# Commercial Considerations for Contemporary Geotechnical Grouting Projects

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## ABSTRACT

The state of the art of geotechnical grouting projects has advanced considerably in the last decade. Notable achievements include the use of computer-aided grouting systems, balanced stable grouts, automated batching, measurement while drilling, borehole digital mapping and deviation measuring tools. When new tools and techniques are employed on projects it is inevitable that older practices that are thought were serving well now prove to be detrimental to overall project success. There are two areas that are significant contributing factors for failure that have not evolved in step with the technical advancements to date. These areas are Budget Costing (pricing, data and measurement) and Scheduling (planning, sequence and effort).

This paper examines the costing side of the modern grouting project referencing scheduling only as required. The structure of how a project is priced has a significant effect on a project's chance for success. New techniques and equipment must be integrated into the whole project costing equation to optimize success for all stakeholders. This has not been the case in many projects in the past few years because for all the successes there appear to have been significant failures also. The simple fact that most geotechnical grouting projects cannot be precisely defined at the onset is a fundamental flaw if commercial requirements are not created to accommodate this variability for all stakeholders' best interests.

## 1. TYPES OF CONTRACTS FOR A GROUTING PROJECT

Contractors and designers can be legally bound to undertake work under a number of different contractual arrangements. Before a contract is agreed, a decision must be taken about the basis upon which the contractor will be paid. The factors which affect the choice of payment method will include:

- the degree to which design information is available when contract documents are prepared;
- the institutional rules of the public/private sector funding parties;
- the state of safety (i.e., risk during construction) and size of the project;
- the time period available to produce specifications and tender documentation;
- the time available to undertake the work.

There are different methods for actually paying the grouting contractor for his work:

- fixed lump sum, with payment usually on completion;
- target lump sum (as above but with more flexibility, including monthly draws);
- progressive payment (hard unit rate) according to tasks/units completed. This is based on agreed rates for specified tasks or quantities of materials/equipment and human resources used;
- progressive payment (cost plus) according to resources expended, (based on an agreed schedule of hourly/daily rates and equipment, materials, and markups).

If the project's scope and specification have been very clearly defined, or a standard type of project is to be constructed, then the fixed lump sum may be used. The risk is passed fully onto the contractor and the project sponsor cannot usually intervene further in the project. This is not a common, or indeed recommended, approach on most grouting projects.

With the target lump sum approach, the contractor prepares an estimate based on a defined scope of work. Before the project sponsor accepts this sum, there will be an agreement on the respective liabilities of the project sponsors and contractor, if the contract overruns on costs.

The "tasks completed" or "materials and quantities" approach involves measuring construction works according to agreed methods. When the works are priced, their total costs plus an element for profit and overheads, form the contract price. This approach is flexible, can deal with change effectively and is used in valuing the work undertaken during the construction phase. For the estimate of quantities and contract value to be realistic, the detailed design of the project must have been completed prior to commencement of construction.

If the activities to be undertaken are known but neither the detailed design information nor the scope of the activities are, then a schedule of rates may be used. The contractor is paid, therefore, on the basis of unit rates that have been included in the tender. Usually, this method yields a higher project cost than the tasks/quantities approach because a higher contingency amount will need to be included to allow for the greater uncertainty involved.

Regarding project handover and completion, a date for the handover of a project from the contractor to the project owner is usually included as an element of the contract. For many reasons this may vary from what was originally agreed in the contract. Typical reasons for such extensions in a grouting project are variations of quantities and safety and operational constraints. Many projects include financial penalties (or rewards) for late (or early) completion. A percentage of the total project costs may also be retained until the project owner is satisfied that the project has been completed as specified.

## 2. INITIAL PROJECT COSTING AND COST CONTROLLING FACTORS

### 2.1 Key Determinants of Initial Project Costs

No two grouting projects will cost the same no matter how similar they are. Apart from basic technical factors, the wide range of economic and institutional conditions in different geographical areas will, themselves, always lead to variations. Nevertheless, the fundamental project costs are based on the actual cost of the materials, equipment and labor in the region where the project is being executed. These basic costs will vary depending upon a number of factors, as illustrated in Figure 1.

