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METHODOLOGY FOR OVERSIZING MARGINAL QUALITY RIPRAP FOR EROSION CONTROL AT URANIUM MILL TAILINGS SITES

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ABSTRACT

Properly selected and oversized local sources of riprap may provide superior erosion protection compared with revegetation at a number of uranium mill tailings sites in arid regions of the United States. Whereas highly durable rock is appropriate for protecting diversion channels to the height of the 5-year flood, marginal quality rock may be adequate for protecting infrequently flooded side slopes of diversion channels, tailings embankments and caps. Marginal quality rock may require oversizing to guarantee that design size specifications are met at the end of the performance period (200 to 1000 years).

This paper discusses a methodology for oversizing marginal quality rock. Results of cyclic freezing and thawing tests are used to determine oversizing requirements as functions of the performance period and environment.

Test results show that marginal quality rock may be used in frequently saturated areas but in some cases oversizing will be substantial and in other cases marginal quality rock may be disqualified. Oversizing of marginal quality rock appears to be a practical reality in occasionally saturated areas (between the 5-year and 100-year floods). Furthermore, oversizing will not generally be required on slopes above the 100-year flood.

INTRODUCTION

Protection of the public health and environment from potential hazards of radioactive waste and uranium mill tailings has stimulated the assessment of waste stabilization procedures and methods. Under current stabilization procedures, mill tailings embankments and caps are allowed to dry out sufficiently to permit the use of heavy construction equipment in their reclamation [1]. Diversion channels protected with riprap are constructed around the tailings to reduce natural drainage across them. The drained tailings are graded and capped with an earthen cover. The engineering design of these covers should provide site stability with little or no maintenance and should insure long-term integrity for 200 to 1000 years. [2]

Impoundment covers are generally comprised of native soils. The emplaced earthen cover is more vulnerable to sheet, rill and gully erosion than undisturbed soil with similar site conditions. Therefore, it is imperative that erosion prevention measures be considered in the design process to minimize cover degradation.

The placement of a rock armor or revetment over the cover is an alternative to the use of vegetation for protecting the waste impoundment. The rock is durable and erosion resistant. Once the armor layer is placed, long-term maintenance programs are usually not required. Therefore, rock protection can be considered a viable alternative for long-term protection of waste storage sites where usable riprap sources are present.

Riprap selection may be based on methodologies developed by Foley et al. [3] and Nelson et al. [4]. Riprap testing consists of a sequence of physical and petrographic tests which can be used to rank rock quality as good, fair, marginal, or unsuitable according to a numerical ranking system.

In some cases, fair and marginal quality rock may be oversized to provide assurance that it will meet design criteria throughout the performance period. This paper discusses a methodology for oversizing marginal quality riprap for use in stabilizing the cover over dry mill tailings. This methodology would not be suitable for oversizing riprap for operating mill tailings ponds or conventional reservoirs where standing bodies of water may effect its long-term durability.

OVERSIZING METHODOLOGY

Riprap oversizing is based on the assumption that the principal failure mechanism is cyclic freezing and thawing. The amount of oversizing is a function of the number of freezing and thawing cycles expected during the performance period as determined from meteorological data and the percent weight loss per cycle as determined by a standardized freezing and thawing test. Assuming a linear rate of weight loss as a function of the number of freezing and thawing cycles, oversizing can be calculated from Equation 1, assuming an even distribution of weight loss around the surface of a sphere:

$$\text{Eqn (1)} \quad r_o^3 = \frac{100}{(100 - wN)} \cdot r_d^3 ,$$

where r_o and r_d are oversizing and design radii, respectively; w is the percentage weight loss per freezing and thawing cycle and N is the estimated number of cycles in the performance period.

Riprap durability requirements are a function of the riprap location relative to surface water flow channels. Riprap placed in frequently flooded locations is most vulnerable and its performance is most critical to the overall embankment stability. If all elements of the tailings containment structure are properly designed and constructed, surfaces will be well-drained so that only materials in the diversion channel will be periodically saturated for prolonged intervals of cyclic freezing and thawing on an annual basis.

