Strengthening of the Permeability of Sandy Soil by Different Grouting Materials for Seepage Reduction

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Abstract

Grouting is an effective way to improve the engineering properties of the soil to reduce soil permeability. In this research, an attempt has been made to study on effectiveness of grouting materials on seepage reduction. The purpose of this paper is to focus on the efficiency of current available grouting materials and techniques from construction, environmental and economical point of view. The seepage reduction usually accomplished by either chemical grouting or cementious grouting using ultrafine cement. In addition, the study shows a comparison between using grouting materials according to their degree of permeability reduction and cost. The comparison is made based on achieving a permeability reduction up to 10-7 m/Sec. The application of seepage reduction is based on the permeation grouting using grout curtain installation. The computer program (SEEP/W) is employed to model of dam rested on the sandy soil, using grout curtain to reduce seepage quantity and hydraulic gradient by different grouting materials. This analysis focuses on defining the best material for seepage control from the economical, installation, environmental effect safety interest.

Index terms— seepage, grouting materials, grout curtain, dam, seep/w.

1 Strengthening of the Permeability of Sandy Soil by Different Grouting Materials for Seepage Reduction

Introduction routing is defined as the procedure of filling or injecting fluid with pressure into the soil, generally via boreholes [18]. The purpose of injecting a grout is to decrease permeability of the soil and to increase the shear strength of the foundation soil. Grouting materials used for filling the voids existing in the soil to reduce permeability of soil [4]. Two classes of grouting materials are classified for seepage reduction: i) suspension-type grouts, ii) solutions-type grouts. The suspension-type grouts include clay and cement, while solutions-type grouts include a wide variety of chemicals such as acrylamide, N-Methaloacrylamide, acrylate and colloidal silica ??9].

Grouting is a technique to inject various types of grout into the ground at a deliberately controlled pressure and flow rate [10]. The grout is based on cement, silicate, or other materials, selected to suit particular ground conditions and improvement objectives. The grout fills in voids and cracks of the ground and permeates into soil pores to produce a solidified soil-grout mass [2]. The grouting is often applied to reduce permeability of soil underneath existing hydraulic structures, such as dams, regulators and others [4].

Permeation grouting for stabilization of fine sand is the longest-established and the most widely used grouting technique to seepage reduction. It involves the filling of the pore space of soils. The objective is to fill a void space without displacement of the formation or any change in the void configuration or volume [17]. In this paper, a comparison between the grouting materials for seepage reduction is presented and defining the grouting material that is environmentally friendly and more cost-effective.

ii.

2 Grouting Material For Seepage Reduction

In order to choose a grout type, several properties of grout should be concerned, such as rheology, setting time, toxicity, strength of grout and grouted soil, stability or permanence of the grout and grouted soil and the penetrability of the grouted soil [12]. Moreover, spreading of the grout plays an important role in the development of grouting technology. In the actual filed, the grouting method requires an extensive consideration on the grout hole equipment, distance between boreholes, length of injection passes, number of grouting phases, grouting pressure and pumping rate [14].

In this type of grouting materials, the micro fine cement is used to permeate between the soil particles. It has an average particle size of 3 to 4 microns [3]. The cement grout decreases the permeability about 5 orders of magnitude as the cement -water mix between (0.5 -5). Cement grouts are the least expensive type, it costs about $1 to $2 per liter of mixed grout [5]. The typical published values of permeability are listed in Table (1). The cement grout would cost about $100 to $ 200 per cubic meter of treated soil ??1].

