Chapter 18

RIPRAP

Introduction

Riprap is preferably a relatively thin layer of large, approximately equidimensional, durable rock fragments or blocks placed on bedding to dissipate water energy and protect a slope, channel bank or shore from erosion caused by the action of runoff, currents, waves or ice (figure 18-1). Bedding is usually a layer of sand and gravel placed under the riprap to prevent erosion of the material from under the riprap. Most dam embankments contain at least one zone that uses rock. Rock is used as riprap for protection against erosion or as rockfill and filter zones that strengthen or drain the embankment.

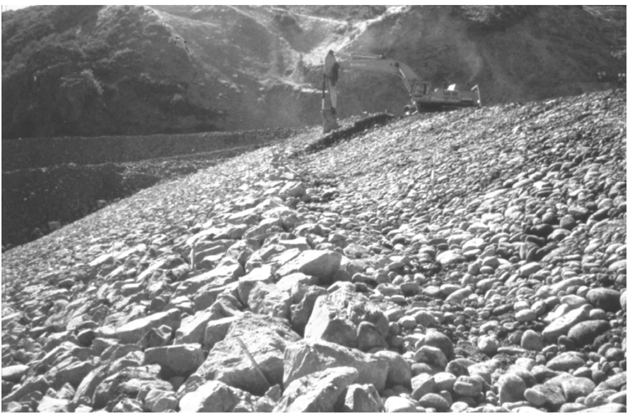

Figure 18-1.—Riprap properly placed on bedding. The riprap is angular, quarried rock, and the bedding is rounded stream gravel. The backhoe is placing and arranging the rock on the bedding.

The terms "slope protection" and "riprap" are often used interchangeably, but not all slope protection is riprap. Soil cement is also commonly used as slope protection. Riprap is an assemblage of rocks "nested" together to protect a structure or area from the action of water. The stability of an assemblage of rocks is a function of the individual rock's size, shape, weight, and durability. An assemblage of rocks depends on the individual rock characteristics for stability and also on the site conditions, grading, and thickness. The assemblage of rocks is designed to minimize voids and thickness of the riprap layer to keep the volume of material as low as possible. Proper placement interlocks the individual fragments into a layer of rocks that resists the action of water. Figure 18-2 shows what can happen if riprap is not designed, obtained, and placed properly.

Riprap should be "hand" placed to reduce the void space and maximize the interlocking arrangement, but rarely is this economical (figure 18-3). Most riprap is dumped and falls into place by gravity with little or no additional adjustment (figure 18-4). Because of this, individual pieces of riprap must have appropriate characteristics so that the rocks can be processed, handled, and placed so that the layer remains intact for the life of the project.

This chapter discusses: (1) riprap source evaluation, (2) onsite inspection to ensure that the samples are appropriate and that specified material is being produced from the source, (3) presentation of information to designers and estimators, and (4) waste factors in riprap production. A geologic background, a knowledge of blasting methods and types of explosives, and an understanding of the equipment involved in the processing, hauling, and placing of riprap is important to riprap evaluation, production, and placement. Most of the following discussion applies to rock adequate for aggregate and to larger

