

# PERMEATION GROUTING IN SYDNEY

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## ABSTRACT

In recent years permeation grouting has developed in Sydney and is now a common choice for building contractors as a simple, cheap and un-intrusive form of ground improvement. There are many sand deposits across Sydney from beach sands, aeolian sand, Pleistocene and Holocene sediments and fill material. These materials may be treated by permeation grouting to reduce their permeability or increase their strength using sodium silicate or microfine cements. The system has been used extensively for underpinning structures, sealing behind or beneath retaining walls, or even creating retaining structures, or for the containment of contaminated ground. This presentation draws upon the application of permeation grouting on many projects across Sydney to explain the technique with different materials and testing regimes for many different end uses. Other examples are presented of the application of permeation grouting and its development on other projects across Australia and elsewhere in the World. The aim of this paper is to show how permeation grouting can be used in Sydney sand formations for different applications instead of more complex and more expensive systems.

## 1 INTRODUCTION

Permeation grouting is essentially filling of the pore spaces between particles in granular soils. It may be defined as the introduction of low viscosity solutions or particulate suspension into the ground under low pressure without disturbing the structure of the ground to reduce the permeability or increase the strength and stiffness of the ground.

### 1.1 HISTORY

Permeation grouting is probably the oldest form of grouting. The first recorded application of grout injection to stabilise civil structures is by Charles Berigny in 1802 for the Port of Dieppe in France, he went on to develop various injection processes in soft ground following the patenting of Portland Cement in 1824 (Glossop, 1960).

In 1856 Darcy published his studies on the flow of water through sand that formed the basis of ground permeability (Littlejohn, 2003). At the beginning of the 20th Century, Portier considered the possibility of grouting sand but argued that the unstable cement would be subject to filtration (Duvivier, 1908).

The use of sodium silicate had been known since 1886 (Karol, 1983). The application of sodium silicate grouting in sands to displace water and form a gel binding the sands together to form a sand mass with compressive strength of 3 to 5 MPa was developed by Joosten in the 1920s by injecting small volumes of sodium silicate in stages through a lance as it was withdrawn (Joosten, 1954). This system was then used on a number of projects in Europe. In England it was mostly used for underpinning with an exceptional example of stabilising the Thames gravels at the Bank Monument Station in 1933 (Harding and Glossop, 1940). 15,500 tonnes of sodium silicate was injected by Rodio for the Barrage of Bou-Hanifia in Algeria, and it was here that Ischy first used his invention of tube-a-machette to enable successive injections in the same hole (Ischy and Glossop 1962).

With regards to injection of cement grouts, Kolbrunner and Blatter noted in 1941 that it was only possible if the pre size diameter was greater than 0.1 mm and the associated permeability was about  $1 \times 10^{-3}$  m/s (Kennedy, 1961). Glossop and Skempton (1945) then presented a review of soil classification based on particle size and limits of applicable geotechnical processes.

The first successful use of finer ground cements by Carlson in 1944 to seal cracks in concrete using cement of < 40 micron to seal crack widths of 0.03 mm. Machis carried out some experiments of cement grout penetration into sands and gravel in 1946 and concluded that *“the cement ceases to pass into pores when the pore becomes small enough for two or three cement particles to bridge across it”* (Littlejohn, 2003).

Lord reports successful grouting of sands with cement with particle size <30 microns in 1955 and noted the need for higher mixing speeds and longer mixing time (Kennedy, 1961). King and Bush (1961) stated that the groutability criterion  $N = D_{10}/D_{95}$  should be greater than 8 because filtering started at a value of 6.

Ultrafine grouts with a maximum particle size of 10 microns and an average of 4 microns was introduced by Shimoda and Ohmori (1982) capable of penetrating fine sand with a permeability of  $3.75 \times 10^{-6}$  m/s. The injection of weak

microfine cement into sand was first reported in 1989 by Arenzena *et al* (1989) with low pressure in fine sands to achieve penetration distance of at least 0.5 m. The introduction of silica fume in cement grout to reduce bleed for grouting sand was noted by Ata and Vipulanandan (1997) to increase compressive strength by 100%.