In this type of grouting materials, the bentonite is used with the micro fine cement to reduce the cost of

3 G a) Suspension -Based Fine Grouts

Global Journal of Researches in Engineering ( ) Volume XV Issue III Version I the grout materials [5]. The permeability of the soil decreases by increasing the percentage of the bentonite [7]. It is a highly porous solid with a low permeability that lies somewhere in the cement and bentonite range, from 1x10-7 to 1x10-11 m/Sec. Typical published values of permeability are listed in Table (1). The cementbentonite grout decreases the permeability about 3-4 orders of magnitude. The cement-bentonite grout would cost about $65 to $ 75 per cubic meter of treated soil [1]. This grout is used to reduce the cost and also is used to reduce the permeability by increasing the percentage of clay [14]. The permeability of the soil is reduced about 3-4 order of the magnitude based on the clay concentration. Typical published values of permeability are listed in Grouters inject acrylamide to reduce the permeability. It has a viscosity and density similar to water. Acrylamide is considered to be permeant. The acrylamide grout decreases the permeability about 6-8 orders of magnitude [2]. A minimum of 10 % acrylamide solution is needed to assume a good gel. The World Health Organization considers acrylamide to be a neurotoxin and a potential carcinogen ??9]. The cost of acrylamide grout is about $500 per cubic meter of treated grout ??1]. used to reduce the permeability. N -Methaloacrylamide is not a toxin. So, NMA is better in use than acrylamide grout where drinking water is found. The reduction of permeability is similar to acrylamide about 6-8 orders of magnitude [13]. The cost of N-Methaloarylamide grout is about $550 per cubic meter of treated grout ??1].

In this type of grouting materials, the acrylate grout is used to reduce the permeability of soil. Acrylate gel is used as a less toxic material. It has a high viscosity. Turner 1998 reported the acrylate grout reduce the permeability about 1-3 orders of magnitude [14]. The acrylate grout would cost about $325 per cubic meter of treated soil ??1]. comprises a mixture of sodium silicate and reagent solution, which change in viscosity overtime to produce a gel. Reagent solution is organic or inorganic materials [15]. CSG has a low viscosity. Yone-kura and Miwa reported the permeability of the soil is reduced about 4-5 order of the magnitude based on the concentration of colloidal silica [19]. Perself 1997 made tests to determine the hydraulic conductivity of sand grouted by silica gel, it was found the hydraulic conductivity is decreased by increasing concentration of colloidal silica in the grout [11]. Colloidal silica grout would cost about $60 to $ 180 per cubic meter of treated soil [1]. Finally, figure (1) explain the maximum permeability of the soil after injecting by the grouting materials [6].

The soil improvement techniques are effective for each of the allowed or required disturbance of existing structures. The following methods, which imply a low level of vibration, are useful to improve soil strengthening and reduce the permeability [16]: ii.? Compacting grouting ? Permeation grouting ? Jet grouting ? Hydro fracture grouting.

Permeation grouting includes the injection of a low-viscosity fluid in the soil pores without changes in the soil physical structure. The main goal of permeation grouting is both to strengthen soil and to waterproof ground by filling its pores with injected fluid [17]. This method improves the soil physical and mechanical characteristics, stabilizes the excavation walls in soft soils and controls the groundwater migration [12]. As a results can be implemented the underpinnings beneath the existing foundations. Cementious grouts are generally used for medium to coarse grained sand. Chemical grouts are used in formations with smaller pore spaces, but are limited to soils coarser than fine grained sands. The process of permeation grouting is schematically shown in Figure (2) [18]. The quality control during permeation grouting is very important to ascertain the effectiveness of the technique. To understand the performance of grouted sand under cyclic loads, a complete record of the changes in the stress strain characteristics is required. The major properties of concern are the variation of affected by the repeated cyclic loading based on the grouting material used. The suspension grouting is fragile, on the other hand, the chemical grouting is soft and flexible material. It is here known as the impact of the repeated load on fragile material. The effect of cyclic loading can damage a fragile material, but the soft material can withstand against these load [4]. iv.

The purpose of curtain grouting is water seepage control, the grout holes are arranged in a series of rows to form a curtain approximately perpendicular to the direction of seepage [18]. The depth of the holes is dependent on design considerations as well as the depth of the soil and the head at upstream. For permeation grouting 38mm probe diameter is the most common in use. Curtain grouting, which can be single-row or multiple row of curtain. Single-row of curtain grouting is drilled as a widely spaced system of primary holes, subsequently followed by secondary and tertiary holes at a progressively smaller spacing. The initial spacing (of primary holes) usually varies between 6 m to 12 m based on the geological conditions and an experience [8]. The standard positions for grouting curtains are at the upstream of the dam to reduce the seepage and uplift pressure [8].

v.

