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	Engineering and Design CONSTRUCTION WITH LARGE STONE	
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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314-1000

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CECW-EG

Engineer Manual
No. 1110-2-2302

24 October 1990

Engineering and Design
CONSTRUCTION WITH LARGE STONE

1. Purpose. This manual establishes criteria and presents guidance for the selection, evaluation, and use of large-stone materials in construction.

2. Applicability. This manual applies to major subordinate commands, districts, laboratories, and field operating activities (FOA) having civil works responsibilities.

3. Discussion. The manual for Construction with Large Stone summarizes the results of many years of experience in the selection and use of rock materials in all forms of engineered structures. As individual stone sizes increase as a function of design requirements, natural and man-made disparities and flaws in rock have an increasingly greater influence on performance and time dependent durability. As a result, the guidance in this manual was developed specifically to be applied on those projects requiring large riprap, jetty stone, and cap stone. However, the principles and guidance found in this manual may be applied to any stone requirements greater in size than concrete aggregate.

FOR THE COMMANDER:

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Colonel, Corps of Engineers
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CHAPTER 1

INTRODUCTION

1-1. Purpose. This manual provides guidance on effective and economical selection, evaluation, and use of large-stone materials in construction. The manual is intended particularly for Corps of Engineers (CE) personnel in engineering or construction divisions. The manual also serves as a supplement to guidance on engineering design of large-stone features and structures available among references.

1-2. Applicability. This manual is applicable to major subordinate commands, districts, laboratories, and field-operating activities (FOA) having civil works responsibilities.

1-3. References. Applicable references, annotated as items, are listed in Appendix A.

1-4. Definitions. Several terms are defined here to minimize confusion from the widespread ambiguity existing in current practice. These definitions are not necessarily applicable beyond this manual. The usefulness of these terms within the manual implies that special care may be needed whenever large stone is described formally in a design memorandum or a construction contract.

a. Riprap, armor, D zone, and protection stone are used in reference to engineered features composed of large-stone materials. Simplest terminology for rubble mounds distinguishes armor and core stone with an underlayer of intermediate stone size commonly sandwiched between. In slope protection, riprap is often placed on a bedding layer of less than large-stone sizes.

b. Jetty stone and cap stone refer to stone of very large size for special engineered features or structures or portions thereof.

c. Rock, stone, field stone, and rubble are used in reference to granular or particulate construction material. Rock or stone can also mean an individual element (for example, one block or boulder) of such a composite material. Stone has been defined occasionally as a construction material, in distinction from rock still located naturally in place. Such distinction is not widely made and is rejected here in favor of a general equivalence. Where judged to be beneficial, separate terms should be carefully defined and consistent.

d. Cut stone, dimension stone, and derrick stone refer to stone with special shape or size resulting from the method of production.

e. Aggregate is a granular, stone construction material mostly used in concrete and distinguished from large-stone materials by its smaller stone sizes.

f. Large-stone refers to the size of granular construction materials generally coarser than aggregate, that is, averaging 3 in. or greater. Protection stone or armor is about equivalent but has the added connotation of the use in protecting a slope or structure.

g. Ledge rock and sometimes rock and field stone refer to rock in situ within a quarry or other possible source.

1-5. Scope. The scope of this manual has been made broad, ranging through subjects as diverse as geology and technically based construction contracting. Chapter 2 reviews the wide spectrum of engineering applications of large stone. Chapter 3 reviews potential problems in using large stone and is based on past CE experience. Chapters 4, 5, and 6 explain good practice in evaluating materials and sources of materials. Chapters 7 and 8 summarize pertinent aspects of contracts and construction. Since these efforts are accomplished by contractors and suppliers, the CE perspective emphasizes quality assurance.

1-6. Exclusions. Certain exclusions are important to recognize in this manual. First, the subject of rock aggregate is omitted except for peripherally important aspects such as the application of aggregate test methods to the evaluation of large stone. Second, and of considerable importance, is the fact that guidance on design procedures using large stone is omitted from this manual. Guidance on design of various structures is available in other engineer manuals (Figure 1-1).

1-7. Use of Manual. Figure 1-1 shows schematically how this manual can be used in coordination with guidance on design of an engineered feature or structure such as a harbor breakwater or a zoned rockfill dam. The need for this special supplemental guidance arises from the variability of the natural material being used and the substantial impact this variability can have on the project. Each generic rock type and the sizes of stone produced from it vary from region to region and quarry to quarry. Variations exist even within a quarry, a single ledge, or a stockpile. This manual guides the user in recognizing and adjusting for these complications in efforts to plan and design the project cost-effectively and, ultimately, to complete the construction as designed.

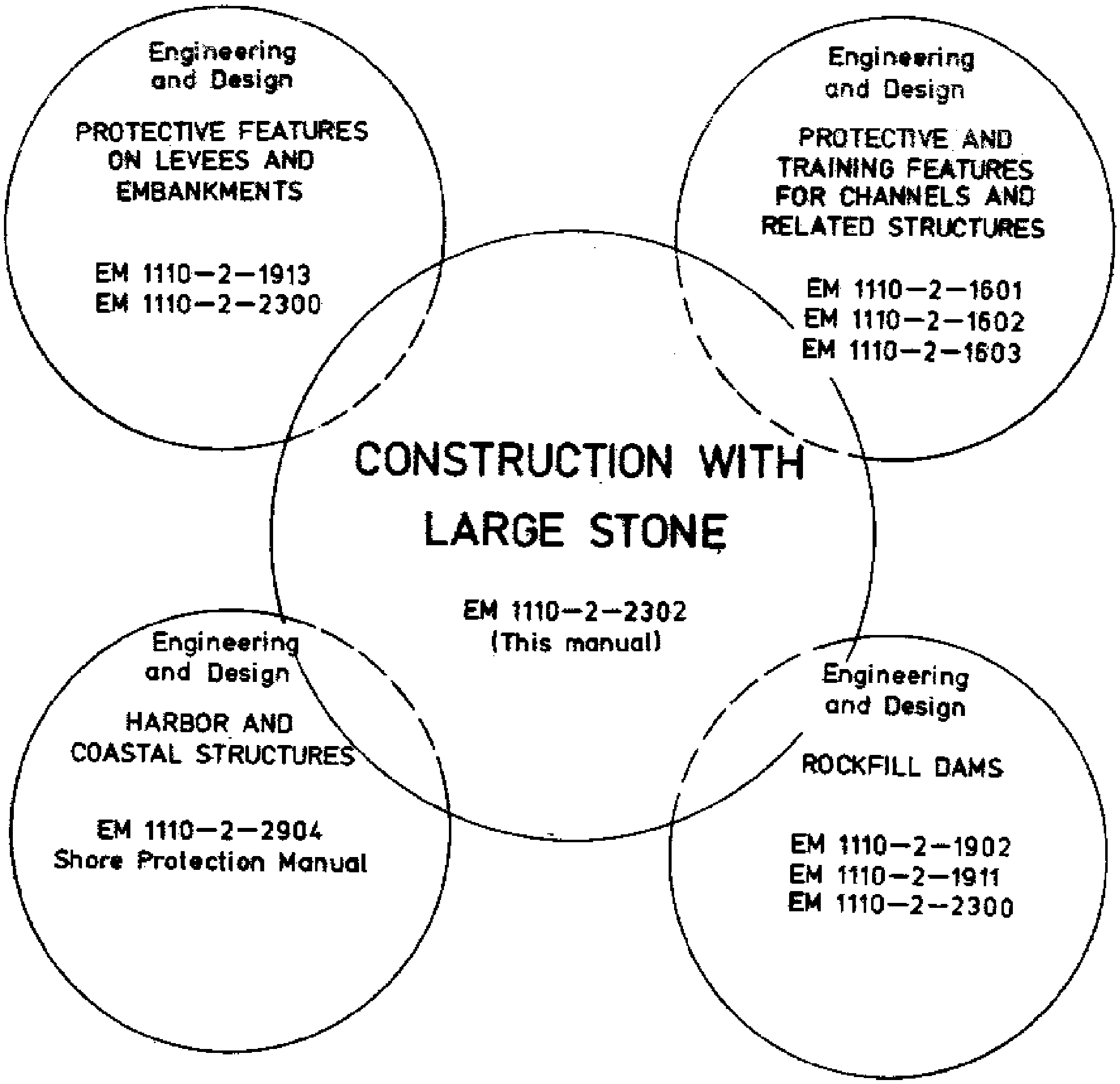

Figure 1-1. Relation of this manual to guidance on design of large-stone structures

CHAPTER 2

ENGINEERED FEATURES AND STRUCTURES

2-1. General. Stone has been used for many years to protect embankments, levees, river banks, and engineered features against erosion and in the construction of dams, breakwaters, and other large structures. Advantages over other materials and designs are often contingent on low cost of large-scale production and processing of stone and placement on the structure. The general types of usage are summarized in Figure 2-1. Despite the categorization of structure types in the figure and in the information below, there is a useful similarity in construction. Experience in one category is potentially applicable in others.

2-2. Slope Protection.

a. Slope protection generally means the engineered feature composed of large-stone material constructed as a relatively thin overlay on a slope otherwise vulnerable to erosion. A bedding layer is usually included. The large-stone material is commonly called riprap. At the heart of some riprap design is the characteristic of physical flexibility. Riprap adjusts to minor flank erosion or undercutting and continues to function in its protective role.

b. One key consideration in slope protection is stone size, and the specifications for riprap should be detailed in regard to median size, gradation, and allowable tolerances. Gradation limits help define these parameters as shown in Figure 2-2. The cost advantage may be even greater where gradation requirements allow quarry-run material to be used. Even here, the importance of well defined specifications must be made clear since there are still limitations on oversize or undersize components that may require at least some separation processing. At the other extreme from quarry-run material is riprap of narrow size range for manual placement in a keyed or fitted-stone arrangement. This labor-intensive and costly method of protecting slopes is practiced only rarely today but may be encountered in maintenance of features constructed years ago.

2-3. Training Structures. River training structures are relatively short, linear features constructed near the bank of a channel to control the pattern and velocity of flow. Examples are spur dikes and groins perpendicular to the bank and vane dikes more or less parallel. Rock training structures may be unzoned or earth-cored but are always designed for low cost, sometimes at the sacrifice of longevity. Groins are also used along coastlines to control sea drift currents and sand deposition. Coastal jetties train the flow of river outlets and may secondarily function as groins and breakwaters.

