Procedure for Sampling and Quality Evaluation Testing of Rock for Riprap Slope Protection

This procedure is under the jurisdiction of the Materials Engineering and Research Laboratory, code 86-68180, Technical Service Center, Denver, Colorado. The procedure is issued under the fixed designation USBR 6025. The number immediately following the designation indicates the first year of acceptance or the year of last revision.

1. 1. Scope

1.1 *Application*.-This designation covers the sampling and quality evaluation testing of rock from operating quarries, potential quarries, talus slopes, or stream-deposited boulders for slope protection (riprap).

1.2 *Additional Use*.-This procedure also provides useful information for:

- Control of operations at the source of supply
- Control of operations at the cite of use
- Acceptance or rejection of materials

1.3 *Units*.-The values stated in SI/metric (inch-pound) units are to be regarded as standard.

1.4 *Caveats*.-This designation does not purport to address all the safety issues associated with its use and may involve use of hazardous materials, equipment, and operations. The user has the responsibility to establish and adopt appropriate safety and health practices. Also, the user must comply with prevalent regulatory codes while using this procedure.

2. Applicable Documents

2.1 USBR Procedures:

USBR 4075 Sampling Aggregates

USBR 4088 Soundness of Aggregates Using Sodium Sulfate

USBR 4127 Specific Gravity and Absorption of Coarse Aggregate

USBR 4131 Resistance to Degradation of Small Size, Coarse Aggregate by Abrasion and Impact in Los Angeles Machine

USBR 4295 Petrographic Examination of Aggregate for Concrete

USBR 4666 Resistance of Concrete to Rapid Freezing and Thawing

USBR 4702 Reducing Field Samples of Aggregate to Testing Size

2.2 ASTM Documents:

ASTM C 294 Standard Descriptive Nomenclature for Constituents of Natural Mineral Aggregates

ASTM D 4992 Standard Practice for Evaluation of Rock to be Used for Erosion Control

ASTM D 5121 Standard Practice for Preparation of Rock Slabs for Durability Testing

2.3 Other Documents:

Design Standards No. 13- Embankment Dams, Chapter 7 - Riprap Slope Protection - Bureau of Reclamation, 1992.

Report No. REC-ERC-73-4 - Riprap Slope Protection for Earth Dams: A Review of Practices and Procedures.

OSHA Regulations (29 CER, CH. XVII, 1926.900-.950, 1989), Blasting Safety.

Design of Small Dams, Bureau of Reclamation, 3rd Edition, 1987.

Engineering Geology Office Manual, Bureau of Reclamation, 1988.

Engineering Geology Field Manual, Bureau of Reclamation, 1989.

Construction Safety Standards, Bureau of Reclamation, 1987.

Petrographic Laboratory Analytical Techniques and Capabilities Reference, pp. 6-8, Bureau of Reclamation, September 1985 .

3. Summary of Method

This procedure describes the various states of riprap investigations. Representative rock samples obtained from quarries, borrow areas, or talus slopes are petrographically classified and physical properties (including freeze-thaw durability> are determined. Laboratory test data are used to evaluate rock quality sad suitability for potential riprap slope protection placements in critical structure zones subject to severe wave action and environmental exposure conditions

4. Significance and Use

4.1 *Slope Protection.*-This practice provides recommendations for investigation, sampling, and quality evaluation testing of riprap rock fragments for use as slope protection. Production sources should produce rock fragments in suitable sizes for the required usage. The fragments should be sufficiently hard, dense, and durable to withstand processes in procurement, transportation, placement, weathering, and the physical forces of nature such as wind and wave action, freezing and thawing, wetting and drying, as well as heating and cooling. Investigations must identify a sufficient quantity of material of required quality.

4.2 *Embankment Dams.*-Most embankment dams built by Reclamation contain one or more zones that require the production of rock. The rock is used as riprap for protection against erosion, or as rockfill or filter zones that strengthen or drain the embankment, thereby increasing its degree of stability. Riprap blankets are also commonly required below spillway and outlet works stilling basins and for canal and channel protection.