## 1.2 PERMEATION GROUTING IN AUSTRALIA

In Australia permeation grouting in sand has been common practice in Perth for many years. The technique was introduced in Australia for underpinning of the Titles Office and Town Hall during construction of the R&I Bank building in Hay Street in 1969. For this application permeation grouting using a ligno-sulphonate based chemical grout was used (Osborne, 2003).

From the late 1970s extensive chemical injection was carried out in the base of red mud storage areas at Alcoa Kwinana to reduce liquor seepage from the storages. This work was undertaken with an imported grout known as AC400. This represents the most extensive application of grouting techniques in the Perth region to affect ground improvement – in this case a reduction in permeability (Osborne *et al*, 1993).

Until the mid to late 1990s, chemical grouts were used, mostly for small scale applications. Specific applications of the process were strengthening of supporting soil beneath existing footings to accommodate additional load and grouting of a zone of soil adjacent to a proposed excavation to support the excavated face and/or adjacent buildings. The technique was used in conjunction with soil reinforcement (soil nails or anchors) either as temporary support during the excavation phase of the installation or where the anchors are installed to provide horizontal restraint to the grouted face (Osborne, 2003).

Sodium silicate was used extensively in Sydney in the 1990s, mainly for underpinning and sealing behind retaining walls. The first application of microfine cement for permeation grouting in Sydney was for Capella Apartments in 2004.

## 2 GEOLOGY OF SOIL DEPOSITS IN SYDNEY

Compared to the aeolian sands of Perth, the Quaternary soils of the Sydney Basin are more variable consisting of both aeolian and alluvial deposits. These can be divided into two groups – namely the Botany sand sheet and the Nepean and Hawkesbury floodplain. The upper sediments are of Holocene age, with the stiffer alluvium at depth of Pleistocene age.

The Botany sand sheet formed from the wind-blown deposition of marine sand swept constantly north along the NSW coast. It starts as a medium-sized sand on the coast and becomes finer further inland. The Hawkesbury–Nepean and Georges River floodplains are composed of sands, silts, cobbles and clay deposits.

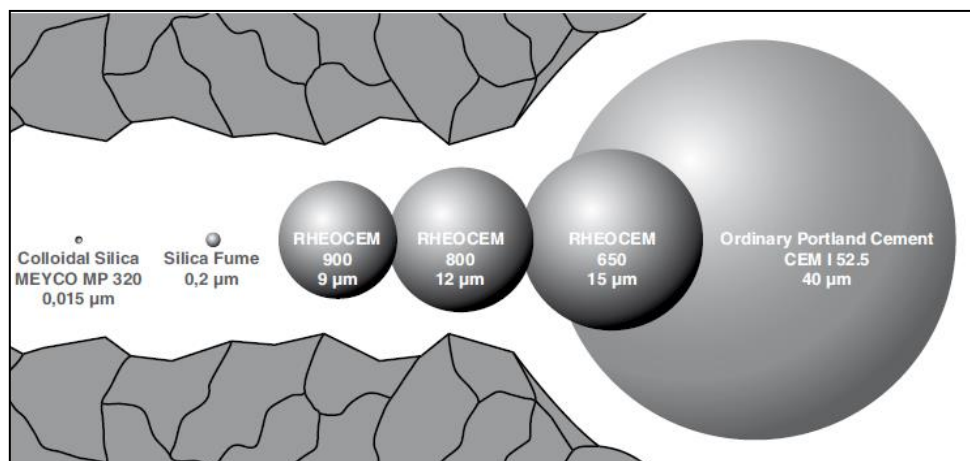
## 3 MATERIALS

### 3.1 SODIUM SILICATE

Sodium silicate is a two-component grout that typically has very low viscosity but will often expunge water after gelling by a process called syneresis. With relatively short gel times down to a few minutes, Babcock (2016) states that sodium silicates are commonly used as temporary solution for water control or structural support, but that sodium silicates can be sensitive, bordering on unstable and have an estimated life span of just a few years. The main advantage of sodium silicate grouts is its low viscosity and low cost, and, apart from the high pH (typically 10.5 to 11.5), there are small problems with work safety and health (BASF, 2011).

