# Stabilization of Loose Man-Made Fills by Grouting

## Stabilisation des Remblais par Injections

D.G. COUMOULOS
T.P. KORYALOS
Ph D. (Cantab) and M.Sc., respectively, Soils and Foundations Engineers, Partners, Castor Ltd., Hellenic Company for Subsurface Explorations, Athens, Greece

SYNOPSIS A grouting technique was developed to stabilize uncompacted man-made fills which were formed by dumping of excavation and demolition materials from the building activity in the Athens area. This grouting technique consists of injecting a cement-bentonite grout mixture through perforated pipes suitably spaced. Criteria were established for maximum pressures at injection points and quantities of cement injected. Simple quality control procedures were adopted to check and adjust proportioning of the grout mixture at the field. The effectiveness of the grouting method is demonstrated with results from boreholes prior and after the grouting operations, and with data on grout take at the various injection points.

## INTRODUCTION

A number of sites exists at the southwest part of Athens which were used in the past as borrow pits of clay for pottery, bricks and tiles. These borrow pits were abandoned when water table was reached and back-filled later with excavation and demolition materials from the building activity, which were dumped without any selection and without compaction. The man-made fills contain large diameter stones, timber, reinforced concrete blocks and quite often garbage. Buildings placed on such man-made fills started presenting cracks soon after completion of their construction and as time passed serious damages were developed.

The Paper describes a grouting technique which was applied successfully to stabilize a number of man-made fills under the foundations of damaged buildings and also prior to the construction of the buildings.

This technique makes use of a fluid grout mixture which penetrates and fills the voids. It is fundamentally different from the "compaction grouting" technique, which consists of intruding a mass of a very thick consistency grout into the soil that does not enter the soil pores but remains in a homogeneous mass and effects controlled densification by displacing loose soil.

## SUBSURFACE CONDITIONS PRIOR TO GROUTING

Boreholes were drilled and trenches were excavated in order to determine the thickness of the man-made fill and to estimate the nature and percentage of the waste matter.

Return of drilling water - whenever used - was not observed in any of the boreholes and this is another indication of how loose the man-made fill was dumped. Thickness of man-made fills in the Athens area is usually 8 to 10 m.

Provided that no oversize stones of other hard matter was encountered, the rate of advance of drilling was of the order of 1.5 m/h when no water was used and about 2.0 m/h when water was used. These rates of advance of drilling are about double than those observed after stabilization of the man-made fills.

Resistance to standard penetration was high and varied between 21 and refusal but based on the above observations these values should be regarded as misleading.

The amount of waste matter was estimated to vary between 20 and 70 percent of the total fill.

Laboratory tests on fill material from various sites free of waste matter and oversize stones yielded the ranges of gradation and index properties which are shown in Figures 1 and 2 respectively.

A detailed study of similar man-made fills in the Athens area with particular emphasis on their compaction characteristics has been conducted by Kotzias and Stamatopoulos (1970).

The natural soil which underlies the man-made fills was at all the sites a hard red-brown clay of the group (CL) of the Unified Soil Classification System with layers of very dense sand of the groups (SC) and (SM).

## DRILLING OF BOREHOLES AT INJECTION POINTS

All boreholes at the injection points were rotary drilled with hole diameter 0.104 m. Boreholes advanced through the man-made fill to the natural soil.

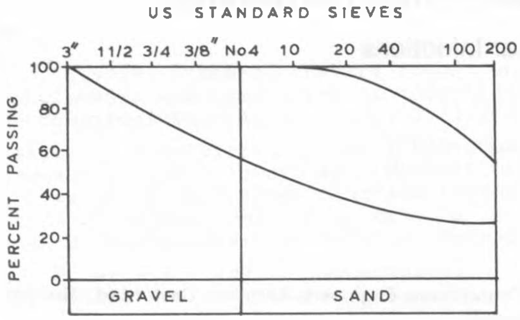


Fig.1 Range of gradation of man-made fill material free of waste matter and cobbles

