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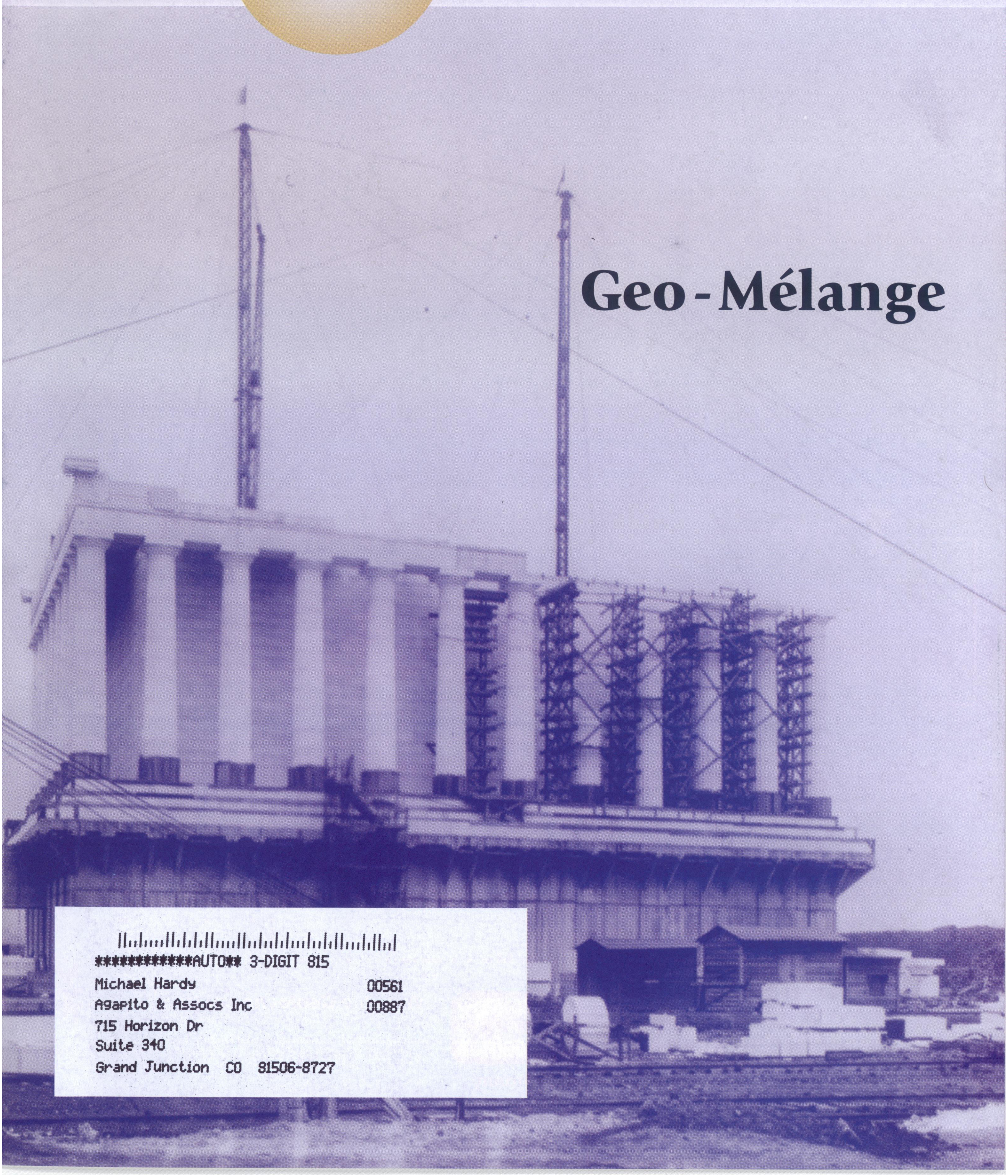


Geo-Mélange

Rock Reinforcement Longevity

By Francis S. Kendorski, P.E.

INTRODUCTION

Rock reinforcement has been accepted in mining and construction since the 1950s. The longevity of rock reinforcement is often questioned in engineering design because it's historical performance is measured in just decades, relies on natural systems to function, and is not easily inspected. The elements of a typical rock reinforcement fixture include an anchoring device, a bar or tube, a plate, a head bolt, and possibly grout.

