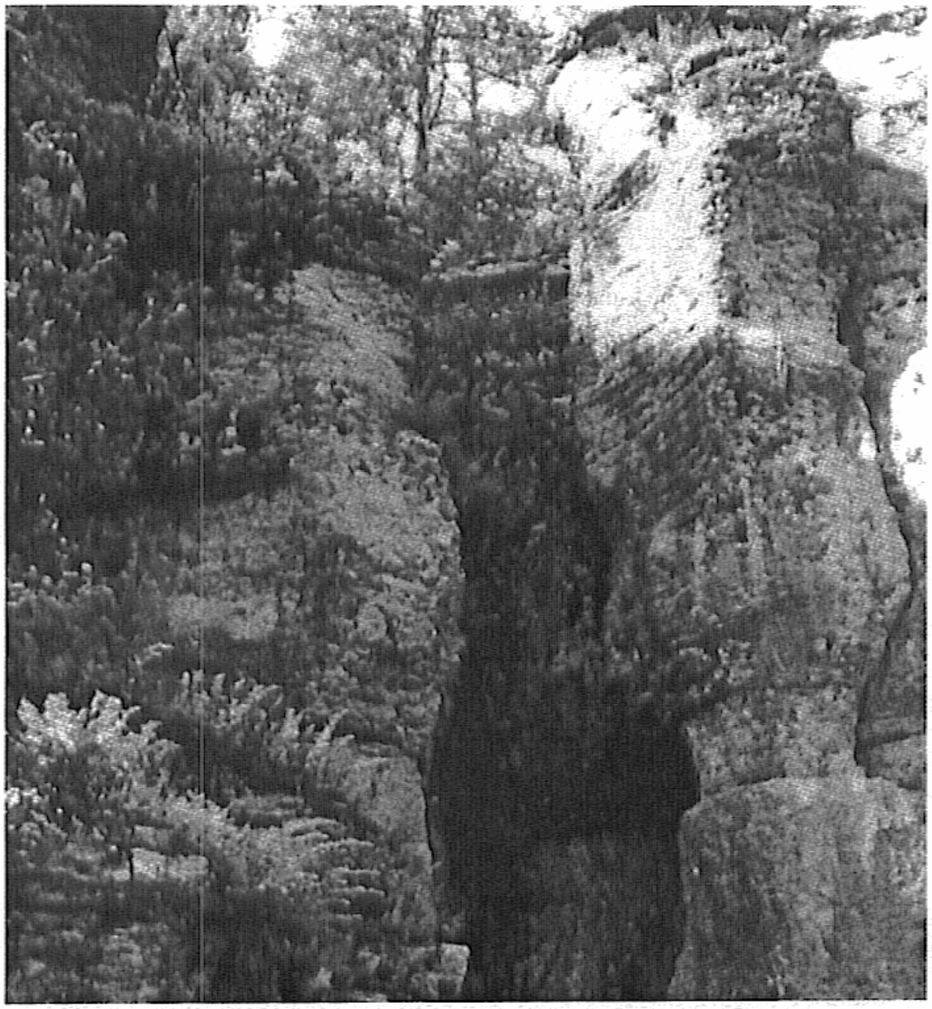

Keeping Water Out of the Quarry Floor

Part 1: Emergency procedures for dealing with water in heavily karstified limestone deposits.

By Donald A. Bruce, Ph.D.

Keeping water out of the quarry floor is a challenge facing aggregate producers working in many conditions, but especially those working in heavily karstified limestone deposits.

Both long- and short-term aspects of an aggregate operation can impact the problem. For example, a quarry in and of itself can create relatively abrupt and unnatural hydraulic gradients in the surrounding ground by forming a massive open space beneath the natural piezometric surface. Short-term disturbances such as blasting, excavation, and the alteration of regional piezometric conditions by pumping may further impact water conditions.

While many limestone quarries are located and engineered to avoid known karstic locations, aggregate producers should be prepared to deal with water infiltration of some extent. Remedies for dealing with water range from simple pumping to the installation of grout curtains. Although aggregate producers are familiar with the former, the latter may also be a viable option under the correct conditions. Grout curtains installed in virgin karst have a finite effective life — the length of which depends on the rock mass characteristics, the intensity and quality of any grouting conducted, and the prevailing hydraulic gradients. Unfortunately, this life cannot be precisely predicted. Such grouting operations cannot be guaranteed to comprehensively treat a very karstic rock mass. Under long-term service conditions, seepage may eventually result in open channels through features in the karst filled with residual clay or other erosional or weathering materials.