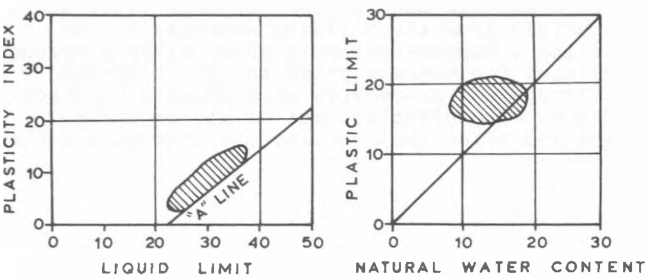


Fig.2 Index properties of man-made fill material free of waste matter

In the case of sites with the damaged buildings all boreholes were drilled without water or any other drilling fluid in order to minimize the disturbance of the man-made fill by the water action which could result in further damage of the buildings. Boreholes were drilled around the buildings along the external walls and close to columns and points of excessive settlements. In this way the use of the buildings was never discontinued. Half of the boreholes was drilled at an angle of about 15 degrees. Boreholes were drilled in two phases. The vertical boreholes were drilled first and after grouting, the inclined boreholes were drilled in an effort to direct the grout mixture under the foundations towards the interior of the buildings. Spacing between injection points varied between 1.5 and 2.2 m.

In the case of a site without buildings, boreholes were drilled at all column locations which were spaced at 6.3 m intervals. All boreholes were vertical and drilled with water. In one occasion while drilling at one injection point a large underground cavity was formed followed by a subsidence with surface cracks extending to a distance of about 3 meters from the drilling location. This subsidence which was caused by the water action on the man-made fill is also an indication of how loose was placed the man-made fill.

## INSTALLATION OF PERFORATED PIPES AT INJECTION POINTS

The perforated pipes which were used to inject the grout mixture had an external diameter of 0.04 m. They were perforated with 0.008 m diameter cross-holes at 0.10 m intervals. The top two meters were not perforated.

Shortly after completion of each borehole, the casing was withdrawn and the perforated pipe was inserted into the borehole. The space between the perforated pipe and the borehole was filled with granular filter material. Concrete was placed at the top one meter around the pipe, to plug the hole.

## COMPOSITION OF THE GROUT MIXTURE

The grout mixture used consisted basically of water and cement with a water-cement ratio varying between 1 and 1.2 by weight with the addition of a small quantity of bentonite of the order of 4 to 6 percent by weight of cement to keep the cement in suspension.

An extensive laboratory research program on cement-bentonite mixtures with various water-cement ratios and various bentonite contents was carried out in order to study the properties of these grout mixtures and determine the most suitable mix proportions which could be pumped easily, penetrate into the voids, not settle quickly from suspension, and develop some strength after hardening.

### Basic grout materials

Some of the properties of the basic grout materials used were as follows:

| | |
|---|---|
| Water: Athens tap water | |
| pH at 20$^{o}$ C | 7.2 |
| Cement: Portland cement Hellenic Type | |
| Pozzolan content | 10 percent |
| Blaine fineness, ASTM C 204 | 2800-3000 cm$^2$/gr |
| Time of set, ASTM C 191 | |
| initial | 90-150 min |
| final | 4-5 h |
| Bentonite (Sodium activated): | |
| Liquid limit, ASTM D 423 | 420-480 |
| Plastic limit, ASTM D 424 | 25-37 |
| pH of slurry with water content close to liquid limit | 9.8 |

The bentonite was used in a form of thick slurry which was stored for at least 24 hours prior to its use to ensure that no further swelling of the material would take place.

## QUALITY CONTROL PROCEDURES

Quality control for the proportioning of the grout mixture was carried out continuously at the site with measurements of viscosity, bleeding, and compressive strength tests. The following simple tests were carried out:

### Flow Cone

The flow charecteristics of the grout mixture were checked according to specification CRD-C79 of the Corps of Engineers by measuring the time of efflux of a standard volume of mix (1725 ml) through an orifice of specified diameter. The time of efflux is a measure of the viscosity of the grout mixture. The time of efflux used varied between 9 and 11 seconds depending on the subsurface conditions and the grout take at each injection point.

Bleeding

This test was carried out as follows: the grout mixture sample was placed inside a 1000 ml glass cylinder and percentage of water on top of the mixture, related to the total volume of the sample was determined at various time intervals. Bleeding after 5 hours fluctuated between 5 and 15 percent.

