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Improvement of Cement Groutmixes for behavior of dissidentcavities in Bhubaneswar

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ABSTRACT

Large sinkholes occurred in a residential suburb in the State of Bhubaneswar, leading to destructionofpropertiesandsubsequentlytopartialevacuationofthisresidentialarea.Fromcomprehensivelyconductedinvestigationprograms,thesinkholeswereattributedtotheexistence and propagation of Karst cavities in the limestone bedrock layer. Accordingly, acompletetreatmentprogramwasadaptedtoreducetheriskofsinkholerecurrencebyminimizingthepossibilities of collapseintheupperlevel cavities withinthelimestonebedrock.In thisproject,twodifferentcementgroutmixesweredesignedandusedfortreatment of the Karst cavities; cavity filling grout and permeation grout.The assessment oftheusedmixesincludedregularevaluation of thecompressivestrength,slump,thermalconductivity, thermal resistance, bleeding, air content, loss of slump, flow and setting time.The treatment was followed by an evaluation program by drilling control boreholes. Somecores of the hardened grout were extracted from the control boreholes and their propertieswere evaluated and compared to those of laboratory specimens. This paper describes differenttypes and mixes of cement grouts utilized in the ground treatment, elements of quality controlprogram, and frequency and types of tests. Assessment of the results in addition to overviewof the project is also presented.The results verified the efficiency of the different cementgroutmixesusedinthis treatmentproject.

Keywords: Karst,cement,grout,sinkholes,qualitycontrol,cavity,treatment,permeation

I. INTRODUCTION

In aresidential suburbintheState of Bhubaneswar,atotal of eightsinkholeincidentsweredetected, four of which occurred between 1988 and 1989 while the other four observed in2004 (Al-Rifaiy, 1990; Abdullah and Mollah, 1999; Abdullah and Kamal et al., 2005).Thefirst sinkhole was recorded when a cylindrical hole enlarged to 15 m in diameter and 31 m indepth in front of a residential house.Few days later the second sinkhole occurred with 4 mdiameter 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 indepth.Following the sinkholes incidents, the residential area was partially evacuated andsubjectedtoextensivestudiesincludingtopographical,geophysical,geologicalandgeotechnical investigation programs leading to underground cavities detection (Al-Mutairi etal.,1998;AbdullahandKamal,2005).

The studies revealed that the geological profile of this residential suburb consists of 35 to 40mthickoverburdensoilcomprisingdensetoverydensepredominantlyquartzsand,overlaying the Dammam Formation Karst limestone bedrock.The cause of the sinkholesattributedtothedissolutionofthelimestonebedrockandsubsequentravellingoftheoverburdensoilcoverintotheunderlyingKarstcavities.Adecisionwasmadetotreatthose cavities by stopping soil migration to the limestone cavities in order to prevent the recurrenceofsinkholeincidentsinthefuture.

Among several treatment measures, filling the Karst cavities with cement grout was selectedas the main treatment measure for cavities problem in this study.The selected treatmentmeasure is considered the most efficient and economical measure for reducing the risk ofsinkholedevelopmenttakingintoconsiderationitscostandeaseofapplication.Thetreatment measure emphasized on filling the underground cavities in the limestone bedrockFormation with cement grout pumped from the ground surface.This paper discusses the twotypes of grouts that were utilized in this treatment project along with their proportions andconstitutive materials. The paper also discusses the testing frequency and types in addition tothe quality control program that was followed to assure the quality of the utilized mixes;hence,assurethe successoftheperformed treatmentprogram.

II. BACKGROUND

Treatmenttechniques

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

Groutingmethods

Grouting is a geotechnical process, which involves injection of cement or chemical grout forthe purpose of filling cracks or voids in the rock mass or soil.Cement is the most commongroutusedinrock treatment.Before treatment,itisimportanttounderstandtherockcondition and properties (Wallner 1976; Lombardi 1985). For choosing the proper grout,both the soil formation and grout characteristics should be considered. The formation shouldhaveabilitytoreceivegrout,andthemechanicalproperties,suchaspermanence,penetrabilityandstrength,ofeach grout determinesitssuitabilityforaspecificjob.