APPLICATION OF THE METHODOLOGY

Several riprap sources were used to investigate riprap deterioration as a result of freeze-thaw cycling. Quarried, unweathered granitic rocks from scattered regions in Wyoming were collected and tested over the last 40 years by the U.S. Bureau of Reclamation [5]. Additional samples were collected and tested for this study, including granitic boulder conglomerates from a mine in the East Gas Hills (East Canyon conglomerate), from an outcrop in the West Gas Hills (Dry Coyote conglomerate), Wyoming, and sandstones (Wasatch Formation) from a mine and outcrops in the Powder River Basin, Wyoming. All the granitic rocks rang when struck with a hammer and were extremely difficult or impossible to break. They ranged in size from cobbles to boulders. Most of the sandstones also rang when struck with a hammer but they were somewhat less difficult to break. The sandstones were boulder sized concretions that were well cemented with calcite and, in some cases, ferruginous cement. Blasting had been required to dislodge samples that were taken from a mine. Petrographic descriptions [6] indicate the amount of smecktite clay minerals present in the sandstones was less than 2%. Based on the above information, it is believed that all these samples would perform satisfactorily in a slaking and abrasion test [3].

For purposes of demonstrating the application of the riprap oversizing methodology presented here, it is assumed that a hypothetical region has 40 complete freeze-thaw cycles per year. Thus,

1) in the area which is below the annual flood elevation and fully saturated conditions exist, riprap would be subjected to 40 annual complete freeze-thaw cycles, and
2) riprap above the 5-year flood and 100-year flood have one-fifth and one-hundredth as many complete freeze-thaw cycles over the long-term as environments that are annually flooded.

Table 1 lists the number of expected cycles (N), below the annual flood and adjacent to the 5-year and 100-year floods, for 200-year and 1000-year performance periods, respectively, using the foregoing assumptions.

The standardized 250 cycles freeze-thaw test was used to determine the percent weight loss per test and per cycle for each riprap source (Table 2). Sodium sulfate soundness and Los Angeles

Table 1. Estimated number of freeze-thaw cycles (N) for various flood levels and performance periods (assuming the annual number of cycles = 40 below the annual flood in a hypothetical region).

Performance Period	Flood Recurrence Interval Annual	 5-year	 100-year
200 years	8,000	1,600	80
1000 years	40,000	8,000	400

abrasion tests were also included for comparison. From a comparison of the test results in Table 2 with the USBR standards in Table 3 for judging riprap durability, quarried, unweathered granitic rocks performed well in all three tests. Granitic boulder conglomerates were intermediate to borderline good in quality based on sodium sulfate soundness and Los Angeles abrasion tests and good quality based on freezing and thawing tests. On the otherhand, concretionary sandstones were extremely poor to poor quality in sodium sulfate soundness and Los Angeles abrasion tests, respectively, while they were intermediate in quality based on freezing and thawing tests. Hence, a full range of riprap quality is provided by the source samples indicated in Table 2.

Equation 1 and data from Tables 1 and 2 were used to calculate oversizing ratios (r_o/r_d) for various riprap samples. Table 4 shows oversizing ratios as a function of performance period and flood recurrence interval. Based on Equation 1, all of the sandstone samples would have completely disintegrated over a 1000-year performance period when subjected to annual flooding. Calculations suggest that two of these sandstones might last 400 years with oversizing ratios ranging between 1.22 and 2.13. According to this methodology only moderate oversizing would be required for concretionary sandstones placed above the 5-year flood and no oversizing would be required above the 100-year flood.

Surprisingly, Eocene boulder conglomerates performed as well as quarried unweathered granitic rock in the freezing and thawing test. These rocks require only nominal oversizing when subjected to annual flooding, very little for flood intervals up to 5 years, and none at all above the 5-year flood.