4.3 *Preparation.*-Production of such rocks generally requires drilling, blasting, and processing to obtain the required sizes.

4.4 *Riprap.*-Igneous, metamorphic, and sedimentary rocks can be used for the production of riprap.

5. Apparatus

5.1 *Excavating Equipment.*-Equipment such as bulldozers, backhoes, draglines, bucket augers, core drills, and jackhammers.

5.2 *Blasting Equipment.*-Dynamite, blasting caps, and drills for providing holes for setting blasting charges.

5.3 *Production evaluation.*-Survey equipment and truck weigh scales for production evaluation.

5.4 *Saw.*- A diamond, slab, or other saw of suitable size and quality to prepare cubical rock specimends from the sample.

5.5 *Miscellaneous Materials*.-Bags and pallets for transporting and handling samples.

6. Precautions

6.1 *Hazardous Materials.*-This test procedure may involve hazardous materials, operations, and equipment and does not claim to address all safety problems associated with its use. The user has the responsibility to consult and establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use.

6.2 *Qualified Personnel.*-Personnel shall be well versed in handling the above equipment. Only qualified and authorized persons shall be permitted to handle and use explosives.

6.3 *Safety Standards.*-Blasting safety must be executed in accordance with Reclamation Construction Safety Standards and the OSHA regulations (29 CFR, CH.XVII, 1926.900- .950, 1989) whichever is more stringent.

7. Source Investigation Stages

7.1 *General*-The complexity of investigations to determine suitable sources of riprap materials will be governed by project development stage and design requirements of the project features, Normally, project development occurs in four stages: reconnaissance, feasibility, specifications, and construction.

7.1.1 *Reconnaissance*.-Initial or preliminary exploration involves field surface reconnaissance using topographic, geologic, and agricultural soil maps and aerial photographs with supplemental information provided by records of known developed sources of material. A study of maps and aerial photographs may reveal possible sources of material. Contours are often an indication of the type of material; sharp breaks usually indicate hard rock, and slopes below cliffs often have talus deposits. During field reconnaissance, the countryside should be examined for exposed rock outcrops or cliffs. Road cuts and ditches may also reveal useful deposits. Data obtained should define the major advantages or disadvantages of potential materials sources within reasonable haul distance to the job site. Reporting accumulated data and information at this stage of investigation is accomplished by construction materials reports to the Technical Service Center.

7.1.2 *Feasibillity*.-Information accumulated during this stage is needed to prepare preliminary designs and cost estimates. Sufficient information concerning potential sources should be gathered to determine whether the Government should acquire the source or if the rock should be furnished by the contractor. Selection of sources should be limited to those which may

eventually be cited in specifications. Core drilling or blast tests may be required to confirm fragment size and quantity of material available in the sources. The potential material sources are examined to determine size and character, and particularly to observe joint and fracture spacing, resistance to weathering, and variability of the rock. The spacing of joints, fractures, schistosity, lineations, bedding, and other planes of weakness may control the size of rock fragments obtainable from the deposit. Observation of weathering resistance of rock *in situ* will provide a good indication of its durability. Particular attention should be given to location and distribution of unsound seams or strat which must be avoided or wasted during quarrying operations. A general location map and report describing the potential sources and containing estimates of available quantities, overburden, haul roads, and accessibility are prepared. Representative samples of riprap material from the most promising potential sources are required to be submitted to the Materials Engineering and Research Laboratories in Denver or other approved laboratory for quality evaluation tests. The extent and detail of information necessary at this stage is described in section 7.

7. 1.3 *Specifications.*-Investigations at this stage furnish design data and information required for specifications preparation. Exploration requests issued by the Technical Service Center will define requirements for riprap materials investigations. Sources indicated by feasibility investigation data to be of suitable quality for project feature work are surveyed and investigated to establish the quantity of material available and determine its uniformity.

