THE DEVELOPMENT AND APPLICATION OF GROUTING AND GROUND TREATMENT

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ABSTRACT

Grouting and ground treatment is the application of engineering practices to provide improvement to the ground. These practices have been developed over the last 200 years. This paper will look at the development of these techniques and some of their recent application to the success of major engineering projects

1 INTRODUCTION

Grouting and ground treatment in particular is an art form. Why? Not because of the civil engineers who do not understand it, and mockingly suggest the addition of a few bats wings and frogs legs to the grout mix will overcome all problems. But because although we can put some numerical applications to our treatment of the ground, how the ground actually reacts to our treatment will vary and requires experienced personnel at the face to ensure the intended outcomes are achieved.

2 BRIEF HISTORY OF GROUTING AND GROUND TREATMENT

The first recorded application of grout injection to stabilise civil structures is by Charles Berigny in 1802 for the Port of Dieppe in France. Berigny went on to develop various injection processes in soft ground following the patenting of Portland Cement in 1824 developments of grouting occurred both sides of the Channel. At the turn of the Century cement grouting was used extensively as a remedial measure to deal with water ingress in the coalfields of France, Belgium and Germany and mines in the USA. Silicate and chemical grouts were introduced by Lemaire and Dumont and others at the turn of the 19th Century with the introduction of dilute silicate and acid solution into finer grained sandstones. This was then developed further by a Dutch engineer Hugo Joosten (1954).

Tube-a-manchettes were introduced by Swiss engineer Ischy in 1933 permitting grouts of different properties to be injected in any order at any interval of time in the same borehole. In the same period Maurice Lugeon (1933) published borehole watertightness criteria which is still the basis of our grouting definitions today. With the invention of the shear viscometer and the Marsh cone in 1931, engineers were able to determine better the flow characteristics of grouts to permeate fracture in rocks or soil panes.

The invention of the colloidal mixer by J.P. Morgan in 1934, manufactured by Colcrete in England from 1937, was a major result for grouting. Its high speed high shear action removed air from the cement, improved wetting and increased the proportion of fine cement particles, resulting in a grout that required less dilution with reduced segregation, lower bleed and higher strength. Much experimentation was carried out by the USBR from 1942 to 1944 on the physical properties of grout and in particular the flow properties of Portland Cement grout.

Developments of sodium silicate grouting in the 1950's included Soletanche's hard silicate gel. In 1957 the ASCE published state-of-the-art data on chemical grouting. By the 1960's grouting of alluvium was accepted worldwide and included construction of the new Blackwall Tunnel in London and the Whiteinch tunnel near Glasgow. By mid 1960 the grouting limits for common grout mixes were well appreciated.

In the 1970's concern over health and environmental pollution led to a ban on many chemical grouts, particularly in Japan. CIRA produced guidelines on the safe use of chemical grouts in the UK in 1982.

Our own Australian guru Clive Houlsby greatly improved the interpretation of the multi-pressure Lugeon tests in his publication in the Quarterly Journal of Engineering Geology in 1976.

Jet grouting emerged as an alternative to chemical grouting in the 1970s. Real time monitoring was introduced in the 1980's and in 1989 the success of microfine cements was recorded in material with otherwise poor penetration. Lombardi and Deere (1985) devised the grout intensity number and new admixtures, such as stabilizers and activators, are recorded in the 1990s with successful backfilling of the Channel Tunnel.

3 DETERMINATION OF GROUND TREATMENT NEEDS

Biggart (1984) presented a table of ground treatment based on soil grain size (Figure 1):