Compressive strength

Compressive strengths were determined by following the basic steps of ASTM C 109. All tests were performed on cylindrical specimens with 0.075 m diameter. Due to bleeding the height of the specimens varied between 0.126 and 0.144 m. All specimens were cured in water. The results of the 28-day strengths varied between 4000 and 6000 kPa.

## INJECTION OF THE GROUT MIXTURE

Following mixing, the grout mixture was collected into a tank adjacent to the mixer from which it was pumped to the various injection points with the aid of a piston pump. The piston pump used for all grouting operations was type BOYLES 12 RD, on which modifications were made to the piston lining and to the valves in order to circulate and inject the grout mixture.

The grout mixture was pumped to the injection points through high pressure resistent rubber hoses of 0.025 m inside diameter. Manometers were installed at the outlet point of the pump and at the head of each perforated pipe in order to measure the pressure of the grout mixture into the rubber hose and the pressure with which it was injected into the man-made fill.

Throughout grouting operations records were kept about the weight of cement injected and the pressure changes at the head of each perforated pipe.

## CRITERIA ESTABLISHED FOR GROUTING OPERATIONS

The following criteria were established for grouting operations, concerning maximum pressure applied and quantities of cement injected.

Maximum allowable pressure at the grout headers of each perforated pipe was specified to be equal to 300 kPa when buildings existed at the site, and equal to 700 kPa when no buildings were at the site.

Grouting at each injection point was discontinued either when the maximum specified pressure was attained or when a total quantity of 30 tonnes of cement per hole was injected. Grouting was also discontinued when grout mixture appeared on the ground surface.

As a rule no more than 12 tonnes cement were injected at the same point in one day and every effort was made never to grout on the following day in the vicinity of points already grouted during the previous day.

By applying the above criteria, the following grout take values were observed:

(i) In the case of the sites with the damaged buildings, for distances between injection points of 1.5, 1.8 and 2.2 m the average grout take per injection point was equal to 0.96, 1.35 and 1.49 tonnes per meter depth of man-made fill respectively.

(ii) In the case of the site without buildings where distance between injection points was 6.3 m the average grout take per injection point was equal to 1.7 tonnes per meter depth of man-made fill.

Based on the above data and on experience it is believed that for stabilization of man-made fills under damaged buildings, distances between injection points should not be greater than 2.5 m.

## EFFECTIVENESS OF THE GROUTING TECHNIQUE

The effectiveness of the grouting technique can be demonstrated on the basis of the following observations:

Quantity of cement versus injection pressure

As mentioned previously, throughout the grouting operations detailed records were kept about quantities of cement injected and pressure changes at each injection point.

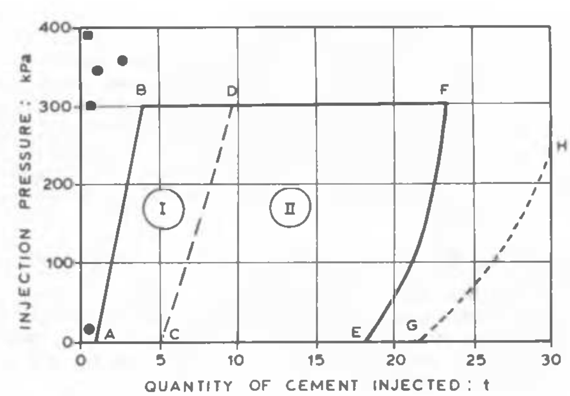


Fig.3 Quantity of cement injected versus injection pressure

Figure 3 summarizes the results of quantity of cement injected plotted against injection pressure from all the injection points at one of the sites. Similar diagrams were obtained from the other sites too. Typical plots of quantity of cement injected versus injection pressures are the curves AB, CD and EF. The five individual points to the left of curve AB refer to grout points where shortly after the injection of a small quantity of grout mixture either high pressures were developed or the grout mixture appeared at the ground surface. The dotted curve GH to the right shows an exceptional case of high grout take.

