

## Development of Cement Grout mixes for treatment of underground cavities in Kuwait

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### ABSTRACT

Large sinkholes occurred in a residential suburb in the State of Kuwait, leading to destruction of properties and subsequently to partial evacuation of this residential area. From comprehensively conducted investigation programs, the sinkholes were attributed to the existence and propagation of Karst cavities in the limestone bedrock layer. Accordingly, a complete treatment program was adapted to reduce the risk of sinkhole recurrence by minimizing the possibilities of collapse in the upper level cavities within the limestone bedrock. In this project, two different cement grout mixes were designed and used for treatment of the Karst cavities; cavity filling grout and permeation grout. The assessment of the used mixes included regular evaluation of the compressive strength, slump, thermal conductivity, thermal resistance, bleeding, air content, loss of slump, flow and setting time. The treatment was followed by an evaluation program by drilling control boreholes. Some cores of the hardened grout were extracted from the control boreholes and their properties were evaluated and compared to those of laboratory specimens. This paper describes different types and mixes of cement grouts utilized in the ground treatment, elements of quality control program, and frequency and types of tests. Assessment of the results in addition to overview of the project is also presented. The results verified the efficiency of the different cement grout mixes used in this treatment project.

**Keywords:** Karst, cement, grout, sinkholes, quality control, cavity, treatment, permeation

### 1. Introduction

In a residential suburb in the State of Kuwait, a total of eight sinkhole incidents were detected, four of which occurred between 1988 and 1989 while the other four observed in 2004 (Al-Rifaiy, 1990; Abdullah and Mollah, 1999; Abdullah and Kamal et al., 2005). The first sinkhole was recorded when a cylindrical hole enlarged to 15 m in diameter and 31 m in depth in front of a residential house. Few days later the second sinkhole occurred with 4 m diameter and 7 m depth; subsequently, other sinkholes occurred in the same neighborhood. The sizes of sinkholes varied between 1.5 to 15 m in diameter and between 0.4 and 31 m in depth. Following the sinkholes incidents, the residential area was partially evacuated and subjected to extensive studies including topographical, geophysical, geological and geotechnical investigation programs leading to underground cavities detection (Al-Mutairi et al., 1998; Abdullah and Kamal, 2005).

The studies revealed that the geological profile of this residential suburb consists of 35 to 40 m thick overburden soil comprising dense to very dense predominantly quartz sand, overlaying the Dammam Formation Karst limestone bedrock. The cause of the sinkholes attributed to the dissolution of the limestone bedrock and subsequent ravelling of the overburden soil cover into the underlying Karst cavities. A decision was made to treat those

cavities by stopping soil migration to the limestone cavities in order to prevent the recurrence of sinkhole incidents in the future.

Among several treatment measures, filling the Karst cavities with cement grout was selected as the main treatment measure for cavities problem in this study. The selected treatment measure is considered the most efficient and economical measure for reducing the risk of sinkhole development taking into consideration its cost and ease of application. The treatment measure emphasized on filling the underground cavities in the limestone bedrock Formation with cement grout pumped from the ground surface. This paper discusses the two types of grouts that were utilized in this treatment project along with their proportions and constitutive materials. The paper also discusses the testing frequency and types in addition to the quality control program that was followed to assure the quality of the utilized mixes; hence, assure the success of the performed treatment program.

## **2. Background**

### **2.1 Treatment techniques**

A number of techniques are available for sinkhole remediation such as full excavation and replacement, pin piles to bedrock, pressure grouting, polymer injection, and combinations of techniques. These approaches may vary widely in cost, feasibility, speed, and effectiveness (Schokker, 2008). Slurry grouting is generally the most appropriate for typical Karst sites in which voids are found in both the rock and the overlying soils, and when facility loadings are light to moderate (Fischer, 1996). Compaction grouting works best when rock is relatively sound and shallow, otherwise tremendous quantities of grout will be needlessly placed into rock and soil voids. Many case studies were also reported (Gobin, 2010; Beck, 2003). Gobin discusses the case history of mitigating Karst conditions during construction of a bridge foundation in central Florida. The installation of a test pile triggered the initial sinkhole and subsequent operations such as drilling test borings and grout injection triggered additional sinkholes. Sinkhole formation at the site ceased only after a substantial quantity of grout was injected.

