Assessing the Condition and Estimating the Longevity of Rock Reinforcement Systems

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Rock fall is increasingly a concern as the larger slopes along the Interstate highways constructed 30 to 40 years ago weather and become unstable. Transportation agencies have used metal reinforcements to stabilize highway rock slopes for more than 35 years. Corrosion of the metal elements and loss of anchorage can shorten the service life of these installations. Evaluating the condition and determining the remaining service life of the systems is a good asset management strategy.

Problem

Rock reinforcement systems have a limited performance history, and accurately determining the condition of the reinforcement elements is difficult; therefore assessing a system's longevity is critical. Although the expected design service life of unprotected rock reinforcement systems is 50 years, conditions and installation procedures vary from site to site and can greatly affect the service life.

Replacement and repair of these systems can be expensive and difficult. The New Hampshire Department of Transportation (DOT) installed its first reinforcement to stabilize a highway rock slope in the early 1970s. Although New Hampshire DOT conducts annual inspections of 10 rock reinforcement sites, inspectors lacked a consistent method for determining the actual condition of the rock reinforcement.

Solution

New Hampshire DOT initiated a two-phase research study to assess the condition of a 32-year-old rock reinforcement along I-93 in Woodstock. The first phase involved measuring the corrosiveness of the surrounding environment and performing nondestructive testing (NDT) on selected reinforcement elements.

Samples of weathered rock and groundwater were tested for pH, resistivity, moisture conditions, and sulfate and chloride ion concentrations. A rate loss model was used to determine potential metal loss from corrosion and to estimate the remaining life of the reinforcement.

Rock bolts wired for nondestructive testing.

The study used four NDT methods, recommended for evaluating metal tensioned systems in the final report from National Cooperative Highway Research Program Project 24-13 (*1*). Two were electrochemical: half-cell potential measurement and measurement of polarization current; and two involved wave propagation techniques: the impact echo test and an ultrasonic probe.

The electrochemical tests identify the presence of corrosion or the vulnerability of the reinforcement steel to corrosion. The wave propagation techniques assess the severity of the corrosion, diagnose the loss of prestress and the lack of grout cover, determine if the cross section had been compromised, and identify locations of potential bending.

The anomalies identified by the NDT were investigated with destructive testing to reveal or confirm distressed elements. Calibrating and verifying the NDT results with destructive testing provided an effective method for identifying areas of possible corrosion, for assessing the condition of the reinforcement system, and for estimating the service life.

The second phase, which was a pooled fund study, used destructive testing to verify results from Phase I. The techniques included the lift-off testing of selected rock reinforcement and the physical, chemical, and metallurgical testing of steel and grout samples retrieved from exhumed reinforcement.

The grout condition was evaluated by observation of the coverage of the reinforcement, by the consistency of the grout, and by the physical properties of the grout mix. Bulk specific gravity and absorption were used to determine the effectiveness of the grout as a barrier against moisture and to mitigate the intrusion of elements that could cause corrosion.

Examination of the exhumed metal elements consisted of visual observations of corrosion and measuring the pit depths and the loss of section. Sample metal reinforcements were subjected to tension tests to measure the percentage of elongation and to determine the corresponding stress-strain curves. Metallurgical tests included a spectrographic analysis to assess the metal composition, and a metallographic examination to observe the microstructure of the thread bar material.

Destructive testing verified that the electrochemical tests correctly identified the presence of corrosion. The lift-off tests and direct measurements confirmed the echo test results. Measurements on exhumed rock reinforcement verified that the greatest loss of section was within the free length behind the anchorage assembly.

Application

Woodstock was a unique site for determining the effectiveness of these techniques because of the age of the reinforcement, the environmental conditions, the variety of installation procedures, and the use of different types of grout.

The loss of measured cross section of the unprotected portion of the rock reinforcement was consistent with the predictions from the mathematical models for the service life of unprotected steel and with the observations from the NDT. Measuring the corrosiveness of the environment therefore is a reasonable method for predicting the remaining service life.

The NDT was a good indicator of the condition of the rock reinforcement but sometimes did not identify specific features that needed rehabilitation along the length of an individual reinforcement. Destructive test methods are the most direct way to assess the condition but are often too expensive and time consuming for extensive use on a large number of reinforcement elements.

Benefits

The research demonstrated that a combination of NDT and destructive tests can provide a cost-effective, technical approach for identifying specific rock reinforcement elements that need replacement or rehabilitation.

Loss of cross section of rock bolt from corrosion.

Overcoring to exhume rock reinforcement.

The initial concern was that nearly all the reinforcement at the Woodstock site would need to be replaced in the near future, at a cost of more than $1.5 million. The results of NDT and destructive testing, however, indicate that only a portion of the reinforcement will require replacement or rehabilitation, at an estimated cost of $400,000—a potential savings of $1.1 million for the site.

Additional savings may be realized from accurate calculations of longevity, which allow optimal use of the reinforcement and timely scheduling of remedial work. Early condition assessment and timely remedial action can prevent rock fall damage to property and injuries to the traveling public.

Benefits can be realized by applying this technology at other sites in New Hampshire and in other states. This approach for assessing the condition of buried rock reinforcement provides a sound technical basis for planning future maintenance and rehabilitation activities, resulting in cost savings. This is a valuable tool in prioritizing long-term budgets for remediation and in making effective use of limited construction resources.

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Reference

1. *NCHRP Report 477: Recommended Practice for Evaluation of Metal Tensioned Systems in Geotechnical Evaluations.* Transportation Research Board, National Research Council, Washington, D.C., 2002.

Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-2952, e-mail gjayaprakash@nas.edu).