2-4. Retention Dikes. Retention dikes are designed to impound saturated materials such as from dredging. Elaborate, zoned designs are sometimes used where the waste is contaminated and the stability and the control of leachates are of high priority. Where wave attack is predictable, two or more zones of large stone are commonly incorporated, with the most critical usually being the outer armor. As designs prescribe larger and larger stones, the problems of quality and cost increase dramatically. Smaller sized stone materials are

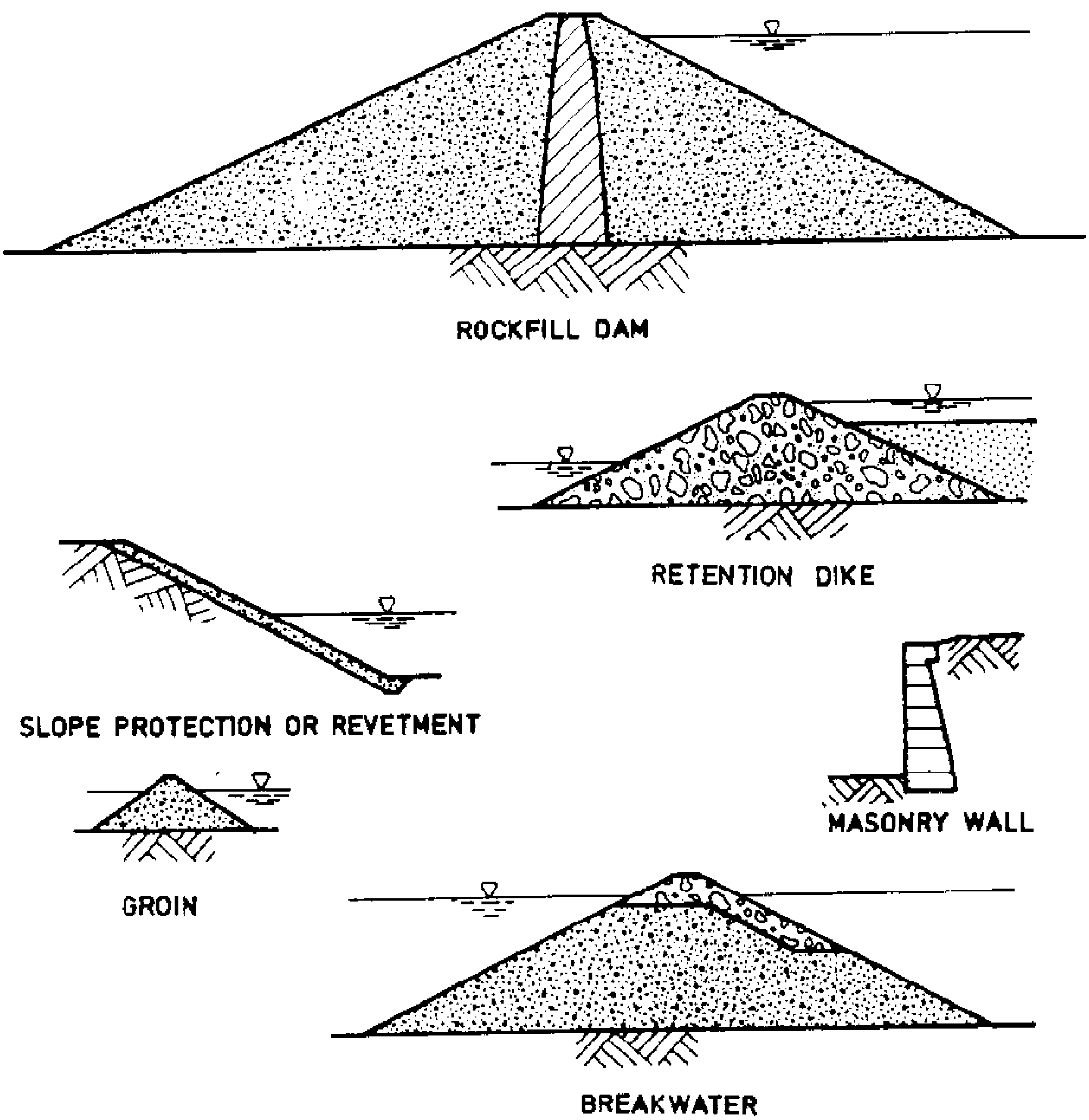

Figure 2-1. Engineered features and structures constructed of large-stone materials

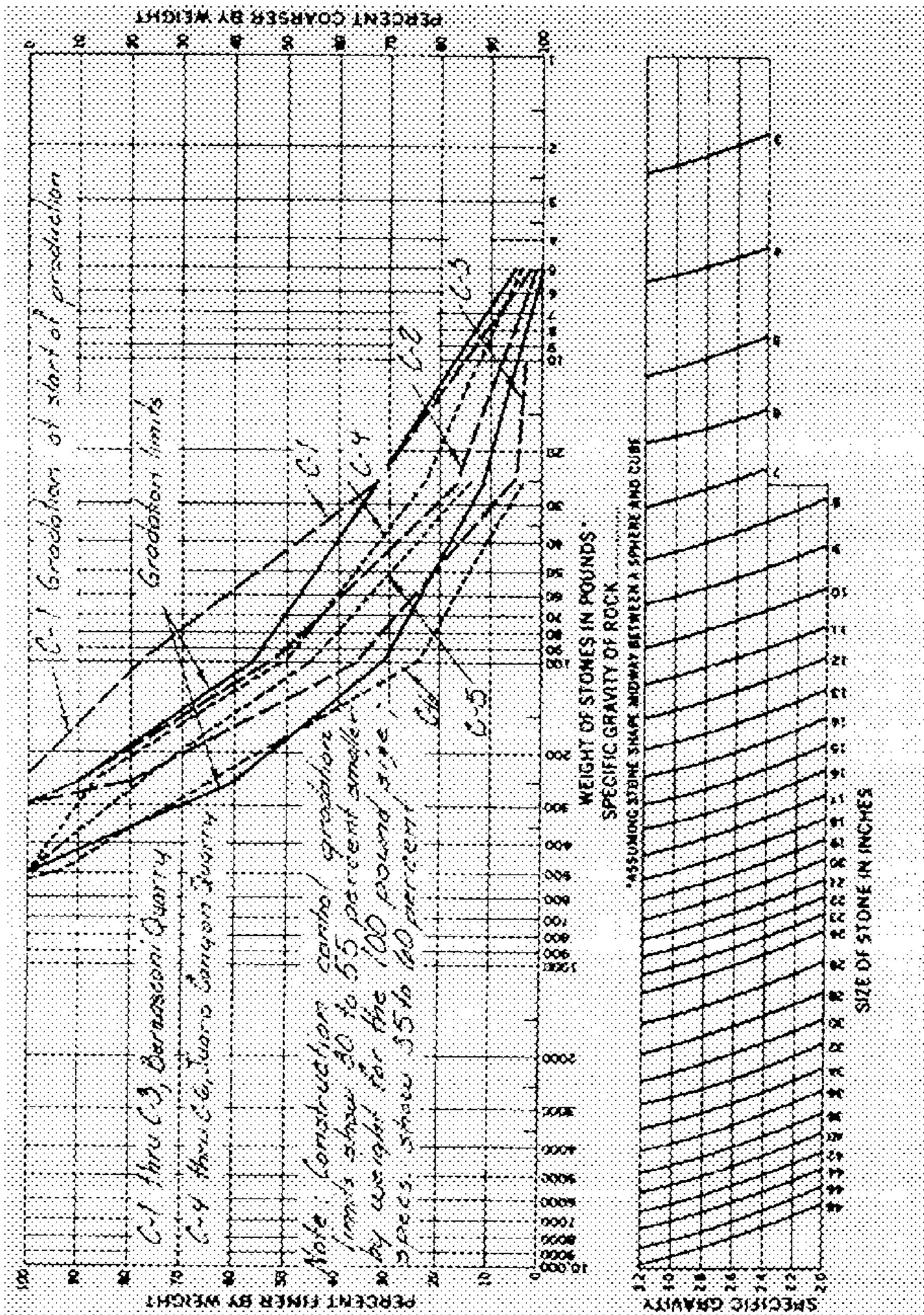

Figure 2-2. Example of gradation limits for riprap and control curves from actual stone production

usually more than adequate to remain stable and support the superimposed layers. Emphasis may then be redirected from high-quality stone to quantity and the need to provide large volumes of core stone.

2-5. Breakwaters and Jetties.

a. Large breakwaters and jetties provide the outstanding examples of construction with large stone. The term rubble mound, though somewhat entrenched in the technical literature, seems inappropriate to describe these engineered structures which are commonly designed with several massive zones of different materials. The special demands for protection against ocean wave attack lead to the ultimate among numerous possible requirements, that is very large, dense, and durable individual stones. At some large size, different for each project, the cost of constructing armor with stones exceeds that of construction with man-made concrete units such as tetrapods and dolosse. For projects near this cutoff, an especially thorough investigation of stone sources is needed. Quarries at great distance are often included, and the cost of transportation and handling must be estimated carefully.

b. Structures in deep water present special construction problems. Placement is partly remote and obscure so that quality control, quality assurance, and measurement for payment are comparably more difficult than in construction above water.

2-6. Zoned Embankments.

a. Construction of zoned rockfill dams has constituted the largest use of large stone in some CE districts. The demands regarding material quality are usually different than for rubble mounds or even for retention dikes, and weak rock can be used. Instead, the focus is on the immense volumes required.

b. Much of the stone material can come from excavations required as part of the project, particularly, excavations for spillways and outlet works. Quarries or stone borrow areas may be needed at least as supplementary sources. An accurate estimate of processing requirements is essential to assure sufficient volumes where suitable deposits are thin or otherwise in short supply or the material quality is marginal. The attendant blasting, handling, and placement sometimes degrade some of the material and can cause shortfall in acceptable stone. Precautions in production and placement (ER 1110-2-1925) may be recognized as advantageous from guidance included in Appendix B and Chapter 8.

2-7. Other Uses. Other uses of large-stone material are subordinate as a group to those identified above. Nevertheless, special uses can be significant.

a. Energy Dissipators. Energy dissipators may be constructed from derrick stone placed in plunge pools to reduce erosion of foundation soil or bedrock. The high-energy environment may preclude long service life without additions of fresh stone.

b. Structure Protection. Stone placed around the upstream end of a bridge pier is an example of protection of structures. Stone placed to stabilize and protect dikes or breakwaters primarily composed of concrete-filled caissons is another example.

c. Masonry. Masonry construction is included in this manual for completeness. The high cost of this labor-intensive method largely disfavors its use today, but stone masonry still exists in CE structures and facilities and occasionally can be repaired with essentially new masonry construction. Dimensional and cut stone for masonry are produced in a relatively few, specialized quarries.

d. Landscaping Stone. Landscaping stone is not part of an engineered structure or feature as such, but it essentially completes some CE projects. Guidance in selecting stone and in estimating or inspecting stone work for landscaping is potentially useful on a broad scale.

CHAPTER 3

MATERIALS PROBLEMS AND CONSTRUCTION PROBLEMS

3-1. General. The primary desired attribute of large-stone materials is intrinsic durability against weathering and other environmental influences. Even those materials buried under other zones are expected to remain strong and to resist effectively any degradation. Otherwise, portions of the mass may suffer damaging settlement, slippage, or alteration of subsurface drainage. To be durable, the material must resist several natural and man-induced disturbances. Table 3-1 lists most of these in three categories: design-related, material-related, and external factors. Clearly, there are numerous factors, not necessarily related to material, which can cause performance problems. The range of problems is increased even further by considering the economics of producing large stone. An extensive review of CE experience in large-stone construction (Evaluation of Quality and Performance of Stone as Riprap or Armor) constitutes the basis of the summary of the numerous problematic factors discussed below.

Table 3-1. Factors Affecting Performance of Large-Stone Materials*

Design-Related Factors	Material-Related Factors	External Factors
Current dislodgment	Sediment abrasion	Snow cover
Wave dislodgment	Rocking abrasion	Ice-block thrust
Flood crest	Water corrosivity	Ice-block rocking
Storm surge	Air corrosivity	Ice cementation
Void plugging	Freezing	Floating debris
Drainage reduction	Freeze-thaw cycling	Root growth
Undercutting	Wetting	Incidental humans
Rapid drawdown	Wet-dry cycling	Vandalism
Rapid filling	Heating	Sedimentation

*Excluding foundation deficiencies.

3-2. Supply Limitations. Economic factors associated with supply are potentially the most important influences on construction with large stone. Large stone is generally scarce and costly to produce and usually commands a premium price. Fortunately, the cost factors can be evaluated with confidence by experienced personnel. Some major aspects of the economics of obtaining and using large stone are summarized below.

a. Production Constraints. Several production characteristics of a source or quarry operation are capable of affecting its suitability in providing the needed stone.

(1) Product Mix. Large stone material is commonly separated as a by-product in quarries mainly operated for aggregate or industrial limestone such as for flux. Two problems can arise. The production of large stone may only constitute a few percent, and unless the demand for aggregate is immense, the stockpile will be depleted and the weekly production may fall short of large-stone needs of the project. Elsewhere, in contrast, the large-stone demand may exceed demand for aggregate and lead to an increasingly large accumulation of unmarketable small rock wasted in the quarry. A burden such as this on the operator occasionally affects the CE project work.