For the long term requirements and durable grout, some properties should be observed whichare water separation during hardening, hardening time, and solubility of the grout in thesurrounding environment (Eklund and Stille, 2008).The most commonly used grout consistsofcementandwaterwithadditivesthatreducethecostorimproveworkabilityandapplicability. When the voids are large and penetration is easy, fillers for bulking out aremixed with the grout. They weaken the grout but strength, however, is not an important issueinthistypeofapplication.Sandisacheapfillerbutrequirescaretoavoidsegregation.Clay, such as Bentonite, could be used as grout filler or as a grout on its own, but it is moreexpensive anddifficulttousethansand.

III. METHODOLOGY OF TREATMENT APPLICATION

The main purpose of the treatment application considered in this study is to reduce the risk ofsinkhole recurrence by minimizing the possibilities of collapse in the upper level cavitieswithin the limestone bedrock.The scope is filling up of the uppermost cavities in the rockformation at depths range from 30 to 50 m, i.e. the cavities that are close to the overburdensand, with stable cement mortar grout pumped from the ground surface. The work wascarried out in a pilot treatment area located within the affected residential area among totalsurfaceareaofaround62,000m^2.AsshowninFigure1,thetreatmentareaunderconsideration is divided into six zones according to their risk factor, based on the previouslyconducted geophysicalinvestigationprograms (Kamaletal.,2007).

Injection method from the ground surface is used with low pressures for proper filling of theunderground cavities.The treatment is not intended to densify the rock or to improve itsstrength, but to fill up the existed voids and cavities and to prevent migration of sand from theoverburden layer into the limestone bedrock.By closing cavities and voids in the limestonelayer and preventing soil raveling, the thick overburden of dense sand will assure sufficientground support for all structures above ground.The cavity filling grout, consisting of cement,sand,additivesandwater,is consideredeconomicalandefficient.

The cavity filling grouting is replaced by a treatment called permeation grouting in locationswhere no open cavities are observed but the uppermost layers of the rock prove to be highlypervious due to open fissures or the presence of frequent small Karst features.Permeationgrout consists of cement-water mix and additives without aggregates injected into the rockmass under pressures using packers. The applied treatment program is extensively used inthe pilot area.All detected underground cavities and fractured rocks in the upper layer of thelimestonebedrockduringthedrillingprogramaretreatedbyeithercavityfillingorpermeationgrout.

The treatment project started with an exploratory program, which is consisted of drillingboreholeandconductingin-situtestingandsamplingtoinvestigatethepropertiesandcharacteristics of the soil.Then, grout mixes are designed and a meticulous quality controlprogram is followed.The grouting program is started by utilizing two different treatmentmethods;thecavityfillingofdeeplimestonecavitiesusingcementbasedmortarandpermeationgroutingofremainingdeepvoids usingcementbased grout.

The treatment requires extensive drilling of boreholes that is used for grout injection of thetwo methods.To ascertain the treatment and examine the soil status after treatment, a controlprogramisproceededwhichconsistsofdrillingboreholesaccompaniedbyin-situandlaboratorytesting(Kamalet al.,2007andb).Theprojectalsoincludedarigorousdilapidation survey to monitor the status of the existing structures before, during and aftertreatmentapplication.

Figure1: Thesixzonesinthepilotarea,TA1to TA6

IV. RESULTS AND DISCUSSIONS

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

Cavityfillinggrout
The cavity filling grout mix is designed to satisfy the requirements of decantation of less than2% 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 every500 m^3 and not less than one series every ten days.The utilized grout mix consists of 1,500kg natural sand, 150 kg cement, 300 litters of water, 1.5 litters of retarders (per cubic meter),and 15 kg of bentonite.Slump is specified between 200 and 220 mm.The cavity filling mixispreparedoff-site andsubmitted intruck mixers,Figure 2.