The depth of a curtain is determined by considerations of the seepage characteristics of the foundation. The depth of the curtain is established by empirical procedures. So the depth equal to 0.5 H to 1.5 H or to reach the impervious layer. The hole spacing relates to the grouting rate to be used, the permeability of ground to be treated, and the allowable grouting pressure. There are mainly three different types of grout hole patterns used for grouting works [13]. These types are called the random spacing, the fixed spacing and split spacing. Houlsby (1990) proposed another way to construct the grout curtain figure (3) [8]. It is based on three stages of holes (primary, secondary and tertiary) each of them has a different depth, and if necessary, quaternary and quandary holes can also be drilled. The primary spacing used is 12.0 m in most of cases, but can also be less (6.0 m minimum) to reduce the permeability to satisfactory level [16].

1.00E-14 1.00E-12 1.00E-10 1.00E-08 1.00E-06 1.00E-04 1.00E-02 1.00E+00

4 Permeability m/sec grout materials H y dr alic c onduct iv ity aft er inje c t ing t he s and s oil by g r o u t m at e rials

cyclic strain and damping ratio with the number of cycles at different stress levels [4]. The grouted area is

5 Grout estimation

The quantity of grout which is used for a particular application depends on the thoroughness required of the work and the volume of the pore void system of that particular soil to be improved. The volume of the voids can vary greatly at a given density, depending on both the shape of the grains and their moisture content [18]. Understanding the soil porosity is a fundamental to determine the amount of grout that will be required to treat a given volume of soil. To make a serious estimation of grouting materials, it requires a geological study to evaluate the void content and the design of the grout curtain [18]. The volume of grouting materials is given by the following formula (Henn 1996) [6].Vg = Vz (?F) (1+L)**(1)**

Where, Vg = Volume of grout intake, VZ = Volume of grouted soil, ? = Porosity of soil. F = Factor of filling (0.85 to 1.0), L = Loss Factor (0.05 to 0.15). Where, each of grout loss and Void filling factor depend on the properties of the grouted materials. Another method for estimating the quantity of grouting materials depend on the porosity of soil. The expected volume of required material depends on Casagrande formula: K= 1.40 e2 K0.85

(2)Vg = ? net Vz (**3**)

Where, K = the permeability of the soil, VZ = Volume of grouted soil, e = Void ratio, ?net = the net porosity of soil.

6 iii. Comparison Between the Grouting Materials for Seepage Reduction

In order to choose the best grout type, several properties of grout should be concerned, such as rheology, setting time, toxicity, strength of grout and grouted soil, stability or permanence of the grout, the penetrability , water tightness of the grouted soil and the cost of each material [12]. Now, the comparison between the grouting materials are used to seepage reduction will be explained based on

7 Estimation of Grouting Materials (volume & cost)

8 Case of Study (Seepage Control under a Dam)

This case of study as shown in Figure (**??**), the dam rests on the sandy soil with depth 14.0 m and followed by impervious layer. The dam is 18.0 m long, 18.0 m wide and 1.5m buried from the foundation. 6.0 m the head at upstream of the dam.

9 b) Grout curtain used in the case of study

The curtain effectiveness may be increased by using multiple grout lines. In curtain grouting the purpose is impermeance, the grout holes are arranged in a series of lines to form a grout curtain approximately perpendicular to the direction of seepage with length 24.0m at upstream of the dam. In this type of curtains, it is usual to drill a widely spaced system of primary holes, subsequently followed by secondary and tertiary holes at a progressively smaller spacing. The initial spacing of primary holes starting with 6.0 m based on the grouting materials to achieve the best design for seepage reduction. In our case of study, two rows of the grout curtain are used to define the cost of each material based on the quantity of grout injection and installation as shown in figure (9). An initial estimate of the volume of required grout depends on the treated zone and permeability of the soil.