(2) Quarrying Method. Problems with quarrying methods frequently center on the use of large charges in blasting patterns designed for fragmentation. Heavy blasting produces incipient cracks in previously solid large stones but is considered beneficial toward producing a small-size product like aggregate. The needs for crushing and secondary blasting are reduced. Heavy fragmentation also facilitates the handling of material. Damage is commonly expected in large stone coming from small-stone operations, and some CE offices contractually avoid, discourage, or prohibit heavy blasting where large stone is to be produced.

(3) Reserves. Reserves quantify not only the amount of large-stone material available in situ, but also the distribution of that material. Obviously, reserves must exceed the amount of stone required plus an extra increment for wastage or there will be a shortfall. Generally, the problems will be greater in producing large individual stones dispersed throughout a quarry than where the large stones are concentrated in a small, accessible area or ledge. Problems of detrimental mixing of material types can also impact peripherally where large stone of marginal quality is intimately mixed with superior stone.

(4) Operational Status. The evaluation of the capacity and quality of an operating stone source is fairly straightforward. Commercial operators are willing to share technical data on operational conditions and proven resources. Frequently, however, it is necessary to consider producing stone from inactive or undeveloped sources including those where proven reserves have been exhausted and only unexplored ground remains. Careful geological investigations (Chapter 4) are required to avoid risking a serious shortfall or quality problem.

b. Transportation. The transportation of material commonly constitutes the largest single economic factor in procurement of large stone for construction. Even where suitable stone is abundant in the immediate region, a distinct advantage goes to the source with lowest transportation cost.

(1) Distance. Distance from source to the project site translates into mileage cost. Choice of mode of transportation and suitability of stone are complicating aspects that must be evaluated in coordination with distance. In some instances, the closest source has been used after testing marginally in engineering properties, only to find that the stone has been ineffective in service. Transportation cost does not always preclude distant sources; stone has been shipped hundreds of miles competitively.

(2) Mode. The mode of transportation is often more critical than the distance. Truck haulage is usually most costly, and truck hauls exceeding

about 25 miles (one way) should be viewed as potentially unfeasible unless other modes of transportation are lacking. Barge transportation has a cost advantage and is usually preferred where it is feasible. Rail haulage may have the advantage for long distances when barging is not feasible.

(3) Handling. Transportation handling refers to all efforts and associated costs following loading of material at the source and preceding unloading at the jobsite. Handling costs of this type are negligible where the stone is loaded on trucks at the quarry face or processing plant and dumped later at the job within reach of the placement equipment. Obviously, a change in mode of transportation adds increments of handling, with additions of cost. Stockpiling may also add substantial costs. It has also been perceived on some past stone work that increased handling tends to damage the material.

3-3. Government-Land Sources. The source of stone may be limited to locations on Government land adjacent to the construction site or to required excavation removed in the course of excavation for a project feature such as an emergency spillway. This choice is highly cost-effective but often reduces the quality of stone to less than would be obtained from established, offsite sources. Occasionally, such required excavation is marginal in suitability, so that a thorough subsurface investigation and documentation in a design memorandum may be needed. See Chapter 5 regarding sources at the project site.

3-4. Material Deterioration. An important axiom is that the same durability requirements are progressively more difficult to attain as the stone size requirement is increased. Problems with material characteristics can be manifested unexpectedly at the time the material is produced or later during exposure to environmental influences after placement. See Table 3-1 listing factors. Those material problems appearing at the time of production impact directly on realizing the design and are discussed in paragraph 3-5. Durability problems take any of several forms distinguished below. Despite their subjectivity, these modes facilitate descriptions and often suggest causative processes.

a. Cracking. The cracking phenomenon is characterized by the development within individual stones of one or more throughgoing cracks. Where a geological fabric such as bedding is present in the stones, the cracks usually propagate parallel or perpendicular to planar geological structures. In those stones where well-healed joints occur, it is common to find the cracking along these potentially weak surfaces.

b. Spalling. Spalling describes the special process of deterioration in which relatively thin shells break away from the stone surface. Corners and edges of stones are particularly vulnerable so that the stone evolves toward a rounded form. The whole process is observationally analogous to spalling of small, dried pieces of some shale or clay-rich rock upon immersion in water.

c. Delaminating or Splitting. Certain rock materials are prone to delaminating, slabbing, or splitting because of inherent geological structure. Many bedded sedimentary rocks and a few layered volcanic or metamorphic rocks separate preferentially along these geological features regardless of the cause of deterioration. This potential problem is widely recognized and most specifications for riprap and armor stone prohibit the inclusion of rocks containing prominent bedding, shaly layers, partings, or stylolites. In many cases, such materials are unavoidable within the constraints of costs or time schedule, and as a result, delaminating or splitting is among the most common forms of rock breakdown following project completion.

d. Disaggregating. Disaggregating can be a particularly severe problem. Disaggregating appears to be more likely to occur in clastic rather than crystalline rocks. In granular or clastic sedimentary rock, individual grains are sometimes held together only by a relatively weak cementing material. This characteristic is distinct from the intergrowth of component grains in crystalline rocks which provides a strengthening mechanical interlock. Disaggregation is manifested by continuing erosion, abrasion, or flaking away of increments of rock (near grain size) leading to stone rounding and reduction in size.

e. Dissolving. Occasionally, under unusual conditions such as emergencies, it has been necessary to use for temporary protection rock types susceptible to slow dissolution that were immediately available. Typical of such stone has been rock containing anhydrite.

f. Disintegrating. Characterization as disintegrating is reserved in this manual for application to cases of notably severe and rapid deterioration resulting from one or more of the processes in b. through e. above. Individual pieces are disintegrated leaving few or no traces of the original stones and making serious, though usually localized, deficiencies in the large-stone feature. Disintegration is rare today and usually involves only small fractions included with satisfactory rock during the quarrying operation.

3-5. Design Problems. Past design problems are briefly reviewed below. The discussion does not include those categories of problems unrelated to the characteristics of the material such as the common problem of deficiencies in the foundation of the structure.

a. Stone Size.

(1) The average weight of the stone is the primary design factor in gradation. Undersized stone, whether by inadequate specification or arising unexpectedly through deterioration from weathering, translates to design deficiencies. Undersized stone can translate into increased maintenance, premature repair or replacement, and occasional failure of the engineered feature. Some example problems related to size are displacement by wave or current action, ice plucking on lakes, and log gouging along streams.

(2) The design of a suitable gradation of material having a reasonable expectation of economical achievement can be a major effort in itself. Potential technical problems can range from a deleterious segregation of stone by sizes to difficulties in achieving rubble mass density and packing.

b. Stone Density. The average unit weight (loosely called density) of rock among individual stones is a design parameter usually causing few problems. Adequate density is of prime importance and receives high priority in evaluation of potential sources during planning and design investigations. However, complications occasionally arise, for example, among sedimentary strata which can vary in density from layer to layer across a quarry face. Where stratification or other variation presents problems, material sampling and testing need to be more comprehensive.

c. Stone Shape. Stone shapes or dimensional ratios are usually limited in specifications to 3:1 length to thickness. Although seldom explained in the past, this importance of stone shape converges from two directions. First, tabular shapes tend to be hydraulically less stable. Second, tabular shapes suggest geological fabric conducive to splitting to even thinner and smaller pieces. See paragraph 3-4c. regarding splitting behavior. Slabbiness may also be detrimental in rockfill applications. Large slabs tend to bridge and form large voids which may result in excessive settlement should the slabs break.

d. Bedding and Zoning. The interaction of large-stone features with adjacent elements of the completed structure can sometimes cause problems. For example, there may be a tendency for deleterious mixing of bedding stone into riprap or visa versa. The interfaces between zones in embankments may deserve similar careful consideration.

e. Foundation. Toe failures and erosional undercutting are problems related to the nature of the foundation, particularly where that foundation is soil rather than rock. Foundation problems are beyond the scope of this manual.

3-6. Construction Problems. Construction problems reflect the problems of economics, materials, and design, greatly intensified by the complexity of a major construction effort under contract. From the CE perspective, many problems are revealed as breakdowns in the inspection and control functions.

a. Material Acceptance. Costly problems have developed as a result of uncertainty or misunderstanding about the acceptability of stone or of a stone source. The wording of some specifications or listing of sources has been construed to have meant approval of material found subsequently to be inferior. Decisions in construction claims tend to show that a large burden rests on the CE staff to define clearly the limitations of materials and sources as a part of a contract.

b. Construction Quality Control. The contractor receives, handles, manipulates, and places the large-stone material with a considerable freedom in selection of equipment and methods. One or more of numerous problems can develop in this setting. For example, some large stone needs a period after quarrying in which to stabilize (paragraph 3-4c.). For reasons of delayed deliveries, such sensitive stone has occasionally been placed immediately following receipt, only to suffer cracking damage subsequently. The contractor quality control program, particularly its reporting function, can constitute the weakness or the strength in construction as explained in paragraph 8-2.

c. Construction Quality Assurance. The program of quality assurance (QA) provides the CE its principal way of minimizing problems during construction with large stone. Accordingly, ineffective inspection carries a share of responsibility for problems that do develop. As an example of a specific problem, a load of stone may be recognized as deficient in stone size and gradation, but the inspector is reluctant to reject it and require returning it to the source at the expense of the supplier. Sufficient provision for QA staffing will largely preclude instances of poor judgment.

3-7. Operations and Maintenance Problems. Problems arising during operations and maintenance usually reflect previous, latent or unrecognized problems. These problems can be correlated in many cases to poor stone characterization and selection processes during project design, and in other cases to construction activities. Regardless, periodic surveillance and evaluation by operations personnel of a project can identify time-dependent degradation of stone before the project is adversely impacted.

CHAPTER 4

INVESTIGATION OF SOURCES

4-1. General. For large-stone construction, it is necessary to locate stone sources and determine the availability, cost, suitability to design, and quality of their materials. Useful methods of geotechnical investigations applicable to investigating sources are reviewed in EM 1110-1-1804. Determining which material is excellent and which is poor is relatively easy, but the intermediate types commonly used are difficult to characterize. Engineer Regulation 1110-2-1150 generally states that sufficient geological information should be included in the feasibility reports and design memoranda to support all findings included therein. Subsequently, the findings become fixed in the plans and specifications. Paragraphs 4-2 and 4-3 below provide general technical background to the investigational and reporting methods reviewed subsequently in paragraphs 4-4 through 4-8.

4-2. Stone Qualities as Criteria. The diversities in climate and in physical exposure in different regions of the United States make suitable, narrow standards of stone quality impossible to specify on a country-wide basis. However, this hinderance in no way lessens the importance of stone quality. In general, the selected stone needs to be adequate to ensure permanence of the structure or feature in the environment in which it is situated. Stone should be durable and sound and free from detrimental cracks, seams, and other defects which tend to increase deterioration from natural causes or which cause breakage during handling and placing. Stone should be resistant to localized weathering and disintegration from environmental effects. The acceptability of stone material should be based on selected laboratory tests as well as visual inspection and service records. Cracks, veinlets, and seams, and overt deterioration are mostly revealed by visual inspection. Documented service records are ideal for quantifying stone quality through performance in the recent past for similar usage.

4-3. Geological Approximation. Stone sources are seldom, if ever, selected on the basis of generic rock type alone. Rock is simply too variable to allow confidence in such predictions. However, the ranking in Table 4-1 has some validity and usefulness for preliminary approximations of stone quality.

Table 4-1. Rock Types Ranked Best to Worst* for Durability

1. Granite	5. Rhyolite and dacite
2. Quartzite	6. Andesite
3. Basalt (Trap)	7. Sandstone
4. Limestone and dolomite	8. Breccia and conglomerate

* Useful for rough estimation only.