### 3.2 MICROFINE AND ULTRAFINE CEMENTS

Normal GP cements have a typical particle size of more than 40 microns, microfine cements are defined as having particle size less than 20 microns and ultrafine cements typically have particle size less than 10 microns (Norwegian Tunnelling Society, 2011). This is presented pictorially by BASF (2011) as presented in Figure 1.



**Figure 1: Comparison of particle size for cement products (BASF, 2011)**

According to Roald *et al* (2001) the use of microfine cement has improved grout penetration to achieve a permeability less than 0.1 Lugeon, whilst producing more stable grouts with reduced shrinkage.

#### 4 METHODOLOGY

Determining the right material for the ground conditions is the first step. As identified by Schwarz and Krizek (1994) during the injection process, preferential flow paths allow the migration of cement particles into the soil and micro structural packing undoubtedly varies within the pore spaces of the grouted sand. The amount of permeability reduction achievable in a particular situation depends on several factors including the hydraulic conductivity of the ground, but also the viscosity of the grout, the surface tension, grout pipe spacing, injection sequencing, quality control and stability of the cured grout.

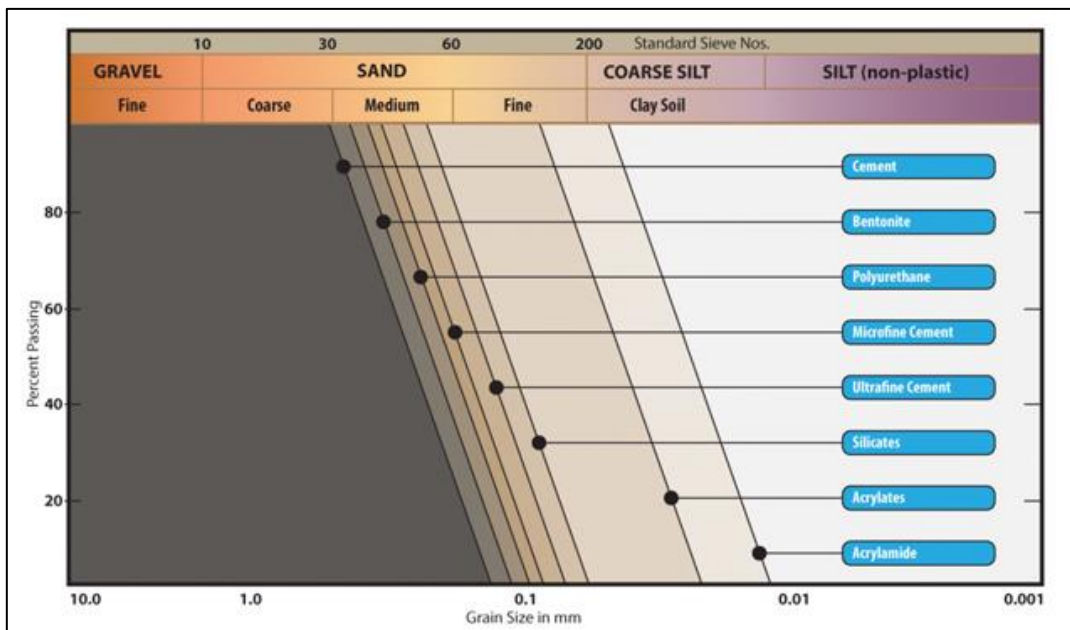
Typically in Sydney, a weak microfine cement grout is used with a water-cement ratio of about 4:1 with added superplasticiser and silica fume to reduce bleed. The grout is injected at low pressure through 20 mm diameter lances that are pushed into the ground with a water flush. A fixed volume is then injected to form a bulb of grouted ground, then the lance is lifted a fixed distance and injected again. The height of the lift and volume of the grout injected will determine the effectiveness of the grouted column of sand and the spacing to adjacent injections. Adjacent installations should be separated into primary and secondary holes with secondary installations carried out after the grout has achieved its initial set, to avoid connection to the previously grouted hole.

In very dense sand it may be necessary to insert the grout lance with compressed air. It is important that the lance is sealed into the hole otherwise the easiest path for the grout is up the outside of the grout lance, this is also why the injection pressure must be limited. Also, if too high injection pressure is used then the soil may be hydro fractured, creating grout lenses rather than bulbs of grouted soil.