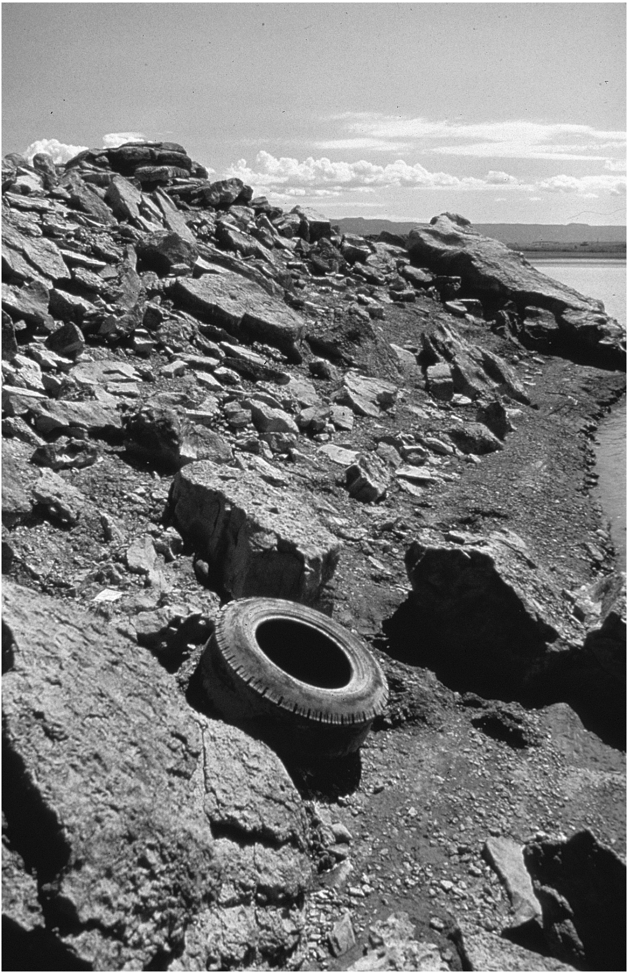

Figure 18-2.—Improperly designed, obtained, and placed riprap.

Figure 18-3.—Hand-placed riprap.

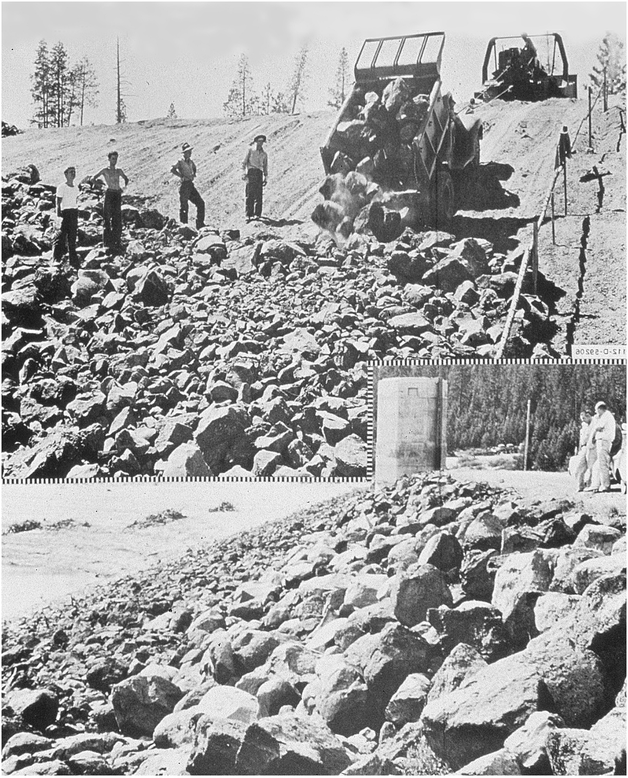

Figure 18-4.—Dumped riprap.

rock fragments used for roads, breakwaters, and jetties. However, this chapter is oriented toward acquiring suitable material for riprap.

This chapter should be used in conjunction with *USBR Procedure 6025, Sampling and Quality Evaluation Testing of Rock for Riprap Slope Protection*, and

USBR Design Standard No. 13 for Embankment Dams (DS13). Riprap design is discussed in "Chapter 7, Riprap Slope Protection," of USBR Design Standard DS13. Other documents, such as the U.S. Army Corps of Engineers' Engineering Manual 1110-2-2301, *Engineering and Design - Test Quarries and Test Fills*, and Engineering Manual 1110-20-1601, *Engineering and Design - Hydraulic Design of Flood Control Channels*, also provide information on design and source evaluation. Note: Test procedures developed to test similar riprap characteristics by different organizations are not necessarily the same. The appropriate test procedure should be selected based on the actual test and the available test equipment.