The required grout quantities can be twenty percent or more of the total treated zone. This is represented by the mean net grout intake. The expected total grout quantities should be predicted. The target grout volumes should be established and assigned to the primary, secondary, tertiary and quandary grout holes. Larger target quantities are usually specified for the primary and secondary holes, and reduced quantities anticipated for the tertiary and quaternary holes.

10 d) Criteria of Grout injection

The pressure, which is measured at the entry of a grout hole, is always higher than the overburden pressure at the level of injection. For good grouting result, it is important to terminate grouting according to grouting pressure, not grouting volume [9]. In the following, a typical grouting termination criterion commonly put in the particular specification is quoted for reference. Grouting shall be stopped if one of the following criteria is met:

? Grouting pressure exceeds 5 kg / cm2 or twice the effective overburden pressure, whichever is greater.

? Intake of grout reaches 100 liters per meter of the grouting section.

The grout intake criteria are usually depends on the maximum pressure. Injection pressure criteria have generally been set relative to the vertical overburden pressure. Available injection pressure equals five times of overburden pressure (European code). In permeation grout, the injection rate for suspension grout is 6 L/min, while the chemical grouting is 8 L/min [1].

11 Case (1) estimating the Total quantity of each material

The cost of the grouting process depends on the true estimation of grouting intake and the grouting technique. According to the case of study, the expected volume of grouted soil and grouting materials depends on the permeation technique for grout curtain installation. For our case study, the grout curtain is install at the upstream of the dam. The split hole is the best choice for seepage control and the two rows of the hole can achieve the seepage control to a satisfactory level. In addition to the injection pressure, which was mentioned previously. The expected volume of grouted soil equal 108.06 m3 as shown in the figure (10). Based on the volume of grouted soil, the volume of grouting materials can be calculated according to (Henn 1996) equation (1) and presented in table (3) [6]. Figure (11) shows the comparison between the grouting materials by the total cost of grouting materials with permeation grout installation. Where the cost of permeation grout for suspension grouts is about $ 130 per meter of grouted soil, while the chemical grouts is about $ 200 per meter of grouted soil [1]. **??**). To achieve this permeability of soil, it depends on the porosity of the soil before and after grouting process. The porosity of the model for the case study is 35 % at the permeability of soil 10-4 m/sec. From Casagrande formula can calculate the new porosity at the permeability 10-7 m/sec. Finally, the new porosity is 1.65 %. In addition to calculating time of injection for each grout material as presented in figure (12).

V.

12 Soil Modeling of Grouting Materials

The most important soil property used in seepage analysis is the hydraulic conductivity. In a saturated soil, all the voids are filled with water, and the volumetric water content is equal to the porosity of the soil. All data used in the model mentioned in the table (5) and table (6) summarizes the permeabilities used in the seepage analysis.

13 Case (3) changes in the depth of curtain grout

This case shows the seepage analysis to assign the seepage quantity under the dam based on the change of curtain depth and different grouting materials where the curtain grout equals (50 cm).

14 Case (4) changes in the width of curtain grout

The width of curtain grout depends on the number of lines. So based on seepage analysis and different grouting materials, the effect of the number of the row of the grout curtain can be defined. In the case of study, the depth of grout curtain is 9.0 m and the width of the of grout curtain changes.

15 VI.

16 Results and Discussions

17 Case (3): change in the depth of curtain grout

The result of the seepage analysis of the modeled dam (Cement -Bentonite and acrylamide grout), shows a seepage quantity under the dam based on the change of curtain depth and different grouting materials for the seepage reduction as shown in Figures (13) In addition to the uplift pressure under the dam that can be extracted from the seepage analysis, there is only one type of the suspension grout (cement bentonite grout) as shown in figure (14).