The surface which is defined by the points A, B, F and E contains the pressure curves from 47 injection points. Areas I and II contain results from 20 and 27 injection points respectively. From this diagram the following conclusions can be drawn·

(i) The smallest quantity of cement injected with zero pressure was not less than one tonne.

(ii) At 20 injection points the pressure at the head of the perforated pipe remained zero for quantities of cement varying between one and five tonnes while at the remaining 27 injection points, which are more than half of all the injection points, the pressure remained zero for significant quantities of cement varying between 5 and 18 tonnes. The location of line CD which separates surface I and II was selected arbitrarily to start at 5 tonnes. It was thought that quantities of cement in excess of 5 tonnes can be considered to be significant. From the above it can be concluded that in more than half of the injection points the extend of voids within the man-made fill was significant.

(iii) The increase of pressure at the end of each injection is an indication that voids were filled and that no further grout mixture could be injected into the fill without further increase of the injection pressure.

(iv) The increase of pressure at the end of each injection indicates also that the permeability of the soil becomes very low or negligible. After stabilization rain and other surface waters could not percolate into the man-made fill and the risk of water action became insignificant.

Boreholes drilled after grouting operations

Fig.4 shows the subsurface profiles of five boreholes which were drilled after the grouting operations at distances varying between 0.5 and 1.0 m from injection points. It can be seen from these profiles that:

(i) Grout mixture was distributed along the whole depth of the man-made fill with the exception of some pockets of clay, and

(ii) Grout mixture penetrated all voids cementing all loose non-cohesive material.

It was observed during drilling that rates of advance were slow through the stabilized fill and varied between 0.7 and 1.0 m/h and difficulties were encountered while drilling through cemented layers. These rates of advance of drilling are about half than those observed prior to grouting.

Performance of buildings after stabilization

After completion of grouting operations damaged building were repaired. Since 1973 when the first grouting project was completed, no further settlements were recorded and no haircracks were observed on the walls.

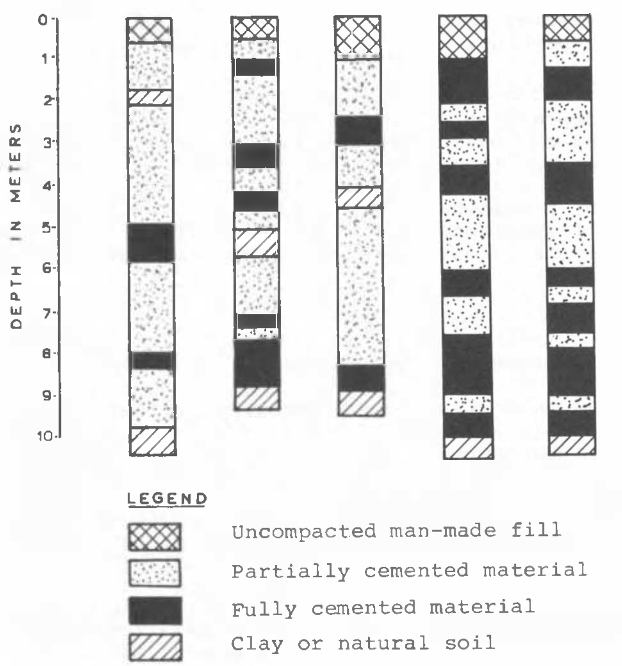


Fig.4 Borehole profiles after grouting

CONCLUSIONS

Uncompacted man-made fills formed by dumping of excavation and demolition materials from the building activity in the Athens area were stabilized with a grouting technique which makes use of a cement-bentonite mixture. The grout mixture was injected into the man-made fill through perforated pipes suitably spaced.

Criteria were established for maximum pressures applied and quantities of cement injected. Simple quality control procedures were adopted to check and adjust the grout mixture depending on subsurface conditions.

Based on grout take observations it is believed that for stabilization of man-made fills under damaged buildings, distances between injection points should not be greater than 2.5 m.

REFERENCES

Kotzias, P.C. and Stamatopoulos A.C. (1970). Städtische Aushub- und Abbruchmassen für geotechnische Bauten. Mitteilungen Institut für Grundbau und Bodenmechanik der T.H. Aachen, Heft 51, Nov., 149-175.