Evaluation

Much of the following discussion is more guidance than hard and fast rules or requirements. What is unacceptable riprap at one location may be acceptable at another site. Remember that a riprap source must be capable of providing suitable material in sufficient quantities at a reasonable cost. The three elements in every source evaluation are: quality, quantity, and cost.

Quality

Rock quality is determined by laboratory testing, but field personnel input and selection of the samples for testing are critical in determining the riprap quality. There are numerous quarries and pits capable of producing aggregate, but not all sources are suitable for the production of riprap. Riprap sources must produce riprap of the necessary weight, size, shape, gradation, and durability to be processed and placed and then remain "nested" for the life of the project. Performance on existing structures is a valuable method of assessing riprap quality from a particular source.

Shape

The shape of individual rock fragments affects the workability and nesting of the rock assemblage. Natural “stones” from alluvial and glacial deposits are usually rounded to subrounded and are easier to obtain, handle, and place and, therefore, are more workable. Rounded stones are less resistant to movement.

The drag force on rounded stones is less than between angular rock fragments. Rounded stones interlock more poorly than do equal-sized angular rock fragments. As a result, a rounded stone assemblage is more likely to be moved or eroded by water action. Angular-shaped rocks nested together resist movement by water and make the best riprap. The rock fragments should have sharp, angular, clean edges at the intersections of relatively flat faces.

Glacial or alluvial deposits are used as riprap sources only if rock quarries are unavailable, too distant, or incapable of producing the appropriate sizes. Unless the design slope is at an angle to the wave direction or wave energy and the erosive action of water on the slope is low, rounded to subrounded stones are typically used only on the downstream face of embankments, in underlying filters, or as the packing material in gabions.

No more than 30 percent of the riprap fragments should have a 2.5 ratio of longest to shortest axis of the rock. Stones having a ratio greater than 2.5 are either tabular or elongated. These tabular or elongated particles (figure 18-5) tend to bridge across the more blocky pieces or protrude out of the assemblage of rocks. During handling, transporting, and placement, these elongated or

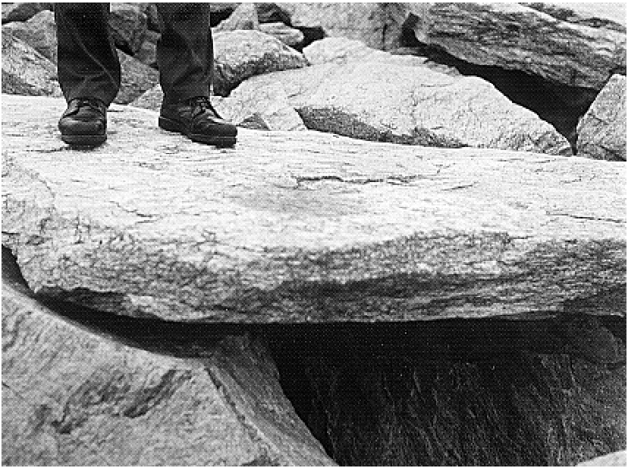

Figure 18-5.—Tabular rock fragment.

tabular rock fragments tend to break into smaller fragments and could significantly change the gradation or thickness of the protective layer.

Nearly all durable rock types can provide appropriately shaped material, but not all rock types can be blasted and processed economically into suitable shapes. Mineral alignment and fractures within the rock mass are the primary factors affecting the development of the shape. Most igneous and some sedimentary rocks are capable of making suitably shaped fragments. However, secondary fracturing or shearing will affect the shape. Rocks having closely spaced discontinuities tend to produce fragments that are too small. Sedimentary rocks that have bedding plane partings tend to produce flat shapes. Metamorphic rocks tend to break along jointing, rock cleavage, or mineral banding and often produce elongated shapes.