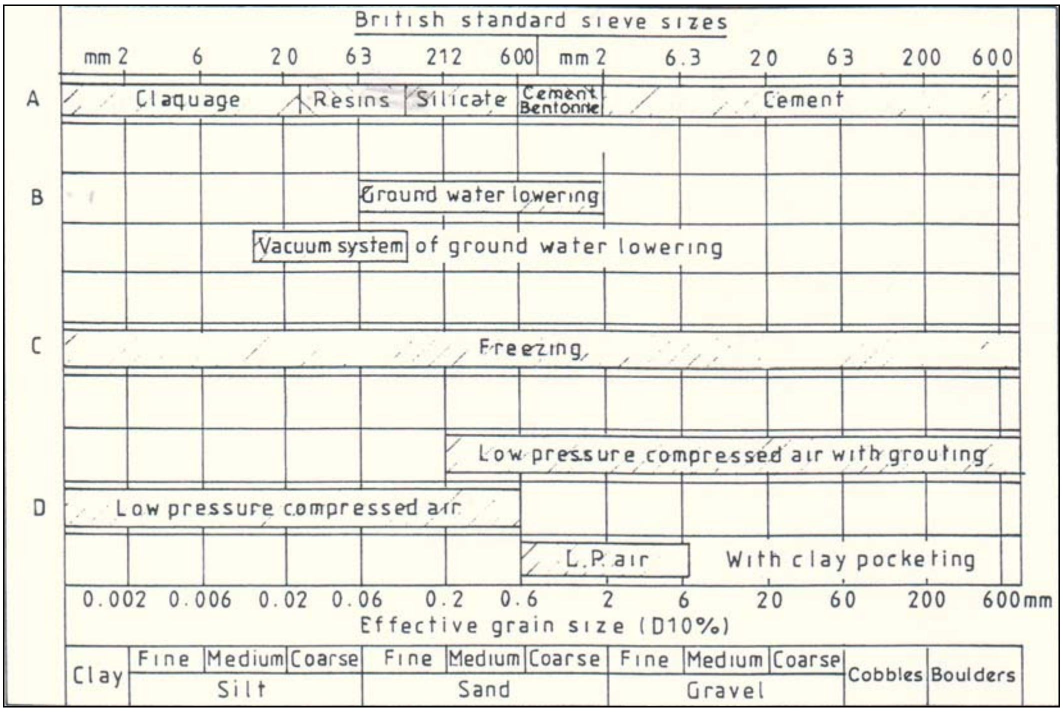

Figure 1: Ground treatment based on soil grain sizes (Biggart, 1984).

Dewatering should be the first choice of any ground treatment in soft waterlogged ground to stabilize the ground or stop groundwater entering an excavation. Well points are installed around the area. A wellpoint is a tube approximately 7 m long and 50 mm in diameter. The bottom one-metre length forms a screen through which the ground water enters. Wellpoints are usually jetted into place, a technique in which water at high pressure loosens the ground to aid penetration of the tube.

Jetting is suitable for soils of moderate to low permeability such as fine sand and sandy silt with an average permeability in the range 10-4 m/s to 10-6 m/s. Twenty-five to 50 wellpoints are usually connected to a single 25-50 m^3/hr pump header.

A filter well consists of a screened casing inserted into a drilled hole with a graded filter material packed around the screen. For temporary installations, the usual diameter of casing is 0.3 m to 0.4 m.

Usual limit conditions to groundwater lowering are

- K between 10-1 m/s to 10-6 m/s
- Substantially uniform soil conditions
- Total drawdown less than 30m
- Total outflow less than 5000 m3/hr
- Residual height H/4 for an aquifer in a given bed

Freezing is an alternative to dewatering where water logged ground is stabilized by introducing freezing material such as liquid nitrogen along tubes into the ground.

Grouting is often discussed in terms of the permeability of a soil or rock mass. Grouting is used to fill pores, fissures or voids in soil or rock to reduced water ingress, to provide increase in strength or stability of the ground, or to reduce ground movements or settlement. For planning purposes neat cement grout can achieve unconfined compressive strengths of 7-10 MPa and chemical grout can develop up to 3.5 MPa.

For rock practical limits for grouting may be set as:

- 5x10-4m/s for cement based grouts
- 5x10-5m/s for clay chemical grouts
- 5x10-5 to 5 x10-6m/s for chemical grouts

But as defined by Todd (1960) permeability is a medium's ability to transmit a fluid and takes no account of the property of the fluid. Todd goes on to say that few formulas give reliable estimates of results because of the difficulty of including all possible variables in porous media. For an ideal medium, such as an assembly of spheres of uniform diameter, hydraulic conductivity can be accurately evaluated from known porosity and packing conditions. Because of the problems inherent in formulas, other techniques for determining hydraulic conductivity are preferable for hydrogeological application.