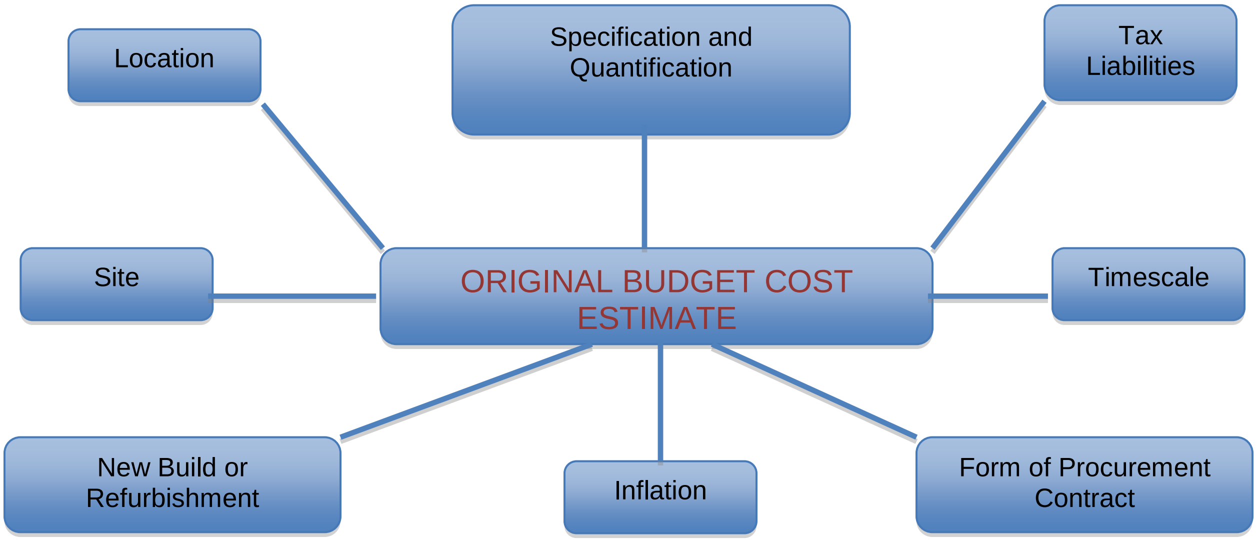

**Figure 1. Key determinants of costs**

## 2.2 The Project Specification

The specification defines the physical attributes of the project. For example, for a grout curtain, performance forecasting will lead to the specification of the required length, depth and width of a barrier, the materials to be used, the number of lines, methodologies, and quantity of stages used, the target residual permeability, and so on. Generally, the more detailed and prescriptive the specification and the larger the project, the more expensive it will be in terms of unit costs.

### 2.2.2 Location

Location affects project costing via institutional factors and through geographical and climatic realities. Institutional factors can affect initial project cost estimates in a number of ways. Consents procedures in particular may be more arduous in some countries than in others, affecting the time it will take to successfully implement a project. Allowance for the costs involved in sustaining a long public consultation exercise is an example. Where major projects are likely to be strongly opposed on environmental grounds, more cost may have to be allowed for environmental mitigation measures.

In geographical terms, construction and material costs, and applicable design standards vary widely. Even within a given country, variations will exist depending on whether a project is being implemented in a peripheral or central area, or in an urban or rural context. Generally, the more remote a project is, the more expensive it will be because of the cost of transporting construction materials and equipment to the site. In an urban location, lay down and storage costs are usually much higher, while other “running costs” such as traffic control, and protection of underground services, will often be considerable.

### 2.2,3 Form of Procurement/Contract

As explained above, the form of procurement and contract used by the project owner can strongly influence the estimated cost of a project.

### 2.2.4 Site Characteristics

A site will have certain soil and drainage conditions and access restrictions, which will affect the original cost estimates. The amount of treatment required is particularly affected by varying and/or poor ground conditions. Where there is uncertainty about ground conditions, accurate project costing cannot be achieved unless trial and/or previous treatment information is available. This risk is best mitigated via a responsive site investigation but, even then, few owners fully appreciate that such investment is really necessary.

### 2.2.5 New Build or Improvements

Generally, the construction of new infrastructure is more expensive than improvements to existing infrastructure, such as the refurbishment of an existing grout/seepage barrier. This is primarily because the "non-building" costs such as previous foundations treatments, provision of services, etc., do not have to be included when simply upgrading existing structures in lieu of total replacement methodologies to the same extent.

### 2.2.6 Tax Liabilities

Every organization may be liable to pay tax on its purchases depending on the location of the project. However, some organizations and types of project are not liable to pay taxes, or else these taxes can be reclaimed. Local government projects and infrastructure for public use are examples. Some public or quasi-public sector companies, voluntary and private sector organizations can be liable however, and these tax costs can have a significant impact on gross construction costs.