The results of the testing program of the cavity filling grout show that the compressivestrength has a minimum value of 1 MPa, maximum value of 4 MPa and average value of 1.64MPa (> 1 MPa), Figure 3.The results show that the saturated unit weight of cavity fillinggrout is ranging between 15.05 and 19.86 kN/m^3 with an average value of 18.77 kN/m^3,Figure4.Inadditiontocompressivestrengthandunitweighttests,otherpropertiesofthe mixaredeterminedincludingaircontent,settingtime,bleeding,thermalconductivity,andthermalresistancecoefficient, asasampleresultsofoneseriesoftestsislistedinTable1.

Figure2: Deliveryofcavityfillingmix

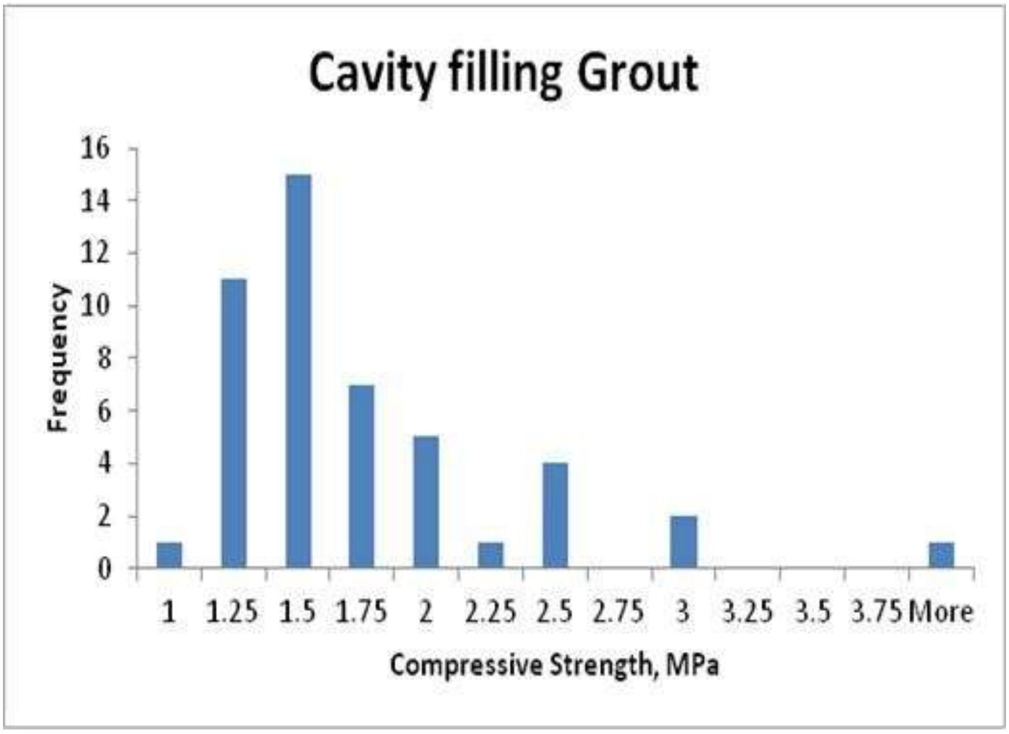

Figure3: Histogramforthecompressivestrength resultsforcavityfilling grout

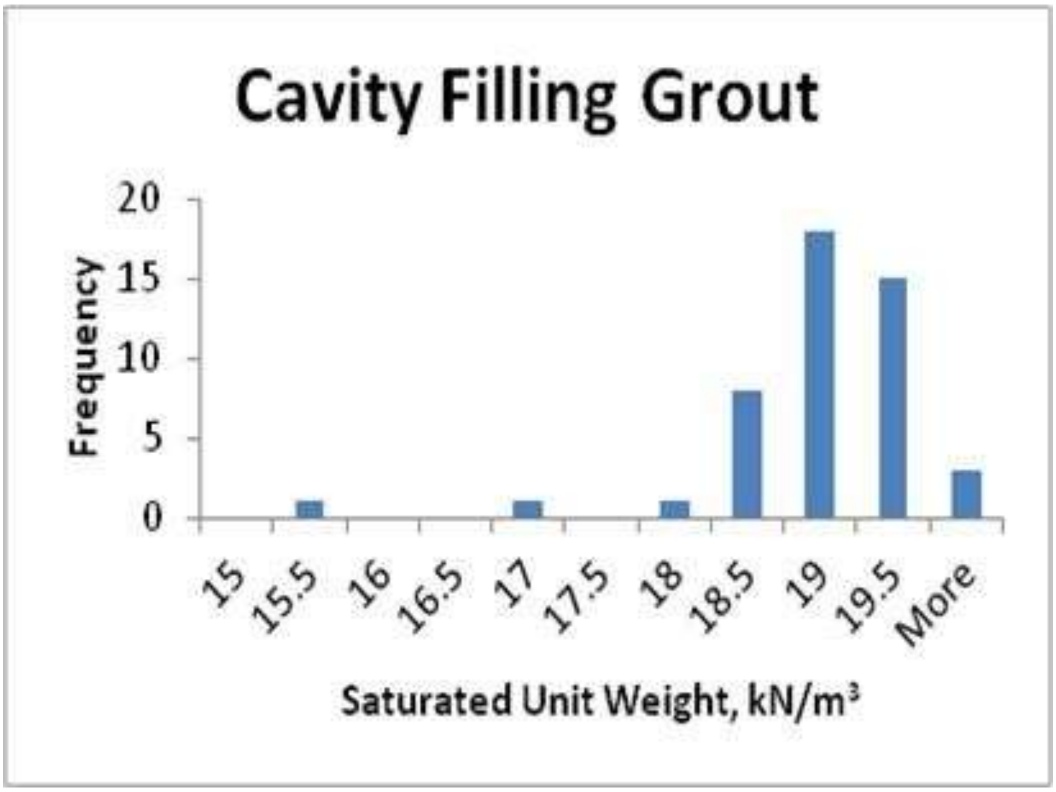

Figure4: Histogramforthesaturatedunitweightresultsforcavityfillinggrout

Table1: Propertiesofthecavityfillingmortar

Property	SampleTestResults	AverageValue
Compressivestrength	(1.12,1.09,1.05 MPa)	1.09 MPa□ 1MPa
Bleeding	1.00%,0.90%,0.95%	0.95%□ 2%
Air content	(2%,2%,2.1,2%)	2%
Settingtime	-	10 hours □ Setting Time □ 24hours
Thermalconductivity	-	0.49365w/m ^{o}K
Thermal resistancecoefficient	-	0.163m^{2o}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 thatallows the cement grout to have workable consistency for longer time.It is measured usingtwo different methods: slump test method (ASTM C143) and flow table test method (ASTMC1437).Loss of consistency versus elapsed time is measured to confirm that the grout mix isworkable during the pumping period and during the time needed to move from treatment of acavity to another.As shown in Figure 5 and yet after 5 hours, the grouting mortar has slumpof more than 100 mm and is workable and pumpable.This period is needed to consume thegrout quantity in a mixing truck for treating a cavity and proper time to move to anothertreatment location.The flow table results as a measure for workability loss, also confirmedthesame resultsofflowableand pumpableafter4hourselapsedasshown inFigure 6.