Weight and Size

The weight and size of individual riprap pieces are essential factors in resisting erosive water forces. The weight of the rock fragment is one design element for riprap but is difficult to obtain in the field for the larger sizes. The relationship between weight and size is approximately:

$$W_n = 0.75\ \gamma D_n^3$$

where: W_n - Percentage of total weight of rock where n percent is smaller
γ - Unit weight of rock
D_n - Representative diameter of rock where n percent is smaller

This formula assumes the shape of the rock fragment is between a sphere and a cube. The weight and size may be determined in the laboratory or in the field. The unit weight of riprap generally varies from 150 to 175 pounds per cubic foot (2.4 to 2.8 g/cm^3) and correlates with surface saturated dry specific gravity (SSSG). Rock having an SSSG above 2.6 is typically suitable for riprap.

Determination of the relationship between weight and size is difficult. Rock is either graded by size or counted and weighed, but rarely are weight and size correlated. Rarely does rock break into perfect cubical shapes; and because of the various shapes and sizes, weighing and sorting the individual pieces is difficult. The American Society for Testing and Materials Procedure D-5519 provides three methods for obtaining size and weight data.

Typically, for sizes up to 36 inches (1 meter) minimum diameter, rock pieces are sorted by size with a sieve or template, and the number of individual pieces is counted within each group. These piles can then be weighed and individual pieces adjusted to determine size. For individual pieces larger than 36 inches, the size is typically determined by using a tape to measure the maximum and minimum size of each piece. The weight is determined from a chart that assumes the shape is between a cube and sphere.

Most rock sources are capable of producing suitable weights and sizes. The size rarely impacts use as a riprap source unless more than 30 percent of the rocks are elongated or flat. In special circumstances, the rock mineralogy and porosity control the weight. The porosity of some sedimentary and extrusive volcanic rock could affect the weight. Rock having an SSSG under 2.3 is typically not considered for riprap. Generally, rock having a low unit weight is weak and tends to break down with handling.

Gradation

The desired gradation consists of size fractions of the individual particles that will nest together and withstand environmental conditions. The gradation design is based on the ability of the source(s) to produce appropriate sizes. Inherent rock mineralogy, cleavage, and fractures control the size of the rock fragments. Blasting, excavating, and processing also affect the size. Most acceptable riprap gradations are obtained by understanding the inherent rock characteristics, by proper blasting techniques, and by processing. Rarely can blending rock sizes achieve an appropriate grading for riprap because the larger fragments tend to separate from the smaller fragments during handling and processing. Processing is typically limited to running the rock fragments over a stationary grizzly (figure 18-6) or sorting with a rock bucket or rock rake (figure 18-7). Rarely is rock processed with jaw or

Figure 18-6.—Stationary grizzly. Rock is dumped on the sloping rails, and the larger material slides off and is separated from the smaller material which falls through.

Figure 18-7.—Rock rake. A dozer-mounted rock rake separates the larger fragments from the smaller material.

gyratory crushers except for testing. Segregation of large and small sizes is controlled by reducing the number and amount of drops during handling and processing. Handling should be kept to a minimum.

Most coarse-grained sedimentary and igneous rock quarries are capable of producing suitable riprap gradations. The range of gradations from sedimentary sources depends on the depositional environment. Rock derived from rapid depositional environments is more likely to produce well-graded riprap.

Size range is controlled by discontinuities in the rock. Columnar basalt, some fine-grained sedimentary rock, and metamorphic rock commonly have inherent planes of weakness that limit larger riprap sizes. Intensely to moderately fractured rock rarely produces suitable riprap gradations.

Durability

Riprap durability affects the ability of a source to provide a consistent shape, size, and gradation and the ability to resist weathering and other environmental influences. Durability is typically determined by laboratory test; but durability can be assessed by observing surface exposures, talus, and waste piles or by examining riprap applications already using the potential source or similar source materials. Cracking, spalling, delaminating, splitting, disaggregating, dissolving, and disintegrating are common forms of rock deterioration. Durability is a function of the rock's mineralogy, porosity, weathering, discontinuities, and site conditions. In rare instances, environmental considerations such as abnormal pH of the water may be a controlling factor in selecting an appropriate riprap source. A high or low pH may accelerate disintegration of the rock.