In particular whilst soils may be more uniform in nature, as determined by the soil grading curves, and ground water flow through it may be represented as an average permeability, ground water flow through a fractured rock cannot be defined in terms of average permeability. The permeability of a rock mass is determined by the fractures, joints and bedding planes within it. Where the rock is not fractured it will be relatively impermeable but where a single open fracture occurs flows may be as high as several litres per second. Hence even determining the RQD of a rock mass may not necessarily determine the water ingress or its groutability.

As stated by Terzaghi "*No fissure can be cemented with a width of less than about 0.1 mm. For the same reason no fine sand or gravel can be grouted if the effective size of a compact sand is smaller than about 1.4 mm or that of a loose sand smaller than 0.5 mm – the grout merely replaces the material.*"

In this line the Groutability Ratio was presented by Mitchell (1970) as

$$GR = \frac{D_{15}}{D_{95}}$$

Where D_{15} is the particle diameter of the soil to be grouted 15% of which is finer by weight and D_{95} is the particle diameter of the grout 95% of which is finer by weight.

Weaver summarizes the possibility of grouting a soil for GR ranges as

$GR>24$ usually, $GR< 19$ not likely and $GR< 11$ not possible

However still the most practical method of determining groutability is still the water test. After all if the ground will take water it may take grout but if the ground will not take water then there is no point in trying to get grout into it. Maurice Lugeon's unit still used international today for grouting:

1 Lugeon unit is defined as water take of 1 litre per metre of test length of hole per minute at 10 bars (1,000 kPa or 150 psi). The Lugeon scale is sensitive at low values between 1 to 5 but with higher values of 50 or more and accuracy of +/- 10 Lugeons is adequate, and at more than 100 Lugeons an accuracy of +/- 30 Lugeons is appropriate.

Lugeon's 1933 work was further developed by Houlsby (1972) and may be summarized as follows:

- 1 Lugeon indicates almost no grouting is required
- Lugeons requires some light grouting
- 10 Lugeons indicates heavy grouting
- 20 Lugeons indicates extensive grouting

Houlsby also interpreted the data to help determine the ground characteristics as shown in Figure 2 .