Quality assurance is critical to success. If the correct volume of grout is injected at a certain level without hydro fracture or grout return to surface, then the grouting will be successful. Site testing can be carried out with water injection through the grout lance. If the ground takes water, then it should take a week low viscosity microfine cement grout or sodium silicate grout.

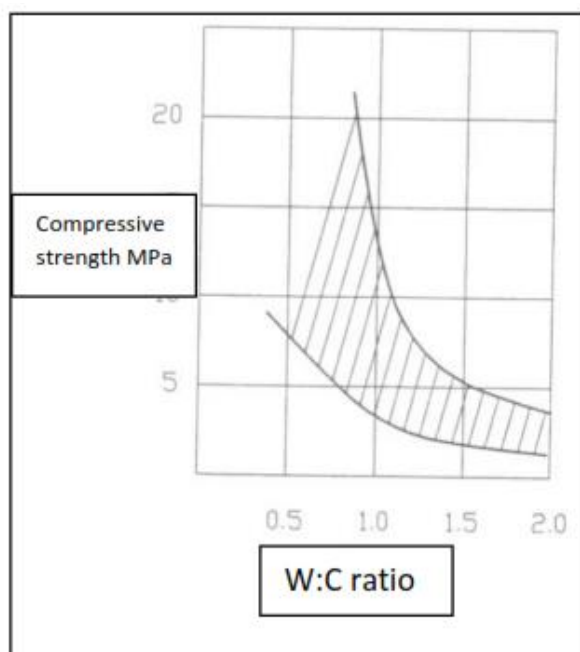
#### 5 TESTING

Typically, permeation grouting is ideal for sandy soil conditions where the grout travels and infiltrates a wider area. However, without a comprehensive site investigation the ground is a hazard, and, as Littlejohn (1982) stated, it is essential to provide a detailed geotechnical classification of the different ground types encountered together with their location and thickness, along with hydraulic gradient and chemical properties of the ground water.



**Figure 2: Permeability of different soils and selection of grout type (Babcock, 2016)**

Grout types for different soils was presented by Babcock (as presented in Figure 2), but there will always be some variability in the response to, and behaviour of, soils with grout, even with soils of the same hydraulic conductivity and grouted strengths (Shodhganga, 1977). Although a soil’s initial hydraulic conductivity is the best indication of the amenability of the soil to permeation grouting, it is not an all-encompassing descriptor. Hydraulic conductivity is a measure of a soil’s ability to transmit water, not grout, which has different properties. A silt with coarse sand layers, may have the same transmissivity or hydraulic conductivity as a silty sand, but the two materials will respond very differently to grouting.



**Figure 3: Compressive strength of grouted sand after 28 days (Bonzel and Dahms, 1972)**

Figure 3 shows the strength development of poorly graded sands as presented by Bonzel and Dahms (1972,) and shows that the strength of the grouted soil is clearly dependant on the water-cement ratio.

**Table 1: Increase in compressive strength of grouted sand with time (Bonzel and Dahms, 1972)**

Age of sample (days)	Compressive strength (%)
2	10 to 30%
7	30-60%
28	100%
120	120%

This research also showed that about 60% of the strength is attained after just 7 days, and that even though 100% strength is achieved at 28 days, the strength of the grouted soil continues to increase up to 120% after 120 days as presented in Table 1. This was further investigated in Perth in 2001 where a 2 m deep spear was grouted in 5 stages and excavated 3 months later to show compressive strengths of 13.5 MPa (Multigrout, 2001).

Furthermore, the permeability decreases with elapsed time, it becomes almost constant beyond 15 days of curing period for lower cement contents (i.e. 4 % and 10 %), but at higher cement contents (e.g. 25 %), the permeability goes on reducing even after 15 days (Kainrath and Adam, 2015). Hence one can presume that reduction in permeability is directly related to the hydration of the cement.

The actual amount of cement controls the strength of the grouted soil. The amount of cement within the grouted soil changes with the void ratio of the soil and the degree of saturation. It can therefore be concluded that whilst the water:cement ratio is a parameter to control the strength of the soil, on its own it is an inappropriate parameter to predict the strength and the stiffness of grouted soil.