### 2.2.7 Timescale

Generally, the longer a project takes, the greater the project costs will be due largely to the extended overhead. Project timescales are dependent on the specification of a project. Although it is usually the case that the larger a project is the longer it will take to implement, this is not always the case since substantial additional resources can be used to accelerate the schedule.

In some cases, work on a project may take far longer than expected because its phasing is dependent upon other, linking projects or public finance programs. A project which involves non-continuous phases is usually more expensive than one undertaken without interruption because of the additional costs involved in re-mobilizing of plant and/or in paying for standby costs.

#### 2.2.8 Inflation

The longer the expected construction period, the more account will need to be taken of expected inflationary price increases over time. This is particularly important where a public authority's expenditure program is involved. Initial cost estimates will need to allow for the value that will need to be paid at the time the project actually goes ahead.

Levels of inflation vary around the world and can in current times be as low as 1-2% or as high as 10% per annum. However, the extreme range of commodity pricing the world is experiencing can actually create a recessive condition.

## 3. METHODS OF MONITORING GROUTING / SEEPAGE BARRIER PROJECTS AND THEIR COSTS

"Basic Minimum" methods are employed on large projects throughout the world to monitor grouting progress. These include simple pressure/flow/volume readings graphically displayed in 2D CADD format commercially available to owners /engineers and contractors.

In contrast, "Modern Integrated Monitoring Instrumentation and Control" (MiMiC) is a fully integrated instrument, equipment and 3D computer-aided monitoring and data analysis approach, which is utilized by many contracting groups throughout North America and the EU. These approaches are discussed in the following sections.

### 3.1 Basic Minimum

#### 3.1.1 Uncertainty in Project Budgeting

The preparation of a project budget estimate is a difficult task because construction projects are subject to risks and uncertainties, particularly in the early stages when very limited information about the project is available. Yet, the cost estimates prepared at this stage are most important to the project owner and the stakeholders because they often form the basis of the budget for funding, or, in some cases for determining if the project will proceed at all.

As a project progresses, more information becomes available allowing costs to be calculated to a greater degree of accuracy. For example, the ground conditions and their response after a grout testing phase will be more reliable. Nevertheless, many aspects remain uncertain and normal costing practice is to include an extra element to provide "insurance" against cost overruns. The word "contingency" is used to describe this additional cost element.

The contingency is typically based on a "rule of thumb" calculation, as a certain percentage of the base cost estimate or a lump sum based on the experience of the estimator. A figure of 10% of gross costs is a common allowance. This risk allowance or contingency sum is often calculated only once and is not reviewed again as the project progresses.

The main weakness of this simple approach to contingency costing is that individual risks are not separately evaluated. As a result, a contingency is often set too high for low risk projects, or too low for high-risk projects. In addition, it is not always appropriate to carry a specific contingency allowance for the duration of a project since many of the risks become known and can then be reduced or eliminated especially when detailed construction/management testing programs are in place.

### 3.1.2 Risk and Contingency Planning

By giving greater attention to which cost determining factors are most likely to change, and why, project planners should be able to develop more accurate contingency estimates. This in turn should reduce the risk of cost overruns. Poorly managed risk reduces the chance of a project to be completed within time and on budget. On the other hand, the level of risk can often be reduced if project planners take the time to identify, assess and manage the main factors leading to cost escalation, namely variation in quantities. Developing realistic and fair quantity estimates should always be conducted from the project onset and never amended to meet a political or perceived overall cost, and schedule milestones

Measurement methods that utilize 2D CAD technology should be tied into project management monitoring systems. One may identify two types of contingency:

- **Design Contingency:** an allowance for use during the technical design/budgeting/testing process to provide for the risks of methodology changes from varying and/or impacted quantity data.
- **Construction Contingency:** an allowance for use during the construction process to provide for the risk of changes due to site conditions or as a result of changed construction methods or poor performance by contractors or sub-contractors.

A better specified contingency will only be effective if suitable project control procedures are in place to control all aspects of project performance. Project control procedures should be organized and managed by the project manager. They should provide essential, coherent management information so that the project stakeholders and project manager can react to changing circumstances.