7.1.3.1 Core drilling may be required, if dictated by geologic conditions. Such core drilling should be done on a grid system, if appropriate, and should include both vertical and angled holes as directed by the geologist or materials engineer. Blast testing should also be done at this time if not performed previously. Blast testing data shall be submitted to the Technical Service Center in the form of construction reports suitable for reference by the specifications. Sampling and testing should also be completed during this stage.

7.1.3.2 If additional deposits are considered at this stage, they must be investigated as thoroughly as the originally considered source or sources.

7.1.4 *Construction.*-Investigations during the construction stage are sometimes required to provide field and design personnel with additional detailed information for proper source development. This information should be obtained sufficiently ahead of quarrying or excavation operations to provide for proper processing and placing of material. If unforeseen changes occur in quality of material being removed from the source, sampling and quality evaluation testing of the rock may be required to confirm material suitability or delineate unsuitable rock areas.

8. Source Information

8 1 *Background.*-Reporting information and data accumulated during any investigation stage is most important. Although detailed information requirements increase with each successive stage, adequate information must be available by the feasibility stage to develop realistic cost estimates and properly select sources for possible use.

Required data obtained earlier than needed should be submitted when available and not withheld. For feasibility studies, the designers should have sufficient information to supplement laboratory test data to determine whether the Government should acquire the source, whether the rock should be furnished by the contractor, or whether other types of embankment protection should be considered. A suggested outline for riprap reports for rock obtained from an undeveloped quarry is:

a. Ownership

b. Location, indicated by map, with reference to the U.S. Public Land Survey legal description (section, township, range, and meridian). If, as will be the case in unsurveyed areas, the legal description is unavailable, the latitudinal and longitudinal coordinates (degrees, minutes, and seconds) should be obtained.

c. General description

d. Geologic type arid classification

e. Joint spacing and fracture systems

f. Bedding and planes of stratification

g. Manner and sizes in which rock may break on blasting as affected by jointing, bedding, or internal stresses

h. Shape and angularity of rock fragments

i. Hardness and density of rock

j. Degree of weathering

k. Any abnormal properties or conditions not covered above

l. Thickness, extent, estimated volume, and average depth of deposit type, extent, and thickness of overburden

m. Accessibility (roads affording access to highways or railroad, giving distance, load limitations, required maintenance, whether privately owned, and other pertinent information)

n. Photographs and any other information which may be useful or necessary

8.2 *Quarry*.-If commercial quarry deposits are considered, the following information should be obtained and included in the report:

a. Name and address of plant operator; if quarry is not in operation, a statement about ownership or control

b. Location of plant and quarry

c. Age of plant (if inactive, approximate date when operations ceased)

d. Transportation facilities and difficulties

e. Deposit extent, plant and stockpile capacity

f. Plant description (type and condition of equipment for excavating, transporting, crushing, classifying and loading, and restrictions, if any)

g. Approximate percentages of various sizes of material produced by the plant

h. Location of scales for weighing shipments

i. Approximate prices of materials at the plant

j. Principal users of plant output

k. Service history of material produced

l. Any other pertinent information

8.3 *Nonquarry*.-When rock deposits other than quarries are considered for riprap use, the rock properties and deposit should be described in the same manner as for quarry rock where applicable and, in addition, the deposit description should indicate shape, average size, and variation in sizes of the rock.

8.4 *Data Sheet*.-A typical source information data sheet is shown on figures 1 and 2.

9. Sampling

9.1 *Representation*.-Sampling, often a weak link in the chain of investigative procedures, is equally important as testing, and the sampler shall use every precaution to obtain samples that will show the nature and condition of the materials which the samples represent. Thus, sampling must be carefully performed by qualified, experienced personnel.

9.2 *Reports*.-Sampling is initiated at the specifications development phase of the project. Sampling is requested by exploration or design data requests, which should delineate size and location requirements for the riprap source. Detailed reports of investigations are submitted to the Technical Service Center as part of design data or Construction Materials reports.