Testing to prove the effectiveness of sand that has been treated by permeation grouting is not easy. For a project for TransGrid to provide support to Cable 41 in Arncliffe Street, Tempe, the effectiveness of the grouting was established in a trial using cone penetration testing (CPT), which showed that the column of permeated soil extended to about 700 mm diameter from the point of injection through the 20mm diameter lance. The CPT also indicated layers where there was a reduction in ground improvement, considered to be due to poor grout penetration due to layers of organic material.

A property in Bay Street in Brighton Le Sands was built on a raft, however it was determined that this raft was needed to be underpinned by permeation grouting down to a depth of 7 m due to the deep basement on the adjacent property. To prove the effectiveness of the grouting it was decided to try to take some small diameter cores (>25 mm) of the material by diamond drilling after 7 days. But the material disintegrated whilst drilling. This was considered to be due to the high shear forces developed in the coring and the effect of this on the cemented sand particles. Finally, it was determined to excavate a section of the underpinning and determine its effectiveness by using a hand-held soil penetrometer.

Victoria Park stowage track alterations in Perth required cutting the existing cut slope to a steeper angle. To enable this excavation permeation grouting was carried out along the slope with some sections also being soil nailed and shotcreted in order to form steep batter slopes. Larger diameter cores (75 mm) were extracted after 10 days using a hand-held Hilti drill and samples were then tested with a hand-held soil penetrometer to determine the unconfined compressive strength.

In conclusion, it is considered if quality cores are need for laboratory testing at an early age then these should be taken using a triple tube core barrel.

Testing of low mobility grout columns installed after the earthquake in Christchurch was carried out using cross-hole seismic testing (Hwang *et al*, 2017). The cross-hole testing involved pushing two dummy CPT cones, one on either end of a linear array which were then used to transmit vertical impulses to the bottom of the rods where the cone tips acted as sources for simultaneously generating both constrained-compression (P) and shear (S) waves in these small-strain tests. At the same time, a custom-built, 3D-receiver in the shape of a CPT cone was pushed using CPT rods in the centre of the array composed of 3 geophones and acted as the receiver for each seismic source. The spacings between each source rod and the middle receiver rod ranged from about 1.4 to 1.8 m. The testing began at a depth of 40 cm and continued in 20 cm increments, usually to a final depth of about 5 m. Both seismic source rods and the 3D-receiver rod were pushed to the same depth for each measurement. The zone across the grout columns was expected to show increases in stiffness due to the presence of grout as well as the densification of the surrounding soil. The results showed zones of improvement at all three grouted test panels, but the improvements was highly variable and showed lack of continuity over the entire depth. Increases in stiffness greater than 50 % were expected and seen on some records. Values less than 50 % were considered could either be due to the presence of partial grout columns in the soil or the densification of the soil and indeed this was identified when the columns were exposed.

## 6 SELECTED PROJECTS

### 6.1 CAPELLA APARTMENTS



**Figure 4: Basement excavation at Capella Apartments**

Capella apartments are located in Kensington at the junction of Doncaster Avenue and Anzac Parade and comprises 164 apartments over nine levels in two low-rise developments plus retail space and basement parking. The basement construction was facilitated by sheet piling into the Botany Sands and with a high natural ground water level around the site, the site was dewatered to enable basement excavation. However, some sheets of the retaining wall had to be stopped at a higher level due to old brick sewers crossing the site. These gaps in the retaining wall were injected with microfine cements at a 4:1 w:c ratio through 20mm injection lances to stabilise the sand. However, when excavated after 28 days of curing, in some place a completed seal around the sewer had not been achieved. This is considered to be due to a flow of water along the sewer around the perimeter due to cracked and damaged pipes where the grout was washed away and the ground was poorly treated in these areas.

**Conclusion:** Permeation grouting cannot be carried out in flowing ground water.

### 3.2 BEACH STREET, COOGEE - NSW



**Figure 5: Grouted sand underpinning Beach Street, Coogee**

Development of the basement area beneath a property in Beach Street, Coogee required shallow footings to a depth of 1.5m to enable underpinning. The aeolian sand was treated by permeation grouting with 20 mm diameter lances through the floor boards of the ground floor with stable ultrafine grout with water-cement ratio of 4:1 and micro-silica in rows with primary holes 1m apart and then secondary holes injected on consecutive days. After two weeks the basement was excavated in small sections and the grouted sand replaced with concrete to provide the final underpinning of the building and allow completion of the excavation of a new basement level.