### 3.1.3 Project Management

Even improved contingency planning cannot be a substitute for good project management. The essential elements of good project management are:

- **Cost Control:** managing the design and construction processes to achieve best value for money and ensuring that the final cost does not exceed the budget.
- **Time Control:** managing the design and construction processes so that the project is completed on or before the agreed completion date.
- **Quality Control:** ensuring that the quality and performance of the completed project meets the project sponsor’s original objectives.
- **Change Control:** ensuring that any changes that are necessary are achieved within the approved budget, that they represent good value for money and that authorization to proceed has been obtained from the project stakeholders.

## 3.2 MiMiC (Modern Integrated Monitoring Instrumentation and Control) and Real Time Computer Monitoring

Bruce (2012) summarized the essential technical real time computer monitoring in grouting industry in their paper. The integration of automated computer monitoring of grouting operations has greatly enhanced the industry’s ability to make better immediate decisions related to the formation’s response to grout injection. Wilson and Dreese (2002) and Dreese et al. (2003), discussed the three levels of technology for the monitoring of grouting operations that were available in the industry as of 2003:

- *Level 1:* Dipstick and Gage Technology
- *Level 2:* Real-Time Data collection & Display Systems
- *Level 3:* Advanced Integrated Analytical Systems (AIA Systems)

This definition applied to rock grouting projects for dams, although the basic framework is equally applicable to other types of grouting, in soils as well as rock. *Level 1* Technology represents the general state of practice prior to around 1997 and does not utilize electronic pressure gauges and flow meters that are widely available in the market. Nor does *Level 1* Technology incorporate the speed and power of the computer that makes most of the calculations required for monitoring fast and accurate. For this reason, only *Level 2* and *3* Technologies are recommended as only they are truly able to produce real-time displays of grouting operations. *Level 3* is considered the superior level of technology in the grouting industry today. Unlike the other levels of technology, the engineer or geologist operating the system has the tools and capabilities to provide onsite technical support and real-time assessment of the grouting results in addition to monitoring the operations. As discussed in detail in the referenced papers, *Level 3* Technology is comprised of 4 major components that when combined, produce a unique and powerful monitoring system: (1) a real-time data display of information retrieved from field operations; (2) a central database to store all collected and calculated information; (3) linked customized CADD functions to automatically display up to the minute information stored in the database on demand; and (4) customized queries to quickly and accurately mine data from the database for daily report generation and up-to-date analytical capabilities. The CADD display allows the project team to visually observe the results as they are obtained, and assess the project status in relation to adjacent hole series and lines. The real-time monitoring and analytical capabilities allows the operator to make sound engineering decisions efficiently. Figure 2 shows a 3-dimensional closure plot of a single grout line through fourth order hole series at varying depth intervals. Analytical capabilities such as this allow the operator to assess grouting performance, resulting in better informed decision making.

The linked functionality of the grouting database to both CADD and customized queries makes true *Level 3* Technology a powerful tool for fast and accurate analysis of grouting results. CADD plots and query analyses can be performed on demand and contain up-to-the-minute information. The speed in which current grouting information can be presented and displayed for analysis by the project team is of substantial benefit over technologies that require a longer turn-around time of information in the form of drawings and queries, time on the orders of weeks, days or even hours. True *Level 3* Technology gives the user the ability to present information on-demand in a matter of minutes. This is especially important for projects of a critical nature that require special attention to grouting progress and risk reduction.

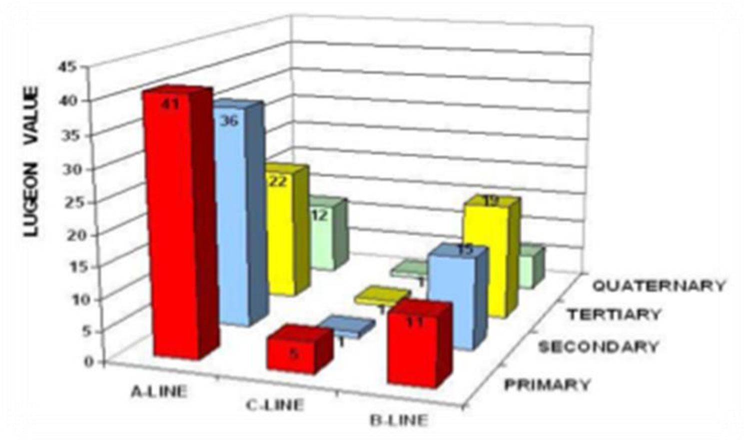

**Figure 2. 3-Dimensional Closure Plot**

True *Level 3* Technology gives the user the ability to present information on demand in a matter of minutes. This is especially important for projects of a critical nature that require special attention to grouting progress and risk reduction. True *Level 3* Technology is also important for projects with widely varied and unpredictable subsurface conditions, such as karst formations, that require careful, but relatively quick analysis and grouting method selection. The same level of care is warranted when conducting any grouting activity of high short-term risk potential, e.g., jet grouting under or adjacent to delicate, existing structures.