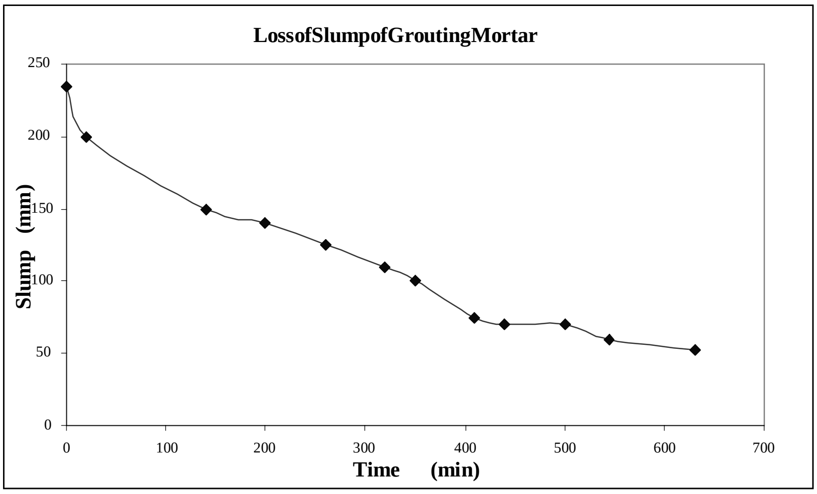

Figure5: Slump ofthecavityfillingmortar

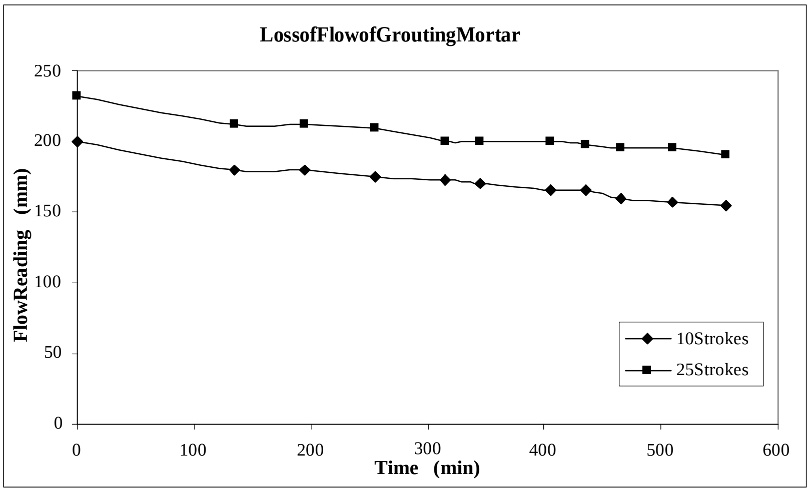

Figure6: Flowtableresultsofthecavityfillingmortar

Permeationgrout

The grout used for permeation is specified to have both cement and bentonite, water-cementratio less than one, average cylinder compressive strength of not less than 5 MPa, bleeding attwohours after mixingless 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, 5liters of retarders, and 15 kg of bentonite.The slurry is prepared on site in a batching plant asshown in Figure 7.Bleeding, density and viscosity are checked on site twice a day as part ofthe control and quality assurance program, Table 2.The compressive strength is checked notlessthanaseries ofthree samples everysevenworkingdays.

The permeation grouting results from the testing program show that the compressive strengthis ranging between 5.6 and 16.4 MPa with an average value of 10.6 MPa (> 5 MPa), Figure 8.Theresultsshowthatthesaturatedunitweightofpermeationgroutingisrangingbetween 13.11and17.75kN/m^{3}withanaveragevalueof15.08kN/m^3,Figure9.Thebleedingofthe groutmixattwohoursaftermixingandtheMarchfunnelflowtimeismeasuredtocontrolthe permeation grouting before injection.The results indicated that the bleeding is rangedfrom 0.5% to 2.5% with an average value of 1% (< 3%).The results of March funnel flowtimeindicatingarangeof30to39swithanaverage value of34s(< 50s),Figure 10.

