The GROUT LINE

Grout Line

Paolo Gazzarrini

Overture

The date of the second birthday of The Grout Line is approaching and here we are at our eighth appointment.

The first article for this issue is by Helen Robinson, Gordon Matheson and Jesus Gomez of Schnabel Engineering. It is related to some tests on polyurethane mixes to be used for grouting. The article is followed by a short discussion with Q/A; the answers are given by Robert Traylor, Grouting Consultant.

Testing Polyurethane Grout Options for Permanent Ground Support

Helen D. Robinson
Gordon M. Matheson
Jesús E. Gómez

Figure 1. Polyurethane Sample Formation. Note grout foaming through drainage holes at the top and bottom.

Introduction

Grout can be defined as any material used to fill cracks or voids in the ground surface in order to stabilize, densify, or modify rock and soil properties. Although grout has been used for over 200 years for various purposes, there is little documentation on the properties of chemical grouts, particularly polyurethanes.

This paper summarizes the findings of a grout research project for the all-important purpose of finding products capable of stabilizing cohesionless soils, and preventing collapse and surface subsidence. It specifically focuses on the use of polyurethane grouts to penetrate gravel. The low viscosity grout is pumped into the material, and once the gravel is permeated, the grout foams yielding a cohesive mass that can sustain significant stresses. This program evaluated several polyurethane

Figure 2. Grout Sample Prior to Unconfined Compression Testing

Figure 3. Grout Sample After Unconfined Compression Testing

foams and categorized them according to function, workability, cost, and longevity.

Polyurethane Grout

Polyurethanes are formed by reacting a polyol (an alcohol with more than two reactive hydroxyl groups per molecule) with a diisocyanate or a polymeric isocyanate in the presence of suitable catalysts and additives (Alliance of the Polyurethane Industry, 2005). Catalysts can be used to control the speed of the reaction but they will affect the properties of the resulting foam. The foam structure is produced by a blowing agent that reacts chemically to produce carbon dioxide.

Polyurethanes can be divided into two types: water-reactive and two-component. Water reactive polyurethanes can also be subdivided into two categories. Hydrophobic resins react with water, but repel it after the material has cured. Hydrophilic grouts react with water, but continue to absorb it after the chemical reaction has been completed. Two-component polyurethanes consist of two liquid resins that are mixed together and form either an elastic gel or rigid foam.

Polyurethanes have a low to moderate toxicity, expand to several times their original volume, and are comparatively low in cost. They have relatively low structural strength, and cannot penetrate particle sizes smaller than a medium-sized sand; however, they are easy to use and can be modified readily on site to meet specific engineering requirements. Polyurethanes have superior water-stop capabilities and are chemically inert when cured.

The Research

It began with an industry survey in which 200 grouts of various types were examined and data was compiled about each material. Mechanical properties such as viscosity, strength, density, and operating temperature ranges were recorded. From this data, 14 polyurethane grouts were chosen for small scale testing. Each material was strength tested and rated for ease of use, chemical hazards, and gravel permeation.

The tests consisted of impregnating coarse granular material with the grout mix. Many of the polyurethane grouts chosen for testing require water to activate their chemical reaction. Therefore, moist Virginia Department of Transportation (VDOT) No. 78 stone, with a maximum size of ¾ inch, was used for testing. The specimen was placed inside a plastic cylinder mold with a diameter of 4 in and a height of 8 in with drainage holes at the bottom.

For each polyurethane grout tested, the catalyst was added to the resin and stirred. After the grout was mixed, it was carefully poured over the aggregate cylinder. A plastic lid, placed on top of the cylinder, was weighted down to ensure a flat testing surface. A photograph of the specimen formation procedure is shown in Figure 1. They were allowed to cure for 24 hours, and then the grout specimens were cut out of the plastic molds.

The weight and dimensions of the cured cylinders were recorded. Unconfined compression testing was conducted on 1-day-old grout samples. The samples were loaded at a strain rate of 0.01 in/min. Lateral expansion of the specimen was measured during loading using a PI tape. Photographs of a sample prior to loading and after failure are shown in Figures 2 and 3.