**Conclusion:** Permeation grouting in Sydney sand increases the strength making it suitable for underpinning large structures.

### 3.3 ALEXANDRIA POST OFFICE SITE

Development of the Post Office site in Alexandria required the stabilisation of contaminated ground due to historic industrial usage of the site. Due to site confines it was necessary to treat one corner of the property with permeation grouting to reduce permeability and demobilise any contaminated groundwater. The natural ground condition was Botany sand and a stable ultrafine grout with water-cement ratio of 4:1 and micro-silica was injected at 0.5m spacing in primary, secondary and tertiary holes over consecutive days to create a grouted block.

**Conclusion:** Permeation grouting can reduce permeability and therefore limit dispersion of contaminants in ground water.

### 3.4 UMINA WOOLWORTHS



**Figure 6: Permeation grouting to limit settlement due to sheet piling at Woolworths Umina**

Sheet piles were installed to provide a retaining wall for basement excavation in Umina through aeolian sands. The site included prefabricated housing along one boundary and a low-level brick building founded on shallow footings in the south east corner as part of the public library complex. During the installation of sheet piles adjacent to the library complex, settlement occurred creating cracks in the brick walls. Therefore, the grouting crew was mobilised to carry out permeation grouting along the interface between the sheet piles and the brick walls to provide underpinning to the shallow foundations. The grout was injected through 20 mm diameter lances installed at 45 degrees to treat the material beneath the shallow footings. The primary holes were spaced 1m apart and secondary holes were installed in between on consecutive days.

When the sheet piling was continued after permeation grouting was completed and the grout allowed to achieve some strength over 7 days - the settlement after was not only reduced but the cracks created earlier were seen to close.

**Conclusion:** Permeation grouting can be used to limit consolidation of soils due to vibration.

### 3.5 MINNEAPOLIS CRESCENT, MAROUBRA

A new development in Minneapolis Crescent, Maroubra required an excavation for basement parking. A retaining wall was created by permeation grouting around the site for a distance of 40 m to enable excavation to bedrock at a depth of 3 m below surface.



**Figure 7: Grouted sand for 3m deep excavation at Minneapolis Crescent, Maroubra.**

The ground conditions consisted of Botany Sands with minor layers of peat and Coffee Rock (a layer of iron enriched sand with higher compressive strength). The sand was stabilised with interlocking 500 mm diameter columns of grouted sand 4 m wide, by installing 20 mm diameter lances with primary holes 1 m apart and secondary holes installed on consecutive days. The depth of the permeation grouting was limited due to a hard layer at the base of the excavation through which the hand installed spears could not penetrate.

The bulk excavation was successfully completed but when the hard layer was later removed by hydraulic hammer some of the permeated columns of sand became detached. Anchors were installed through the permeated ground to provide tie backs and stabilise the sides of the excavation.

**Conclusion:** Permeation grouting can be used to stabilise ground to be used as retaining walls for excavations but the excavation but may need to be further supported to maintain stability.

## 6 CONCLUSIONS

This paper has shown that permeation grouting is a suitable process for many applications of ground improvement in Sydney. However, its application is limited by the soil conditions and whilst ideal in the aeolian sands, it may not be appropriate in the fluvial deposits which are richer in silts and organic matter. However, it has been shown that the process can be used for underpinning and construction of small retaining walls, and retention of contaminated ground water.

It is considered that if constructed properly, with good quality assurance, then the contractor can have great confidence in the effectiveness of the result. However, testing the result is not easy. CPT testing has been used to show ground improvement but if this is not carried out immediately after grouting then the ground will become too hard to test. Coring with diamond cores in small diameter has been shown to be ineffective as the shear force of the coring causes a breakdown of the cemented sand particles. It is considered if quality cores are need for laboratory testing then these should be taken using a triple tube core barrel. Further, samples of grouted sand have been shown to have increased strength characteristics up to 120 days after grouting.

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