Table 2: A Sample of daily tests of the permeation groutFirst test -attime:10:45 am Second test -attime:1:30pm

Bleeding(%)	1.5	Bleeding(%)	1
Density(t/m^3)	1.52	Density(t/m^3)	1.51
Viscosity(sec.)	36	Viscosity(sec.)	35

Figure7: In-site slurrypreparation

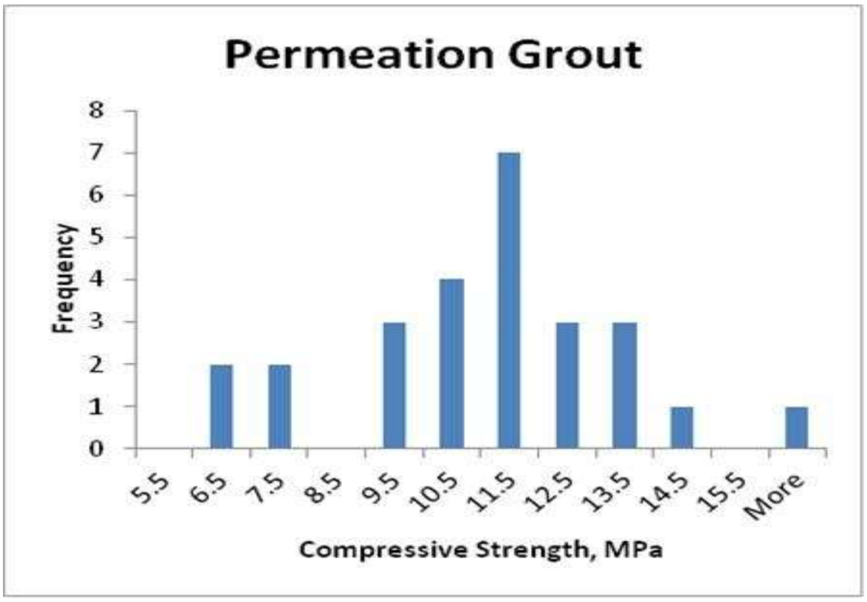

Figure8:Histogramforthecompressivestrengthresultsforpermeationgrout

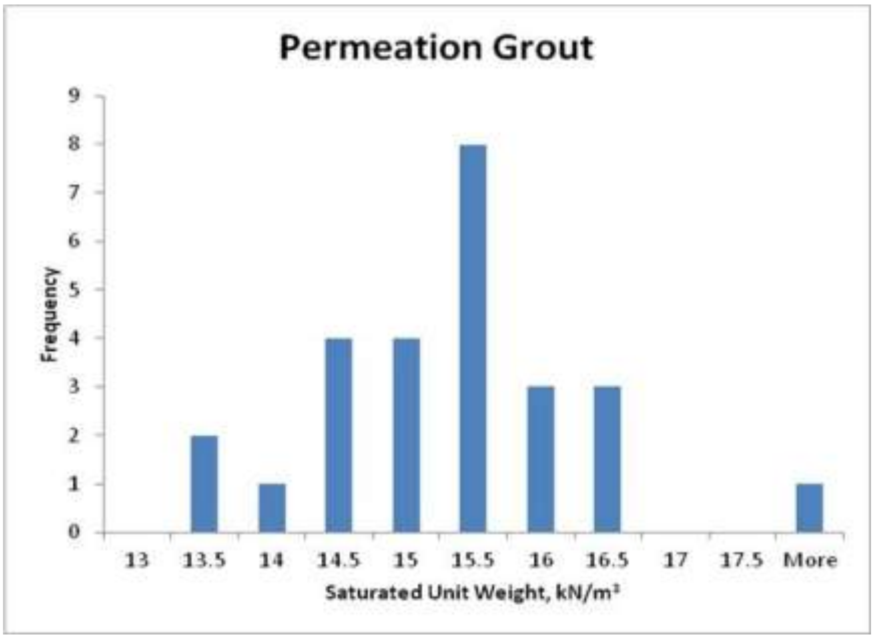

Figure9: Histogramforthesaturatedunitweightresultsfor permeationgrout

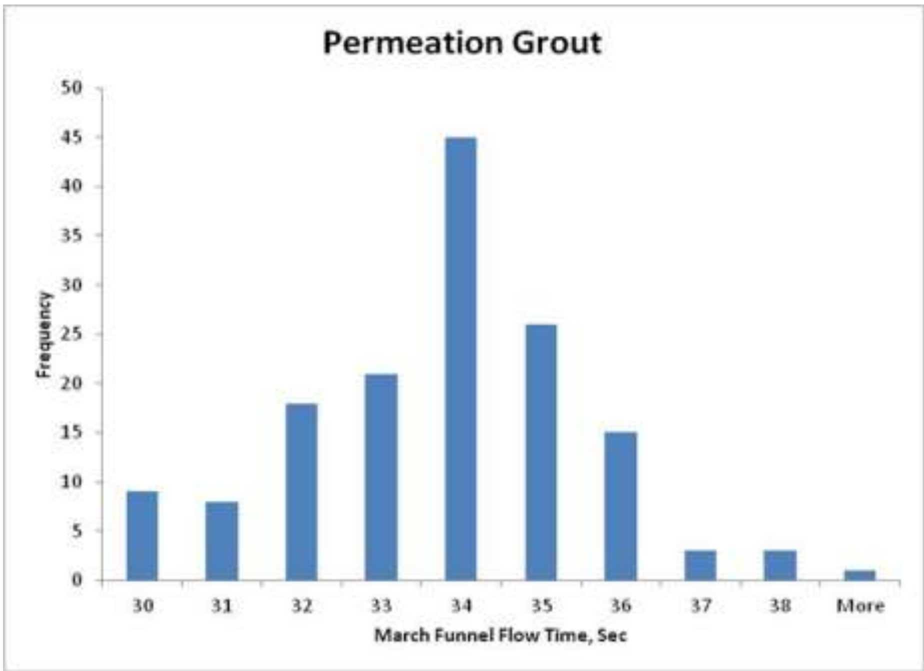

Figure10: HistogramfortheMarchfunnelflowtimeforpermeationgrout

4.4Controlprogram

Toverifytheefficiencyoftheinjectedgrouts,acontrolprogramisconductedaftercompletingthetreatmentapplications.Thecontrolprogramforthegroutincludeddetermination of the compressive strength of the hardened grout cores extracted from thecontrol holes for both grouting; cavity filling and permeation.The results of the cavity fillinggrouting indicate that the compressive strength has a minimum value of 1.69 MPa, maximumvalue of5.49MPaandaverage valueof2.72MPa(> 1MPa).

It is clear that grout compressive strength after treatment application is greater than beforetreatment application.The average value of saturated unit weight for cavity filling grout isdetermined as 19.78 kN/m^3.The grout extracted samples indicate that no washing out of thecement during grouting due to the existence of bentonite in the grout mix.The results of thepermeation grouting indicate that the average compressive strength equals to 8 MPa which isgreater than the designed strength.The results alsoshow that the average value of thesaturated unitweightofpermeationgroutingequalsto15.71kN/m^3.

V. SUMMARY AND CONCLUSIONS

In large projects, it is essential to utilize comprehensive quality control program in order toassure the quality and hence the adequacy and durability of the project.The lack of suchprogram may jeopardize the credibility of the whole project. This is more apparent wheresoil treatment projects are involved, as the deterioration signs will not be visible.In thetreatment application project under consideration, two grouting methods and mixes were usedto treat underground deep cavities.A comprehensive quality control program was adaptedthat included testing of constitutive materials, mix design and frequent evaluation of themechanical and physical properties of the adapted mixes.The frequency of testing dependsontheimportance ofthe testedpropertyandthemixsize.

Compressive strength and workability were considered the mostimportantproperties fromthe used grouts.Workability was selected to assure that the mix can be transferred, placedand still retain enough workability to fill the designated cavity.As a measure for slump lossand flow time, the cavity filling mortar retained more than 50 mm slump after more than 10hours.Thecompressivestrengthwasgreaterthanthedesignedstrength.Thecloseadherence to the quality control program assures the quality of performed treatment.It ishighly unlikely that a major cavity still exists in the treated area after this comprehensivetreatment project.The grout mixes used in this project can be used for areas and problemswithsimilarnature.

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