CHAPTER 3 – GROUT STABILIZATION METHODS

The following section presents an overview of and comparisons between traditional cementitious grout stabilization systems and polymer injection systems.

COMPARISON OF CEMENTITIOUS GROUTS WITH CHEMICAL GROUTS

Grouts fall into two basic categories: cementitious or chemical. Cementitious grouts typically consist of Portland cement mixed as slurry that can be injected or poured. In some cases, fine aggregate is added to increase strength or consistency. The cement grout is used in bonding rock reinforcement (e.g., rock bolts, cables), subgrade improvement, compaction, and mud jacking, to list a few. Additives such as deflocculants, accelerators, expansion, and polymeric agents may also be used to reduce washout and bleeding of the grout. In addition, fillers such as fly ash, pulverized fuel ash, fine sand, and pea gravel can be used to enhance the strength of the grout, particularly where filling of large fissures or cavities is required.

Chemical grouts comprise many systems, including sodium silicate, acrylate, lignin, urethane, and resin grouts. The most commonly used chemical grouts are sodium silicate based; reacting a silicate solution to form a colloid that polymerizes to form a gel capable of binding soil or sediment particles together and filling voids.

The main difference between polyurethane and epoxy grouts, when compared to cementitious grouts, is that the viscosity, strength, and set-up time of PU, PUR, and EP grouts can be varied and controlled to a much greater extent than the cement or sodium silicate grouts. The compressive strength of fully cured cement grouts typically range from 20 to 35 MPa (3,000 to 5,000 psi) with setup times from hours to days. The compressive strength of in-place sodium silicate grouted materials typically ranges from 1 to 10 MPa (100 to 1,000 psi). Conversely, the compressive and tensile strength of PU, PUR and EP products can range from 1 to 140 MPa (100 to 20,000 psi). The PU, PUR and EP products have typically three to four times the strength of cement or sodium silicate based grouts. Setup times will vary, but PU, PUR, and EP products will setup from 1 minute to 1 hour gaining significant strength in a short time interval. Cementitious grouts set up times vary from hours to days to gain significant strength. PU, PUR, and EP products are usually more viscous to pump (comparable to light motor oils) when compared to cementitious grouts, and may not flow as readily once they are injected (though rock mass migration is greatly aided by the presence of moisture, as previously noted).

POLYMER METHODS USED FOR UNDERGROUND STABILIZATION

PU Membrane Spray for Underground Stabilization

Spray-on polymers have been used for a variety of underground applications in the mining industry[(1)]. Based on a literature review, it appears that the spray-on products are typically used in underground mine areas with the potential for rock bursts or where smaller rock material may tend to ravel or fall from the ribs or roof of the mine. Comparisons of the spray-on products with shotcrete indicate the spray-on polymers have 2 to 10 times the tensile strength of shotcrete with a thickness less than half of the shotcrete[(2)].

PUR Injection for Underground Stabilization

PUR grout injection has been used for roof stabilization in underground coal mines for more than 30 years. The use of PUR injection and stabilization is most commonly used in difficult ground conditions characterized by fractured, broken rock that is progressively failing or actively caving. The injection of the PUR material into the fractures and discontinuities of the rock mass is intended to reinforce the fractured rock to the point where it can support its own weight and the weight of overlying unconsolidated rock by forming a grout-reinforced beam. The beam structure then bridges the weaker or more fractured rock to adjacent abutments having greater supporting strength. The use of easily-mobilized injection systems has made polyurethane resin stabilization a common practice, especially for longwall shield recovery operations in coal mines – where caving, unstable roof strata conditions are commonly encountered. Polyurethane injection, employing a range of PUR mix designs, has also been used as a sealant to manage and/or prevent groundwater inflows.

The National Institute for Occupational Safety and Health (NIOSH) has conducted research into the application and effectiveness of PUR injection for stabilizing deteriorating ground conditions in underground coal mine operations. The NIOSH paper, "Evaluation of Polyurethane Injection for Beltway Roof Stabilization in a West Virginia Coal Mine" [(3)], describes the use of PUR for consolidating and reinforcing roof bed separations in a coal mine entry. The paper describes a number of variables that need to be considered for underground applications of PUR:

1. Location of fractures. This information will help determine the zone to target for PUR injection.
2. Extent of the fracture zone. An estimation of the total void space should be used to calculate the volume of PUR needed. In a highly fractured rock mass, more test holes may be required.
3. Characterization of the fractures. A determination of the nature of fractures, whether they are bedding separations or a random fracture zone, aperture opening, moisture condition and persistence.

The Australian Coal Research Organization (ACARP), working in cooperation with STRATA Engineering (Australia), has also investigated PUR use in underground coal mining, documenting findings in the report entitled, "Cost Effective Use of PUR and Optimizing Large-Scale Injected Strata Reinforcement" [(4)]. The report outlines the following goals:

1. Conducting a range of trials to investigate various aspects of strata consolidation and, ultimately, produce guidelines in the form of a single handbook-style reference covering the range of strata consolidation techniques used in Australian mines; and
2. Providing Australian coal producers methodologies for the rational application of PUR technologies.

The report presents a number of PUR case studies covering a variety of geotechnical environments, and further provides application guidelines based on assessments of PUR ground consolidation mechanisms and current industry practice relating to design, operations, monitoring and quality control. Key findings of the ACARP study include:

1. Some of the case histories failed to prove that PUR provided a critical role in recovering or maintaining ground stability. This was due to either there being no definitive proof that instability would have occurred at some point or because the PUR was used in conjunction with other support systems.
2. The economic advantages of using PUR were significant when compared to driving new workings (abandoning problem ground areas) and the possible the loss of coal reserves.
3. Some of the cases illustrated unequivocally the importance of PUR injection to a successful outcome.

In a second study, described in the report entitled "Underground Monitoring of Roadway Roof Behaviour in Relation to the Use of Highwall Mining Techniques for Initial Punch Mine Entry Development" (5), ACARP and STRATA Engineering (Australia) investigated the use of PUR for coal mine portal stabilization. In this study, 11.6-m (38-ft) long PUR injection holes were drilled within the immediate roof of a mine portal to stabilize the overlying rock mass. The report indicates the use of PUR in this application was considered highly effective and contributed significantly to favorable ground conditions at the portal.

PU FOR SUBGRADE IMPROVEMENT

For pavement and subgrade improvement, the injection of one- and two-component polyurethane products has been used extensively in the United States. PU has been used to expand and fill voids under concrete pavement slabs and raise slabs to correct joint faulting and/or slab settlement. Based on a literature review, the polymer components are considered proprietary and specific details of the products and systems are not readily available. PU for subgrade improvement will react with water (i.e. hydrophilic) resulting in foaming and subsequent lower strength and density. Based on the brief description of the case histories, it appears the product generally stabilizes and/or raises the roadway to an improved condition when water is not present.

Overall PU, PUR, and EP have been used for various applications to stabilize a roadway or structure. To fully appreciate the technology transfer potential of PUR to transportation-related ground and/or structure stabilization projects the product was used in three full-scale demonstration projects along Colorado highways, as described in the following chapters.