Technical challenges are faced frequently on any given grouting project, specifically due to the unknown nature of the subsurface. Technology in the grouting industry has fortunately advanced to new levels of sophistication to include additional methods of assessing the subsurface conditions to customize the program in order to effectively accommodate the geologic formations encountered. Two technologies that have proven to be valuable in analyzing subsurface conditions are Monitoring While Drilling (MWD) and High Resolution Borehole Imaging. While these technologies are not new, recent advances in the technology and their use in conjunction with the real-time monitoring and analytical tools has greatly enhanced and improved the ability to understand the subsurface conditions, resulting in a more efficient and productive program.

Additionally to the *Level 3* computer monitoring controlling technical parameters we now have integrated 3-Dimensional monitoring systems in technical use on projects. MiMiC (Modern Integrated Monitoring Instrumentation and Control) now allows integrated borehole imaging measurement while drilling and electronic logging along with other instrumented technologies into one comprehensive technical data base. But they should be more fully integrated into the project design, construction execution, testing, contract administration and quality assuarance. By fully utilizing the MiMiC approach, grout/ seepage barrier design and construction would benefit from significant performance and costing improvements. MiMiC does exist - it is simply not properly utilized and integrated into large scale grouting/seepage barrier projects utilizing all its potential capabilities.

When a curtain is required, the design, testing, measuring, construction, cost control and QC should be managed and executed at the same technical level from initiation to handover. This would fall in place with the age-old saying: “A project that starts well always ends well.” Conversely a poorly conceived and started project will be significantly more challenging for all the stakeholders in different ways.

## 4. BARRIERS, MISCONCEPTIONS AND GAME THEORY THAT ARE REDUCING THE POTENTIAL OF THE MIMIC APPROACH

Most advances in modern business and technology have a multitude of back stories complete with exorbitant amounts of self-justifying information that need to be distilled. This certainly holds true in the modern grouting industry. At the turn of this century the industry had embraced computer-aided grouting technology along with the other technical advances that make it possible. To date it is fair to say we have eliminated the dip stick the same way as the automotive industry has: it is available but nobody uses it. What we have yet to accomplish with this technology is to completely apply it across the entire spectrum of a grouting project, design, construction and administration. Why has this not happened through the evolution of the technology over the past 25 years? The following reasons can be named as main contributors of stalling development of full use of the MiMiC concept:

- Asymmetric information, sometimes referred to as information failure, is present whenever one party to an economic transaction possesses greater material knowledge than the other party. This normally manifests itself when the seller of goods or services (owner/operator of computer-aided system) has greater knowledge than the (client/engineer) buyer, although the opposite is occasionally found. Almost all economic transactions involve information asymmetries of some nature.

  This condition is quite common on the computer-aided project where the specification requires the contractor to supply the technology, operate it and present the technical data raw and/or refined to a low level to the owner/engineer. Commonly the owner/engineer is completely unaware of, or has not specified, cost control platforms complete with the digital integrated measuring devices which do exist and which the contracting party may actually already possess.

  The number of computer-aided systems that have the matching contract payment tables built in to their systems is surprisingly small, so that the program is not shared in real-time with the owner/engineering team, the decision makers.

  Technical decisions have a cost and schedule impact together with a performance impact. Cost benefits to decisions must be accounted for also in real time to exact best value and not risk final performance. Lacking this level of transparency on the project from the beginning is the greatest risk to project success.

  Stakeholders of a major grout/seepage project who do not apply MiMiC technology in their program from the beginning to create the best possible budgeting (to avoid incurring early costs like ECI “contracting early contractor involvement” or capital expenditures) will result in escalating programs and cost overruns.