Figure 4 shows a set of typical data from the Unconfined Compression Tests. Note that the strain at failure increases with increasing catalyst ratio. For this grout, the strength was maximized with catalyst ratios of 5% and 7% by volume for this specific aggregate and moisture content.

Six products were tested with VDOT No. 78 stone: HA Cut (DeNeef), HA Soil (DeNeef), Ultrafine Resin (Multiurethanes, Ltd.), Flex-Rok Injection Resin (Strata Tech), Primeflex 910 (Prime Resins, Inc.), and WEBAC 151 (WEBAC Corporation). These products were used with varying catalyst ratios and aggregate moisture contents and produced maximum strengths from 37 psi to 116 psi. Figure 5 and Table 1 summarize the compressive test results for these six products.

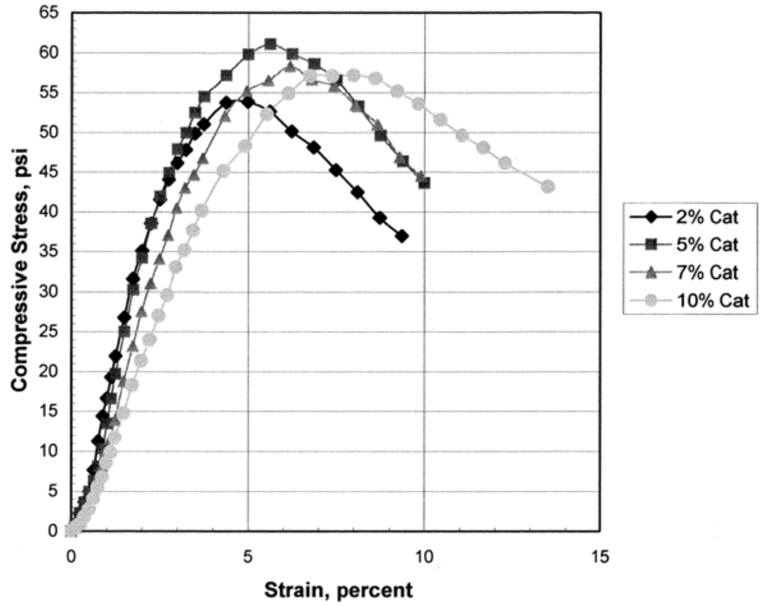

Figure 4. Typical Data from Unconfined Compression Tests on VDOT No. 78 Stone Treated with a Polyurethane Grout

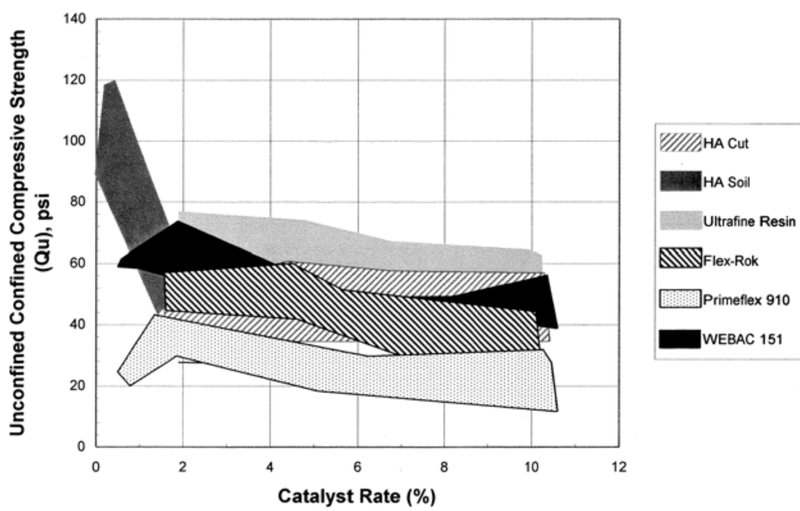

Figure 5. Range of Unconfined Compressive Strength versus Catalyst Rate for Foam-Impregnated VDOT No. 78 Stone

