Low Mobility Grouting (LMG) and Compaction Grouting, "Application Review"

Sam Bandimere

Abstract

While the concept of using Low Mobility Grout (LMG) mix designs originated with the "Compaction Grouting" concept as far back as the 1950's, it is time to look at compaction grouting and all its derivatives in their own right and begin the process of properly identifying (and classifying) them. As a result of the total market size for LMG, application uses are growing at a fantastic pace although it should be noted that not all meet the true definition of "Compaction Grouting.

At the ASCE GeoLogan Conference, Byle (1997) presented a paper entitled, "When Compaction Grouting Is Not Compaction Grouting". As a result of that paper there has been a movement within the grouting industry to begin classifying grouts by either their mix design properties or application purpose. (Plate #1).

The purpose of this paper is to begin that process and give the industry a current look at the LMG applications in terms of its market size and application possibilities.

Introduction

Because grouting is such a multi-faceted discipline where materials and applications entwine, classifying them to everyone's satisfaction is a difficult task to say the least. However, due to the confusing terminology battle that continue to plague this industry, it is the opinion of this author that it's time to categorize grouting in a format that is visual and useful.

The two most basic differential distinctions are between geotechnical and structural grouting (see Plate #1) This paper is focused on the "Geotechnical Grouting" as it pertains to Low Mobility Grouts (LMG) in their total application distinctions and markets.

Because the term "Compaction Grouting" infers that it is an application designed to compact soils, it should be obvious that its injection rate will be crucial to the success of the work. Yet it is not uncommon to see specifications requiring contractors use compaction grout to fill Karst solution cavities or fill an abandoned mine with no limits on the injection rates (and rightfully so) but the question is; What does that have to do with compaction grouting? Except for the fact that the engineer wants a "low mobility grout" to be used.

That of course is the crux of the dilemma and why there needs to be a family of "LMG" grouting applications defined with compaction grouting and other applications being separately categorized. The common denominator to the family of "LMG" applications is the fact that the mix design has a very limited ability to travel (from its point of injection). Current practice principally limits LMG travel index through internal friction created by the use of silts, sands and gravels in its mix design [Warner, et. al. 1997].

Within this current family of LMG grout applications, the three main distinctions are as follows;

• Where the injection rate is held to < 2 ft^3 per minute to allow for pore pressure dissipation and other time dependent properties, (usually associated with a compaction grouting application).

• The injection rate is held to < 2 ft^3 per minute for reasons other than pore pressure dissipation issues. (usually associated with technical grouting applications that may or may not be geotechnically related, i.e. tunneling compensation applications).

• Injection rates are unregulated or specified to be > 2 ft^3 per minute, (usually associated with large void fill projects, large water cut-off).

1. LMG Marketing Applications

1.1. Compaction Grouting "injection rates <2 ft^3/min." [Bandimere, 1997].

1.2. Improve soft (collapsible) soils (typical N values 0 to 30).

1.3. Stabilize/re-level existing structures experiencing foundation settlement, proper placement procedures should accommodate most any foundation configuration with settlement caused by most any reason. i.e. site consolidation, scour, earthquake, load change etc.

1.4. Repair or enhance defective piles by inserting bells at tips, fill/repair voided sections, increase side friction, reduce/reverse down drag etc.

1.5. Stabilize/re-level existing underground structures, i.e. pipes, tunnels and subway structures [Berry & Farrar, 1997].

1.6. Pre-treating sites for new construction to eliminate deep foundation systems, structural floors etc.

1.7. Liquefaction mitigation, pre- or post construction applications. [Baez & Henry, 1983].

1.8. Insertion of compaction piles in various shapes, sizes, or dimensions to be used as structural elements (dictated by conducive site conditions).

1.9. Assist site excavations or tunneling operations by ground improvement.

1.10. Reduce water seepage by reduction of permeability through the densification of water bearing soil.

1.11. Void Fill (injection rates > 2 ft^3/min.).

1.12. Abandoned Mine or cavernous void fill, roof support.

1.13. Karst solution cavity void fill. [Henry, 1989].

1.14. Immediate replacement of ground loss during tunneling operations and/or re-establish improved ground support.

1.15. Large water cut-off projects (injection rates > 2 ft^3/min.).

1.16. High water flows can be cut-off by slugging or choking access routes. Injection rates are a function of what one mass requires to overcome another. The use of proper admixtures in the mix design and the utilization of redi-mix trucks with high capacity concrete pumps may be helpful.