Metamorphic rocks that have sometimes proven satisfactory are gneiss and massive schist. Common among unsatisfactory rocks have been shale, slate, laminated schist, siltstone, and porous or chalky limestone. It should be emphasized that many exceptions to the above generic ranking are found, and beyond preliminary generalizations, the test results, performance records, and visual inspections should be the determining factors in selecting a stone source.

4-4. Potential Sources and Listing. The search for suitable sources of large stone for a specific job culminates in the designation of one or more satisfactory sources for incorporation in the special provisions of the contract. Most of these sources come from a permanent district file maintained on all prospective quarries located within a reasonable distance from district projects. Figure 4-1 shows how an investigation of sources begins in the district quarry file and usually leads to the list of sources incorporated in the construction specifications as a special provision.

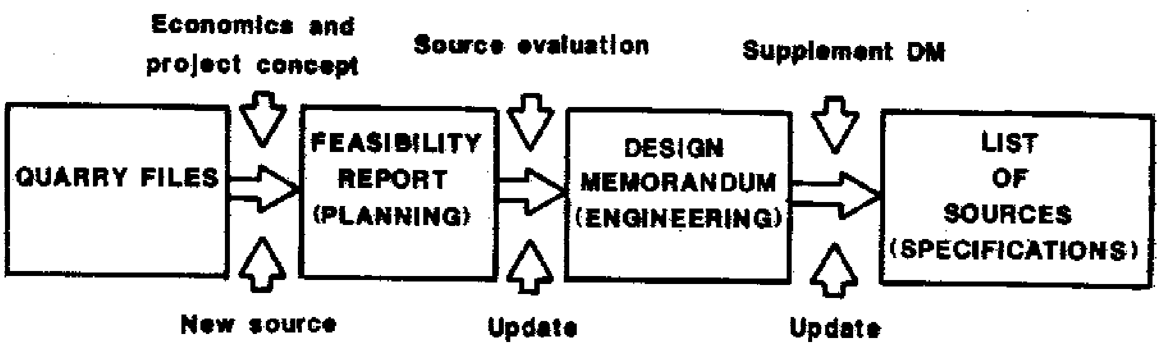

Figure 4-1. Presentation of stone source information in project development

a. Selection Criteria. Candidate sources are evaluated and then reported in appropriate design memoranda (DM's) prior to preparation of plans and specifications. Local sources engender savings on transportation, and project design may even be varied according to stone type available. Sources selected as being capable of producing stone of the required density, size, and quality and located within a reasonable economic distance from the project can be listed in the specifications. Figure 4-2 shows how such listings might ultimately appear as a special provision in a contract with separate sources designated for different stone types. Any source reported in a DM and subsequently listed in the contract must have been evaluated and accepted as a satisfactory source. The use of stone from marginal quarries can result in an inordinate expenditure on quality control and QA with inevitable increased cost and associated problems.

b. Large volumes. Stone for large projects can come from required excavation or field stone deposits in the surrounding area as well as from commercial quarries. If a Government source is listed, it is noted in the specifications that the source is owned or controlled by the Government and will be made available to the contractor within the prescribed contractual constraints. Suitable commercial sources can be listed along with Government sources. A decision to list only Government or only commercial sources or both should be based on economic reasons as well as the availability and suitability of stone.

SP-02. LISTED STONE AND AGGREGATE MATERIAL SOURCES

(a) The following listed sources of stone material and aggregate have been inspected and tested and/or have previously furnished materials that meet the quality requirements specified in the TECHNICAL PROVISIONS. Each source shown contained at the time of inspection and testing and/or previous use suitable in-place stone, gravel, or sand from which the specified material quality and type could be or was produced. More detailed information for each of the listed sources is available for inspection by the Contractor in the ____________ Branch, Engineering Division, of the U.S. Army Engineer District, (Address) ________________ ___________________. The project materials are indicated in accordance with the identification table shown below.

TYPE	DESCRIPTION	SIZE RANGE
A	Armor Stone	9 - 20 tons
B	Underlayer Stone	0.65 - 2.0 tons
C	Underlayer Stone	600 - 1,300 pounds
D	Bedding Stone	Fines - 60 pounds
E	Coarse Aggregate for Concrete	#8 - 1-1/2 inches
F1	Fine Aggregate (Natural sand)	#200 - 3/8 inches
F2	Fine Aggregate (Manufactured sand)	#200 - 4 sieve

LISTED SOURCES
(Dates Indicate Last Inspection and Testing)

1. Basic Industries Co.: quarry at Maple Grove, OH; rock formation, Niagaran Dolomite; F2; inspected 2/2/79 and tested 1/2/78, by _________________ District.

2. Brough Stone Co.: quarry at West Millgrove, OH; rock formation, Niagaran Dolomite; B, C, D, E; inspected 3/2/79 and tested 2/2/78, by _________________ District.

3. Quality Quarries: quarry at Kelleys Island, OH; rock formation, Lucas and Amherstberg Dolomite; A, B, C, D. The chert horizon in Lift 1 is not acceptable for any rock type. Only the massive rock horizons, Lift 1A and the upper 10 feet of Lift 2 are acceptable for armor stone. Inspected 4/4/79 and tested 2/8/78, by _________________ District.

4. Indiana Limestone Co.: quarry at Bedford, IN; rock formation, Salem Limestone; A; inspected 12/11/79 and tested 3/20/78, by _________________ District.

5. Mentor Cartage Co.: stockpiles at Lorain, OH; E, F1; inspected 11/15/78 and tested 2/8/78, by _______________ District.

Figure 4-2. Example list of sources in special provisions. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

c. Small Volumes. For small projects (usually for riprap) where the amount of material involved does not warrant the investigation and listing of sources, it may be stated in the specifications that state-listed and otherwise approved sources can be utilized if inspected and approved by the Government.

4-5. Quarry Files. A general file of records and documentation on quarries and other sources of stone is potentially the most important data source for large-stone construction. The importance is such that stone usage and potential problems can be set in the context of past experience documented in the file. Then developing new data simply amounts to updating the file as necessary to match needs of an upcoming project.

a. Scope.

(1) Quarry files may easily grow to include fifty or more sources in a typical CE district. Each file or folder on an individual quarry can hold numerous reports of visits, inspections, sampling descriptions, test results, service records, claim summaries, and problems as well as many other useful details accumulated over the years. Based on past experience, a high priority should be given to maintaining the file or to restoring the file where it is deficient. Ordinarily, a geologist within the engineering division is the active custodian.

(2) As files grow and are duplicated or loaned out, the need for an effective organization or system will increase and can become critical, even to the extent of detrimental loss of information. Such a system need not be as sophisticated as computerization, but must be well conceived.

b. Source Status. A list of sources (Figure 4-2) should include enough operating quarries to provide competition. More than one source for each material type are listed where practical. Claims have resulted because of restricted source lists. Indicate the zones or horizons that are acceptable. List only the required stone types that the source is potentially qualified to produce. Sources are usefully divided according to current status.

(1) Current Usage. Current sources are those that have been recently tested and have passed all other prequalification criteria. These sources require only a final Government inspection before consideration for listing. Typically, a current source is one which has supplied satisfactory stone of essentially the same sizes to another CE project within the past five years.

(2) Past Usage. Past usage sources are those previously qualified and successfully utilized but now deemed to need further testing before consideration for listing on the new project. The usual reason for needing new tests is that previous tests are outdated, for example, more than five years old. Typically, substantial rock has been quarried in intervening years, and the rock is variable within the source. Necessary testing is usually made at the expense of the Government. The evaluation of the material should be completed prior to considering the source for recommendation.

(3) Undesignated. For completeness, it is appropriate to recognize a third grouping of other potential sources as yet neither used nor tested. This category includes known potential sources not previously used and new

sources as yet unidentified. See paragraph 7-4 regarding unlisted sources at the contract stage.

c. Updating. The new studies undertaken to investigate sources under consideration for a specific project serve to upgrade the quarry file. File updating should be a continuing process. These new data may come incidentally to engineering for feasibility studies or preparation of DM's. Paragraph 4-7 reviews the range of information often assembled and evaluated in preparation of DM's. Ultimately, a source or combination of sources is chosen and used for the project, upgrading the status of that source to current usage and facilitating its evaluation for a future project.

4-6. Feasibility Studies. Feasibility studies are plans made prior to authorization for construction to determine the environmental, economic, and engineering feasibility of a recommended project. General planning guidelines for such studies are contained in ER 1105-2-10, and amplification on general content for those studies addressing geotechnical aspects is found in EM 1110-1-1804.

a. Scope. Detailed studies of potential sources are not usually necessary at the feasibility stage. Instead, there are usually an approximation of material requirements, a preliminary search for possible new sources, and a field reconnaissance and review of existing commercial and Government sources as well as those newly identified. All likely sources, developed and undeveloped, should be considered and visited if reasonable to do so.

b. File Update. Files on quarries and other sources (paragraph 4-5) by expanding over the years become increasingly useful, and they form the basis for evaluating feasibility. Effectiveness of the files for feasibility work is contingent on the files being current. Accordingly, the review and updating of quarry files are important adjunct tasks initiated with feasibility studies and continuing after authorization of the project.

c. Unit-Price Estimate. Estimation of material cost deserves special emphasis here. Estimates can be from commercial suppliers or past experience. Unit prices should include costs of production, hauling, and processing. These data are project-specific and thus not directly available in quarry files. Only the cost at the quarry might be available and even this may need updating.

d. Reporting. Although a separate report is not required, preliminary investigations on materials may be usefully summarized in a section of the feasibility report addressing several reconnaissance aspects.

(1) Study of available data sources for the location of new undeveloped quarry sites. Contact federal and state agencies concerned with the mineral industry. Mapping agencies, state highway departments, universities, mining companies, geotechnical firms, and local governments can also be helpful.

(2) Inspection of road cuts, pits, and outcrops to identify rock type, weatherability, and structure as well as extent of deposit, overburden, topography, and ground-water conditions. This inspection should be sufficient to recognize potential problems such as faint joints that could contribute to deterioration of the stone and provide limitations on size or gradation.

(3) Material cost aspects as in c. above.

(4) Preliminary field work to identify and characterize potential sources, particularly for projects such as breakwaters constructed primarily of large stone. For commercial sources, technical data may be available from the owner which can be used in lieu of CE-developed data. Depending on available funding resources, a minimal testing program may be initiated beginning with petrographic examinations of hand samples or cores. The gradations of stone can also be estimated and compared with anticipated needs.

4-7. Post-Authorization Studies. Post-authorization studies reaffirm planning decisions made in the feasibility studies and refine or reformulate the project based on current criteria and costs. Design memoranda are largely synonymous with post-authorization reports and provide the basis for the preparation of plans and specifications.

a. Scope. Post-authorization studies include sufficient data to establish an up-to-date list of sources containing stone of adequate quantity and quality for the specific project. Inclusion of several sources is intended to increase competition among suppliers. The list and supporting data are usually presented formally in the General DM (GDM) or a Feature DM (FDM). New field exploration, sampling, and testing of stone should be undertaken, complementary to the work previously accomplished for feasibility reports. Where valid information is available from past investigations, it may not be necessary to repeat the sampling and testing of previously used sources. However, geological field verification should be performed on all sources prior to listing in DM's. The need for new sampling and testing sometimes depends upon the volume of stone removed since last CE usage and the variability of stone within the source and whether a satisfactory service record is available. If a satisfactory service record is not available, the requirements should be made more stringent.

b. New-Source Evaluation. In preparation for presenting a list of sources in a DM, rock quality and other aspects of any new sources must be evaluated. Information is assembled on numerous details.

(1) General data including quarry location, name and owner, history, previous use, service record, present users, and highway department files available.

(2) Topography of quarry site and operation. If the quarry is active, show its dimensions with respect to the plant, working face, benches, haulage roads, stockpiles, and waste areas.