### **2.2 Grouting methods**

Grouting is a geotechnical process, which involves injection of cement or chemical grout for the purpose of filling cracks or voids in the rock mass or soil. Cement is the most common grout used in rock treatment. Before treatment, it is important to understand the rock condition and properties (Wallner 1976; Lombardi 1985). For choosing the proper grout, both the soil formation and grout characteristics should be considered. The formation should have ability to receive grout, and the mechanical properties, such as permanence, penetrability and strength, of each grout determines its suitability for a specific job.

For the long term requirements and durable grout, some properties should be observed which are water separation during hardening, hardening time, and solubility of the grout in the surrounding environment (Eklund and Stille, 2008). The most commonly used grout consists of cement and water with additives that reduce the cost or improve workability and applicability. When the voids are large and penetration is easy, fillers for bulking out are mixed with the grout. They weaken the grout but strength, however, is not an important issue in this type of application. Sand is a cheap filler but requires care to avoid segregation. Clay,

such as Bentonite, could be used as grout filler or as a grout on its own, but it is more expensive and difficult to use than sand.

### **3. Methodology of Treatment Application**

The main purpose of the treatment application considered in this study is to reduce the risk of sinkhole recurrence by minimizing the possibilities of collapse in the upper level cavities within the limestone bedrock. The scope is filling up of the uppermost cavities in the rock formation at depths range from 30 to 50 m, i.e. the cavities that are close to the overburden sand, with stable cement mortar grout pumped from the ground surface. The work was carried out in a pilot treatment area located within the affected residential area among total surface area of around 62,000 m<sup>2</sup>. As shown in Figure 1, the treatment area under consideration is divided into six zones according to their risk factor, based on the previously conducted geophysical investigation programs (Kamal et al., 2007).

Injection method from the ground surface is used with low pressures for proper filling of the underground cavities. The treatment is not intended to densify the rock or to improve its strength, but to fill up the existed voids and cavities and to prevent migration of sand from the overburden layer into the limestone bedrock. By closing cavities and voids in the limestone layer and preventing soil raveling, the thick overburden of dense sand will assure sufficient ground support for all structures above ground. The cavity filling grout, consisting of cement, sand, additives and water, is considered economical and efficient.

The cavity filling grouting is replaced by a treatment called permeation grouting in locations where no open cavities are observed but the uppermost layers of the rock prove to be highly pervious due to open fissures or the presence of frequent small Karst features. Permeation grout consists of cement-water mix and additives without aggregates injected into the rock mass under pressures using packers. The applied treatment program is extensively used in the pilot area. All detected underground cavities and fractured rocks in the upper layer of the limestone bedrock during the drilling program are treated by either cavity filling or permeation grout.

The treatment project started with an exploratory program, which is consisted of drilling borehole and conducting in-situ testing and sampling to investigate the properties and characteristics of the soil. Then, grout mixes are designed and a meticulous quality control program is followed. The grouting program is started by utilizing two different treatment methods; the cavity filling of deep limestone cavities using cement based mortar and permeation grouting of remaining deep voids using cement based grout.

The treatment requires extensive drilling of boreholes that is used for grout injection of the two methods. To ascertain the treatment and examine the soil status after treatment, a control program is proceeded which consists of drilling boreholes accompanied by in-situ and laboratory testing (Kamal et al., 2007 and b). The project also included a rigorous dilapidation survey to monitor the status of the existing structures before, during and after treatment application.



**Figure 1:** The six zones in the pilot area, TA1 to TA6

## 4 Results and Discussions

### 4.1 Grout types and materials

Two main mixes are utilized in the treatment project in this study, the cavity filling and permeation grouts. Constitutive materials are first inspected, tested and approved. Cement is supposed to satisfy the requirements of EN 197-1:2000, while the bentonite is supposed to have less than 10% sand and a liquid limit of not less than 300. Aggregates are checked routinely on each delivery for the grain size distribution, water soluble chloride salts, sulphate content and moisture content. Water and additives are also checked and approved. Based on the general project requirements, mixes are designed and tested as described hereafter.