- The recognition from the beginning that a grout/seepage barrier is 3- dimensional and commonly composite (i.e., it forms part of a curtain/diaphragm wall system). Therefore all design, quantity values, measurements and performance criteria should embrace that perspective.
- Developing the barrier in a 3D model format allows the treatment methods to be clearly visualized along with accurate quantification of the units/type and level of effort for each construction operation and verification step. It can be modeled with different levels of intensity to better define and manage risk. There is no reason any project cannot be modeled after a review of site geology records and/or early drilling results. It is impossible to be highly accurate with the preliminary model but it is fair to say that it will be orders of magnitude more comprehensive than any rule of thumb.

  This level of effort expended following the 3D model approach from the onset yields levels of performance through the project never thought achievable before. It limits the possibility of significant over runs of values derived from a substandard preliminary curtain scope budget estimate, which helps to limit deficit cost budgeting scenarios.

  In their QA/QC programs, the oil and gas industry players mandate that all borings are "executed" on paper by the drilling team first. They call it "drilling the well on paper" (DWOP). MiMiC is simply a more complicated grouting program. Mistakes found on paper in the office are much cheaper than those which otherwise would occur in the field.
- Failure to implement unit cost measurement and payment items that can be harmonized within the MiMiC type program. In this regard:
  - The unit of measurement for most of the world grouting market is metric;
  - Most international equipment manufacturers supply equipment based on metric units and gauges;
  - Grouting using metric units is the most efficient in a multitude of applications and conversions for analysis;
  - Failing to consistently use metric units for measurement and payment because institutional clients will not change administrative contracting policy exposes them to potential errors and rounding factors;
  - Global equipment costs for standard measurement machines are 20% to 35% higher which is impacted on standard measurement project costs and schedule because of supply chain shortages;
  - Grouting formatting can easily be layered on top of pre-existing as built drawings so the 3D design is generated with both measurement references (from the baseline) which can help eliminate survey quantity errors and help record project baseline geology.
- Failure to adopt a volumetric measurement for treatment and performance testing of all operations for comparative measurement and analysis.
  - The debate rages on radius of spread calculations, but some clear principle of treatment must be made from the onset for informed decision making on

  treatment quantities and higher order treatments. Whereas a radial over length measurement can be rejected in favor of a straight treated volumetric quantity over length, a dry material volume over a lineal borehole length cannot;

- Without the 3D volumetric approach, how can decisions be made on effort and quantity? Limiting quantities of material to less than a 10% void ratio over a stage treatment volume is flawed and will certainly result in additional orders of stages and effort;
- Refusals should be measured and clearly defined from the onset and completely covered in the measurement for payment items as to their scope and payment;
- Inconsistent and poorly executed refusal is the greatest cost escalator to a grout/seepage remediation project;
- Refusals should be a fully functional measurement item on a MiMiC grout/seepage project with full alarms and lock downs for completion of a stage;
- The normal exceptions to the refusal criteria exist, such as interconnection, breaches to surface, and exceptional dilation in the stage.

Most of these problems are generally a result of a poor geological model that has not balanced treatment zones and methods volumetrically. A basis to start out with is the “rule of three”: 3 lines, 3 orders (primaries, secondaries, tertiaries), 3 m stage lengths, 3 meter centers on hole collaring in all directions, 3 percent contingency per line for selective treatment utilizing a 3 meter diameter of spread for the perfect prescription.

- Measurement instruments and data for MiMiC approach to grouting should capture, store and refine the technical data along with the contract quantities for payment data for the entire project effort. The instrumentation field as it is applied to grouting works is extensive but has variable levels of reliability and accuracy. However, regardless of the details of the instrumentation, every measurement for a pay/ technical item should have as much human interaction and control as possible eliminated from its capture in the field. Curtain success is the ability to repeat (1 lineal meter along the axis of treatment on a 60 meter deep curtain using the rule of 3 is 60 repetition cycles) identical tasks consistently through the entire project: 95% grout/seepage reduction is a failure on most erodible foundation projects. It is sealing the final 5% that provides the best long-term value solution.

- It is essential to have general performance values that can be measured in place prior to starting any work, and which are archived through the MiMiC approach. The values can be adjusted as the work and information are developed but the goal values must be mandatory from the beginning and agreed upon by stakeholders.

- All data must be shared in a transparent manner without prejudice between all stakeholders. Withholding and manipulating results is the fastest path to project failure. Evaluation of the actual facts and figures on a project on a near real time basis is the only way to manage technical/cost risk in an effective model of improvement and balanced value no matter what the news.