Alteration of minerals, such as feldspars to softer clays, will impact rock durability. Fine-grained rock types, rocks having high porosity, and chemically altered rocks may tend to slake after cyclic wetting and drying or freezing and thawing. Some rocks tend to break up because of discontinuities such as bedding plane parting, cementation or secondary mineralization, unstable minerals, banding, or foliation. Jointing, rock cleavage, and bedding plane partings often result in excessive finer sizes or tabular and elongated rock fragments.

Rock that breaks down either physically or chemically should be avoided. Obvious examples are most weathered or altered rocks, rock containing soluble or expansive minerals, vesicular basalts, shale, claystone, siltstone, weakly cemented or porous sandstone, schist, or phyllite. Even durable rocks such as slate and some gneisses may generally be unusable because other physical characteristics (cleavage and foliation) will not allow production of large, nearly equidimensional blocks.

Mechanical breakdown and weathering may be accelerated by microfracturing from the blasting, handling, weak cementation or may be the result of alteration of more stable minerals to clay. In addition, there appears to be a significant correlation between porosity, absorption, and durability of rock. Rock that has more than 2 percent absorption is commonly impacted by freezing and thawing and by wetting and drying processes.

Quantity

Every riprap source investigation must provide the estimated quantity required. Estimating realistic quantities depends on an understanding of subsurface geologic conditions. The uniformity of rock and discontinuities within a source area must be assessed. This estimate (often referred to as the reserve) provides not only the amount of riprap available but also provides an understanding of wastage resulting from blasting, handling, processing, haulage, and placement. In stratified deposits such as limestones or sandstones, uniformity must be evaluated because individual beds often differ in character and quality. The dip of stratified rocks and contacts between dissimilar rock types, such as igneous intrusions, must also be considered. The larger the individual pieces required, the more difficult it is for any rock type to supply suitable quantities. Zones or layers of undesirable clay or shale seams may be so large or prevalent that selective quarrying or wasting of undesirable material is required. The geologic conditions, ability of the rock to produce suitable sizes, and the potential reserve should be determined.

Existing commercial sources may be capable of producing riprap but may not be capable of expanding their operation into similar quality rock. In any new source, the amount of burden that must be removed, stability of the cutslopes, uniformity of the rock, depth to water, and ability to blast or process the rock into the appropriate gradation must be evaluated. Since riprap is a surface layer, a smaller sized riprap of increased thickness may be acceptable, or a less durable riprap may be used with the understanding that the riprap may require replacement.

Cost

A primary factor in determining a suitable riprap source is cost. Design and environmental requirements, access, subsurface conditions, testing, depth to water, quantity of suitable rock, and location also affect the cost and should be assessed early in any source investigation.

Producing sources should be located first. Using existing quarries or pits is generally cheaper because there is considerably less cost associated with permitting, developing, and evaluating an existing source. An existing source provides easier access to rock; a history of the source provides an understanding of the source's ability to provide suitable rock; regulatory requirements are often more easily met; development and processing costs are often known; and often, some testing of material has been performed so that the quality is known. Although existing sources may be known, each of these elements should be evaluated to ensure that information is representative and appropriate for the particular requirement.

In areas where existing sources are not economical, evaluating the surrounding undeveloped areas or abandoned pits or quarries should be considered. Evaluating new or abandoned sources typically involves considerable expense. A new quarry or pit investigation involves understanding subsurface conditions; obtaining, evaluating, and testing subsurface samples; and evaluating subsurface conditions to determine if appropriate riprap can be produced. Factors such as the haul distance, grade, width, and type of roadway should also be assessed.

Investigation Stages

The complexity of investigations for suitable sources of riprap is governed by the development stage and design requirements of the project. Projects are normally developed in four stages: reconnaissance, feasibility, design, and construction.