### 4.2 Cavity filling grout

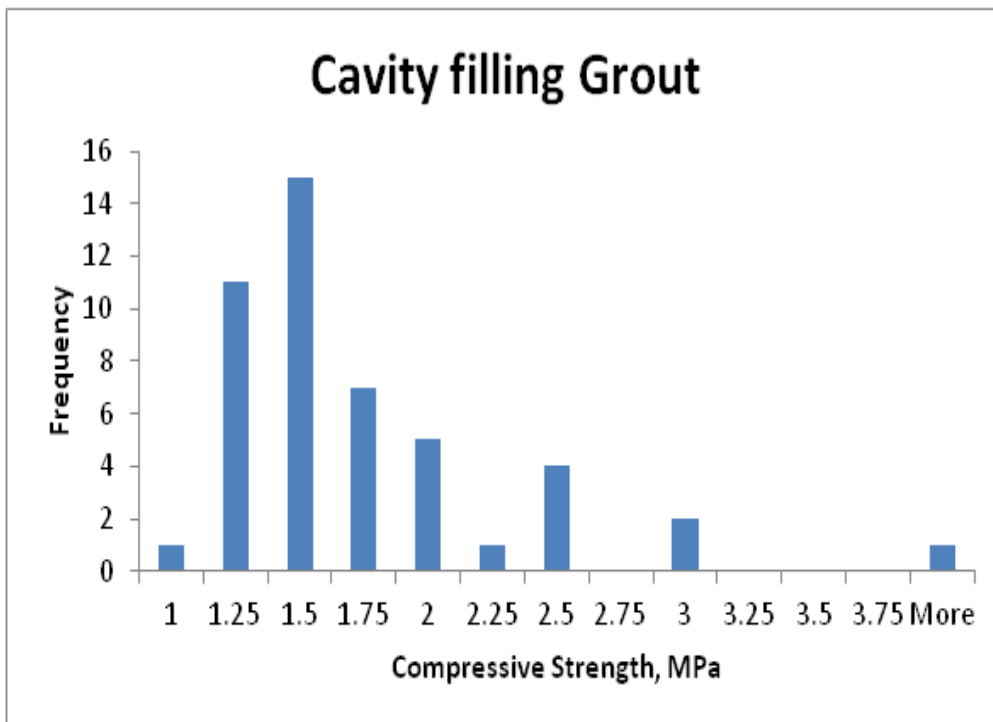
The cavity filling grout mix is designed to satisfy the requirements of decantation of less than 2% after two hours (ASTM C940), and cylinder compressive strength of more than 1 MPa (ASTM C39). Those requirements are checked as frequent as one series of three sets every 500 m<sup>3</sup> and not less than one series every ten days. The utilized grout mix consists of 1,500 kg natural sand, 150 kg cement, 300 liters of water, 1.5 liters of retarders (per cubic meter), and 15 kg of bentonite. Slump is specified between 200 and 220 mm. The cavity filling mix is prepared off-site and submitted in truck mixers, Figure 2.

The results of the testing program of the cavity filling grout show that the compressive strength has a minimum value of 1 MPa, maximum value of 4 MPa and average value of 1.64 MPa (> 1 MPa), Figure 3. The results show that the saturated unit weight of cavity filling grout is ranging between 15.05 and 19.86 kN/m<sup>3</sup> with an average value of 18.77 kN/m<sup>3</sup>, Figure 4. In addition to compressive strength and unit weight tests, other properties of the