One type of mechanical anchorage device (Fig. 1a) is an expansion shell that expands as the threaded bar is rotated inside an expansion nut within the shell. This causes the shell to expand outward to grip and often crush the rock along the drill hole. To maintain the required anchorage with time, re-torqueing is necessary. If not re-torqued, the bolt becomes progressively less effective. I often tell clients with little familiarity with rock reinforcement that a mechanical-anchor rock bolt is a machine, and machines require maintenance. A spring-loaded tube (Split Set® in Fig. 1b) or a hydraulically-pressurized bolt (Swellex™ in Fig. 1c) are two other types of mechanical anchorage devices.

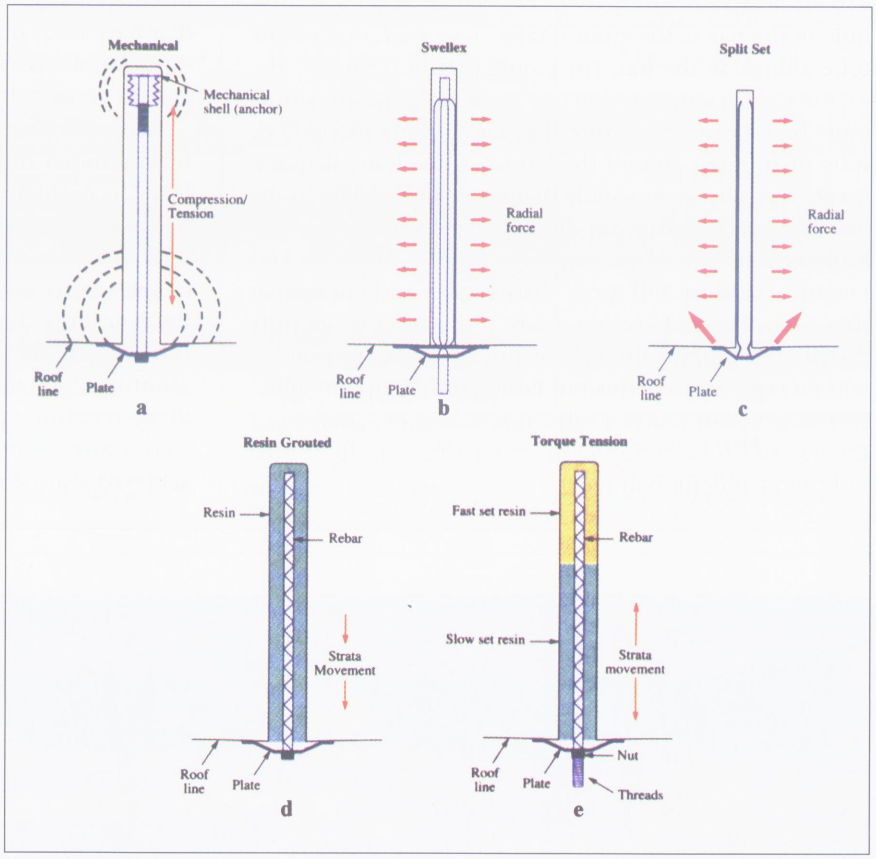


Figure1: Types of Rock Reinforcement.

The plate at the rock face distributes the load at the bolt head and helps transfer force into the surface rock. Its failure can lead to increased amounts of rock falling out between adjacent bolts. A bar is used to develop tension between the anchor and the bolt head and thus place the rock into compression. Steel bars or tubes are subject to corrosion, but stainless steel, fiberglass, and plastic fixtures are available.

Grouted anchorages employ Portland cement, or polyester, vinyl, or amine resin, all of which are very inert in most rock mass environments. In resin-grouted rock reinforcement (Fig. 1d and 1e), the resin is contained in a frangible plastic package. The package has two components - resin and setting catalyst - separated by either a plastic barrier or a thin zone of set-up resin at the interface of the resin and catalyst. When the package is broken by rotating and inserting the rock reinforcement bar through the package which has been previously inserted in the hole, the resin and catalyst are mixed and the resin set begins.

CORROSION

Corrosion is the chief consideration in rock reinforcement longevity. Steel mechanical-anchor (non-grouted) rock reinforcement is the most vulnerable type to corrode in aggressive or even non-aggressive ground-water environments. Corrosion of steel in the ground is due to electro-chemical loss of metal ions at anodic points or areas, and available oxygen from the groundwater combines with iron cations from the steel to form ferrous hydroxide, $FE(OH)_2$. Other corroding environments involve brines, acid waters, and alkali waters.