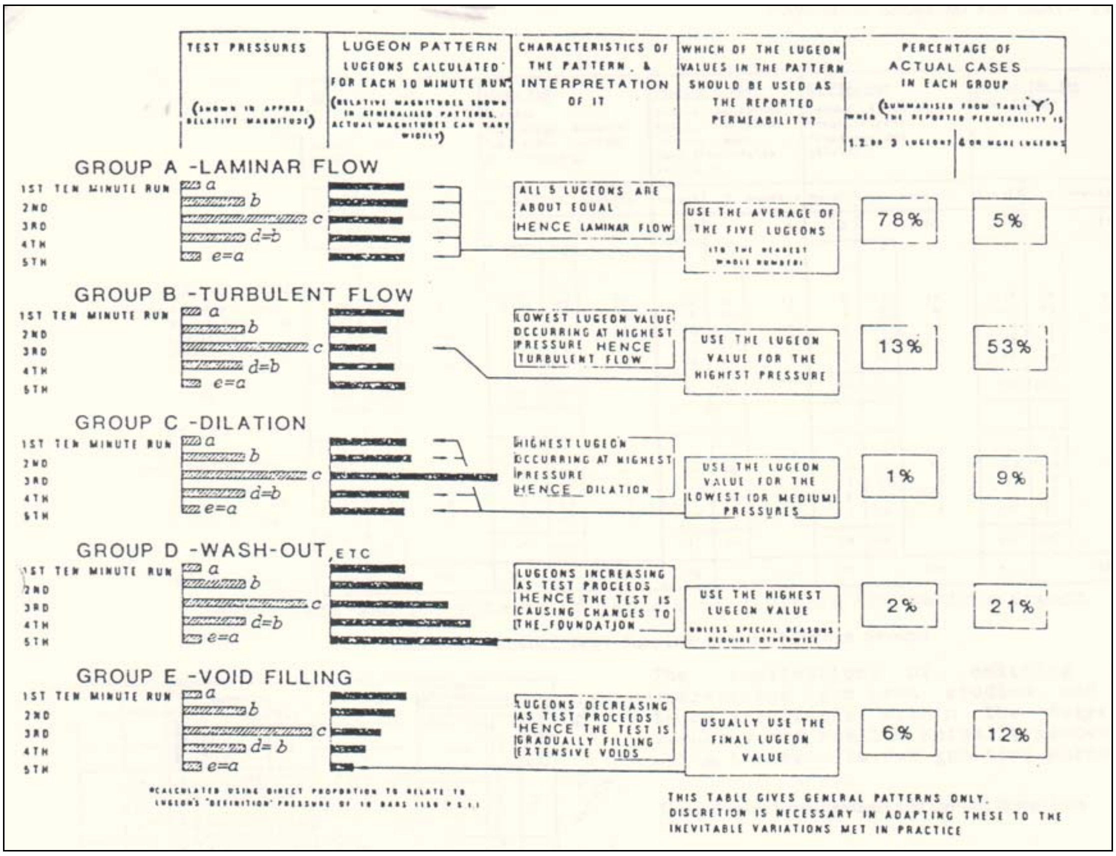

Figure 2: Interpretation of water pressure test results (Houlsby, 1972).

4 GROUND TREATMENT TECHNIQUES

Permeation Grouting – is the filling of interstices of the rock or soil, using appropriate materials and techniques to control water or to improve the structure of the ground. Vibrocompaction uses this aspect to compact the soil particles closer together.

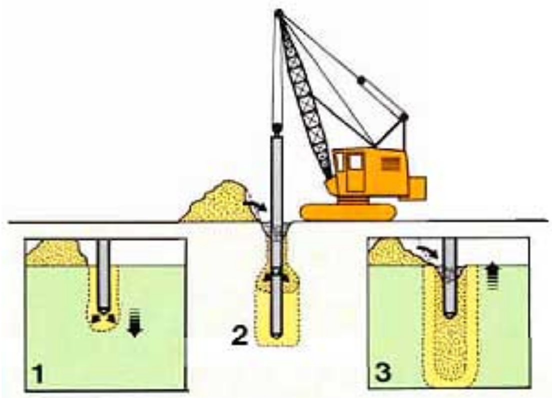

Figure 3: Compaction grouting.

Compaction grouting (Figure 3) – is the injection, under relatively high pressures, of a thick mortar. Because the grout is so thick it is unable to enter the pore space of the soil allowing displacement to compact the ground surrounding it. Stone columns are a further development of this process where granular material is injected into the ground to create a matrix of piers in an area of soft ground.

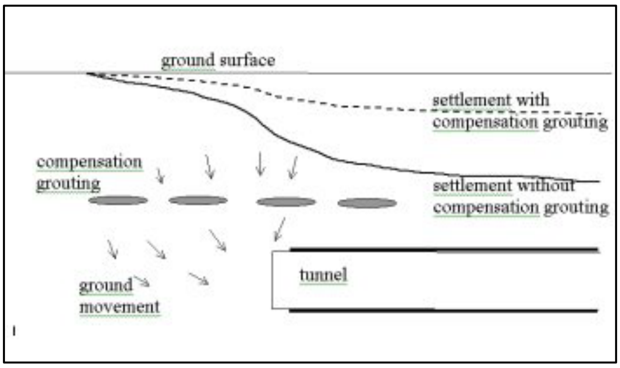

Figure 4: Compensation grouting.

Compensation grouting (Figure 4)– is essentially conducted through sleeved grout pipes or tube-a-manchettes to adjust ground levels as tunnels pass through compressible ground and was used extensively on the Jubilee Line Extension project in London.