Summary and Conclusions

The following findings and conclusions can be made after completion of this project:

- The density of the aggregate has a measurable effect on the unconfined compressive stress and creep behavior of the grouted mass.
- The moisture content present in the aggregate may affect the grout reaction yield and the density of the polyurethane foam.
- Unconfined compressive strength values showed significant scatter. Therefore, representative testing is necessary for each project.
- Overall, the polyurethane grouts had very similar properties and provided unconfined compressive strengths in the range of 20 to 70 psi.
- In general, axial strain at failure increases with increasing catalyst ratio for polyurethane grouts.

Some Useful References and Websites!

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Table 1. Summary of Results for Polyurethane Grout with VDOT No. 78 Stone

Material	Supplier	Supplier Reported Viscosity (cP)	Catalyst Ratio[1]	Expansion Ratio (times original volume)	UCS[2] Max (psi)	UCS[2] Min (psi)	Set Time (min:sec)
HA Cut	DeNeef Construction Chemicals	120	5%	6	61	40	08:00
Ultrafine Resin	Multiurethanes, Ltd.	40	5%	7	66	62	03:30
Flex-Rok	Strata-Tech	**	7%	4	43	35	03:30
Pimeflex 910	Prime Resins, Inc.	40	5%	4	29	24	05:30
WEBAC 151	WEBAC Corporation	160 to 200	7%	5	46	43	16:00
HA Soil	DeNeef Construction Chemicals	25 to 35	0.5%	3	116	51	(3)

1 Determined as optimum from testing
2 Unconfined Compressive Strength
3 Was not determined

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And some Q/A related to the article

How in the field can you pump the Polyurethanes into the soil? From what I understood, the "prime" material (2 components) is a sort of gel (?), so what are the procedures to inject them? I don't believe the procedure is similar to the tube a manchette (sleeved port pipe and packer). So is the grouting done through a casing?

Can it be done as a compaction grouting type of procedure? Up-stage I presume.

Polyurethanes used in grouting soils, including the Prime Resins sample, are low-viscosity only. Typical viscosity range is 20 to 200 cps. The grouts are injected through tube-a -manchette or single point stingers. Gel materials are used in crack injection in concrete structures.

To have a comparison with a cementitious grout, what kind of reological characteristic (marsh, specific densisty, cohesion -bleeding of course is zero) does the initial mix have?

Rheology is not a consideration with chemical grouts such as polyurethanes. Rheology is typically used with particulate grouts such as cementitious grouts where particle size within the suspension is a limiting factor in penetrability into soil, pressure filtration during pumping must be managed, and bleed during cure leads to shrinkage. With chemical grouts, parameters such as gel time, viscosity control penetrability, pressure filtration does not occur, and there is little if any shrinkage.

Considering the very low UCS (unconfined compressive strength) obtained, how can these products be used for permanent ground support? For impermeabilization they seem ok, but what about consolidation (soil strength improvement)?

For consolidation, isn't it better to use the classical cement? What are the advantages of the Polyurethanes? The expansion?

The applicability of polyurethanes in permanent ground support depends on the soil strength required for the specific application. Different polyurethane grouts yield differing density, shear strength and permeability. The DeNeef HA CUT grout expands more than the HA SOIL, and consequently yields at a lower strength. The greater the expansion, the lower the strength. Chemical grouts penetrate soils with very fine particles. If greater strengths are required, particulate grouts, including cement based grouts, may be used if the soil porosity allows injection of particulates.

Grouting vs. Diaphragm Walls (or so called Slurry Wall)

About fifteen years ago Donald Bruce wrote an article for Geotechnical News, regarding "grouters" and "diaphragmers" (I cannot find a better word to define a Diaphragm wall specialist) and John Dunnicliff responded in the following issue with a very fun poem. Considering the topic of the Grout Line, and the old age of the article and poem, I thought that it would be a good idea to re-publish them for the new "grouters" readers. Here they are.