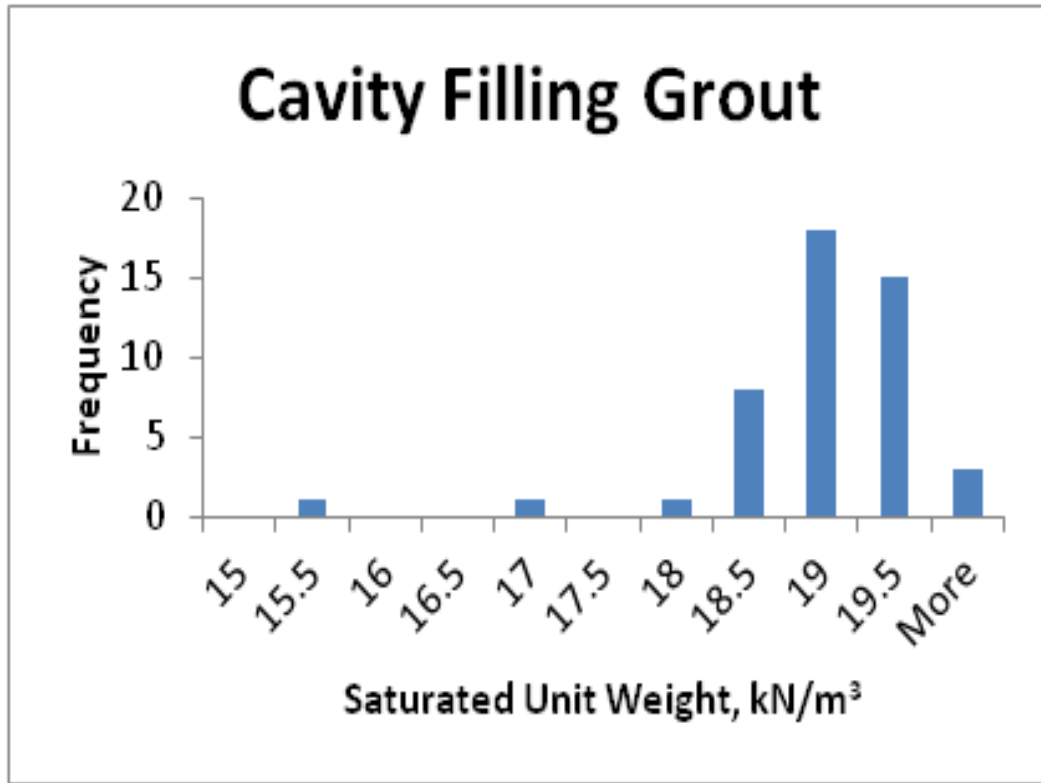
mix are determined including air content, setting time, bleeding, thermal conductivity, and thermal resistance coefficient, as a sample results of one series of tests is listed in Table 1.