Reconnaissance

Initial exploration involves field surface reconnaissance using topographic maps, geologic and groundwater maps and reports, and aerial photographs. Supplemental information is provided by records of known developed sources of material. Areas having steep topography could have the best rock exposures. Geology maps provide generalized locations of rock types. Groundwater maps provide indications of rock permeability, depths to water, and information on the need for dewatering or unwatering within the source area. During field reconnaissance, the countryside should be examined for exposed rock outcrops or talus piles. Roadcuts and ditches may also provide useful exposures. Existing sources and any projects that previously used the rock source should be examined.

Service records are an excellent indication of the potential durability of rock. Federal (Reclamation, U.S. Army Corps of Engineers, Department of Transportation), State (highway, environmental quality), and county or local (highway or building) agencies usually maintain lists of sources. The local telephone "Yellow Pages," Internet, and construction companies may also provide information.

Data obtained should define the major advantages or disadvantages of potential material sources within reasonable haul distance. A reconnaissance construction material report should be prepared at this stage.

Feasibility

Information acquired during the feasibility stage is used to prepare preliminary designs and cost estimates. Sufficient information concerning potential sources should be gathered to determine whether the rock should be obtained from an existing source or a new source.

Selection of sources should be limited to those that may eventually be used in specifications. Core drilling and blast tests may be required to confirm fragment size and quantity of material available in each source. The potential material sources should be 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, banding, bedding, and other planes of weakness may control the rock fragment sizes and shapes. Weathering resistance of the rock will provide a good indication of durability. Quarry or pit development and the impacts of groundwater should be addressed. Particular attention should be given to location and distribution of unsound seams or beds that must be avoided or wasted during the quarry operation. A general location map and detailed report describing the potential sources and containing estimates of available quantities, overburden, haul roads, and accessibility should be prepared. Representative samples of riprap material from the most promising potential sources should be submitted to the laboratory for testing. A feasibility construction material report should be prepared at this stage.

Design

Investigations during the design stage furnish data and information required for the specifications. Sources indicated by feasibility investigations to be suitable are further investigated to establish quantities, determine the capability to produce the required gradation, and to determine uniformity. Depending on project needs, service records may be used in conjunction with or instead of laboratory testing. Blast and processing testing should be considered for new sources. All sampling and testing and the laboratory's Riprap Quality Evaluation Report should be completed at this stage. If additional sources are necessary, the new sources must be investigated as throughly as the original sources.

Construction

Investigations during construction provide field and design personnel with additional detailed information for proper source development. This information should be obtained sufficiently ahead of quarrying or excavating to provide for proper processing and placing of material. If unforeseen changes occur in the quality of material in the source, sampling and quality evaluation testing of the material may be required to confirm material suitability or to delineate unsuitable areas.

Reports

Reporting the results of any investigation is important. The level of detailed information requirements increases with each successive stage. Adequate information must be available by the feasibility stage to develop realistic cost estimates and to properly select sources. A suggested outline for reports for rock or riprap obtained from any potential quarry or pit is as follows:

a. Ownership
b. Location of source and project shown on a map
c. General description of site
d. General hydrologic and geologic descriptions
e. Structural geology information (distribution and arrangement of rock types and discontinuities within the deposit.)
f. Manner and sizes of rock breakage
g. Estimate of uniformity and wastage

h. Shape and angularity of source material
i. Hardness and density of source material
j. Degree and extent of weathering
k. Any abnormal properties or conditions not covered above
l. Estimate of extent, volume, and depth of suitable deposit(s)
m. Accessibility
n. Photographs
o. Geophysical and geologic data (e.g., drill logs, borehole geophysical logs, and seismic refraction or reflection survey data)

If commercial quarry or pit deposits are considered, obtain, as appropriate, the following information in addition to the data needed for a new source.