Equal Rights for Grouters

Donald Bruce

Reprinted from Geotechnical News, Vol. 9, No. 1, March 1991, pp 47,48

"Grouting doesn't work!" - for some of us, the three most dreaded words in the English language. We hear it from disillusioned consultants who have, as a last desperate resort, been forced to try grouting as the immediate solution to the impossible problem. We infer it from the number of major dam owners now suffering from leaky dams as a result of flawed grouting practices in earlier decades. And we certainly get it from contractors who have been ripped off by so-called experts who have been paid by the gallon of grout pumped, and not by the results achieved.

Now, we do accept that grouting, like every other specialist geotechnical technique, has its limitations. We do acknowledge that aspects of its design and execution, especially in the U.S., have now been exposed as inappropriate. We cannot deny that it has traditionally created more than its fair share of income for attorneys and their ilk. However, there are those of us who firmly believe that grouting can be made to work **if** it is aptly applied, properly designed, conscientiously executed and equitably rewarded.

A paper recently presented at the ASCE Convention in San Francisco confirms this view. The paper is a structured compendium of published case histories of major dam repairs by grouting. It illustrates how modern grouting techniques have been used to seal existing concrete and embankment dams against seepage through, around, and under these structures. It shows how the same techniques can be used to fill undervoids caused by erosion, and strengthen heterogeneous rock masses to prevent differential settlement and unacceptable lateral deflections. Today, at least as significant is its more recent emergence as a reputable and controllable engineering tool to combat liquefaction potential in susceptible foundation soils.

Despite this body of evidence, the grouting brotherhood has the distinct feeling that it is an oppressed and repressed minority. The main focus of its ire (some would say jealousy) is its perception that the major dam repair market is falling prey to the apparently indiscriminate use of the diaphragm wall (slurry trench) as the universal solution to sealing existing embankment dams. Using a sporting parallel, some of the brothers liken it to the current obsession in the NFL with the "run and shoot" offense, and readers in Detroit and Atlanta may draw their own conclusions.

Grouters feel that the growing popularity of diaphragm walls in existing dams is a result of several factors, but principally a historic distrust of grouting on the one hand, and a fantastic promotional campaign by vested interests on the other. These interested parties include certain consultants, out to establish a new "niche" in the market, and certain (European) specialist contractors who are trying to shape the dam remediation market in North America to suit certain exclusive skills and equipment. We find it rather droll that our (European) brothers note that these same (European) specialist contractors systematically have repaired their leaky (European) dams by grouting.

It would be wrong to think that this viewpoint is entirely due to sour grapes (and empty pockets) amongst the brothers. No sir, not entirely, and, in fact, many of us are also actively involved in the diaphragm wall technique as used in other markets. We have followed the progress of these diaphragm wall contracts over the past few years in the popular and technical press and through the (sour) grapevine. We would be almost the first to admit that there have been stunning successes, wherein the concept and design of the solution, and the efforts of the contractors have been outstanding. However, we would certainly be among the first to ponder on some of the darker facets of this phenomenon:

Example 1
A 127 m high dam in Washington where massive escape of slurry during trench excavation caused fundamental splitting of the embankment. With great aplomb, however, the contractor negotiated a huge remedial grouting extra, to repair the dam —— to allow the continued construction of the diaphragm wall

Example 2
An important utility-owned dam in the Northeast where the glacial foundation material has again defied attempts to economically excavate it. In this instance, an intensive grouting operation was conducted over 30 years ago, and which yielded impressive results within the barriers of the contemporary technology.

Example 3
A landmark dam repair in the East, where intensive monitoring has been maintained for well over 10 years. One writer recently concluded " . .site observations indicate that the embankment has performed in a satisfactory manner; however, near the tie-in of the embankment wall and the concrete-gravity structure, the piezometric head drop across the wall has been less than was expected."