2. Market Locations

2.1. Anywhere soils have "N" values <30 or high void ratio's with low Dry Density Weights (DDW).

2.2. Locations with high water tables (Coastal Area's, Mississippi Delta).

2.3. Seismic area's (West Coast, Mississippi Valley, Pacific Rim).

2.4. Abandoned Mine or Sink Hole problem area's.

2.5. Karst formational area's.

2.6. Basically Market Locations for LMG can be "Anywhere".

3. Clients

3.1. Engineering Community (Geotechnical, Geologist, Geophysicist, Structural).

3.2. Governmental Agencies (Federal, State, Municipalities).

3.3. End users "Private" (Property Owners, Property Managers, Developers).

3.4. Industrial.

3.5. Commercial.

3.6. Residential.

3.7. Railroads.

3.8. Utility Companies.

3.9. Dam owners.

4. Design Approach

4.1. It is seldom a good idea for either the Owner's Engineer or the Grouting Contractor to be in total control of the design and implementation aspects of a project. Most grouting companies do not carry "Errors & Omissions Insurance" and most design engineers have little first hand experience at working with LMG's and State-Of-The-Practice placement procedures. The attached "Project Flow Chart" (Plate #2) has been found to be an efficient and cost effective approach to a project from inception to completion. (Exceptions are typically for projects in the "private sector" where total project costs will be under $10K. Below that point independent engineering cost ratios for Q/A are usually too high).

4.2. (Plate #3) is a diagram of what is known as "Project Players". It is important that these positions be carefully correlated to the Project Flow Chart. (Plate #4) is a "Project Information List" that is needed (from the engineer) to help specialty contractors put together competitive and meaningful "Technical Proposals". These proposals are then submitted back to the engineer for technical review, the owner's insurance agent and lawyer should review the submitted proposals for insurance and contractual issues and the owner ultimately decides which contractor to award the project.

4.3. LMG is unique in that it can be specified to an acceptance criteria (end-result) because of the "control" it affords. Owner's consulting engineers should be the agent in charge of Quality Assurance (Q/A) which involves verifying the desired project results with testing procedures. It is important that the engineer not tell the contractor "How" to accomplish the projects results, the contractor is responsible for Quality Control (Q/C).

4.4. When a projects time frame allows for a Plate #2 scenario to occur, Owner's pay items should be for lump-sum costs for the contractor achieving "to the engineers satisfaction" (Q/A) the specified resultant requirements as per the contractors pre-submitted technical proposal and agreements (Q/C). In the case of emergency response or other project circumstances, there is always the T&M or unit cost approach to a project.

5. LMG Advantages

5.1. **Flexibility**; LMG Grouting has and always will have unlimited application possibilities because its principles work so well with laws of physics, basic soil mechanics and simple mechanical attributes thereof that it is often overlooked because of its simplicity.

5.2. **Non-destructive**; LMG applications need not be excessively messy and limited access should not be a problem. In fact contractors should be responsible for any damage they cause. Typically there are no excavations or concrete breakout required.

5.3. **Control**; LMG technological advances have allowed the grouting industry to gain (and maintain) control of the grout travel index in their applications. [Warner, 1992]

5.4. **Ground Improvement**; compaction grouting (specifically) uses soil displacement as its mechanism and thus the compaction of that influenced soil. The result is ground improvement over a treated area which results in minimal point-loading to foundation systems or underground structural components. [Griffin, 1998].

5.5. **Lifting**; proper placement procedures of LMG can relevel surface and/or subsurface structures with minimal distress to the structural element.

5.6. **Replaces or improves**; existing deep foundation systems.

5.7. **Compaction piles**; properly placed LMG can result in contiguous structural elements known as compaction piles. These piles can be primary or secondary to the overall scheme of the projects application goals.

5.8. **Increases soil density**; reduces permeability, changes behavioral characteristics of treated soil mass.

5.9. **Rheological properties**; of the grout give precise control of travel index.

5.10. **Mix Designs**; grout mixes use very common materials, silt, sand, gravel, cement and water which are readily available and have known engineering properties. (Warner, 1992).

5.11. **Cut-off criteria**: grout can be injected to "one" of three cut-off criteria, 1. pressure (at a given and known injection rate), 2. volume, 3. Unwanted movement of structure or formation being grouted. These controls can be easily regulated on a predetermined or field observational basis.

5.12. **Labor requirements**; are minimal, typical crew will have 3 to 5 workers per rig (includes drilling and pumping operations).

5.13. **Cost**; it is very difficult to demonstrate costs that should be geared to the "result" rather than units but for budgetary purposes, typical compaction grouting costs should average one of the following: (other LMG applications will typically be less).

5.13.1. $40.00 per vertical foot (per grout hole location, grout volumes <5 ft^3/ft.). 5.13.2. $ 13.00 per cubic yard of treated soil mass

5.13.3. $10.00 per cubic ft. of grout placed.

These costs are (typically) all inclusive but can vary as much as 50% one way or the other depending on specific project conditions, stipulations, requirements, restrictions, specifications etc. Most importantly, bids will vary drastically based on the amount of information made available to the contractors during the bid preparation phase (see Plate #2).

6. Verification Methods

Due to the amount of information available on this subject and the size limitations of this report, One must simply refer to ASCE's publication on this subject [National Grouting Committee, Special Publication No. 57, 1995]. There are three tables on pages 67, 68, & 69 of that report that are worth the price of the volume alone. Table Al, charts "Applicable Verification Methods by Grouting Method". Table A2, charts "Applicable Verification Methods by Grouting Purpose" and Table A3, charts "Applicable Verification Methods by Soil Type".