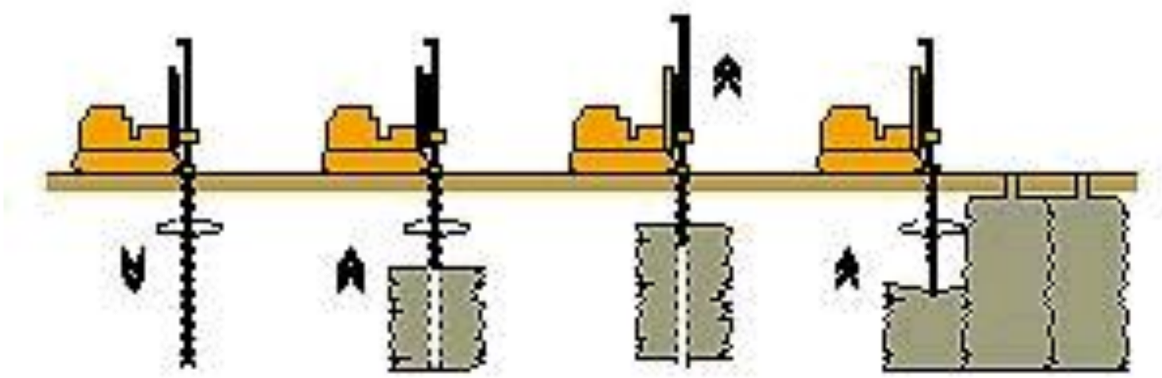

Figure 5: Jet grouting.

Jet grouting (Figure 5) – In jet grouting grout is passed at a very high pressure out of the side of a rotating tube. This grout cuts into the ground around the central hole and mixes this material to form a cylinder of grouted ground It is a grouting process developed in Germany and Japan for uniform sands and silts using very high pressures to provide pile columns up to 1.5 m in diameter. A lower pressure form of this technique is soil mixing.

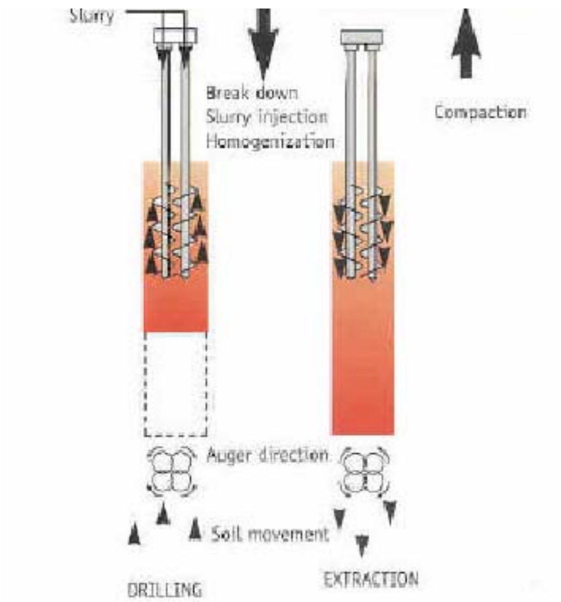

Figure 6: Colmix®.

Soletanche-Bachy have been responsible for developing soilmixing with their patented system Colmix® (Figure 6). It is a technique for consolidating face slopes in cut and fill in inaccessible or restricted places and is suitable for very poor engineering ground. The loose soil is stabilised and compacted with the aid of two or more augers which first break up the material before adding a special binder and recompacting the resulting pile.

Consolidation grouting – involves the filling of open joints, bedding planes, fault zones, cavities and other openings up to some distance beyond the excavation hence strengthening the ground and reducing groundwater flow.