For electro-chemical corrosion, the bolt section must resist attack. For a 3/4-inch diameter bolt or bar shank, the service life could be decades. But for a Split Set® or Swellex™ type of rock reinforcement with a 0.10 - inch steel tube wall thickness, the estimated service life could be less than 10 years. Of course, these estimates assume the entire steel section corrodes through so that structural failure by overload would occur sooner. Such a shortened service life has been reported for expansion-shell rock bolts which have corroded and failed in less than five years within the bolt hole in a saline-water environment.

GROUT DISTRIBUTION

In Portland-cement-grouted rock reinforcement, the grout is pumped into the annulus between the bar and the drilled hole. The grout is introduced through a central hole in the bar as the grout intake or air vent, or a plastic tube alongside the bar. For grouted reinforcements, the manufacturer's instructions or engineer's specifications must be followed to ensure that the grout is properly or fully distributed around the bar or in the hole. Requirements typically include hole diameters appropriate to the bar diameters, maximum drilling depths for holes, and number and size of packages for the bar diameter and length to achieve full grout distribution and encapsulation of the bar and anchor, if any. If the grout is not fully distributed around the bar anchorage in the ground, it will be exposed to corrosion. Resin grout is not an adhesive or glue, but rather a filler. It develops the strength of the bar and rock by filling in irregularities in the drilled hole and bar deformations.