As with any publication on the subject of "Grouting" there may be some updated methods that could be added to those tables, but it appears these are the most current evaluations of Testing Methods available to date.

7. Disadvantages

7.1. **Overburden pressures**; the compaction grouting system requires confining pressures to work, typically a minimum of five feet overburden or a surface structural element are required to react against. Void filling for barrier installations or free-standing piles in abandoned mine or cavernous voids are an exception to this requirement.

7.2. **Specifications**; flexibility of grouting procedures make it difficult for the engineering community (as a whole) to specify. This of course can be overcome by using "end result or performance based" specifications requiring technical proposals from contractors as per Plate #2.

7.3. **Craftsmanship requirements**; requires more than just "experience", there needs to be more specialized applicators that possess a good working "knowledge" of the intricacies involved with LMG applications and are willing to supply field personnel with proper equipment and training.

7.4. **Complexity**; compaction grouting requires close coordination between the issues of: soil properties, grout injection rates, grout mix designs, in-situ soil conditions, equipment capabilities etc. Failure to properly deal with any of these issues can result in project delays, cost over-runs and/or project failures.

7.5. **Q/A & Q/C**; verification is difficult to acquire (under low-bid, unit cost system).

7.6. **Service**; is not necessarily available on a local level but it should be noted that with today's communications and travel capabilities it is not difficult for "out-of-town" contractors who have efficiency built into their systems to be very competitive with local contractors who may not have that capability.

8. Market Size

Based on research performed by this writer, it appears the current (1999) U.S. Market is around $60M per year and is growing by approximately $10M/year. Note: These market analysis include all facets of LMG grouting including, compaction grouting (for all its purposes), sink hole applications, abandoned mines and Karst site mitigation.

9. Conclusions

9.1. Definitions and terminology in the Grouting Industry continues to be a real problem.

9.2. The Grouting Industry needs to chart by visual means an understanding (and placing) family groups of applications. (Plate #l is only a start to this process).

9.3. LMG is a versatile, cost effective process capable of solving many geotechnical related problems.

9.4. LMG can resolve many subterranean structural problems.

9.5. Keys to maximizing the effect of any LMG application is the rate at which the grout is injected and the rheological properties of the grouts mix design.

9.6. Projects require a team approach consisting of the Owner, Owner's Consulting Engineer and Specialty Contractor. It requires a team approach.

9.7. For many projects current technology allows for bidding processes that require an "end result", lump sum costs but must be approached properly.

9.8. LMG's market share is currently around $60M and is growing at a rate of approximately $10M per year.

9.9. LMG may not be readily available on a local level but is not a problem with today's communications and traveling capabilities.

9.10. The engineering community (as a whole) needs a better awareness of what LMG applications can do for their clients.

References

[1] Byle, Michael J. (1997) "Limited Mobility Displacement Grouting; When Compaction Grouting is Not Compaction Grout". Grouting proceedings of the Geo-Institute, ASCE, Geotechnical Special Publication No. 66, page 32.

[2] Warner, J., Schmidt, N., Reed, J., Sheperdson, D., Lamb, R., and Wong, S., 1992, "Recent Advances in Compaction Grouting Technology", ASCE, Proc. Grouting, Soil Improvement, and Geosynthetics, New Orleans, LA, pp. 252-264.

[3] Bandimere, Samson W. (1997) "Compaction Grouting" State Of The Practice" Grouting proceedings of the Geo-Institute, ASCE Geotechnical Special Publication No. 66, page 18.

[4] Berry, Richard M. and Farrar, Robert R. (1997) "Grouting Around Trenchless Repairs - The Forgotten Technology", Proceedings of the Pipeline Division Conference, ASCE, page 342.

[5] Baez, J. I. and Henry, J. F., (1983) "Reduction of Liquefaction Potential by Compaction Grouting at Pinolpolis West Dam, S. C.", ASCE, Geotech. Spec. Publ. No. 35; Proc. Geotechnical Practice in Dam Rehabilitation, pp. 493-506.

[6] Henry, James F. (1989) "Ground Modification Techniques Applied to Sinkhole Remediation", Proceedings of the Third Multidisciplinary Conference on Sinkholes, p327.

[7] Warner, James (1997) "Compaction Grouting Mechanisms - What We Know", Grouting, Proceedings of the Geo-Institute, ASCE, Geotechnical Special Publication No. 66, page 1.

[8] Griffin, Clay (1998) "Grouting Rehabilitation Without Disruption of Plant Operations", Proceedings, Underground Technology Conference, Houston TX.

[9] Warner, J., (1992) "Compaction Grouting; Rheology vs. Effectiveness", ASCE Proc. Grouting, Soil Improvement and Geosynthetics, New Orleans, LA, pp. 694-707.

[10] National Grouting Committee, Special Publication No. 57, 1995, Edited by Michael J. Byle, et. al.

If you have any questions, please contact **Dr. C.Vipulanandan**