# Evaluation of Rock Slope Protection Material

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A study of quality control of rock slope protection material (riprap) is reported. The objectives of the study were to determine what rock properties were important for satisfactory slope protection and to develop workable specifications that would provide satisfactory quality control with minimum cost. An extensive field evaluation of rock slope protection materials was performed, and samples were obtained for physical testing. A significant finding of this visual and physical evaluation was that the 1964 California Standard Specifications were too severe and resulted in the rejection of satisfactory rock. Test methods evaluated as potential specifications are sodium sulfate soundness, Los Angeles rattler, apparent specific gravity, absorption, durability index, wet-dry, freeze-thaw, rapid abrasion, petrography, X-ray diffraction, differential thermal analysis, and durability absorption ratio (DAR). The DAR combines the results of easily performed and inexpensive tests that are relatively accurate in predicting performance and that measure complementary physical properties. The DAR correlates with visual evaluation 97 percent of the time, and the California Division of Highways is converting to this specification for quality control of rock slope protection material.

•THE NUMBER, size, and cost of highway construction projects have increased rapidly in recent years. Accompanying this increased construction activity has been an ever-increasing need for adequate rock slope protection material (known as riprap). To fill this need, the various districts of the California Division of Highways have frequently requested waiving or modifying the quality control requirements of the Standard Specifications. Apparently the quality control provided by the Standard Specifications was somewhat conservative.

The California Division of Highways first utilized Standard Specifications for controlling the quality of rock slope protection material in 1935. Modifications of the Standard Specifications to make them conform to the known performance of various materials throughout the state have not been completely successful. Table 1 gives the history of the Division's Standard Specifications.

In 1963, the California Division of Highways, with the cooperation of the U. S. Bureau of Public Roads, began a study of quality control for rock slope protection material. The objectives of this research project were (a) to determine the properties of rock that were important in satisfactory rock slope protection material and (b) to develop workable specifications based on physical tests that would provide satisfactory quality control with minimum cost.

To achieve the objectives of this project, two avenues of investigation were followed. The first consisted of an extensive field evaluation of rock slope protection installations throughout the state. The second was a thorough study of common physical test methods that were believed to have potential for evaluating the quality of rock slope protection material. This report describes the methods that were used in conducting this investigation and discusses the results.

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TABLE 1

HISTORY OF STANDARD SPECIFICATIONS FOR ROCK SLOPE PROTECTION MATERIAL IN CALIFORNIA

| Test Specifications | 1935 | 1940 | 1960 | 1964 | 1969 |
|---|---|---|---|---|---|
| Apparent specific gravity, minimum | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Absorption, maximum (percent) | – | – | 2 | 2 | 2 |
| Sodium sulfate soundness, maximum loss (percent) | – | – | 5 | 5 | 10 |
| Los Angeles rattler, maximum loss (percent) | 37 | 40 | 45 | 45 | – |
| Wet shot rattler, maximum loss (percent) | 37 | 37 | 40 | – | – |

## EVALUATION OF INSTALLATIONS

A total of 65 installations were inspected, and the field performance of the material was determined. These installations are located throughout the state and in climatic environments that vary from marine shoreline to high mountains to desert. The rocks on each of these installations were classified as igneous intrusive, igneous extrusive, metamorphic, or sedimentary. The selection of installations evaluated was based on the desire to include a wide range of both environment and rock types.

The performance of rock on each of the installations was categorized as either "good" or "unsatisfactory" by visually studying such factors as hardness, shape, fractures, weathering, resistance to abrasion, and mineral decomposition. All classifications of rock were found in each performance category, except that no igneous intrusive rocks were categorized as unsatisfactory. To eliminate the human variable as much as possible, the same two engineering geologists conducted the inspection of all installations included in this study.

Two factors (age of the installation and environment) that were not used in evaluating the performance of rock on an installation should be mentioned at this point. The age of an installation is not considered a critical factor in the performance of an initially sound rock. Rocks found to be disintegrating on an installation were also found to be of poorer quality and their condition of failure cannot be attributed to the relatively short period of exposure on the installations. Although the environment itself was not considered in evaluating the performance of a material, the properties of the material affected by environment were considered. The presence of fractures or voids that could be opened by freezing water and the presence of minerals that expand when wet or hot are examples of properties considered that may become significant in a given environment.

A very important part of the inspection procedure was the obtaining of representative samples for use in the testing phase of this research project. Photographs of the installation and of the material were also taken as part of the inspection (Figs. 1, 2, 3, 4, 5, and 6).

During this phase of the investigation, the field performance of the rock was correlated with the individual Standard Specification tests, with visual evaluation of a sample of the rock by an experienced engineer or geologist, and with the entire Standard Specifications. The method having the highest percentage of agreement (94 percent) with field performance was visual evaluation. The absorption test was a close second (91 percent agreement). The entire Standard Specifications had the lowest percentage of agreement (71 percent).