18 VII. Conclusion

The efficiency of grouting depends mainly upon the penetration of grouting material through the pores of sand and the percent of fine particles in the sand. Based on the case of study and references can extract the following: 1) In acrylamide grout, creep can occur nearly 20 % so, the use of acrylamide grouts should be limited to seepage reduction. 2) NMA grout will be stable, but it absorbs water up to 200 % of its original volume, so the use of these grout should be limited to seepage reduction because of swelling. 3) Under repeated cyclic loading, chemical grouting is better in use than the cementious grouting because of its fragile behavior. The destruction of bond for chemical grouting would be partial, while the destruction of bond for cementious would be full. 4) In our case of study, the acrylamide grout can reduce the permeability up to 40 % at one row of curtain grout and the exit gradient up to zero. But this grout is more expensive and toxic. Can be recommended, the best type of grouting materials in Egypt is a cement-bentonite grout for seepage reduction. Cement -bentonite grout can be excellent grout, available alternative material and it also lee expensive than the other materials. [1] [2]

Figure 1:

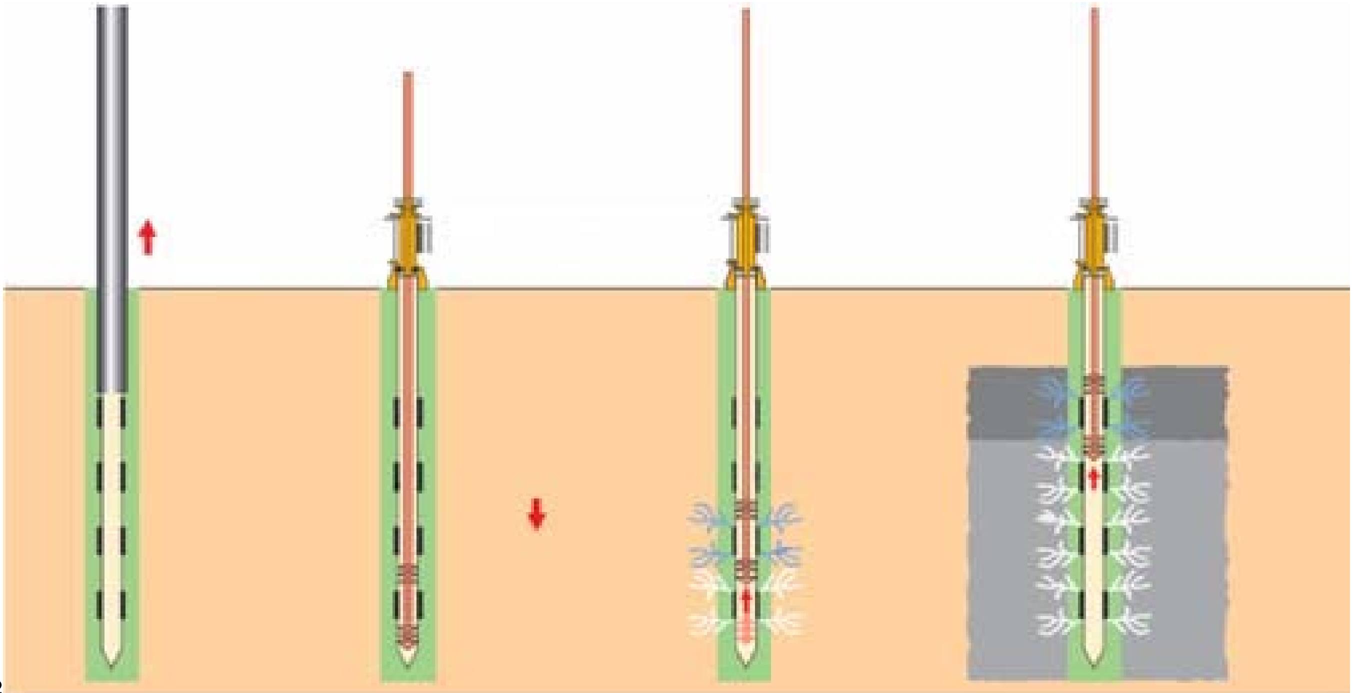
2 

Figure 2: Figure 2 :