**Figure 2:** Delivery of cavity filling mix



**Figure 3:** Histogram for the compressive strength results for cavity filling grout

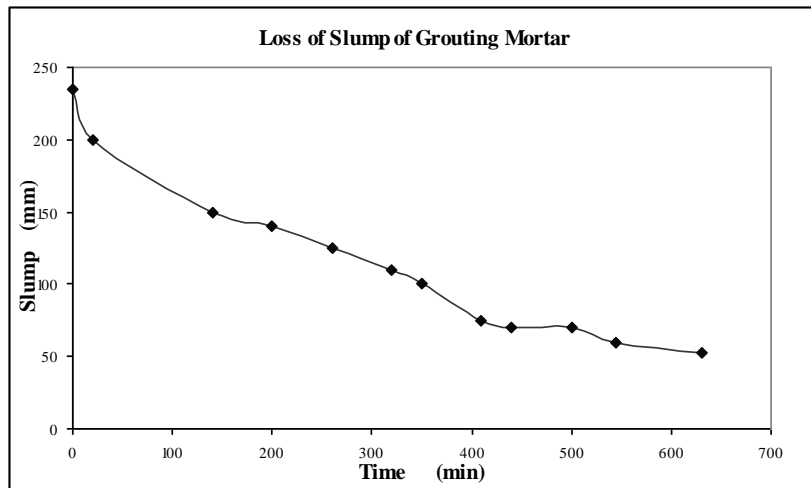


**Figure 4:** Histogram for the saturated unit weight results for cavity filling grout

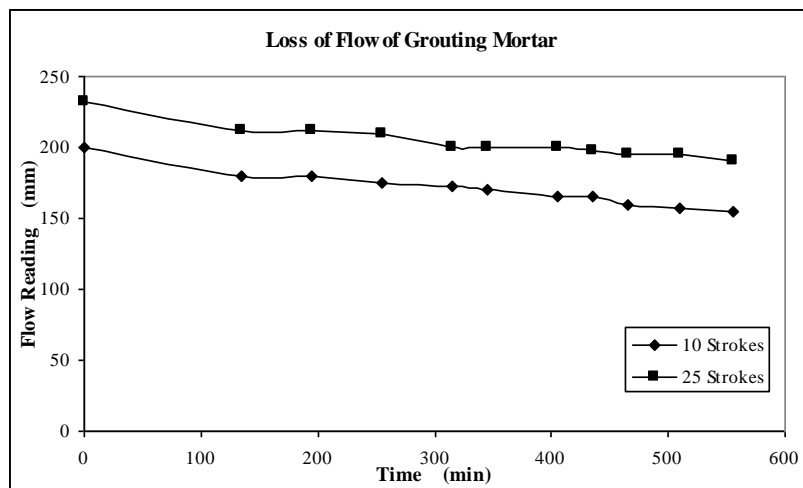
**Table 1:** Properties of the cavity filling mortar

Property	Sample Test Results	Average Value
Compressive strength	(1.12, 1.09, 1.05 MPa)	1.09 MPa > 1 MPa
Bleeding	1.00%, 0.90%, 0.95%	0.95% < 2%
Air content	(2%, 2%, 2.1, 2%)	2%
Setting time	-	10 hours < Setting Time < 24 hours
Thermal conductivity	-	0.49365 w/m °K
Thermal resistance coefficient	-	0.163 m² °K/w

Consistency of the cavity filling mortar is a measure of the workability of the cement grouts. Workability time of the cavity filling grout is increased by adding retarding admixture that allows the cement grout to have workable consistency for longer time. It is measured using two different methods: slump test method (ASTM C143) and flow table test method (ASTM C1437). Loss of consistency versus elapsed time is measured to confirm that the grout mix is workable during the pumping period and during the time needed to move from treatment of a cavity to another. As shown in Figure 5 and yet after 5 hours, the grouting mortar has slump of more than 100 mm and is workable and pumpable. This period is needed to consume the grout quantity in a mixing truck for treating a cavity and proper time to move to another treatment location. The flow table results as a measure for workability loss, also confirmed the same results of flowable and pumpable after 4 hours elapsed as shown in Figure 6.



**Figure 5:** Slump of the cavity filling mortar



**Figure 6:** Flow table results of the cavity filling mortar

### 4.3 Permeation grout

The grout used for permeation is specified to have both cement and bentonite, water-cement ratio less than one, average cylinder compressive strength of not less than 5 MPa, bleeding at two hours after mixing less than 3% and March funnel flow time less than 50 seconds (ASTM D6910). The permeation mix consists of 800 kg of cement, 718 liters of water, 5 liters of retarders, and 15 kg of bentonite. The slurry is prepared on site in a batching plant as shown in Figure 7. Bleeding, density and viscosity are checked on site twice a day as part of the control and quality assurance program, Table 2. The compressive strength is checked not less than a series of three samples every seven working days.

The permeation grouting results from the testing program show that the compressive strength is ranging between 5.6 and 16.4 MPa with an average value of 10.6 MPa (> 5 MPa), Figure 8. The results show that the saturated unit weight of permeation grouting is ranging between 13.11 and 17.75 kN/m<sup>3</sup> with an average value of 15.08 kN/m<sup>3</sup>, Figure 9. The bleeding of the