(3) Quarrying methods indicating explosives, blasting procedures, stone handling, and storage capabilities. List the sizes and quality of stone produced. Measure the largest stone size currently produced and estimate the maximum stone size that can be produced by the quarry. Describe the onsite equipment, hourly production, and production capacity.

(4) Transportation including distance to proposed project. Explain the method of transportation or combinations of methods available.

(5) Water conditions such as potential flooding, seepage, and saturation.

(6) Subsurface information where available.

(7) Geologic map and profile showing lithologic units, production beds, current ledge, gradational changes, principal joints and other structures, color, and texture. Chert, clay, shale, and platy seams are logically important as are rock damage and fracturing due to blasting and the nature of the overburden. Locate and describe areas in the quarry where stone is unsuitable for the project. Include colored photographs of outcrops, cores, and quarry faces (optionally mark the photos to emphasize features).

(8) Cost of stone at the quarry for design sizes.

(9) Test results as prescribed in Chapter 6.

(10) Willingness or desire of quarry to participate.

c. Old-Source Documentation. Much of the data required to describe an old quarry and its materials in the detail required in GDM's and FDM's should already be available in the comprehensive quarry file (paragraph 4-5). In that case the task amounts to applying the updated quarry file (paragraph 4-6b) to specific project needs such as stone size, gradation, and quantity. Transportation cost is another important specific. To the extent that the quarry file is out of date or otherwise inadequate, additional studies and testing will be needed. The objective is to provide information comparable to that required for new sources (paragraph b. above), regardless of whether the potential source is new or old.

d. Processing Study. A review of processing methods, costs, and potential problems should be considered for rock sources likely to need processing to meet the gradation requirements. Experience and capabilities in processing large stone are advantageous. Also, a large sample can be processed to the gradation and particle shape requirements of the project by grizzlying and other means appropriate to simulating full scale. A test shot conveniently produces a large, typical sample (paragraph 4-8b) suitable for study. Stone counting should give information on which to base an estimate of processing needs and wastage and should also provide an indication of potential problems such as volume shortfalls and marginal products such as tabular stones.

4-8. Sampling.

a. Rules. The selection of samples for laboratory testing or more general examination is an important step in source evaluation since the results will only be as representative as the samples. Rock in a source is rarely homogeneous and its properties probably vary both vertically and laterally. Accordingly, some general rules or precautions for the selection of samples need to be recognized.

(1) Representation of method. A sample must be representative of material produced by excavation and handling methods expected in full production. In this way, hidden defects such as those from blasting will not be overlooked. Ledge sampling is recommended where the operation is full-faced.

(2) Natural stone sizes. The gradation and size of stone reflecting jointing and bedding effects may need to be represented accurately.

(3) Critical stone sizes. Small stone pieces containing few partings, beds, and joints may be biased toward favorable test results. This misleading scale effect tends to disappear when full-size stones are taken for the sample.

(4) Representation of defects. A sample should include flaws common to the stone to whatever degree flaws will remain and be included in stone produced routinely. When the spacing of seams or other possible flaws is less than the average required stone size, stones with seams must be included in the sample to reveal delayed opening. The abundance of seamed rock must be measured also.

(5) Large-stone sampling. There is an inherent problem of drawing valid conclusions from huge samples composed of only one or few stone pieces.

b. Trial Blasting. Representative stone samples for testing can be advantageously taken from a trial shot conducted in the same manner as expected in production blasting. In Government quarries or required excavation, the trial can be organized and conducted under the direction of the Government and accordingly should produce representative results (paragraph 5-4). Test quarrying is sometimes coordinated with test fill studies in which compaction methods are explored (paragraph 5-5). Test blasting is not possible in some commercial quarries since the Government is not in control. However, an explanation of the usefulness of such trials may convince the quarry operator to test on his own.

c. Stone Size.

(1) Sampling is severely constrained by cost where the stone material is composed of large blocks. Sophisticated statistical concepts involving estimators are seldom, if ever, applicable. Instead, the strategy for each sampling effort emphasizes the organization of sampling and testing to reveal likely problems and the degree to which those problems would affect project design requirements and material durability. See a. above and Chapter 6 regarding size and testing needs.

(2) For material tests and examinations concerned with relatively simple indices of physical properties such as abrasion loss, the sampling prior to laboratory preparation needs to follow the guidance in a. above since full-size stones are not used and a scale effect is likely.

(3) For physical tests requiring large specimens, such as the large slabs tested for freeze-thaw resistance, observe the limitations of the laboratory equipment; otherwise use the largest size within the specified gradation up to 2,000 lb.

d. Bulk-Sample Size. Bulk sampling may be appropriate where the stone-size gradation and its effect on material suitability are perceived as especially critical to design. Bulk samples may exceed 10 tons. Elsewhere, a modified sampling procedure will be sufficient, wherein the sample is left on the ground and evaluated visually. Another option is to evaluate a truckload of similar material selected randomly during operations. Obviously, the judgments exercised in defining, assembling, measuring, and evaluating are critical.

CHAPTER 5

EVALUATING SOURCES AT PROJECT SITE

5-1. General. Projects requiring large volumes of rock for massive structures such as embankments use rock from required excavation or develop a source quarry on adjacent Government land. These prospective new sources are untested with respect to the suitability of rock and the available volumes, so that they must be investigated in considerable detail. Investigations are conducted by the CE geotechnical staff, either by contract studies or with in-house personnel and drill crews. Where the volume of rock is very large, an FDM or appendix on quarries and rockfill characteristics may be needed.

5-2. Geological Mapping.

a. Geological mapping and characterization of rock materials exposed in outcrops are essential parts of project site selection studies or detailed investigations focused on project design. An accurate picture of geology of the project area is developed and integrated with the specifics on rock strength and variability, joint spacings and orientations, weathering effects, and landsliding. Mapping coverage normally extends outward from the immediate project to the surrounding area influencing or influenced by the project and encompasses sites situated properly for supplying stone or rock fill.

b. Geological details should be expanded from those described in a. above in any areas pinpointed specifically as prospective quarry sites. This increased scrutiny and documentation at potential quarry sites should at a minimum provide all rock types and adequate descriptions of surficial weathering, hardness, and joint spacings sufficient to draw cross sections and to understand the subsurface conditions in three dimensions. Volumes of rock in place can then be calculated. This requirement for subsurface projections are seldom satisfied by surface mapping alone, and core drilling is usually a necessary supplement.

5-3. Subsurface Investigations.

a. Core Drilling.

(1) The most effective means of obtaining subsurface information is by core drilling to recover continuous samples of rock (CE-1201). Core drilling is costly and mostly limited to post-authorization studies where it is often indispensable. Most core drilling is done in preparation of DM’s and is done not only in foundation areas at the immediate project site, but also in the surrounding area to a radius of several thousand feet depending on project study requirements. Numerous uses and methods of core drilling and documentation in project investigations are explained in EM 1110-1-1804. Associated techniques such as borehole photography and pressure testing, occasionally useful in evaluating stone sources, are also reviewed there.

(2) Since rock materials taken from required excavation are usually explored thoroughly in the course of core drilling to define engineering characteristics and boundaries of rock to be excavated, additional holes specifically for outlining the source of stone are unnecessary. Factors related to quarrying and production of stone are included for characterization at the

time the coring is accomplished. These product-related factors center on natural joint spacing as well as quality and variation in quality of intact stone.

(3) The standard NW-size core of 2.15-in. diameter is ideal for evaluation of stone sources. Tests for unconfined compressive strength may be made and the core is large enough for observing the degree and arrangement of jointing. Larger core may be useful for other testing and will sometimes reveal more details in zones of soft or fractured strata. Vertical holes are standard for defining stone sources, although inclined holes may be more practical on steep slopes or where the geological structure of the rock mass is suited to the use of inclined holes. The inclined holes are best for intercepting and characterizing predominantly vertical joints but are more costly.

(4) Engineer Manual 1110-1-1804 reviews the information to be included when logging core and quantitatively accounting for drilling observations and zones of poor core recovery. Each stratum or lithological unit should be described systematically for formation designation, rock type, hardness and degree of weathering, texture and structure, and evidence of material instability such as a tendency to slake after exposure. These general characteristics are always important, but extra emphasis must be placed on joint-related features. Such features as joint spacing, joint orientations, fissure width, fissure filling, alteration, and secondary mineralization along joints all relate to the character of the rock eventually produced from the source. The optimum picture can sometimes be developed by combining stratigraphy and structure from core drilling with jointing details from cores and surface outcrops.

b. Pits and Calyx Holes. Calyx holes and pits are occasionally drilled or excavated to investigate a potential rock source. The fresh, large exposure is especially useful since the undisturbed sidewall can be mapped, photographed, and studied in its entirety. A calyx core, typically about 3 ft in diameter, also presents an exceptional sample for examination and testing.

c. Geophysical Surveys. Geophysical surveys are an option for subsurface investigation occasionally useful as a supplement to core drilling. Engineer Manual 1110-1-1802 reviews methods and equipment but recognizes the importance of past experience with specific methods in obtaining valid results.

5-4. Test Quarry.

a. A test quarry may be feasible where large quantities of rock will be needed. Test quarries range from little more than large test pits up to excavations of hundreds of thousands of yards accounting for as much as ten percent of all required excavation. A test quarry is useful where there are questions about the suitability of rock, especially in required excavations, and is often made in conjunction with test fills exploring ultimate placement (paragraph 5-5). Test quarries also provide information on cut slope design, appropriate blasting techniques, and methods for processing materials. Results of quarry tests help designers and prospective bidders anticipate effective drilling and blasting methods and the characteristics of the rock. A well conducted test program is useful but expensive. Consequently, a test quarry, if possible, is always located within the required excavation or planned quarry and the product is used directly or stockpiled for later use. Conditions must be representative of the large volume to be excavated later so that results are generally applicable.

b. The upper fragment size is fixed by geological factors. Other sizes and gradations can be influenced by the blasting techniques as explained in EM-1110-2-3800. If smaller rock sizes are needed, fragmentation may be increased in several ways.

(1) Increase the powder factor.

(2) Vary the blasthole spacing or burden.

(3) Modify the firing sequence or delays.

(4) Use high-velocity explosive or blasting agent.

(5) Add satellite blastholes.

c. Assuming that the source has been confirmed by mapping and drilling to have adequate volume and suitable upper block size, the product characteristics needing investigation by test quarrying are the overall size gradation, the yield or percentage of critical size classes, and the overall rock quality. One or more of the blasting parameters indicated above are varied in test shots. For each test, the blasted rock is gathered, sized or screened, and weighed to obtain gradation. As individual tests are completed and gradations are determined, modifications to the blasting techniques can be made. The final results are used to determine which combinations of blasting parameters fulfill design requirements.

5-5. Test Fills. Test fills are utilized as an optional design technique for evaluating the suitability of stone for embankments. Preliminary information is developed on the rock fill as it will be used in construction. Among controlled variables are fill lift thickness, number of passes, compaction equipment type, and test-quarry parameters. Results are evaluated in terms of material degradation, segregation, density, grain-size distribution, and operational problems. Engineer Manuals 1110-1-1804, 1110-2-1911, and 1110-2-2300 explain test fill programs and how they are integrated with a test quarry program. The important measurement of in-place density is described in paragraph 6-3f.

5-6. Estimating Volumes.

a. The quantity of rock material available at a new site must be carefully estimated. Difficulties such as deterioration of quality or the presence of water may arise which can reduce the estimated output. For this reason, quantity estimates should be conservative, and it is necessary to select a site containing a greater volume than is required, rather than one which is estimated to meet the immediate requirements.

b. The volume is estimated by selecting a horizontal reference plane, such as excavation grade or a convenient quarry floor level, and computing the volume by summing among parallel vertical cross sections or smaller triangular prismatic increments. Thickness of the deposit is normally tied directly to core borings which also form the vertical edges of the volumetric prisms. Overburden and weathered rock should be carefully delineated and excluded from rock volume calculations. Separate gradation zones may sometimes be distinguished on the basis of detailed core logs provided there is a need for separate materials and a capability of quarrying those zones individually. To convert from quantity in place to quantity when broken, a multiplying factor is usually needed. Volume bulking factors for fresh rock average about 1.4, but specific values range widely. An accurate estimate may be based on experience or on a measurement obtained in a test quarry or test fill.