## 5. CASE HISTORIES

Case histories that document the successful use of the state of the art technology (*Level 3* and MiMiC) discussed in this paper include three U.S. Army Corps of Engineers (USACE) DSAC-1 Dams. DSAC, or Dam Safety Action Classification is a USACE initiated risk-informed approach and ranges from DSAC-1, which is the highest priority and highest risk to DSAC-5. The three DSAC-1 dams discussed herein are Clearwater Lake Dam, Missouri; Wolf Creek Dam, Kentucky; and Center Hill Dam, Tennessee.

### 5. 1 Clearwater Lake Dam, Missouri

Clearwater Lake Dam is located in Piedmont, Missouri. In 2003, a sinkhole was discovered on the upstream slope of the 4,200-foot-long, 150-foot-high earthen embankment dam. As an interim risk-reduction measure (IRRM), the USACE decided to install a grout curtain approximately 200 feet in length immediately downstream of the sinkhole to investigate and determine the cause and extent of the sinkhole. During this initial exploration, a large solution feature, approximately 25 feet wide by 170 feet tall was discovered in the foundation bedrock. Low mobility grout (LMG) was successfully utilized as the appropriate grout type to fill the feature, but it was determined that additional treatment would be necessary in the vicinity of the sinkhole. To accommodate this additional work, and to explore the foundation bedrock underlying the remaining embankment to identify potential locations of other solution features, two other projects were awarded; Phase 1 and Phase 1b Exploratory Drilling and Grouting. More extensive efforts were performed along the entire length of the embankment during the Phase 1 and 1b contracts. The two projects (essentially combined into one) consisted of a 2-line grout curtain with holes drilled on 10-foot centers from left to right abutment, with the intention of characterizing and pre- treating the foundation material in preparation for a proposed cutoff wall.

*Level 3* Technology plus developed alpha version of MiMiC was also utilized in parallel for real-time monitoring, display, and collection of all data. To complement this technology, high resolution borehole images were obtained to map bedrock discontinuities and other geologic features, identify opening sizes for determining most appropriate grout type, verifying complete treatment of openings, and for performing borehole deviation. MWD was also utilized at Clearwater on various drilling rigs for obtaining real-time drilling characteristics of the underlying material for correlation of drilling characteristics with borehole images, pressure testing results, and injected grout volumes. The treatment of the solution feature and pre-grouting of the karst bedrock has permitted the construction of the cutoff wall without a major slurry loss incident.

In fact the evolution of the Clearwater Dam Project from a full cut-off wall solution to the composite barrier solution was a direct result of the use of an integrated data approach and MiMiC. The application of the technology from the start and the use of its cost-tracking features with the client was the main contributor to making best value technical and costing decisions. Three prominent decisions that were made in the Project that are directly related to the MiMiC approach were:

1. The exploratory program was reduced significantly when the MiMiC system was able to determine the scope of the Project early on with the scalable costing models being able to be put forward to the team. This resulted in the savings from the early completion of the exploratory program, which cost savings were integrated into the final barrier solution.

2. The Phase I portion of the Project in concert with the MiMiC approach effectively treated the epikarst zones and provided an accurate forecast costing, which allowed the analysis to create the combination of best value barrier methodologies and scope. This led to the composite approach of raising the bottom of barrier wall with more intensive grouting below the raised wall elevation to full depth resulting in significant overall project savings.
3. The high level of confidence that the MiMiC approach provided allowed the cut-off wall installation to proceed without any significant slurry loss and need for additional slurry containment methods, which in turn enabled for the open trench cutter methodology. The cut-off wall overall installation cost was significantly reduced (30%).

### 5.2 Wolf Creek Dam, Kentucky

Wolf Creek Dam is located near Jamestown, Kentucky, and impounds Lake Cumberland. From 2007-2008, a grouting program was implemented both for interim risk reduction measures, and as an initial phase for the construction of a composite cutoff consisting of a grout curtain and a concrete barrier wall along the length of the embankment section of the dam. Additional grouting at the right abutment, the rock foundation below the concrete section of the dam, and along a downstream section adjacent to the concrete/embankment interface has also been performed, or is currently under construction.

