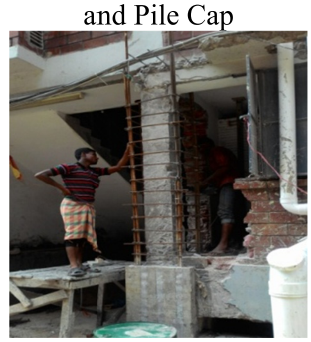


Figure 2: Designed location of Jet Grout Columns

Reinforcement Arrangement for Deep Beam

Reinforcement Arrangement for Deep Beam and Pile Cap

Reinforcement Arrangement for Shear wall



Reinforcement Arrangement for Column Jacketing

Figure 3: Retrofitting of different elements of the building

JET GROUTING SCHEME

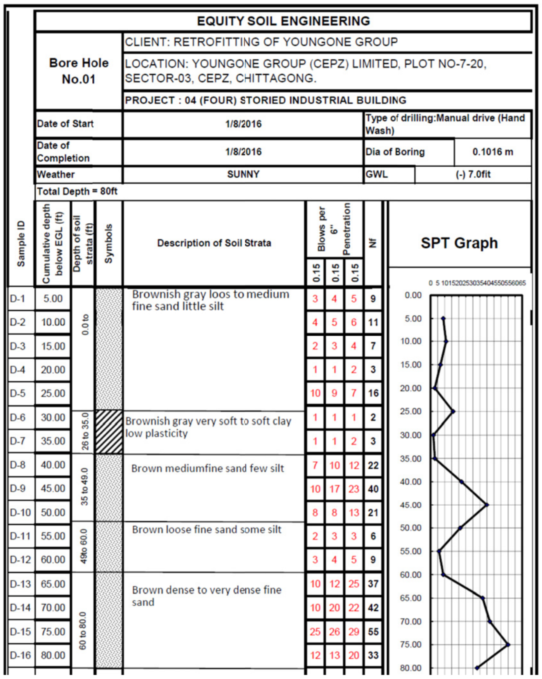
Jet Grouting is adopted as the measure for soil improvement for this project to overcome the foundation deficiencies. A drill rig advances the jet grout monitor to the bottom of the proposed treatment zone at which high velocity injection of fluids (often sheathed in air) are initiated as the monitor is slowly rotated and lifted. The jet erode and flush out a portion of the in situ soil and mix the remaining soil with cement grout to form a mass of stabilized soil, referred to as jet grouted soil (Sweeney et al., 2001). Currently, there are three major forms of jet grouting which involve the injection of a single fluid, two fluid or three fluids (Kauschinger and Welsh, 1989). Double fluid system has been used in the present case.

1. Selection of Jet Grout for this Project

The major concern of the project is laying the deep beam in a base with sufficient bearing capacity or transfers the load to other load bearing elastic foundation. The soil needs to be treated to increase its bearing capacity having settlement within tolerable limit. Otherwise install a deep foundation under the beam. The deep beams to be constructed are adjacent to the building and the working space is congested. In this working space, installation of a deep foundation is almost impossible. Due to this reason, improving the soil improvement through JGC is the only viable solution. JGC is the most viable solution due to its capability to create large columns of cemented material by drilling small holes into the ground, with limited disturbance of the surrounding subsoil. Moreover jet grouting is an erosion-based process, and subsequently can be effective across the widest soil spectrum (Burke and Sehn, 2003). With a number of jet grouted column in a row will provide a level platform which will prevent any detrimental settlement. For the above reasons jet grout columns have been selected for this project.

2. Design Methodology

In designing jet grout, the first thing is to decide how much of soil need to be improved to attain the desirable soil properties. Based on that designer decides the volume of jet grout to be done and the arrangement of jet grout columns as per volume requirement. Design process, strictly related to the quantification of the technological effects: the choice of the jet grouting procedure, the quantification of treatment parameters, the prediction of the dimensions and the mechanical properties of the jet grouted piles and the analyses of possible undesired collateral effects on the surrounding constructions and on the environment. In this project, the main purpose of jet grout column is to transfer loads to deeper and more competent subsoil strata, bypassing weaker or more deformable soils. Also to prevent any detrimental settlement to provide the deep beam an elastic base foundation. The design of jet grout column is done as per subsoil condition as shown in Figure 4. The soil report shows that the soil is mainly silty fine sand up to a depth of 24.4m except from 7.62m to 10.67m, the soil is soft clayey silt. The capacity (tip resistance and skin friction) of a single JGC has been estimated based on the available data which is obtained from the subsoil investigation report.