5-7. Environmental Constraints. Engineer Manual 1110-2-38 emphasizes the preservation of environmental quality in all project work. Accordingly, the evaluation of a potential stone source should consider the extent that a quarry development might detract from natural beauty and otherwise cause environmental concern during and after operation. The quarry area should be graded and landscaped as practicable to restore a natural appearance and to control erosion upon closure.

CHAPTER 6

STONE TESTING

6-1. General. Stone testing is part of the investigation of sources but involves laboratory testing and other methods sufficiently distinct to warrant separate consideration in this chapter.

a. Physical testing and examination are important in two or more separate ways. First, the direct preview of physical characteristics and behavior of the stone material is useful in planning and design. Second, some contract specifications are stated in terms of these physical properties, and the properties may reemerge again as important to construction inspection. The determination of which methods and tests are most revealing of stone quality must incorporate considerations of loading to be imposed, climatic conditions, and severity of exposure of the stone in the project area. For example, freezing and thawing effects are important considerations in the northern regions. Attention usually focuses on visual characteristics, unit weight, and porosity, and on durability against abrasion and wetting and drying as well as freezing and thawing. Standard tests according to ER 1110-1-2005, Handbook for Concrete and Cement, Rock Testing Handbook, and American Society for Testing and Materials are preferred, but simple, rapid and much less formal methods of evaluation are also useful and sometimes even more revealing than standard tests.

b. Methods appropriate to evaluate large stone may vary from region to region, for example, cold versus warm regions. Generally, some of the testing should simulate the critical environmental factors. However, even methods developed initially to evaluate small stone for concrete aggregate have been useful (EM 1110-2-2000). Poor results from testing of aggregate abrasion can hardly be explained as other than indicative of poor stone, regardless of the intended purpose of the stone. For this particular test, the problems come in the converse, since good abrasion test results may indicate unrepresentative sampling rather than good stone (paragraph 4-8a). Since no single test is satisfactory for predicting the performance of all stone types, it is usually best to apply a combination of tests based partly on local experience.

c. Nonapproval of locally available stone usually increases project costs since stone meeting the requirements may have to be hauled from another source at a substantial distance. As a check, compare the test results against service records and results of the field examination. Using good judgment guided by test results as well as all other information is usually the appropriate strategy for avoiding unnecessary costs.

6-2. Laboratory Methods. Laboratory testing is ordinarily accomplished by or under supervision of the Government. The factors in sampling material for testing are discussed in paragraph 4-8. In choosing testing methods, try to represent important design or environmental aspects. More than one test method is usually necessary. The ranges of acceptable test values in Table 6-1 should be regarded as broad generalizations still needing verification or adjustments for local experience. Test procedures are in accordance with methods in the Handbook for Concrete and Cement unless indicated otherwise.

Table 6-1. Criteria for Evaluating Stone

Test	Approximate Criterion for Suitability*
Petrography	Fresh, interlocking crystalline, with few vugs, no clay minerals, and no soluble minerals
Unit Weight	Dry unit weight 160 lb/cu ft or greater
Absorption	Less than 1 percent
Sulfate Soundness	Less than 5 percent loss
Glycol Soundness	No deterioration except minor crumbs from surface
Abrasion	Less than 20 percent loss for 500 revolutions
Freezing-Thawing	Less than 10 percent loss for 12 cycles
Wetting-Drying	No major progressive cracking
Field Visual	Distinctions based on color, massiveness, and other visual characteristics
Field Index	Distinctions based on scratch, ring, and other physical characteristics
Drop Test	No breakage or cracking
Set Aside	No breakage or cracking after one season cycle

* Marginal test results usually indicate the need for supplemental testing for definitive evaluation.

a. Petrography.

(1) While petrographic examination is often essential for evaluating the suitability and potential durability of large stone, it is limited to qualitative rather than quantitative appraisal. Petrographic examination identifies the composition and homogeneity of samples and their general physical condition and should recognize potential parting planes. Although the existing method CRD-C 127 is directed to petrographic examination of concrete aggregates rather than large stone, useful guidance can be found under its ledge rock category. The American Society for Testing and Materials (ASTM) designation is C 295. Beyond that guidance, one should emphasize flaws that may be found in large stones. Accordingly, samples selected at the source should include flaws common to large stone that is or will be produced. Supplemental descriptive information should be supplied to aid the petrographer in giving a total evaluation of the rock for its intended use.

(2) Among special methods for studying large stones are polishing, etching, and staining of cut slabs. Serious defects identifiable in these

ways are platiness, shaliness, slabbiness, and a tendency to slake. Potential for such defects may be present in the form of clay seams, bedding, fractures and joints, rounded or planar surfaces, nodules, and indications of weathering or chemical alteration. High-quality stone sometimes exhibits an interlocking fabric and absence of bedding. A useful technique is to wipe the rough or cut stone with a wet cloth to emphasize defects.

b. Stone Density. Intrinsic properties of stone related to its mass or density are important in design: unit weight, specific gravity, and absorption. Appropriate test methods are found in CRD-C 107. Tests are usually conducted on scraps remaining after slabs have been cut for other tests.

(1) Specific Gravity. Care should be exercised in using specific gravity to characterize stone since only the solid components (mineralogical) are considered in true specific gravity. However, the terms "apparent specific gravity" and "bulk specific gravity (saturated, surface-dry basis)", adapted from aggregate testing, are entrenched in past experience, and any departure, regardless of its sensibility, may introduce ambiguity. Carefully defining and limiting such terms in the specifications is essential to avoiding ambiguity. A more useful parameter sometimes is dry unit weight in which the important parameter porosity is included. However, specific gravity of solids must be determined for calculating porosity unless specific gravity of solids can be estimated confidently from the petrographic analysis.

(2) Unit Weight. The overall stone density is conveniently characterized in terms of dry unit weight to take account of porosity as well as mineral density. Commonly used rock types range from about 140 to 160 lb/cu yd. There is a tendency for rocks with dry unit weight exceeding 160 lb/cu yd to be among the least troublesome. Toward and below the low end of the common range, the durability of stone tends to decrease as a reflection of increasing porosity.

(3) Absorption. A portion of rock porosity functions to draw water in from the surface by absorption. Absorption of water is a common precursor of stone deterioration, and the absorption test is particularly useful for revealing vulnerability. Absorption values exceeding two percent generally suggest potential durability problems. Values in the range from one to two percent are common among suitable and unsuitable stone materials alike and, therefore, these values are less diagnostic. Absorption below one percent usually indicates stone of good quality.

c. Soundness. Tests which subject the rock to severe chemical treatments are intended to reveal weaknesses in a shortened time frame. The dissimilarity in comparison to natural weathering is sometimes a source of concern in translating laboratory results into estimates of stone performance. Both tests below are relatively simple and inexpensive.

(1) Magnesium Sulfate. Standardized testing follows CRD-C 137, a method developed for evaluating aggregate. Samples soaked in a sulfate solution will break apart when the solution invades weak planes or cracks and then crystallizes upon heating and drying. A major shortcoming of this test for large stone is that the test specimens are broken from the large stone to a weight of approximately 100 g each. The breakage and segregation will eliminate weak areas when preparing the sample, and test results tend to be too

favorable. Nevertheless, a loss exceeding 10 percent generally indicates poor-quality stone. The test is usually meaningful for sedimentary rocks when augmented by an absorption or abrasion test, except for some sandstones.

(2) Ethylene Glycol. Standardized testing follows CRD-C 148. This method is used to detect the presence of swelling clay minerals and provides an indication of the severity of deterioration of the stone to be expected in service. Ethylene glycol enters the clay mineral structure and causes rapid expansion. The test has been particularly useful in distinguishing questionable varieties among altered basaltic rocks.

d. Abrasion. The Los Angeles abrasion test follows method CRD-C 145. The test is useful in determining the resistance of stone to abrasion and battering and also provides an index of toughness, durability, and abundance of incipient cracks. The significance of the test for large stone is indefinite since individual test pieces are limited to about 100 g in weight. Weaknesses along widely spaced surfaces are missed in this test. Roughly, losses less than 20 percent for 500 revolutions are generally considered satisfactory while losses exceeding 40 percent suggest probable poor service. The test is sometimes effective for evaluating metamorphic rock, particularly when supported by absorption and sulfate soundness tests.

e. Freezing-Thawing.

(1) The standard method follows CRD-C 144, but modifications for large slabs cut perpendicular to bedding or for whole large stones are preferred by some laboratories because of better representation. Large-stone testing is discussed at length in Evaluation of Quality and Performance of Stone as Riprap or Armor. Regardless of details, a consistency in procedure is desirable, at least within a division laboratory and its service area. The test simulates the effects of a cold environment by inducing numerous cycles of freezing and thawing through a bath of water and alcohol. Again, the number of cycles to which the specimen is subjected and the overall interpretation of the results should be determined on a district or laboratory basis. The number of cycles commonly exceeds 10, occasionally going to 50 or more, depending upon local climate or established method. Failures along weak surfaces should be given special attention since their impact is easily underestimated.

(2) For small pieces wherein bedding and jointing are insignificant, a loss of 10 percent by test CRD-C 144 should cause concern. Large stones and slabs losing more than 25 percent during 12 cycles will probably not perform well in service. Large stones losing no more than 10 percent commonly do perform satisfactorily. The effects of geological structure and other important characteristics of a material are less likely to be overlooked when at least three specimens are tested simultaneously in the same test bath.

f. Wetting-Drying. Testing large stone for wetting and drying effects generally follows division-level guidance since no standard method is recognized nationally. A method suitable for testing large stone has been proposed in Evaluation of Quality and Performance of Stone as Riprap or Armor. No generally applicable experiences are available correlating quantitative test results and stone service in place. Considerable judgment has to be exercised even in descriptions of scaling and flaking, random cracking, and slabbing along bedding and similar fabric. Photographs are especially helpful in characterizing the rock and its behavior in regard to deterioration.

g. Other Tests. Tests other than those mentioned above could prove helpful in distinguishing stone suitable for large-stone construction. These tests usually involve inexpensive and quick methods for determining index properties. They include tests for compressive strength, Schmidt rebound, and water content. Preferences usually reflect experience and satisfactory results within an individual district or division.

6-3. Field Methods. Field methods include numerous tests and techniques that can be conducted quickly and inexpensively. Some of the tests provide on-the-spot evaluation and are suitable for QA. However, visual inspection and simple field tests ordinarily should not be considered as conclusive in regard to acceptability of stone.

a. Visual Examination.

(1) The visual examination of rock in the field corresponds in some ways to the petrographic analysis in the laboratory but without the benefit of equipment for preparation and detailed examination. The lack of sophisticated equipment is sometimes more than balanced by the large volume of material available for examination. The visual examination in the field is not limited to the stones in a face pile or stockpile but should include rock in place.

(2) The specific features of most interest are clay seams, bedding, fractures and joints, rounded or planar surfaces, deleterious materials, chert nodules, and indications of weathering or chemical alteration. Frequently, important observations can be made on durability by comparing the features and conditions of stone in the face with features in freshly blasted and stockpiled or wasted stone from operations months or years in the past. The suitability of the material for size and gradation is a high-priority question distinguished separately in paragraph e. below.