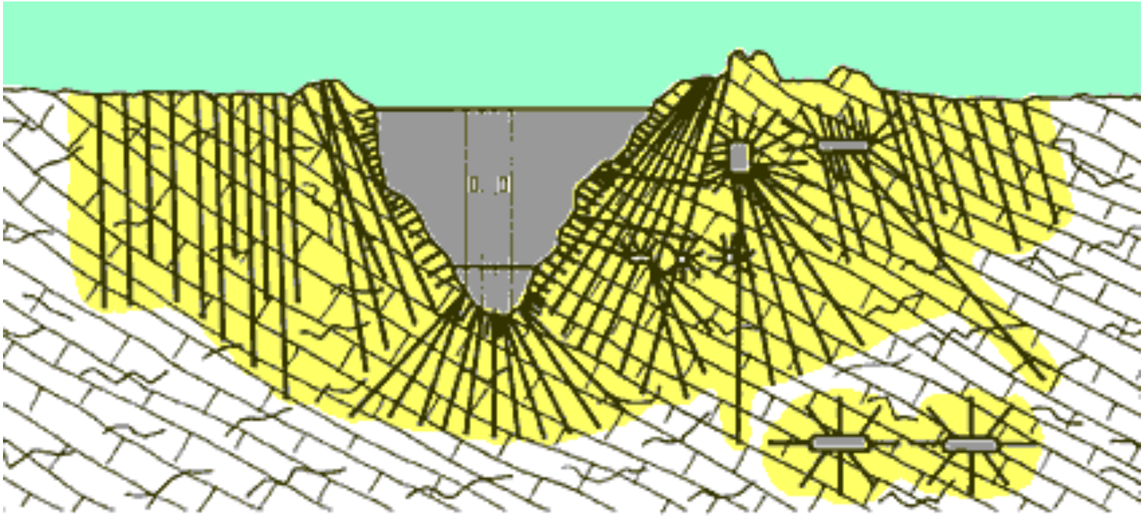

Figure 7: Curtain grouting.

Curtain grouting (Figure 7) – is the creation of an impermeable cut off usually radially around a shaft, tunnel or cavern to reduce the inflow of groundwater or the outflow of stored fluids such as LPG. Generally the grouting is carried out by widely spaced primary holes then infilled with secondary and tertiary holes until the barrier to water flow is fully achieved.

5 GROUTS AND GROUTING

There are essentially four groups of grouts, particulate grouts, colloidal solutions, pure solutions and others.

Particulate grouts are the most commonly used. These are essentially suspended mixtures with Bingham properties. This group consists of neat cement grouts (including microfine cements), clay/bentonite cement grouts and cement grouts with other additives to enhance penetration. Depending on the mix, the grout may be stable or unstable (having significant bleed). Water to solids ratio is the prime determinant of their properties and basic characteristics of stability, fluidity, strength and durability. These grouts are generally unsuitable for sealing high water flows, or high head conditions where they are likely to be diluted or washed away prior to setting

Colloidal solutions are evolutive Newtonian fluids in which viscosity increases with time. They comprise of mixtures of sodium silicate and reagent solutions which can change in viscosity over time to produce a gel. These grouts are generally unsuitable for providing permanent barriers against high-flow/high-head conditions because of their relatively long setting time, low strength and poor durability.

Pure solutions are organic resins. Their viscosity remains essentially consistent with the adjustable setting time. These are non-aqueous solvents capable of forming a gel or foam with specific mechanical properties under normal temperature conditions and in a closed environment such as poly-urethane, poly-acrylamide and epoxies. Resins are used where particularly low viscosity is required and fast strength gain. They are particularly resistant to high groundwater flows.

Miscellaneous grouts include other organic compounds which, in addition to providing waterproofing and strengthening, also provide qualities such as resistance to corrosion. These may be limited in their application due to their toxicity.

6 APPLICATION

6.1 DEWATERING – NEW SOUTHERN RAILWAY

The New Southern Railway is a 10 km twin track underground rail tunnel linking the Sydney Central Railway Station with the Kingsford Smith Airport and the previously existing East Hills Line. Five new stations were provided along the route. Bachy were responsible for the construction of the TBM launch shaft at Tempe, the new station box at Green Square and grouting behind the concrete tunnel lining segments.

Figure 8: Dewatering excavation for New Southern Railway.

The tunnel boring machine was 10.75 metres in diameter and over 75 metres long, the largest ever used in Australia and at that time the fourth biggest diameter tunnel in the world. The assembly shaft for the TBM was located in waterlogged ground adjacent to the Alexandria Canal. Bachy's engineers introduced an innovative slurry wall and dewatering system around the diaphragm wall box to assist in control in the high water table and ease construction (Figure 8).

6.2 FREEZING - DEEP TUNNEL SEWER SYSTEM SINGAPORE

The decomposed granite interface at the T05 shaft intersected the tunnel horizon. Shaft sinking was completed without the need for freezing but during blasting excavation of the tunnel horizon a major collapse took place. Soletanche-Bachy was asked to stabilize the area. Soletanche-Bachy used liquid nitrogen to provide the freezing medium. Freezing took approximately 3 ½ weeks for each section. Freezing was then switched to "maintenance mode" after the proper temperatures were reached to decrease nitrogen consumption. About 8 tanker trucks per day of nitrogen were delivered each day for initial freeze, maintenance dropped to 2 tankers per day

Excavation of the tunnel then continued with drill and blast of the frozen ground and shotcrete support (Figure 9).