In addition to the use of *Level 3* Technology for monitoring grouting operations, other technologies utilized at the site included weekly upload of grouting as-built drawings to a website, and high resolution borehole imaging for the Phase I program. The *Level 3* Technology of the grouting operations allowed for the rapid dissemination of grouting results to critical personnel at various levels of project oversight within the USACE and an independent Board of Consultants tasked with making technical decisions concerning grouting methods and determining whether additional holes were required and their appropriate locations. Borehole imaging was utilized to identify the condition of the rock foundation in critical areas, and to identify zones that required additional grouting. In addition to the image data, the camera probe also recorded borehole deviation data that were used as a quality control measure to ensure the consistent alignment of the grout curtain along the entire grout curtain length to a maximum depth of 345 feet from the top of work platform. The incorporation of these technologies resulted in the fast and accurate construction of 3,750 feet of a two-line curtain, which was completed within an accelerated project schedule and allowed for the timely start of the second phase of work, the construction of the barrier wall.

Automated instrumentation was added to key critical areas of the dam after Phase I for analysis of the performance of the subsequent work phases. The automated system was installed by the USACE to supplement the manual instrumentation system of piezometers, survey points, inclinometers, and extensometers that already existed at the site. The automated instruments were designed to record and display the response of the subsurface foundation and embankment to future grouting operations as well as the construction of the barrier wall. However, the real-time monitoring of the grouting operations and the automated instrumentation were not integrated. Consequently, operators were not always aware of issues for hours or days after completion of a stage, and forensic investigation to identify all activities at that specific time were not always possible.

There was no use of a unit cost tracking tool in concert with the *Level 3* system employed, so analytical technical cost evaluations were not provided by the *Level 3* system to the team. This resulted in escalation of unit quantities of the grouting portion of the project by traditional rules of adding sequential series of holes with the split spaced approach, which in conjunction with *Level 3* accomplished a quality cut-off.

### 5.3 Center Hill Dam, Tennessee

Center Hill Dam is located near Lancaster, Tennessee. From 2008-2010, Phase I of the remediation at Center Hill Dam was performed as both interim risk reduction measures and as part of an overall grout curtain and composite barrier wall cut-off, built to reduce overall grout/seepage and instability at the site. Phase I work consisted of the grouting of the main dam embankment, left abutment groin, and left rim sections of the dam. Phase II of the project involves the construction of the barrier wall portion of the composite wall cut- off along the embankment section of the dam. Work for Phase II is scheduled to begin in late 2011.

State-of-the-art technologies utilized during Phase I operations included Level 3 computer monitoring, weekly update of grouting as-built drawings to a website for technical review, geophysical analysis of subsurface conditions using electrical resistivity, high resolution borehole imaging, down the hole camera technology for inspection of a large open-air cavity encountered during drilling operations in the left rim, and a real-time automated instrumentation system consisting of vibrating wire piezometers and weir monitors. Real-time monitoring results and on-demand grouting as-builts were used by USACE personnel and an independent Board of Consultants to make rapid, but informed technical decisions and program modifications, including the addition and deletion of holes based on grouting results.

The incorporation of the automated instrumentation system by the contractor that included alarm levels allowed for the real-time display and analysis of the piezometric response of the subsurface foundation to the drilling and grouting operations. The ability of the automated system to both record and display in real- time the changes in foundation pore pressures during operations allowed for the comfortable use of increased grouting pressures in specified zones to more effectively penetrate difficult rock formations with grout, and was integrated with the computer monitoring as a result of experiences at Wolf Creek Dam. Subsequently, automated instrumentation is required in the Center Hill Phase 2 Cut-off Wall contract.

A MiMiC approach was not used for the grouting portion of this Project, and a *Level 3* System was employed. To compensate for escalating unit quantities of the grouting work because of the use of traditional split spacing to maintain cost and schedule, portions of the originally designed grout/ seepage barrier were reduced. Consequently, an additional grouting program will have to be executed in the future to compensate for these reductions.

## 5. CONCLUSION

Creating modern budget costing requires the development of reasonable quantities of work on a best and worse case scope scenarios utilizing 3D type tools and state of the industry techniques.

Failure to establish realistic engineered budgets utilizing the equivalent state of the art means and methods from the beginning will set the path to project cost underperformance.

By not developing reasonable performance criteria that can be measured on a continual basis from the project’s inception along with an accurate baseline development approach will certainly lead to project costing underperformance. Overtreatment certainly will affect the costing performance metric though the technical performance was exceeded, a common result in a basic cost control approach.

Only with a properly designed scope of quantities can a viable table of unit price items be developed and utilized confidently in costing and cost-control.

In conclusion, grouting projects at the MiMiC level are a Win/Win situation for all stakeholders. Is it not time that we work toward eliminating the zero sum game approach from grout/seepage barrier design, construction and delivery?

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