(3) The important product of a visual inspection in the field is an adequate documentation of observations. Descriptions and maps will ordinarily be included in a report for the quarry file along with test results and photographs.

b. Index Tests. Index tests may be performed in the field where the necessary testing equipment is easily portable. The choice of index test generally reflects the experience of the district. Schmidt rebound is an example of an index easily extended to field usage; however, its basic usefulness is not well established. Even a parameter as simple as scratch hardness can be formulated into usefulness where numerous values roughly distinguish subtle variations within rock otherwise appearing to be uniform. Color is another potentially useful index parameter; for example, brownish gray tones occasionally distinguish slightly weathered stone from fresher rock with straight gray tones.

c. Drop Test.

(1) A drop test provides an immediate evaluation of the suitability of very large stone material and is also potentially useful for quality control

and QA. For comparability, the test stone(s) should be dropped from a bucket or cherry picker, or by other means from a height half the average diameter of the stone onto a rigid surface or second stone of comparable size. Dumping with other stones from a haulage truck is usually unsatisfactory practice.

(2) The stone should be examined carefully before testing as well as afterward. Failure criteria are development of new cracks, opening of old cracks, and loss of small pieces from the surface.

d. Set Aside. The set-aside test is a particularly good method of forewarning of future problems with stone deterioration. Typically, large stones are set aside in the quarry and immediately examined and photographed. These specimens are examined and photographed again after a predetermined period of exposure. Stone that endures without signs of deterioration may be considered for acceptance. Observations from set-aside exposure are potentially useful in identifying materials in need of curing. The one disadvantage of this test is the long exposure period required, that is, preferably a year or more.

e. Stone Size Count. Careful measurements of stone size and gradation are appropriate for evaluating a quarry or later for evaluating the suitability of stone destined for the project. Estimates short of actual counting or measuring individual stones should be questioned for accuracy. The preferred measuring technique for large stones in the sample is with a tape or caliper and a scale. It may be appropriate to screen or grizzly the smaller stones. Gradation is quantified by weight in each size class or stone by stone on a cumulative basis.

f. Fill Density. The unit weight of the stone material in place is a particularly important parameter bearing on strength, settlement, and drainage of rockfill embankments. Test fill investigations (paragraph 5-5) use fill density as a key criterion for confirmation of design and selection of suitable construction methods, but the test is also useful for spot checking placement. Five steps are involved.

(1) Place 6-ft diameter steel ring or other template on a level surface of the fill.

(2) Remove stone material inside to the depth of interest, leaving the wall of the hole undisturbed.

(3) Weigh all material removed in a dry condition.

(4) Line hole with flexible impermeable sheet and fill to the surface with a measured volume of water.

(5) Calculate the unit weight from the weight and volume in (3) and (4) above.

6-4. Test Blasting. Trial or test blasting constitutes large-scale testing to confirm or demonstrate that an unproven source and quarry methods are capable of producing the desired large-stone products. Confirmation comes through stone counts by size and with visual examination of the product. Several portions of the source may be tested to demonstrate uniformity over a large area. Variations in blasting patterns and techniques may also be investigated. Test blasting may be undertaken by contract or elsewhere may be on the initiative of the contractor or stone producer.

6-5. Reporting Results. Material is accepted or rejected largely on the basis of test results and geological characteristics. Accordingly, the results need to be organized and reported with care. The following are helpful in organizing reports.

a. Standard Forms. Where available, use forms established for reporting the results of testing by standard methods. Supplemental information may also be appropriate.

b. Raw Data. Work sheets should be preserved in files for ready reference.

c. Evaluation. Test reports should provide the test results completely and in a form to facilitate evaluation by others later. The evaluation and supporting interpretations by the district should be clearly distinguished from laboratory testing and results.

d. Comparisons. The testing laboratory is in the position to make a useful comparison of results with past results of testing similar stone. In this way the experience and judgment of the staff are passed along for consideration.

e. Summarization. A summary of test results is helpful where extensive raw data and work sheets have been included in the report.

6-6. Evaluation Criteria. The use of testing criteria to evaluate stone materials is complex and should proceed with great care, especially when dealing with new sources or new portions of old sources. The evaluation should come after completion of testing and examination and reporting of results. Guidance on possible testing criteria is provided in paragraphs 6-2 and 6-3 as part of the explanations of the test methods. These numerous generalized criteria are also summarized in Table 6-1. Exceptions to the criteria are so plentiful that the criteria provide little more than first estimates of stone performance that may or may not prove valid within a region. Their principal value comes when evaluations based on test criteria reinforce other indications and thus increase confidence in judgmental decisions in planning and contracting.

CHAPTER 7

CONTRACT DESIGNATION

7-1. General. A list of stone sources is usually supplied as a part of the contract specifications. The contractor is allowed to furnish large stone from any listed source. An unlisted source may be used by the contractor provided that subsequent inspection and testing by the Government indicate that materials are in compliance with the contract specifications. To minimize business risk and possible delay associated with opening a new quarry, many contractors prefer to use listed quarries. After the award of the contract, the contractor is usually required to designate in writing the source or the combination of sources proposed for each specified stone material. Determining the suitability and use of large stone from required excavation for project construction (Chapter 5) is the responsibility of the Government. Contracting should always conform to the Federal Acquisition Regulation.

7-2. Specifications.

a. Riprap Construction. Guide specifications for riprap are available in CE-1308. These specifications are used for construction contracts as appropriate and are supplemented with the list of sources of stone for the specific projects.

b. Breakwater and Jetty Construction. Guide specifications are not available Corps-wide for construction of breakwaters and similar massively armored structures. Previously satisfactory job specifications are often used as a nucleus and carefully modified for project location, conditions, available transportation, and construction methods (Figure 7-1). Use of recently approved project specifications or sections thereof is in accordance with paragraph 7d. of ER 1110-2-1200.

> Each stone shall be individually placed by equipment suitable for lifting, manipulating, and placing stones of the size and shape specified. No stone shall have a longest dimension less than two or more than three times its shortest dimension as determined along perpendicular axes passing through the approximate center of gravity. Each stone shall be placed with its longest axis perpendicular to the armor slope. Placing efforts shall ensure that each stone is firmly set and supported by underlying materials and adjacent stones. Loose stones shall be rest or replaced.

Figure 7-1. Example of method specification for armor-stone placement. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

c. Rockfill Construction. Satisfactory construction of an embankment of rock fill often depends heavily on the construction practice. Accordingly, it has been common practice to prescribe in the specifications the methods of construction as well as the results to be obtained. Such specified methods include type roller, lift thickness, and number of passes. Lifts are commonly limited to a maximum thickness known from previous experience or from field tests to produce the required overall results. Practices capable of leaving detrimental stratification or low-density pockets are explicitly prohibited in specifications. Engineer Manual 1110-2-2300 gives general guidance on design and construction of rockfill dams.

7-3. Listed Sources.

a. Listed sources are those identified in the GDM or in the FDM on construction materials. Changes and updating may be necessary, particularly after a long delay since preparation of the DM. Special factors or conditions which might conceivably interfere with satisfactory supply from the listed source need clarification. The exclusion of certain rock strata or the use of special quarrying procedures such as a low bench height are examples of such limitations.

b. When a listed source is selected for use, the contract usually requires that the contracting officer be notified in writing of the selection 30 calendar days before the material will be used in the work. The written notification should identify the specific areas, ledges, lifts, and geologic units to be used within the source. The contractor should be notified of approval or approval with restrictions in regard to the choice within the contractually allotted time.

7-4. Unlisted Sources.

a. Requirements. The contractor is usually allowed to designate one unlisted source or combination of sources for each class of stone. Once that unlisted source is selected, its name and location must be furnished to the Government in writing. Additional useful information such as areas, lifts, specific strata, and available laboratory testing records is usually required. Next, the contracting officer’s representative should inspect the selected source to verify the presence of material that meets all requirements specified in the technical provisions. Stone from the proposed source must then be sampled and tested.

b. Sampling and Shipping. The contractor should provide suitable samples for testing as required by the contract specifications. Figure 7-2 shows how this requirement might be presented in the special provisions of the contract. It is axiomatic that samples be representative of the size and quality of stone to be used in the project.

c. Testing. Testing necessary to evaluate an alternate source selected by the contractor but not among the listed sources should be made at the Government’s expense at a division laboratory or substitute approved by the Government. The required testing and criteria for acceptability should be stated in the contract. Ambiguities should be avoided and terms such as "suitable" and "durable" should be defined. Guidance is provided in Chapter 6.

Sampling and Shipping. The Contractor shall provide for a suitable sample(s) of the materials proposed to be furnished for testing and approval. Stone and aggregate sample(s) shall be furnished and delivered to the laboratory ninety (90) calendar days prior to the need of such materials at the site of the work. The ninety (90) days time shall begin at the time the samples are actually received at the Laboratory. Samples for acceptance testing shall be provided as required by Sections _____ and _____ of the TECHNICAL PROVISIONS. Samples shall be representative of the size and quality of materials to be used on the project. Material actually furnished under the contract shall be of quality at least as good, in the judgment of the Contracting Officer, as sample(s) furnished. The Contracting Officer's representative shall be present during sampling and approve the selection of all samples before shipment. The Contracting Officer's representative may personally select all samples if he so elects. Sampling and shipping of sample(s) shall be at the Contractor's expense. Sample(s) shall be selected from the proposed sources of supply and shall be shipped and/or delivered to the Director, Division Laboratory, Corps of Engineers, ________________________(Address)________________________________.

Figure 7-2. Example special provisions on sampling representative stone from unlisted source of armor. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

d. Completion Time. The time for completion of Government testing should be realistically chosen and coordinated with the Government laboratory of choice. If a commercial laboratory is used, an appropriate length of time including sample delivery, testing, and data analysis should be stated. Guide specification CE-1308 indicates at least 60 days of lead time for riprap. The stated contract completion time should not be extended for sampling and testing unlisted sources.

e. Unsuitable Unlisted Source. When an unlisted source designated by the contractor is disapproved by the contracting officer, the contractor must choose a listed source.

7-5. Modification. Variations possible within some material types have occasionally led to production of stone differing substantially in unit weight from requirements in the specifications. To avoid design deficiencies, an appropriate technical provision for redesign has been used in some contracts (Figure 7-3). The contracting officer may modify the stone sizes requirement and layer thickness and make a new determination of quantities as a part of the approval process.

14.3 Allowable Range of Specific Gravity and Conditions for Redesign. If the Contractor, after award of the contract, requests approval of stone from a listed or other source(s) which has a bulk specific gravity, saturated surface dry basis (SSD), whose limits are different by more than plus or minus 5 percent from those specified in Section __ of TECHNICAL PROVISIONS, it shall be cause for the Contracting Officer to redesign the stone sizes and/or layer thickness subject to the following conditions:

(1) Savings due to redesign based on changes in specific gravity, if any, shall not be subject to the clause entitled VALUE ENGINEERING INCENTIVE CONSTRUCTION of the contract GENERAL PROVISIONS.

(2) Only one such redesign modification will be allowed. The required completion time shall be extended not more than 30 days as a result of redesign for any reason, including acts of the Government.

(3) The modified design bulk specific gravity, SSD of stone proposed to be used shall conform to that specified in paragraph __.

(4) The stone sections of the required structure will be redesigned by the Government at Government expense. Such redesign will be based on the Contractor's proposed revision of the specified design average bulk specific gravity, SSD and will include any required revisions to allowable tolerances.

(5) The Government shall be allowed a period of 21 calendar days after receipt of the test records for the bulk specific gravity to make the redesign.

(6) Upon completion of the redesign, it will be furnished to the Contractor, including revised estimated quantities for the PRICE SCHEDULE, based on the proposed modified average bulk specific gravity SSD.

(7) There will be no change in the unit prices, prior to application of the VARIATION IN QUANTITIES clause of the contract.

(8) When stone to be furnished is within the specified range of specific gravity, no redesign will be considered or made.