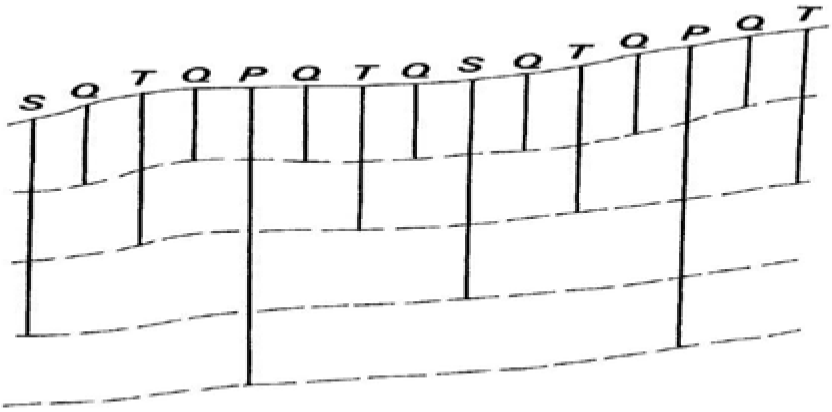
3 

Figure 3: Figure 3 :

Figure 4:

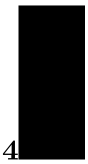
4 

Figure 5: Figure 4 :

5

Figure 6: Figure 5 :

67

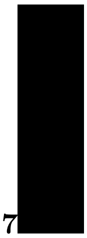


Figure 7: Figure 6 :Figure 7 :

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Figure 8: Figure 8 :

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Figure 9: Figure 9 :

Figure 10:

10

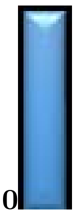


Figure 11: Figure 10 :

11

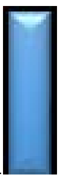


Figure 12: Figure 11 :

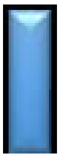


Figure 13:

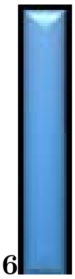
141516 

Figure 14: Figure 14 :Figure 15 :Figure 16 :

1

Figure 15: Table 1 :

2

Grout Type	Characteristics	k (m/sec)	
Acrylamide grout	Toxic grout	10 -12	
NMA grout	Non toxic	10 -12	
Acrylate grout	Less toxic	10	- 5
Colloidal silica grout	Non toxic	10 -9 to 10 -11	

Figure 16: Table 2 :

3

the expected volume of grouting materials (Henn1996)

Material type	Void filling factor %	Grout loss factor %	Total quantity
Water-cement	90	5	35.74
Cement-bentonite	85	5	33.75
Clay grout	85	10	35.36
Acrylamide Grout	95	15	41.32
NMA Grout	95	15	41.32
Acrylate Grout	85	10	35.36
Colloidal silica	90	10	37.44

Figure 17: Table 3 :

4

Material type	The permeabil ity reduced	The volume of required materials to achieve 1 % of porosity m 3	Total quant ity requir ed
Water-cement	1X10 -09	1.02	34.21
Cement-bentonite	4 X10 -08	0.994	33.15
Clay grout	3.4 X10 -07	1.03	34.68
Acrylamide	1 X10 -12	1.18	39.38
NMA Grout	1 X10 -12	1.18	39.38
Acrylate	1 X10 -5	Cannot reach	?????????
Colloidal silica	2 X10 -09	1.07	35.92

Figure 12 : Time of injection for each grout material

	Property of Soils		
Parameter	Name Unit		Soil
Material model	Model -		Sandy soil
Type of material behavior	Type	-	Drained
Soil unit weight	?sat	KN/m 3 15	
Permeability	K	M/s	.0001
Young's Modulus	E	KN/m 2 20000	
Void ratio	e	-	.53
Poisson's ratio	?	-	0.3
Porosity	n	%	35
Cohesion	c	-	0
Friction angle	?	-	35

Figure 18: Table 4 :

6

Material	Permeability (m/s)	Description
Sand	1X10 -4	Sandy Soil
Neat cement	1X10 -9	Grout curtain
Cement/bent onite	4X10 -8	Grout curtain
Bentonite slurry	3.4X10 -7	Grout curtain
Acrylamide	1X10 -12	Grout curtain
NMA grout	1X10 -12	Grout curtain
Acrylate grout	1X10 -5	Grout curtain
Colloidal silica	2X10 -9	Grout curtain