Figure 9: Freezing deep tunnel system, Singapore.

6.3 PERMEATION GROUTING – TRANSGRID CABLE 41 SUPPORT

TransGrid's Cable 41 is a high voltage supply for Sydney's CBD that comes through Arncliffe and crosses the Cooks River from south of the city (Figure 10). The cable consists of 1600 mm^2 stranded copper core with a flexible corrugated aluminium sheath, with fluid filled paper insulation and a PVC outer cover. The cables are rated at 750 MVA continuous or 900 MVA cyclic loading.

Figure 10: Location of cable crossing

Following the construction of a new sewer main in Arncliffe Street in Arncliffe, TransGrid were concerned that the founding sediments beneath the cable had become disturbed and that the cable could potentially settle and bend causing it damage.

Figure 11: Ground treatment at Arncliffe.

GFWA were asked by the geotechnical engineers to determine a grouting method to stabilize the ground with minimum risk to the 330kV cable. A system of permeation grouting using microfine cements was suggested and trials were carried out with a number of different types of product to determine an optimum spacing of grout holes and mix details (Figure 11).

Figure 12: Grouting for manhole construction.

The original contractors needed to carry out some additional manhole constructions in the street and asked us to assist. The excavations needed to be 7 m deep and due to our concerns over the silty peat layers within the sand we proposed to carry out a soil mixing process where grout was injected through nozzles as the drill bit was put into the ground. Intersecting grout holes of about 150 mm diameter were created around the perimeter of the excavation in two rows (Figure 12). When the excavation was carried out shoring was still required but the excavation was dry and no further undermining of the TransGrid cables occurred.

6.4 VIBROFLOTATION AND STONE COLUMNS – DARWIN EAST ARM PORT

The Darwin East Arm Port project forms part of the second stage of the East Arm Wharf Development. The project is being carried out for Department of Transport and Works, Northern Territory Government by Thiess Contractors. The $54M contract will involve extensive piling and concrete works and include the construction of a 110 m extension to the common user wharf, and a 160 m long bulk liquids and multi-user wharf. The project was to be completed in August 2004 to meet the needs of the AustralAsia railway (Figure 13).

Figure 13: Darwin East Arm Port.

Stage 2 consists of construction of a 16 m wide railway access causeway to link the Adelaide to Darwin railway and national rail network to an Internodal Container facility incorporating 200 m of wharf with priority access for container vessels, common user berth facility with capacity for the provision of 3 quay cranes able to handle third generation container vessels. The project included reclamation of a nominal 4 hectares for an internodal container terminal with capacity to handle in excess of 250,000 TEU per year. The facility has provision for two rail sidings and mobile terminal operating equipment. GFWA carried out the vibrocompaction of the backfill over a treatment area of 110 m x 28 m (3080m^2) x 16 m deep (Figure 14).

Figure 14: Ground improvement by vibrocompaction.

6.5 SOIL MIXING – PORTLAND LANDSLIDE, NEW ZEALAND

The Portland Project on New Zealand's North Island was a combination of a slip with settlement issues attributable to poor ground conditions. Ground investigation boreholes were carried out to determine the failure mechanisms, followed by design of a Colmix column layout to stabilise the slipping and settlement movements. The designed layout was four rows of columns with 2.5 m spacing between rows and columns at 2.5 m centres over the 50 m length of road (Figure 15).

Treatment of the Portland slip took several days longer than anticipated to complete due to the necessity to construct additional columns in one area of the slip where the ground conditions were exceptionally poor. This additional work was performed within the lump sum price provided for the design and construction of the Colmix columns. Even though the duration of the work was extended by several days, the work was still completed inside program due to the relative swiftness of constructing Colmix columns versus traditional slip repair solutions.

Due to the difficult nature of the job, the fact that the slip was a long standing maintenance issue for TNZ and also high profile being on SH 1, Portland was selected as a site to be monitored on a long term basis for any signs of further settlement or movement. Approximately every three months a series of monitoring pins, installed after Colmix, are surveyed for position and level to provide precise records of any movement that occurs. To date no movement has occurred as we pass the two year mark after completion of Colmix

Figure 15: Treatment of Portland Landslide by Colmix.

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