Visual evaluation, although extremely reliable, is difficult to use as a specification. In this project, the accuracy of the various methods of determining rock quality was calculated using field performance or visual evaluation as references. This provided a ready value for comparison between tests, although the absolute accuracy of any given method may vary by as much as 6 percent from the comparative value. Table 2 gives a summary of the percentage of correlation of various quality determination

Figure 1. Good installation of sedimentary and igneous rocks. Severe rounding caused by wave action.

Figure 2. Good installation of sedimentary rock in place for 23 years. This material does not comply with the Standard Specifications.

Figure 3. Unsatisfactory installation of good igneous rock.

Figure 4. Good metamorphic rock in place for 8 years.

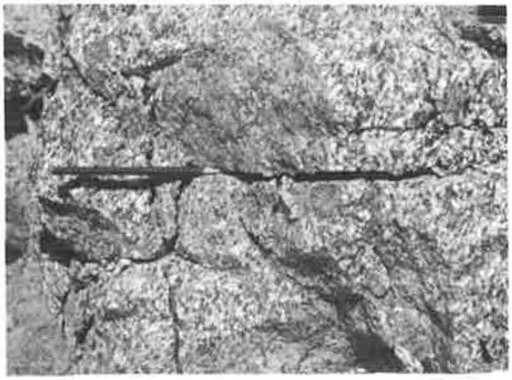

Figure 5. Unsatisfactory igneous rock.

Figure 6. Unsatisfactory sedimentary rock.

TABLE 2

CORRELATION OF VARIOUS METHODS OF EVALUATING THE QUALITY OF ROCK SLOPE PROTECTION MATERIAL

| Test Method | Specification | Number of Samples | Correlation (percent) |
|---|---|---|---|
| Apparent specific gravity | 2.5 minimum | 65 | 86[a] |
| Absorption | 2 percent maximum | 65 | 91[a] |
| Los Angeles rattler | 45 percent maximum loss | 65 | 83[a] |
| Sodium sulfate soundness | 5 percent maximum loss | 65 | 77[a] |
| 1964 Standard Specifications | | 65 | 71[a] |
| Durability index | 52 minimum | 264 | 94[b] |
| Rapid abrasion | 24 percent maximum loss | 112 | 88[b] |
| Durability absorption ratio | >23, acceptable<br><10, unacceptable<br>10-23, acceptable if durability index >51 | 261 | 97[b] |
| Visual evaluation | | 65 | 94[a] |

[a]Correlation with field performance only.

[b]Correlation with field performance or visual evaluation.

methods with field performance or visual evaluation. Visual evaluation is given in the same table and is compared to known field performance.

The most significant finding of this evaluation of installations was the fact that 29 percent of the rocks that had performed satisfactorily in the field failed to comply with the Division's 1964 Standard Specifications. Obviously, the Standard Specifications were too severe, resulting in the rejection of satisfactory material and in the numerous requests for waiving or modification to permit the use of materials with known performance records.

Another weakness of these specifications was the apparent discrimination against different types of rock by some of the test methods. The term "discrimination" as used in this report refers to the rejection by a given specification of a disproportionate number of samples of satisfactory material of a given rock type. Igneous intrusive rocks exhibit unusually high losses in the Los Angeles rattler test. Igneous extrusive rocks have unusually high percentages of absorption. Sedimentary rocks have unusually high losses in both the Los Angeles rattler test and the sodium sulfate soundness test.

Because of the severity of the Standard Specifications, the discrimination against rock type, and the relative inaccuracy of the tests in predicting rock performance at an installation, a thorough study of the specification test methods was undertaken.

## TEST METHODS—STANDARD SPECIFICATIONS

In order to efficiently and effectively evaluate the factors being studied, a data retrieval system was necessary. After some study, a 5- by 8-in. card file incorporating an edge-punched data retrieval system was developed.

This card file contains data on all samples of rock slope protection material submitted for use by the California Division of Highways between January 1, 1957, and June 30, 1968. The categories of data that are retrievable from this card file include whether the sample passed or failed the 1964 Standard Specifications, test results, rock classification, location and age of the installation, and type of environment. The rock classification and installation location were number-coded to reduce the number of edge-punched spaces required. This system has been satisfactory and provides a means for efficient data analysis, as well as serving as a permanent record of data on rock slope protection materials.

### Sodium Sulfate Soundness Test (Test Method No. Calif. 214-D)

The 1964 Standard Specifications of the California Division of Highways permitted a 5 percent maximum loss in the sodium sulfate soundness test. Analysis of data from the card file showed that this specification correlates with visual evaluations 83 percent of the time. Further study showed that a specification limit of 10 percent maximum loss would raise this percentage of correct predictions to approximately 88 percent. The California Division of Highways adopted this specification limit of 10 percent in June 1967.