Depth (ft)	Sand (%)	Silt (%)	Clay (%)
15	91	9	0
30	29	62	9
40	95	5	0
50	92	8	0
65	96	4	0
80	92	8	0

Figure 4: Subsoil report at the project site

As per site condition, three different diameter of grout columns have been selected, they are 800mm, 600mm and 500mm Due to lack of access in some locations, higher diameter columns have been used as the spacing is higher. Also when the spacing is less, the smaller diameter has been used. The length of the designed column is 18.3m. For this project site, the estimated column capacity for 600mm diameter is 300kN, for 500mm diameter the estimated column capacity is 235 kN and for 800mm diameter the estimated column capacity is 500 kN. This has later been verified by static pile load test (ASTM 1143, 1994) for the for 600mm diameter column. Jet grout strength is primarily determined by the soil type; however the amount of cement used per unit volume and the water-cement ratio also has an effect. In design, the compressive/bearing strength of the soil is assumed to be 3000kN/m^2, which is also verified by collecting cores from the JGCs constructed at the site. The grout mix is composed of water and cement dosed according to weight ratios (W/C), usually ranging between 0.6 and 1.3. Selection of these parameters is very important for achieving design strength. In this project, the selected the water and cement is 1:1.

3. Construction Methodology

Jet grout columns are installed by initially drilling a small hole, typically 100 mm in diameter to the required depth. In the double fluid system, the grout is encased within a shroud of compressed air. The air acts as a buffer between the groundwater and the grout, greatly increasing the cutting efficiency. It also creates turbulence in the waste spoil, improving the efficiency of its removal. In this method a special coaxial drill string and jet monitor has been used. The cutting jets are located above the grout supply, which allows a nearly complete replacement of the soil with grout as the monitor is withdrawn. The double fluid jet grouting system used for this project is shown in Figure 5. Double fluid jet grouting is typically constructed from the bottom upwards. Column size is dependent on parameters such as rotation rate, lift rate, injection pressure and grout flow rate. Selection and control of these parameters are the main task in construction stage to attain desirable results for the structure.

4. Application procedure

In construction of the project, all necessary machinery for jet grouting needs to be placed in a convenient way to facilitate the work condition. For jet grouting pump machine a temporary work station has been selected. The air compressor as shown in Figure 5 (c) has been placed near the work station. Near this place the mixing plant for grout has also been set. The drilling rig has been positioned on top of two pipes so that the machine can easily be moved to its desired point. In this project, jet grouting pile installation process has been executed with the help of four operators. A supervisor has also been involved to take care of the grout mixing. After finishing one jet grout column, the machine has been shifted to the alternative point of jet grout column, skipping the adjacent pile. This way time is given to newly installed pile to be cured, at the same time maintaining the time schedule.

5. Type of Treatment

The soil beneath the deep beam needs to be treated. The deep beam is about 600mm in width and length of around 21m. The soil beneath the beam needs to be improved for an area of 21m long strip with a width of 600mm. In that case, a series of jet grouted pile needs to be installed in a single row along the strip having a diameter of around 600mm as shown in Figure 2. As per design, to transfer the imposed load to a hard stratum, JGCs has been formed up to a depth of 18.3m. It has been observed that during actual construction some of the JGCs can't be placed according to the design as shown in Figure 2 due to existing pipes and other installations. For this reasons, the diameter of some of the JGCs have been increased or decreased as per requirement so that the overall objective of grouting may be fulfilled (as discussed in design methodology).

(a) Grouting Machine

(b) High Pressure Jet Grout Pump System

(C) Air Compression System

Figure 5: Jet Grout Column Construction on site

6. Operational parameter

In JGC construction, the operational parameters are injection pressure, number and diameter of nozzles, rotation and lifting speed of the rods and flow rates. These parameters have been set according to appropriate calculation and as a result of required diameter according to the design. Following factors may affect the selection of operational parameter: subsoil condition, desire pile diameter, desire jet grouted soil bearing capacity, applied jet grouting technique. For this project, operational parameter has been determined by a field trial. The operational parameters used in this project are presented in Table 1.

Table 1: Operational Parameters of JGC construction at the project

Operational Parameter	Unit	Value for different diameter, D of Jet Grout Column		
		D=800mm	D= 600mm	D= 500mm
Injection Pressure	MPa	20~35	20~35	20~35
Number of Nozzles	No	2	2	2
Diameter of Nozzles	Mm	1.8	1.8	1.8
Rotational Speed	Rpm	20	20	20
Lifting Speed	cm/min	15	20	25
Flow rate	Liters/min	5.25	2.65	1.81

7. Performance

As the project is the first project for the designer and the contractor, the result of their assumption need to be verified by field trials. The first thing is to check the diameter of the grout piles. The diameter is physically checked by excavating the JGC heads. It has been found that the diameters are okay as per design requirements. Figure 7 shows one of the excavated areas to find out grout pile diameter and the process of core collection. The compressive strength has been ascertained for eight collected core samples. Table 2 shows the core test results.

(a)

(b)

Figure 6: Exposed (a) JGC and (b) Sample Core Collection

Table 2: Crushing Strength of Jet Grout Core

Sl No	Grout Pile Diameter	Crushing Strength (MPa)
1	800mm	3.6
2	800mm	1.4
3	600mm	2.6
4	600mm	2.6
5	500mm	3.1
6	500mm	2.7