Figure 19: Table 6 :

Clay grout

Seepage quantity m3/day 0.00 20.00 40.00 Non grout One row Two row Three row

grout curtain

Clay grout

Seepage quantity m3/day 0.00 20.00 40.00 20.16 Non grout One row Two row Three r

Seepage quan- tity m3/day quan- tity m3/day 0.00 5.00 10.00 15.00 20.00 25.00 50.00 Non grout Acrylate grout One row Two row Acrylate grou

Seepage 0.00 Non grout One row Two row

Colloidal silica grout

Figure 20:

[Corps and Engineers ()] , U S Corps , Engineers . UFC 3- 220-06. *GROUTING METHODS AND EQUIPMENT* 1970 & 2004.

[AV-100 Chemical Grout (Powder Blend) Avantigrout.com ()] 'AV-100 Chemical Grout (Powder Blend)'. `<http://www.avantigrout.com/100PWsum.html>` *Avantigrout.com* 2014. (References Références Referencias 1)

[Bell ()] F G Bell . *Methods of Treatment of Unstable Ground*, (London, Newness-Butterworths) 1975.

[Chemical Grouting (1110)] *Chemical Grouting*, 1995. Manual No. 1110-1-3500. Washington, DC, USA. US Army Corps of Engineers

[Houlsby ()] *Construction and design of cement grouting*, A C Houlsby . 1990. John Wiley and Sons, Inc.

[Dr and Shroff ()] *Development in Design & Execution in Grouting Practice*, A V Dr , Shroff . 2009. Baroda, India. M. S. University (31st Annual Lecture)

[Persoff et al. ()] *Effect of dilution and contaminants on strength and hydraulic conductivity of sand and soil grouted with colloidal silica gel*, P Persoff , G J Moridis , J A Apps , J M Whang . 1997. (manuscript in preparation)

[Ozgurel and Vipulanandan ()] 'Effect of Fines Content on the Mechanical Behavior and Groutability of Acrylamide Grouted Sands'. H G Ozgurel , C Vipulanandan . *Center for Innovative Grouting Materials and Technology* 2010. CIGMAT), University of Houston

[Yonekura and Miwa ()] 'Fundamental properties of Sodium Silicate Based Grout'. R Yonekura , M Miwa . *Eleventh South East Asian Geotechnical Conference*, (Singapore) May 4-8,1993.

[Rawlings et al. ()] 'Grouting for ground engineering'. C G Rawlings , E E Hellawell , W M Kilkenny . *CIRIA C* 2000. 514.

[Bruce et al. ()] *grouting materials for ground treatment*, Donald A Bruce , G Member , Sturat Little , John . 1999. (a practitioner's Guide)

[Shroff and Shah ()] *Grouting Technology in Tunnelling and Dam Construction*, A V Shroff , D L Shah . 1999. A.A Balkema Publishers. (2nd edition)

[Nonveiller ()] *Grouting Theory and Practice*, E Nonveiller . 1989. New York, US: Elsevier Science Publication Company, Inc.

[Henn ()] *Practical guide to grouting of underground structures*, R Henn . 1996. Thomas Telford.

[Warner ()] *Practical handbook of grouting -Soil, rock and structures*, J Warner . 2004. New Jersey: John Wiley and Sons Inc.

[Turner ()] *Review of grout material properties and methods for micropiles*, Turner . `DEW/MJT/dj/P3335/A000` 1998.

[SEEPAGE ANALYSIS AND CONTROL FOR DAMS (1110)] *SEEPAGE ANALYSIS AND CONTROL FOR DAMS*, (Washington, DC, USA) 1993. Manual No. 1110-1-3500. US Army Corps of Engineers

[Dr and Henn ()] *Ultrafine cement primer (Part A)*, Raymond Dr , Henn . 2008. Denver, Colorado: Lyman Henn, Inc.