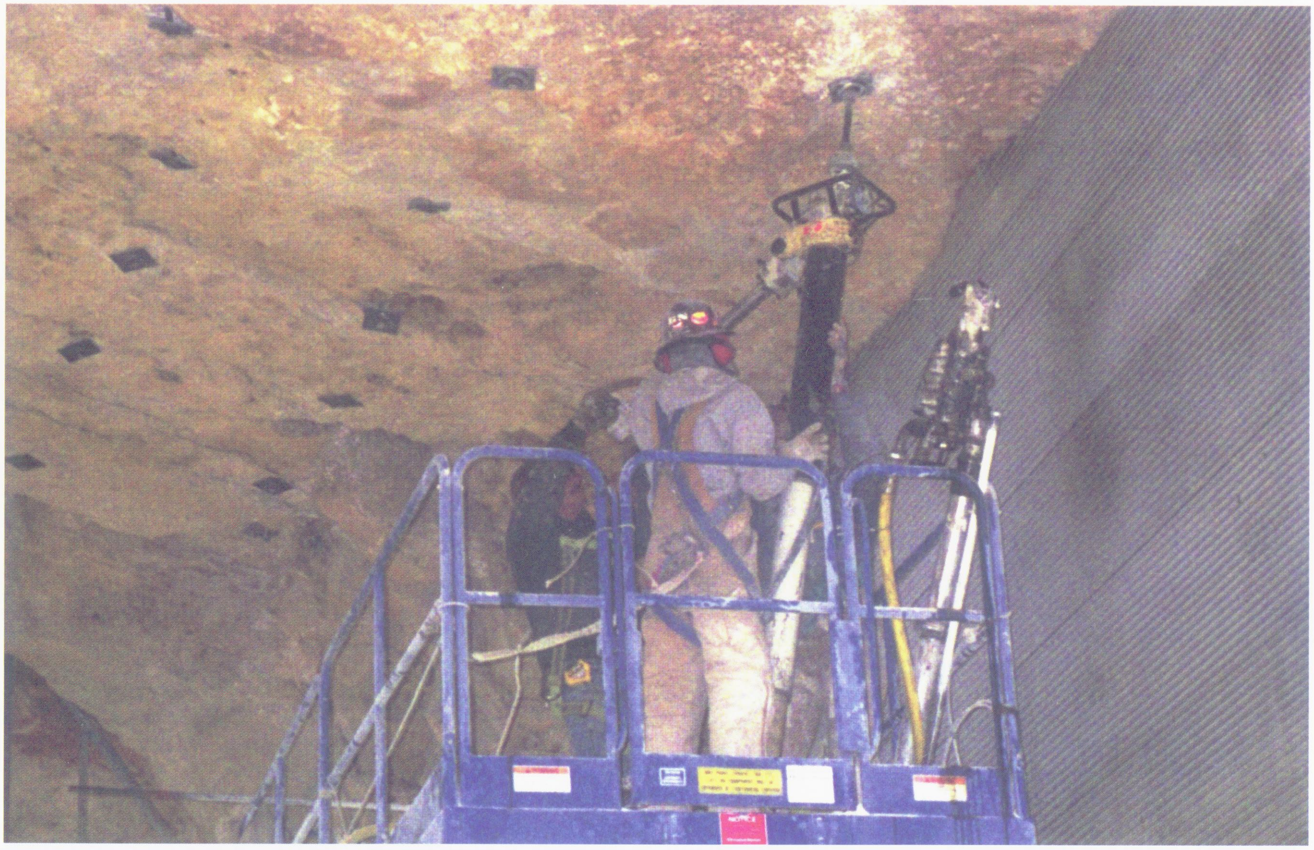
CASE HISTORIES

Since their introduction, researchers, designers and manufacturers have monitored rock reinforcements to assess their performance and identify measures to predict and extend their service life. Table 1 highlights a few case histories compiled from these efforts. The case histories presented are not a representative sampling of all rock bolt installations, but serve to highlight some of the problems that have been observed. In general the past performance of rock bolts is considered satisfactory, but problems can and do occur.

My experience, and that of others, shows that most resin-grouted rock reinforcement failures have resulted from incomplete encapsulation of the bar. These problems were caused by difficulties in installation or from lack of adherence to manufacturer's recommendations or the specifications. Two very important factors are (1) limiting hole depth so that resin does not get pushed into the empty hole end and become unavailable for grouting the bar, and (2) being careful about the hole diameter. Some problems from water flowing in holes were noted, but extra water relief holes or extra resin achieved a successful application.

TABLE 1. EXAMPLES OF ROCK REINFORCEMENT PERFORMANCE

Reinforcement Type	Environment	Observations	Source
Ungrouted expansion-shell	Underground mine	General corrosion after 16 years of service	Helfrich (1990)
Swellex™	Underground mine	Severe corrosion and lost anchorage after 7 years service	Helfrich (1990)
Cement-grouted	Underground mine	General to severe corrosion after 20 years service	Helfrich (1990)
Resin-grouted	Underground mine	Local to thin films of rust after 16 years of service	Helfrich (1990)
Resin-grouted bolts	Copper mine with saline ground water	Rare problems occur when rock fractures intersect resin-grout column and expose bar to corrosion	Litsenberger (2000)
Cement-grouted rock bolts	Tunnel	After 13 years, no corrosion on grouted sections, but unprotected and exposed sections were corroded	Baxter (1996)
Cement-grouted rock bolts	Underground caverns	Inspection after removing plates shown to be sound	Baxter (1996)
Cement-grouted steel bars	1896 sewer tunnel	Severely corroded for portion in air but in perfect condition within 10 mm of rock surface	Baxter (1996)
Resin-grouted rock reinforcement	Exploratory tunnel adit	Failed 3 months after installation because only 25% of length was grouted	Baxter (1998)
Cement-grouted rock reinforcement	Hydroelectric tunnel	No corrosion problems since installation in 1958	Baxter (1998)
Resin-grouted rock bolts	Navigation lock	Flowing water in drill holes led to loss of resin during grouting	Avery (1988)
Resin-grouted rock bolts	Navigation lock	Low anchorage strengths due to inadequate flushing of drill hole to remove cuttings	Avery (1988)
Cement-grouted rock anchor tie-backs	Anchored retaining wall	Wall failure 7 years after construction due to overloading and overstressing	Thompson and Martin (1984)



Installing long-life resin-grouted rock bolts in a limestone mine being converted to post-mining business uses. (Photo courtesy of Penta Engineering and Agapito Associates.)

CONCLUSIONS

Unprotected mechanical-anchor rock reinforcement and Split Set™ or Swellex™ type reinforcements have limited service life in most water-bearing rock mass environments. But if longevity is not a concern (e.g. temporary support applications), then there is no potential stability problem. Typical ground-water environment corrosion rate estimates for unprotected elements indicate a few decades of longevity for expansion-shell anchor bolts, and a few years of longevity for Split Set™ or Swellex™ type reinforcement.

Portland-cement and resin-grouted reinforcements can have many decades of longevity if installation is carefully controlled and the grout fully encapsulates the bar. Exposed element features such as the bolt length extending from the drill hole, bolt head, and plate can corrode and fail sooner if not protected.

In most mine and tunnel situations, if longevity of already-installed rock reinforcement systems is questioned, overcoring and extraction of select elements can be used to assess their condition. Where long-term performance is desired it may be more economical to simply rebolt an area as needed to reset the clock.

The case histories of problems with resin-grouted rock reinforcement can each be assigned to specific problem categories, and once recognized, can be overcome to provide satisfactory long-term performance. The best long-term performance for Portland-cement and resin-grouted installations is provided by a double barrier of epoxy-coated (or other protective coatings) bars and full encapsulation with Portland cement or resin. But during installation, care must be taken that the coating is not damaged. ❍

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