CONCLUSIONS

As illustrated by the above examples, freezing and thawing tests combined with meteorological data yield practical oversizing results for marginal quality rock. Critical assumptions of this methodology are: (1) linearity of weight loss as a function of the number of cycles of freezing and thawing, (2) a semi-arid to arid environment which reduces the influence of chemical weathering, and

Table 2. Average percent weight loss for riprap samples during standard durability tests.[1]

Rock Sample	No. of Samples[2]	$Na_2 SO_4$ Soundness (5 cycles)	LA Abrasion (100 cycles)	Freezing and Thawing (250 cycles)
Quarried, unweathered Wyoming granitic rock	5-7 Composite Samples	1.3	5.1	0.1 (0.4×10^{-3})
Granitic boulder conglomerate from a mine	4	5.1	8.8	0.1 (0.4×10^{-3})
Granitic boulder conglomerate from an outcrop	4	4.0	7.2	0.1 (0.4×10^{-3})
Calcite cemented sandstone concretions from a mine	4	97.4	27.5	1.4 (5.6×10^{-3})
Calcite cemented sandstone concretions from an outcrop	4	Not tested[3]	Not tested[3]	6.9 (28×10^{-3})
Calcite cemented sandstone concretions from an outcrop. Minor iron oxide cement	4	99.7	42.3	0.7 (2.8×10^{-3})

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[1] Tests were performed by the U.S. Bureau of Reclamation (USBR), % weight loss per cycle in parentheses.

[2] No. of individual samples unless otherwise noted.

[3] According to the USBR, sample would probably have completely disintegrated had this test been performed.

Table 3. U.S. Bureau of Reclamation standards for judging riprap durability. [4]

Test	Quality		
	Poor	Intermediate	Good
Bulk specific gravity	<2.5	2.5 to 2.65	>2.65
Absorption (% weight gain)	>1.0	0.5 to 1.0	<0.5
Freeze-thaw weight loss, %[a]	>5	0.5 to 5	0 to 0.5
Na_2SO_4 weight loss, %[b]	>10	5 to 10	<5
Los Angeles abrasion weight loss, %[c]	>10	5 to 10	<5

[a] 250 cycles
[b] 5 cycles
[c] 100 revolutions

(3) areas to be protected by riprap are well drained. The accuracy of oversizing estimates also depends on how well one can predict the annual number of effective freezing and thawing cycles that occur while riprap is nearly or completely saturated.

Some mill operators and their contractors object to the use of freezing and thawing tests because of their long duration and cost. One might be tempted to develop the Los Angeles abrasion test as a substitute for the freezing and thawing test, based on the fair degree of correlation that apparently exists between the two tests as shown in Table 3. However, marginal quality rock did not perform very well in Los Angeles abrasion tests relative to freezing and thawing tests. Because of its potential use in oversizing marginal quality rock the freezing and thawing test should be retained for evaluating the durability of riprap. However, the number of cycles of such tests might be reduced while still providing useful data for the estimation of oversizing.

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Table 4. Oversizing ratios (r_o/r_d) for 200 and 1000 year performance periods and annual, 5-year and 100-year flood recurrence intervals.

	Flood Recurrence Interval					
	Annual		5-year		100-year	
	Performance Period		Performance Period		Performance Period	
Rock Sample	200 years	1000 years	200 years	1000 years	200 years	1000 years
Quarried, unweathered Wyoming granitic rock	1.01	1.06	1.00	1.01	1.00	1.00
Granitic boulder conglomerate from a mine	1.01	1.06	1.00	1.01	1.00	1.00
Granitic boulder conglomerate from an outcrop	1.01	1.06	1.00	1.01	1.00	1.00
Calcite cemented sand stone concretions from a mine	1.22	Unacceptable (2.13 - 400 yrs)	1.03	1.22	1.01	1.01
Calcite cemented sandstone concretions from an outcrop	Unacceptable (1.31 - 50 yrs)	Unacceptable	1.21	Unacceptable (2.05 - 400 yrs)	1.01	1.04
Calcite cemented sandstone concretions from an outcrop. Minor iron oxide cement	1.09	Unacceptable (1.22 - 400 yrs)	1.02	1.09	1.00	1.00

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