The first installment of this two-part series addresses what to do when water flow velocity or volume reaches a level that demands action. Such interludes are typically highly stressful for all parties, especially given the consequences of failure. They invariably present a technical scenario that is extremely challenging to resolve. It is at such times that logic is often lost in the rush, and the "ready, aim, fire" syndrome kicks in. The second installment will focus on construction techniques and considerations.

Crisis management

The following eight-step sequence reflects three fundamental stages in implementing any successful remedial grouting operation:

- Exploration and situation assessment;
- Responsive execution; and
- Verification and monitoring of performance.

Sudden, significant, and obvious changes to the preexisting structural and hydrological regimes characterize a karst-related flow event. Flow or seepage rates may increase substantially — by an order of magnitude or more — the flow may be discolored, new seepage entry and exit points develop (e.g., "eddies" and "boils"), piezometric surfaces drop, or surface manifestations may occur in the form of depressions in embankments and sinkholes in overburden.

At such times, normal facility operations are interrupted or suspended, and depending on the severity of the situation, a fundamental safety situation may be declared and a wide range of technical, operational, managerial, financial, and statutory bodies may become involved. Time will be of the essence in order that resolution is achieved as quickly and cost effectively as possible, and that any safety-related issue is correctly and firmly managed. The following steps reflect the approach the author has developed over the course of several such events.

Step 1. Appoint a project manager to act as a coordinator of the short-term emergency and the subsequent long-term remediation efforts. This manager should be from the ranks of the facility owner and should have long and direct experience with the construction and operation of the site and with the modus operandi of the ownership. The manager should be relieved from his prior routine duties as much as possible and should be fully empowered to seek further assistance, both from internal resources and external consultants. Establish a separate "mission control" room for collecting and analyzing all data and for holding all technical meetings. Formally record every meeting.

Step 2. Evaluate exactly what the situation is, via analysis of all available data sources, but at this time paying special attention to documenting verbal accounts from witnesses. Such accounts can be of great benefit in subsequent analysis, but their value depends on their accuracy and completeness, both of which will rapidly recede with time.

Step 3. Implement all necessary short-term measures which legally, administratively, or practically have to be taken. From the technical viewpoint, this may include installing additional, simple instrumentation (to help quantify the issue, e.g., structural movement monitoring, flow measurements); increasing the frequency of reading existing instrumentation; inspecting the site; relocating equipment that is threatened by inundation; or installing extra pumping capacity. These actions help create a baseline, mitigate the impact, identify if the situation is deteriorating further, and help the project manager determine the level of imminent danger.

Step 4. Design and conduct a focused program of new site investigation. The purpose of the investigation is to establish the exact path of the flow (typically it is in a massive conduit as opposed to in a widely dissipated "delta"), its rate and velocity, and the nature of the rock around the conduit. (A conduit in a zone surrounded by other clay-filled karstic features that have not, as yet, been "flushed out" will represent a severe problem during subsequent remediation and service.) This study will permit a remedial design to be conducted and priced. It will also highlight if the flow has the potential to create further distress to overlying or adjacent structures. During this time, maintain the instrumentation reading schedule of Step 3.

The site investigation should comprise the following two complementary tasks:

- Desk study: review all relevant construction records; historical performance data; instrumentation data; regional, local, and site geology; climactic and seismic records; aerial photographs; personal recollections; and published technical papers.
- Field study: install investigation holes by the fastest and most economical method to try to physically locate the conduit. This should be done as far "upstream" as possible. These holes can then be instrumented to provide ongoing data on groundwater levels, chemistry, temperature and pH; can be used for various types of geophysical testing, such as seismic tomography; or can be used as grout holes in subsequent remediation. Other types of geophysical testing, such as Ground Penetrating Radar, Spontaneous Potential, Electrical Resistivity (Dipole-Dipole or Wenner Schlumberger), and magnetic or gravimetric surveys, can be conducted. Dye testing, if properly conducted, can be extremely useful.

It may happen that despite best efforts and intentions, the exact source or path of the flow cannot quickly be determined with accuracy. Perseverance is essential: do not commence the subsequent steps until Step 4 is satisfactorily concluded.

Step 5. Assuming the situation is to be

References

Bruce, D.A. (2003). "The Basics of Drilling for Specialty Geotechnical Construction Processes." *Grouting and Ground Treatment, Proceedings of the Third International Conference,* Geotechnical Special Publication No. 120, Ed. L.F. Johnsen, D.A. Bruce, and M.J. Byle, American Society of Civil Engineers, pp. 752-771.

Bruce, D.A. and Gallavresi, F. (1988). "The MPSP System: A New Method of Grouting Difficult Rock Formations." ASCE Geotechnical Special Publication No. 14, "Geotechnical Aspects of Karst Terrains." pp. 97-114. Presented at ASCE National Convention, Nashville, Tenn. May 10-11.