- Name, address, and phone number of the plant operator
- Location of the plant relative to quarry
- Description of the operation and plant with emphasis on capabilities for additional riprap production and maintaining current operation capabilities
- Blasting methods and problems related to production of riprap
- Transportation facilities and any potential difficulties
- Actual or estimated riprap gradations achieved or achievable by current or adjusted operations
- Location of scales
- Estimate of reserve and wastage

- Approximate prices of riprap material
- Service history of material produced
- Any other pertinent information

Sampling

Sampling is often the weak link in any source evaluation. The samples should represent the nature and condition of the materials and be appropriate for testing. Sampling is initiated at the specifications stage of the project. Sampling should cover the entire riprap source. The sample size should be at least 600 pounds (275 kilograms) and represent the quality range from poor to best as found at the source in the same proportions as the source can supply. If the material quality is quite variable, it may be preferable to obtain three samples that represent the poorest to best quality material available. The minimum size of individual fragments selected should be at least 0.5 foot (15 cm) square. An estimate of the relative percentages of material at each quality level should be made.

Representative samples may be difficult to obtain. Overburden may limit the areas where material can be obtained and obscure the true characteristics of the deposit. Outcrops will often be more weathered than the subsurface deposits. Samples obtained from talus piles or outer surfaces of rock outcrops are seldom representative of quality, quantity, or gradation. Fresh material may be obtained by breaking away the outer surfaces, or by trenching, blasting, or core drilling. If coring is the only method of obtaining samples, the preferred size is 6 inches (15 cm).

Shipping

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.

Testing

The Riprap Quality Evaluation Report is based on laboratory testing of the shipped representative samples. The quality evaluation tests include detailed petrographic examination, determination of physical properties and absorption, and a rapid freeze-thaw durability evaluation.

Petrographic Examination.—The petrographic examination follows USBR Procedure 4295 or ASTM Procedure C 295, which were developed for concrete aggregate. The decisions concerning specific procedural methods and specimen preparation depend on the nature of the rock and the intended use of the rock.

The rock pieces are visually examined and the different rock facies and types are segregated for individual evaluation. The following are evaluated:

- Size range
- Fragment shape
- Shape and size control by discontinuities such as joints, banding, or bedding
- Surface weathering
- Secondary mineralization or alteration
- Hardness, toughness, and brittleness

- Voids and pore characteristics and their variations
- Texture, internal structure, grain size, cementation, and mineralogy of the various facies and rock types
- Thin sections, sometimes supplemented by X-ray diffraction as required

Freeze-Thaw Test.— For freeze-thaw durability testing, two 7/8-inch (73 millimeter) cubes are sawed from rock fragments selected by visual inspection to represent the range from poorest to best quality rock for each rock facies or type. Because the rock pieces could have significant physical or structural discontinuities, the number of cubes obtained for testing will vary from sample to sample. The samples are photographed, the cubes are immersed in water for 72 hours, and specific gravities (bulk, SSSG, and apparent) and absorptions are determined by USBR Procedure 4127 or ASTM Procedure C 127. The cubes are reimmersed in water to maintain a saturated condition for freeze-thaw testing.

Rapid freezing and thawing durability tests are performed on riprap samples according to USBR Procedure 4666 or ASTM Procedure D5312. The rock failure criterion 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.

Sodium Sulfate Soundness Test.—Sodium sulfate soundness tests are performed on riprap samples according to USBR Procedure 4088 or ASTM Procedure D5240. The loss after an interval of screening is determined after at least five cycles of saturation and drying of the samples. The test is a good indicator of resistance to freeze-thaw deterioration.

Physical Properties.—Material remaining after the petrographic examination and freeze-thaw testing is crushed into specific size fractions (USBR Procedure 4702). Representative samples of each size fraction are tested for bulk, SSGS, and absorption following USBR Procedure 4127 or ASTM Procedure C 127; abrasion is tested using the Los Angeles abrasion test following USBR Procedure 4131 or ASTM Procedure C 535. Both the Los Angeles abrasion and sodium sulfate soundness tests are durability tests. The Los Angeles abrasion test is used to determine the ability of the rock to withstand handling and processing and water action. The sodium sulfate soundness test simulates weathering of the rock pieces.