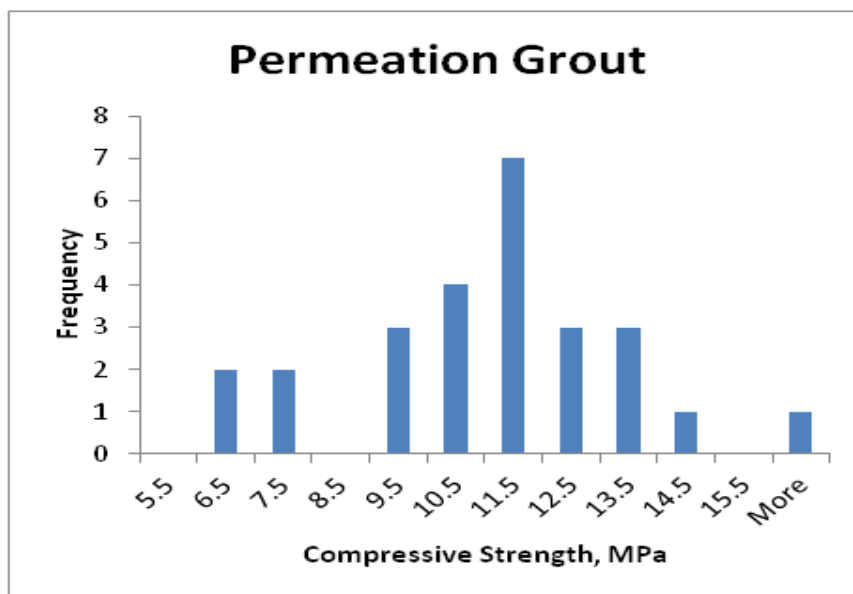
grout mix at two hours after mixing and the March funnel flow time is measured to control the permeation grouting before injection. The results indicated that the bleeding is ranged from 0.5% to 2.5% with an average value of 1% (< 3%). The results of March funnel flow time indicating a range of 30 to 39 s with an average value of 34 s (< 50 s), Figure 10.

**Table 2:** A Sample of daily tests of the permeation grout

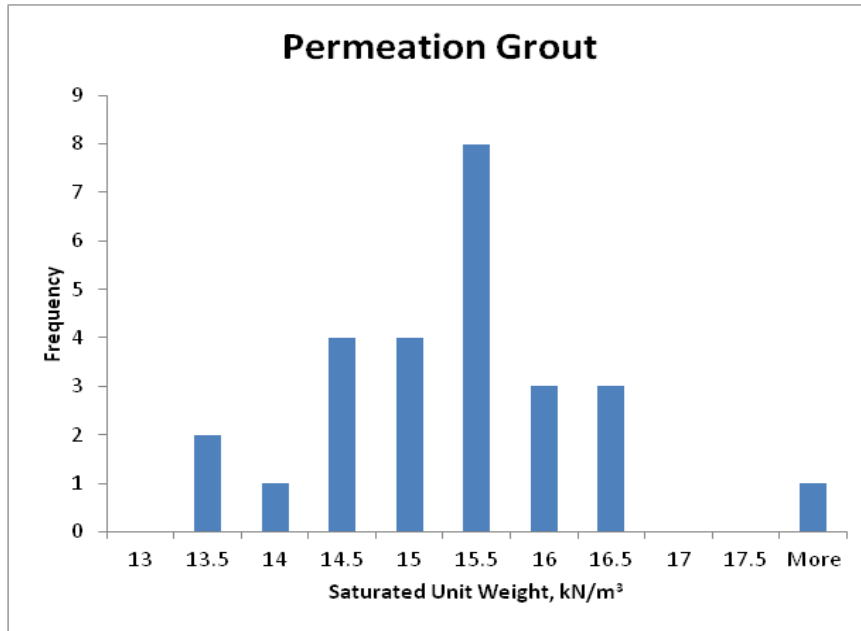
First test - at time: 10:45 am		Second test - at time: 1:30 pm	
Bleeding (%)	1.5	Bleeding (%)	1
Density (t/m <sup>3</sup> )	1.52	Density (t/m <sup>3</sup> )	1.51
Viscosity (sec.)	36	Viscosity (sec.)	35