9.3 *Size*.-The sample size should be at east 275 kg (600 lbm) and represent proportionally the quality range from poor to medium to best as found at the source. If the material quality is quite variable, it may be preferable to obtain three samples which represent. respectively, the poorest, medium, and best quality material available. The minimum size of individual fragments selected should be at least 0.014 m^3 (1/2 ft^3) in volume, if possible. An estimate of the relative percentages of each material quality should be made and included as information relating to the source. Samples from undeveloped sources must be very carefully chosen so that the material selected will, as far as possible, be typical of the deposit and include any significant rock-type variations.

9.3.1 Representative samples may be difficult to obtain. Overburden may limit the area from which material can be taken and obscure the true character of a large part of the deposit. Surface outcrops will often be more weathered than the 'interior of the deposit. Samples obtained from loose rock fragments on the ground or collected from weathered outer surfaces of rock outcrops are seldom representative. Fresh material may be obtained by breaking away the outer surfaces, or by trenching, blasting, or core drilling. In stratified deposits such as limestones or sandstones, vertical and horizontal uniformity must be evaluated, as strata often differ in character and quality.

9.3.2 The dip of stratified formations must also be considered. Strata inclination with respect to surface slope will expose different strata at the surface in different parts of the area. Attention should be directed to the possibility of zones or layers of undesirable material. Clay or shale seams may be so large or prevalent as to require selective quarrying or excessive wasting of undesirable material.

9.4 Shipping Samples:

9.4.1 Samples of rock fragments can be shipped by conventional transport such as motor freight. Large rock fragments should be securely banded to shipping pallets. Smaller fragments should be transported in bags or containers to preclude loss, contamination, or damage from mishandling during shipment.

9.4.2 Shipping containers for rock fragments shall have suitable individual identification attached and enclosed. A data sheet outlining details of the shipped sample should be included. It is often desirable to identify individual rock fragments by painted numbers or similar markings.

10. Procedure

10.1*Tests*.-Quality evaluation tests performed in the Technical Service Center laboratories on representative samples submitted from the field include detailed petrographic examination, determination of physical properties, and rapid freeze-thaw durability tests. These tests serve as a guide for determining if the material can be considered acceptable for use as riprap or rockfill material

10.2 *Petrographic Examination*.-Laboratory petrographic examination procedures for riprap/rockfill materials are not detailed, but USBR 4295 (although developed for concrete aggregate) may serve as a guide. Decisions concerning specific procedural methods and specimen preparation depend upon the nature of the rock, the intended usage of the rock, and the petrographer's judgment.

102.1 The rock pieces comprising the sample are visually examined and different rock facies and rock types, if present, are segregated for individual evaluation. The size range and characteristic fragment shapes are noted. The rock pieces are studied to evaluate if fragment shape and/or size is determined by discontinuities such as joints, fractures, bedding planes, or shear zones. Surface weathering and secondary deposits of alkali salts or clay are noted. Fracture or vein systems are described as well as the ease with which fractures or veins can be opened. Hardness, toughness or brittleness, and visible voids or pore characteristics and their variations are noted, The texture, internal structure, grain size, and mineralogy of the various facies and rock types are determined. Special attention is given to internal voids and fractures and to the type and amount of cementing material in sedimentary rocks. Thin section analyses, sometimes supplemented by X-ray diffraction analysis, are made as required.

10.3 *Freeze-Thaw Test Specimen Preparation*-For freeze-thaw durability testing, 73-mm (2 7/8-in) cubes are sawed from rock fragments selected by visual inspection to represent the poorest, medium, and best quality rock for each rock facies or type. Because the rock pieces could exhibit significant physical or structural features (e.g., joints, fractures, bedding planes), the number of cubes obtained for testing will vary from sample to sample. Prior to freeze-thaw testing, 'before test" photographs are taken and oven-dry cube masses are determined. Before testing, the cubes are immersed in water for 72 hours and specific gravities (bulk oven-dry, bulk saturated-surface-dry, and apparent) and absorptions are determined by USBR 4127. The cubes are reimmersed in water to maintain a saturated condition for freeze-thaw testing.