Waste in Riprap Production

Production of riprap generally requires drilling, blasting, and processing to obtain the desired sizes. This section is a guide to help estimate the amount of waste that can be expected from riprap production.

Numerous factors in the parent rock contribute to waste in quarrying operations. The natural factors include:

- Weathering
- Fracturing (joints, shears, and faults)
- Bedding, schistosity, and foliation
- Recementing of planar features

Other important, somewhat controllable contributors to waste are:

- Construction inspection
- Size and gradation requirements
- Drilling and blasting
- Processing, hauling, and placement

Factors a through d relate to the geology in the quarry and probably are the most important factors that govern what sizes can be produced. Weathering can extend 20 to 60 feet (6 to 18 meters) below the original ground surface. Weathering breaks down the rock and weakens existing planar features such as bedding, schistosity, and jointing. In rocks such as limestone and dolomite, secondary deposits of calcium carbonate can cement existing joints. When first examined, this cementation appears to be sound; but processing the rock can refracture these planes. Existing quarries, or quarries that have been in operation for many years, probably will produce material with less waste because excavations are partly or completely through the zone of weathering. New quarries, or quarries where rock production has been limited, must contend with the weathered zone and will likely produce a less desirable product.

Gradation Requirements

Gradation requirements and inspection control are governed by the agency issuing the construction specifications. Adjustments in gradation or inspection requirements can drastically change the waste quantities produced. Except in isolated cases, it becomes more difficult to produce riprap when rock sizes are increased and gradations are tightly controlled.

Production Methods

Production methods that include drilling, blasting, processing, and hauling also play an important role in the sizes that can be obtained. Rock that is well-graded and has a large maximum size can be produced more readily when using large diameter, widely spaced shot holes. Close spaced, small diameter shot holes tend to maximize fragmentation. Blasting agents, delays, and loading methods vary considerably and have a significant effect on how the rock fractures. The most efficient and economical drilling and blasting methods must be determined by test blasting and performing gradations on the blasted product. Test shots should be modified to achieve the desired product. Production should not start until it is proven that the required product can be produced with a minimum of waste.

Many rock types, especially those that are banded (bedded or schistose) or contain healed joints, can break down significantly during processing. Some limestones are especially susceptible to breakdown when the rock is dropped during blasting and processing operations. Rock from most quarries will fracture badly when dropped more than 50 feet (15 meters).

Quarries must tailor their blasting techniques to get the required gradations. Quarries that normally produce aggregates for concrete, road metal, and base course usually have a very difficult time producing a reasonably well-graded riprap. This is because their normal operation already has shattered the face at least 100 feet back. To obtain good riprap, a working face or ledge should be reserved for riprap production.

The quantity of quarry waste shown in table 18-1 is typical of riprap quarries. Items that should be considered when using the table include:

- Waste includes undersize and excessive intermediate sizes. Oversize riprap is reprocessed to the proper size.

- Rock produced is reasonably well graded from 6± to 36± inches (.15 to 1 m), and the inspection control is very strict. Much less waste will be incurred if smaller rock sizes

Table 18-1.—Rock types and typical usable quantities of riprap

Rock type	Estimated percent waste to produce suitable riprap	Remarks
IGNEOUS		
Intrusive	25 to 75% Average 50%±	
Extrusive	40 to 85% Average 60%±	
METAMORPHIC		
Gneiss	40 to 75% Average 55%±	Based on limited data
Schist	50 to 75% Average 65%±	Based on limited data Very little riprap would be salvaged in the weathered zone
SEDIMENTARY		
Limestone/ Dolomite	55 to 85 % Average 65%±	Based on several good quarry sites
Sandstone	Average 60%±	Based on limited data

are required or if the deposit is shot for rockfill or the specific rock product.

- Drilling, blasting, processing, hauling, and placing are accomplished by a typical contractor.

- Rock quarried is the best material available and is not severely fractured or weathered.

- Riprap production is generally limited to new quarries or unshot ledges or benches.