As previously noted, the soundness specification discriminates against sandstone. Sandstone makes up only 25 percent of all samples tested but is nearly 50 percent of all samples that failed the soundness test. Another inherent disadvantage of the soundness test is that a minimum of 10 days is required to obtain results. The period of time is too long for efficient quality control of construction materials. These two facts have created doubts as to the effectiveness of the soundness test as a specification for rock slope protection material.

## Los Angeles Rattler Test (Test Method No. Calif. 211-C)

The 1964 Standard Specifications of the California Division of Highways permitted a maximum loss of 45 percent in the Los Angeles rattler test. Analysis of data indicated that the Los Angeles rattler test correlated with visual evaluations 83 percent of the time. Approximately 10 percent of all samples tested failed the Los Angeles rattler test. Most of the samples failing the Los Angeles rattler test also failed one of the other Standard Specification tests. Of those samples that failed the Los Angeles rattler specification without also failing one of the other specification tests, approximately 25 percent have satisfactory performance records.

Because only a small percentage of samples failed to comply with the Los Angeles rattler specifications without also failing to comply with one of the other specifications, because even this small number of samples showed a significant percentage of incorrect predictions of performance, and because the Los Angeles rattler test has been demonstrated to discriminate against igneous intrusive rocks and sedimentary rocks, it was felt that the Los Angeles rattler test was not a satisfactory specification test. The California Division of Highways deleted the Los Angeles rattler specification in June 1967.

## Apparent Specific Gravity (Test Method No. Calif. 206-D)

The 1964 Standard Specifications of the California Division of Highways specified a minimum apparent specific gravity of 2.5. Approximately 91 percent of all samples tested complied with this specification. The apparent specific gravity test correlated with visual evaluation approximately 86 percent of the time. The specification for apparent specific gravity assured the use of rock of sufficient density to remain in place, an important consideration in designing adequate slope protection installations. For this reason, the apparent specific gravity is still used as a specification test for rock slope protection material.

## Absorption (Test Method No. Calif. 206-D)

The 1964 Standard Specifications of the California Division of Highways allow a maximum absorption of 2 percent. Using this specification, the absorption test correctly predicted performance approximately 91 percent of the time. Although this test method obviously discriminates against igneous extrusive rocks, it was kept in the 1969 Standard Specifications because it has one of the highest percentages of correct performance predictions.

## Summary of Tests Used

In concluding the discussion on these four 1964 Standard Specification tests, it should be pointed out that even though the tests individually have relatively good correlations with visual evaluations, collectively they are only accurate approximately 71 percent of the time. If the 10 percent soundness specification revision is applied on the same set of data, the accuracy increases to 77 percent.

## TEST METHODS—MISCELLANEOUS

The test methods described in the following are by no means a complete set of tests for evaluating the quality of rock. They are tests that have been recommended for use in determining the quality of rock slope protection material, or they are tests that other agencies use with varying degrees of success in determining rock quality. Because our objective was to determine a specification based on physical test results that would be inexpensive and quick to perform and that would correlate well with performance, the study was terminated when such a test method was found. Brief descriptions of our findings on the test methods that were investigated in this study are included in the remainder of this report.

### Durability Index (Text Method No. Calif. 229-E)

The durability index is, to some extent, a measure of the quality and quantity of fine material washed or abraded from the surface of the material being tested. Analysis of data indicates that a minimum durability index of 52 would correctly correlate with visual evaluation 94 percent of the time. Although this is substantially better than the existing Standard Specifications, this test method was not recommended as a specification for an individual test because of its tendency to discriminate slightly against igneous intrusive rocks and to favor igneous extrusive rocks.

### Wet-Dry Test

The wet-dry test method used in this study was as follows: A 2,500-gram sample of crushed rock fragments was placed in a stainless steel basket and alternately submerged in water and oven-dried. Wet-dry testing was normally terminated after 15 cycles. The sample was then shaken for 2 minutes in a mechanical sieve shaker to shake off any loose or small-sized particles. The sample was then reweighed and the percentage loss was calculated. Our investigation of this test method indicated that it lacked severity, small fragments had more loss than large fragments, tap water was more severe than seawater, wetting agents did not appreciably increase the severity of the test, and increasing soaking and drying time or increasing the number of cycles did not necessarily increase the percentage loss.

The extremely small losses with this test method made it difficult to correlate with visual evaluation or known performance. The inability to obtain correlation with visual evaluation or performance and the relatively long time required to perform the test indicated that this test method was not satisfactory for quality control purposes.