Bruce, D.A., W.G. Smoak, and C.C. Gause. (1997). "Seepage Control: A Review of Grouts for Existing Dams," Proceedings of the Association of State Dam Safety Officials, 14th Annual Conference, Pittsburgh, Pa., Sept. 7-10, Compact Disc.

Cadden, A.W., D.A. Bruce, and R.P. Traylor. (2000). "The Value of Limited Mobility Grouts in Dam Remediation." Association of State Dam Safety Officials Annual Meeting.

Bruce, D.A., R.P. Traylor, and J. Lolcama. (2001). "The Sealing of a Massive Water Flow through Karstic Limestone." *Foundations and Ground Improvement,* Proceedings of a Specialty Conference, American Society of Civil Engineers, Blacksburg, Va., June 9-13, Geotechnical Special Publication No. 113, pp. 160-174.

Chuaqui, M. and D.A. Bruce. (2003). "Mix Design and Quality Control Procedures for High Mobility Cement Based Grouts." *Grouting and Ground Treatment,* Proceedings of the Third International Conference, Geotechnical Special Publication No. 120, Ed. L.F. Johnsen, D.A. Bruce, and M.J. Byle, American Society of Civil Engineers, pp. 1153-1168.

positively rectified, as opposed to merely being monitored or managed by other means (e.g., ongoing pumping from the quarry floor), the project manager and his or her advisors develop the design for remediation.

At this stage, seek input from specialty contractors and other specialists and review the technical literature for case histories of similar nature. It is essential that the design clearly identifies the "measure of success" of the project in terms of, for example, the residual flow rate or piezometric levels at various locations.

It is common to find that few grouting contractors will have faced such a severe problem before, and unfortunately, most will tend to initially underestimate the difficulty of the remediation. Considerable amounts of time and money have been lost by using local contractors in haste, using simple and conventional methods which are later proved to be wholly inadequate. It is also usually the case that such contractors have been hired on a "cost plus" or "time and materials" basis and so may not be highly motivated to achieve a quick and definitive solution, even if they did possess the technological resources.

Step 6. With the design and budget approved, hire the contractor. This should be done on the basis of "best value" as opposed to "low bid," although the two may be the same. Emphasize the contractor's experience, expertise, and work plan, as opposed to price. Hiring the wrong contractor will certainly lead to disappointment and dispute over schedule, performance, and cost, and indeed, inappropriate construction methods may worsen the situation and make further remediation attempts even more challenging.

Step 7. Execute the work. During this phase, all data relating to the contractor's operations (e.g., drilling, water testing, and grouting records, and progress) and to the impact on the overall structure/bedrock system (e.g., flow characteristics, piezometric levels, structural movements, changes in groundwater chemistry, and temperature) must be collected and studied in real time by the project manager and his team in "mission control." Only in this responsive, integrated fashion can the effect and effectiveness of the work be revealed progressively, and a sound engineering basis created upon which to instruct changes to the program if required, such as additional or deeper holes or different grout mixes. Such data are also invaluable in the ongoing process of reevaluating the soundness of the design (Step 5). This step is in place until the remediation has been completed and a short-term (e.g., seven days) confirmation period has successfully elapsed. Prepare a fully comprehensive "as built" report covering all the relevant data from Steps 1 through 7 as soon after the remediation as practical.

Step 8. Long-term monitoring. Many — if not all — the piezometers and other monitoring devices installed beforehand should still be functional at this point. The project manager must establish a regular schedule for reading these instrumentation sources, analyzing their data, and for conducting any relevant revised site or structural inspections. Establish a database and a well-defined series of protocols to follow if certain instrumentation trigger and threshold levels are reached, or if any significant flow or pressure aberrations reoccur. These protocols should include details of the responsible person(s) to be notified, and appropriate emergency response plans.

The most effective a grout curtain in karst will ever be is immediately after its construction. In service, as the full hydraulic gradient is being placed on the curtain (i.e., as the quarry is pumped dry) pockets of ungrouted or ungroutable weathered material will be exposed to pressures which may prove sufficient, over time, to cause such pockets to "blow out." This will occur despite the very best efforts of the design and construction teams. However, there is no predictive capacity as to how severe this increase in residual permeability will be or how fast it will develop. Clearly, such deterioration will depend on the nature of the karst (i.e., how much erodible material remains), the applied hydraulic gradient, and the length of time over which it acts. ■

■ ***Donald A. Bruce, Ph.D.*** *is president of Venetia, Pa.-based Geosystems, L.P. He can be reached at 724-942-0570.*