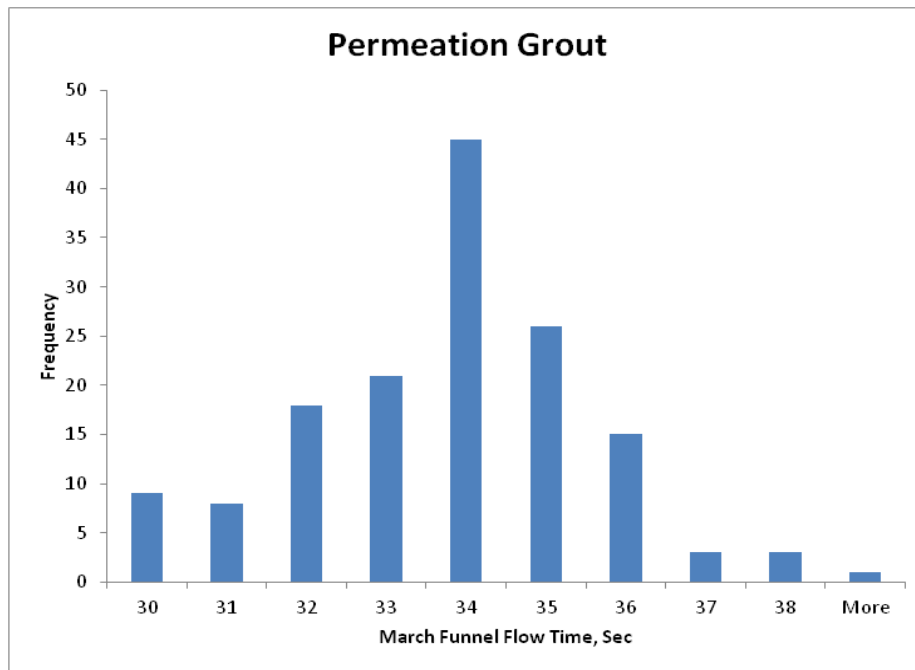
**Figure 7:** In-site slurry preparation



**Figure 8:** Histogram for the compressive strength results for permeation grout



**Figure 9:** Histogram for the saturated unit weight results for permeation grout



**Figure 10:** Histogram for the March funnel flow time for permeation grout

#### 4.4 Control program

To verify the efficiency of the injected grouts, a control program is conducted after completing the treatment applications. The control program for the grout included determination of the compressive strength of the hardened grout cores extracted from the control holes for both grouting; cavity filling and permeation. The results of the cavity filling grouting indicate that the compressive strength has a minimum value of 1.69 MPa, maximum value of 5.49 MPa and average value of 2.72 MPa (> 1 MPa).

It is clear that grout compressive strength after treatment application is greater than before treatment application. The average value of saturated unit weight for cavity filling grout is determined as  $19.78 \text{ kN/m}^3$ . The grout extracted samples indicate that no washing out of the cement during grouting due to the existence of bentonite in the grout mix. The results of the permeation grouting indicate that the average compressive strength equals to 8 MPa which is greater than the designed strength. The results also show that the average value of the saturated unit weight of permeation grouting equals to  $15.71 \text{ kN/m}^3$ .

## **5. Summary and Conclusions**

In large projects, it is essential to utilize comprehensive quality control program in order to assure the quality and hence the adequacy and durability of the project. The lack of such program may jeopardize the credibility of the whole project. This is more apparent where soil treatment projects are involved, as the deterioration signs will not be visible. In the treatment application project under consideration, two grouting methods and mixes were used to treat underground deep cavities. A comprehensive quality control program was adapted that included testing of constitutive materials, mix design and frequent evaluation of the mechanical and physical properties of the adapted mixes. The frequency of testing depends on the importance of the tested property and the mix size.

Compressive strength and workability were considered the most important properties from the used grouts. Workability was selected to assure that the mix can be transferred, placed and still retain enough workability to fill the designated cavity. As a measure for slump loss and flow time, the cavity filling mortar retained more than 50 mm slump after more than 10 hours. The compressive strength was greater than the designed strength. The close adherence to the quality control program assures the quality of performed treatment. It is highly unlikely that a major cavity still exists in the treated area after this comprehensive treatment project. The grout mixes used in this project can be used for areas and problems with similar nature.

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