10.4 *Freeze-Thaw Test Performance*.- Rapid freezing and thawing durability tests (USBR 4666) are performed on all riprap samples, including those from areas not subject to freeze-thaw environments. The test detects structural weaknesses and is a good indicator of potential rock durability.

10.4.1 After saturated-surface-day cube masses are determined, the cubes are inserted in 76-mm (3-in) square rubber sheaths and sufficient water is added to cover the specimens. The rubber sheaths containing the specimens are placed in automatically controlled freezing and thawing cabinets, where the cubes are subjected to rapidly repeated eyelet of freezing and thawing in water, Each cycle consists of 1½ hours freezing at -12 °C (10 °F) and 1½ hours thawing at 21 °C (70 °F). During the test, cube mass loss determinations are made at periodic intervals and the appearance and manner of cube deterioration is noted. Termination of the test is 250 cycles or when the rock splits or fails (see section 10.4.2).

10.4.2 The criterion for rock failure is 25 percent loss of cube mass calculated from the difference in mass between the largest cube fragment remaining after testing and the initial cube mass. Cube specimen failure modes (e.g., splitting, disaggregation, popouts, exfoliation) are noted and "after test" cube photographs are taken. Apparent and actual mass loss values are calculated when a cube specimen fails along preexisting fractures, joints, bedding planes, or stylolites into a few large fragments. Apparent mass loss is calculated as described above, using the mass of the largest remaining fragment. Actual mass loss is calculated from the difference between the combined masses of all fragments remaining after testing and the initial cube mass.

10.5 *Physical Properties Sample Preparation and Testing* -Material remaining after petrographic examination of the rock sample (excluding any pieces selected for more detailed petrographic analysis and freeze-thaw durability tests) is crushed into 37.5- to 75-mm, 19.0- to 37.5-mm, 9.5- to 19.0- mm, 4.75-109,5-mm (1½- to 3-in. 3/4 to 1½-in, 3/8-to 3/4-in, and No. 4 to 3/8-in) size fractions. Representative samples of each size fraction are obtained for physical properties tests (USBR 4702). Physical properties tests performed on the various size fractions of crushed material are: (a) bulk saturated-surface-dry specific gravity and absorption, USBR 4127; (b) Los Angeles abrasion, USBR 4131; and (c) sodium sulfate soundness, USBR 4088. Typical laboratory work forms appear on figures 3 and 4.

Note 1.-Representative samples are also obtained for petrographic examination if the material is to be evaluated for use as crushed concrete aggregate.

11. Riprap Quality Evaluation Report

11.1 *Rock Type*.-Rock for riprap should be hard, dense, durable, resistant to abrasion, and free from discontinuities that will tend to increase destruction or displacement by wave action or exposure to various environmental conditions such as wetting and drying, heating and cooling, and freezing and thawing. Structural design requirements vary and each site presents unique problems. To allow designers to work within these structural and environmental parameters, the standard Reclamation riprap quality evaluation for slope protection is based upon material requirements for placements in critical zones, frequently

inundated for long periods of time with fluctuating water levels, and subject to heavy wave action and severe environmental exposure conditions. Economic factors are also considered in selection of riprap material sources.

11.2 *Test Significance*.-Riprap quality evaluation reports are based on physical properties test data, freeze-thaw durability, and petrographic examination. In Reclamation's experience, no single specific test has proven to be of significantly greater importance in evaluating rock quality for riprap usage than any other single test. Petrographic analysis (although a subjective evaluation) and freeze-thaw durability tests generally provide the most reliable and consistent measure of riprap quality. Each potential riprap material is judged independently with all available test data considered. The significance of test data is discussed, if appropriate, because some materials are suitable for slope protection even though the test data indicate the rock to be of marginal or poor quality. If applicable, recommendations are presented for improving and extending the life and durability of a riprap blanket.

11.3 *Report Form.*-A typical riprap quality evaluation report form is shown on figure 5.