### Freeze-Thaw Test

The freeze-thaw test method was designed to determine the effect of alternate freezing and thawing of samples of rock slope protection material. The temperature range used in this test was -16 F to +65 F. The thawing of the samples was accomplished by circulating ordinary tap water around the samples. All of the tests were terminated at 200 cycles. It is believed that the conditions existing in this test procedure closely simulate actual field conditions on an installation at which alternate freezing and thawing occur. The freeze-thaw test method was found to be unsatisfactory as a quality control test for rock because of the time required to perform the test and because of the small percentage loss by this test method. As in the case of the wet-dry test, the losses in the freeze-thaw test were so small that no correlation between them and the performance of the material could be determined. The test does have value in evaluating the degree to which such features as foliation, fractures, and veins affect the performance of a rock under freeze-thaw conditions.

### Rapid Abrasion Test

The rapid abrasion test method used in this study was developed by the California Division of Highways. The study of this method was based on the assumption that there is some correlation between the resistance of rock to water-borne abrasives and the ability to provide adequate protection on rock slope protection installations.

The test method was adapted from the tumbling technique used by "rock hounds" for polishing small rocks. It consisted of tumbling, for a given period of time, a sample of crushed rock together with water and commercial abrasives. After tumbling the sample, it was washed and oven-dried, and the percentage of weight loss was calculated. Using a specification of 24 percent maximum loss, this test method correlated with visual evaluation for 88 percent of the samples. Although this test method was somewhat more accurate than the 1964 California Standard Specification tests for determining the quality of rock slope protection material, it was not recommended as a specification test because the property of abrasion resistance is not necessarily the most significant property on a given installation. The test method also discriminates significantly against igneous intrusive and metamorphic rocks and favors igneous extrusive rocks.

## Petrologic Methods

Petrography, X-ray diffraction, and differential thermal analysis are three methods of classification and mineral identification available at the Materials and Research Laboratory. Petrography is the only method regularly used for evaluating rock slope protection at this time. However, there are no specifications for this method and, although it has been shown to be more accurate in predicting performance than any of the specification tests, no specification is anticipated. The X-ray diffraction and differential thermal analysis methods are used when detailed information on mineral composition is desired for a sample of special interest. The combined results from these three methods yield information that (a) can be used for predicting the performance of rock slope protection material and (b) cannot be obtained or inferred from the specification test results.

It is believed that greater used should be made of these methods to determine the probable performance of rock slope protection material. However, to obtain meaningful results from these specialized techniques they must be performed by qualified personnel experienced in their use.

## Durability Absorption Ratio

The combining of test results in a formula was considered desirable as a specification for rock slope protection material because it would allow the use of material that is weak in one property but is strong enough in some other property to compensate for the weakness. Another advantage in combining test results in a formula is that a test method that discriminates against a material may be compensated for by a test method favoring that same material.

A desirable formula should combine the results of easily performed and inexpensive tests that are relatively accurate in predicting performance and that measure complementary physical properties. The 1964 California Standard Specification tests required 3 to 4 weeks between the time of obtaining the sample and the time of receiving complete test results. It was believed that this time lag was too long for an effective construction material quality control test. For this reason, a decision was made to work with tests that could be performed at the district materials laboratory or, in some cases, on the job. Test results could then be available within a few days of the sampling.

It was also decided that a simple formula was desirable and so only two tests, the durability index and absorption, were selected. These tests were complementary in that the durability index favors igneous extrusive rocks whereas the absorption discriminates against the igneous extrusive rocks. The results of this study were so encouraging that formulas using other tests were not tried.

The formula used was

$$\text{Durability Absorption Ratio (DAR)} = \frac{\text{Durability Index}}{\text{Percent Absorption} + 1}$$

The plus one term in the denominator was necessary to avoid complications on those samples with zero percent absorption. Analysis of data indicates that the DAR correlates with visual evaluation 97 percent of the time and the results are less strongly influenced by rock type than any other test method studied. To achieve this percentage of correct predictions, the following specifications were used:

1. Durability absorption ratio greater than 23, material passes;
2. Durability absorption ratio less than 10, material fails;
3. Durability absorption ratio 10 through 23 and (a) durability index 52 or greater, material passes, and (b) durability index 51 or less, material fails.

These specification limits were obtained by determining the values that resulted in the highest percentage of correlation.

The California Division of Highways is currently converting to this durability absorption ratio specification for quality control. Its adoption will reduce the amount and cost of shipping and testing samples, will reduce from weeks to days the time required to evaluate the material, and will increase substantially the correlation with field performance in comparison to the present Standard Specifications. Of additional benefit to the state is the fact that the durability absorption ratio is a more lenient specification permitting greater use of local material and should result in lower material costs and shorter hauls. This study shows that these benefits can be realized without lowering installation performance.

## REFERENCE

1. Smith, T., McCauley, M. L., and Mearns, R. W. Investigation of Rock Slope Protection Material. California Division of Highways, Res. Rept. No. 632561, interim report, April 1967; final report, June 1969.