Example 4
A more recent, extremely well publicized repair of a major embankment

dam in the Southwest. During construction there were five separate major losses of slurry at various times, the largest being about 400 m^3 of slurry and 80 m^3 of sand and gravel. In one instance 15-40 m^3 of slurry was observed to exit 120 m "downstream at the dam's groin." Again the brothers have noted the comment that "the area was then grouted and wall construction was completed successfully ..." So, having finally built this "positive" cut-off, how did it function? "The amount of seepage stopped by the wall is, however, not as much as had been hoped for. Water levels in the downstream portion of the embankment immediately adjacent to the wall dropped a maximum of 30 feet. This was less than anticipated." "The piezometric contours within the ..core did not change substantially." "All (wall) panels have cracks which are presumed to be caused by shrinkage", although we must admit that they were "predominantly not open." "The joints between the panels were found to range from concrete to concrete bonding with a thin bentonite coating to some with ¼ inch bentonite seams between the concrete." This state of affairs does not seem to have caused undue alarm to the owner, although the brothers would regard these observations in a 80 cm wide membrane 120 m deep as being, perhaps, potentially classifiable as defects.

Some of you may think we have been highly selective in extracting the above information, without referring to the trouble-free repair of the handful of other dams repaired recently with diaphragm walls. We do not deny it. You may even think we are even taking cheap and xenophobic shots at the diaphragm wall industry as applied to existing dams, and you may well be right. However, the brothers felt that we should set out the other side of the argument, because feelings are running high in our community.

We're tired of being prevented from drilling 10 cm diameter holes through dam cores, for fear of causing hydrofracture, whereas others are permitted to open up (and fill with bentonite slurry, sand and gravel) panels perhaps 1 m thick, 10m long, and 120 m deep. We don't understand the logic, especially given recent developments in overburden drilling technology.

We're tired of hearing that grouting is precluded "because we tried it years ago and it was no good." What happened in the days of our industry's dinosaurs and black magicians, and hamstrung inspectors, really has little bearing on the potential of the techniques and materials we now have at our disposal today, as grouters.

Grouters should not fall into the trap, on the other hand, of advocating grouting for every problem involving seepage, settlement or liquefaction: we must acknowledge - however painful it may be to some of us - that diaphragm walls are the logical solution at times, and we should be ready to bid accordingly.

All we ask for, however, is the right to be heard, the right to introduce and describe the new grouting technologies and materials, and the right to bid grouting-based alternates to open-minded owners, given the appropriate application. Already we hear the cry of "Death to the Diaphragm!" in certain (albeit biased) circles. Perhaps it would be kinder and gentler to instead press for "Equal Rights for Grouters" as the rallying call?

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Donald Bruce, President, Geosystems, L.P., P.O. Box 237, Venetia, PA 15367, email: dabruce@geosystemsbruce.com (2007 contact information)

Question: After fifteen years do we (grouters) have the same rights? Has the Donald Bruce article changed something?

Closure

A couple of "errata corrige" for the December issue:

- Page 60, first column, point 1 "… granular or fine soils, which present a high percent thense age…". Interesting and quite fun interpretation of percentage. There is a lot of fantasy in the word! But believe me: it is not a translation from Italian!
- Page 61. Mr Giovanni Dugnani's correct email is **g.dugnani@sbcglobal.net**

Has anyone had the time to surf the net and view the Grout Line web page? Comments? Suggestions? Ideas?

Send me your grouting stuff, papers, articles or comments to: Paolo Gazzarrini, fax 604-913 0106 or paolo@paologaz.com or paolo@groutline.com.

Ciao!

More on the Grouters' Rallying Call

John Dunnicliff

Reprinted from Geotechnical News, Vol. 9, No. 2, June 1991, p. 51.

"Equal rights for grouters",
cries Donald Bruce with glee.
He challenges the doubters,
with pungent repartee.

Slurry wall or grouting?
Which method works the worst?
The brotherhood is touting
that grouting should be first.

Casagrande's basis
for sealing every crack
Was "use both belt and braces"
to hold the water back.

So let's stop all the shouting
and use them, one and all:
The wall to seal the grouting;
the grout to seal the wall.

The brothers will be wealthy.
The grapevine will be sweet.
The dams will all be healthy,
and flow nets obsolete.

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