Figure 7-3. Example specificatiosn for modifying design after awared of contract. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

CHAPTER 8

QUALITY CONTROL AND QUALITY ASSURANCE

8-1. General.

a. Quality control and quality assurance are defined and explained generally in ER 1180-1-6 and EM 1110-2-1910. In the context of construction with large stone, it is useful to distinguish within the program of contractor quality control the responsibility for material suitability as well as the broad responsibility for satisfactory construction procedures and results. The following guidance is organized with this distinction in mind. The quality assurance program of the CE tracks similarly in its role of monitoring quality control and achieving the specified engineered structure.

b. Satisfactory construction is realized by adherence to the requirements of structural or hydraulic design. Toward this objective, plans and specifications establish requirements of stone material and construction from among several key factors.

(1) Source, including specific stratum.

(2) Size and gradation and limiting percentage of undesirable materials.

(3) Shape limit, as a ratio of length and thickness.

(4) Stone quality characteristics.

(5) Engineering design such as unit weight, layer thickness, and tolerance as well as (2) above.

(6) Placement limitations such as not dropping stones.

(7) Packing, also expressed as keying.

(8) Quarry limitations such as blasting patterns and choice of blasting agent. Such restrictions are seldom used.

(9) Test methods, including frequency.

8-2. Contractor Quality Control. Contractor quality control (CQC) refers to the contractor's own system for managing quality of construction activities as well as activities of suppliers and subcontractors. A daily report is usually required to summarize CQC.

a. Specifications.

(1) The contract documents normally establish the minimum level of quality and control required in a project to be constructed. Specifications must clearly define the quality of materials and workmanship required. The construction contractor must comply with the contract documents and produce the required end product.

(2) As explained in ER 1180-1-6, provisions for CQC are required in all construction contracts. In contracts exceeding $1,000,000, detailed CQC is needed and a special clause entitled "Contractor Quality Control" is included. Application of detailed CQC to construction contracts under $1,000,000, such as limited riprap repair, is discretionary, and the contract clause entitled "Inspection of Construction" may be used instead.

b. Material Control.

(1) Preparations.

(a) Prior to stone production, the contractor explains in writing for CE approval the details of testing methods and observations to be followed. Details should include size, weight, processing, and handling of the sample. All CQC tests are performed by and at the expense of the contractor. Samples for testing should be selected by the contractor with the concurrence of the contracting officer's representatives. Tests should be made as specified in the contract, and any adjustment to the contractor's operation necessary to provide stone meeting contract requirements should be at the contractor's expense.

(b) The contractor's quarry inspector and the contracting officer's representative should meet at each quarry designated to supply stone before delivery of stone to the job. At this time they select representative large stones for set-aside at the quarry as reference samples (paragraph 6-3d). Both satisfactory and unsatisfactory reference stones should be clearly identified. The defects in unsatisfactory stone should be marked. These typical samples often remain useful to CQC through completion of the project. All stone types need to be set aside. Samples should consist of at least one stone representing each size class in the gradation range.

(2) Testing.

(a) Stone produced during start-up operations at the quarry should be scrutinized for quality, unit weight, and gradation to indicate quarry or supplier capability for meeting specifications. Typically, three consecutive samples should pass all requirements, witnessed by the contracting officer's representative, prior to full operation and shipments to the project. The basic tests are visual examination, index tests, drop test, and size counts and any other tests required by the contract.

(b) Stone quality is tested at the quarry or jobsite regularly throughout construction; alternating between quarry and jobsite may be preferred. Tentative acceptance of stone is sometimes made based on the test results. Tests producing unacceptable results should not be counted in the required number. Samples for production testing should be taken from materials as they are produced or handled. A format for a schedule of tests at a large dike project is given in Table 8-1. The number of tests is based on experience in the particular region. Where the frequency of production testing needs to be increased to control the material quality, any additional expense is borne by the contractor.

Table 8-1. Format for Production Control Testing of Large Retention Dike Project

Stone	Stone Sizes	Type of Test	Minimum Size of Sample	Minimum Number of Tests
Armor or Underlayer		Visual exam		All stones
Armor or Underlayer	Over 500 lb	Measurement and weight	Truck load or equivalent weight per barge load	One for each ______ tons produced
Underlayer or Armor	500 lb and under	Measurement and weight	Truck load or equivalent weight per barge load	One for each _____ tons produced
Core or Mattress	All sizes	Gradation	1 ton	One for each _____ tons produced
Bedding Material	All sizes	Gradation	1 ton	One for each ______ tons produced

The minimum number and size of tests will vary with each project.

(c) Stones less than 500 lb are weighed and tabulated in a manner approved by the contracting officer for comparison with the specified gradation. Stones over 500 lb should be measured on three mutually perpendicular axes. Measurements and computed weights are all recorded along with a description of methods of weighing and calculating. Stones over 500 lb are weighed on scales as necessary to verify questionable computed weights. Stone selected for measurement should represent all sizes specified in order to verify conformance with the specified weight limits. The contractor is normally required to supply scales and certification of their accuracy.

(3) Visual Inspections. Visual checks of all stone are frequently required at the quarry or at the project for size, gradation, and slabbiness, as well as for cracks and other weaknesses visible on the stone surfaces. Wetting a small representative portion of stones may accentuate minute cracks and reveal if additional inspections are necessary on all stone. Stone with cracks and other defects that are not in accordance with the specifications should not be shipped to the project site. Photographs are useful in documenting quality.

c. Placement Control. Stone placed but then found to be damaged, deficient in weight, or improperly placed must be removed and replaced with new stone or be corrected. The contractor has a vested interest in carefully controlling the handling and placement of stone at the jobsite. This control is summarized in the daily CQC report to the Government.

(1) Visual Inspection. All stone should be visually inspected under CQC for size, gradation, and fractures to assure that handling during loading, transporting, unloading, and placement has not caused degradation and to assure that stone meets the requirements of the specifications. Close visual inspection after placement reveals the degree of uniform distribution of different sizes and close-knit arrangement among individual pieces as well as deficiencies such as large voids. Reworking is often necessary but can be minimized with care in ensuring that each arriving load has the proper gradation.

(2) In-Place Testing.

(a) In-place tests of stone material are made early in placement operations and should continue intermittently to confirm that the placement procedures and equipment are satisfactory. Satisfactory stone size and quality, layer thickness, and density in terms of void space and stone interlock underlie evaluation criteria. In-place tests should be located and witnessed by the contracting officer's representative. Test failures ordinarily necessitate reworking or replacement. Work should not continue until the initial placement test results are acceptable to the contracting officer. Test areas are marked as guidance for all the remaining work.

(b) For riprap, EM 1110-2-1601 recommends that provisions be made in the specifications for testing an in-place sample as soon as a representative section has been completed, with additional testing of in-place and in-transit samples at the option of the contracting officer. The frequency of testing depends on the ease of producing riprap that complies with the specifications. Engineer Manual 1110-2-1911 suggests tests be made as frequently as each 10,000 cu yd placed. The size of test samples should be sufficient to be representative of the riprap. Truck-load samples are usually satisfactory for in-transit material. Table 8-2 summaries guidance from EM 1110-2-1601 for the volume of in-place samples. Results of gradation tests are reported on ENG Form 4055 or 4056 and appended to the CQC report.

Table 8-2. Suggested Sample Volumes for Riprap In-Place

Riprap Layer Thickness, in.	Sample Bulk Volume, cu yd
12	1
18	2
24	5
30	10
36	16

(c) Testing suited to construction of retention dikes may be established much as follows and should also be carefully explained in the contract. Each test area is about 10 by 10 ft for stones 500 lb and over and 5 by 5 ft for those under 500 lb. All stones within the area are removed, examined, and measured or weighed individually on certified scales or otherwise as appropriate. For stone to be placed under water, only loose samples for gradation and weight are taken, just prior to placement.

d. Check Surveys.

(1) Check surveys are required in CQC on each layer to verify lines, grades, and thickness on completed work. The surveys are made as the work progresses. This paragraph emphasizes the rather elaborate methods needed in surveying large-volume jobs such as breakwaters. More expedient methods usually suffice for riprap features and rockfill embankments.

(2) Figure 8-1 shows technical provisions that have been used to describe the required surveying. Elevations of stone above the water surface or with respect to another datum should be determined with a leveling instrument and a rod on a base 12 in. in diameter. Other means approved by the contracting officer may be used. However, an electronic sounding method should not be used on riprap or larger stone material.

11.4 Check Surveys.

11.4.1 General. Surveys made by the Contractor will be required on each material placed for determining that the materials are acceptably placed in the work. The Contractor shall make checks as the work progresses to verify lines, grades, and thicknesses established on completed work. At least one (1) check survey as specified below shall be made by the Contractor for each 50-foot section as soon as practicable after completion. A copy of the record of the check survey shall be provided to the Contracting Officer on the next work day following the survey. Following placement of each type of material, the cross section of the finished work shall be approved by a representative of the Contracting Officer. Approval of cross sections shall not constitute final acceptance. Cross sections shall be taken by the Contractor on lines 50 feet apart, measured along the breakwater reference line, with readings at 10-foot intervals and at breaks along the lines. However, other cross section spacings and reading intervals may be used if determined appropriate by the Contracting Officer. Additional elevations and soundings shall also be taken as the Contracting Officer deems necessary or advisable. The surveys shall be conducted in the presence of a representative of the Contracting Officer, unless waived by the Contracting Officer.

Figure 8-1. Example technical provisions for check surveys. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

(3) Figure 8-2 shows technical provisions used to describe methods needed for surveys of material placed below water. Figure 8-3 shows by example the degree of control or standard under which the contractor might work in constructing and checking a major large-stone project.

11.4.3 Below Water. For portions of the work that are under water, sounding surveys shall be performed as specified below.

11.4.3.1 Lead line. If the lead-line method is used, each survey will consist of soundings taken either by means of a sounding pole or a sounding basket weighing about 8-1/2 pounds, each of which has a base measuring twelve (12) inches in diameter.

11.4.3.2 Electronic depth recorder method. When using an electronic depth recorder, the following procedures shall be used. The depth recorder will be calibrated and adjusted for the gauge, with check bar, at least six (6) times within a normal 8-hour work day. Normal calibration times shall be at the beginning of the work day, mid-morning, end of morning’s work, start of afternoon’s work, mid-afternoon, and end of the work day. Further calibrations will be taken whenever there is any malfunctions within the depth recorder or transducer which might affect the soundings, a major gauge change, or change in water temperature due to industrial discharge. The check bar will be set at approximately the deepest sounding in the area to be sounded. The depth recorder will be calibrated to read at low-morning, mid-afternoon and end of work day, the same settings used for the previous calibration will be used. If the calibration check does not agree with the previous calibration, the depth recorder will be calibrated to the proper setting. Under no circumstances shall the setting of the depth recorder be changed between calibrations.

11.4.3.3 Tagline method of horizontal location along station. If a tagline is used with a depth recorder, the soundings will be marked with a fix every five (5) feet.

11.4.3.4 Predetermined transit angle method or ranges method. The interval between predetermined angles or ranges along a sounding line shall not exceed 200 feet along the entire length of the sounding line. No predetermined angle shall form an intersection with the sounding of less than 45 degrees.

11.4.3.5 Speed of sounding boat. When sounding, the speed of the sounding boat shall be as constant as possible, preferably between 180 and 220 feet per minute.

11.4.3.6 Checking gauge. The gauge will be checked prior to each calibration and recorded on the sounding chart or in the field notes.

11.4.3.7 Electronic depth recorder. The survey depth recorder used must be a standard model acceptable to the Contracting Officer using a sounding chart that can be read directly to the nearest foot and estimated to the nearest tenth (0.1) of a foot. Accuracy shall be better than 1/2 of 1 percent.

Figure 8-2. Example technical provision for underwater check surveys. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

10.8 Tolerances. The finished surface and stone layer thickness shall not deviate from the lines and grades shown on the contract drawing by more than the tolerances listed on the table below. Tolerance thicknesses are measured perpendicular to the indicated neatlines. Extreme limits of the tolerances given on the table below shall not be continuous in any direction for more than five (5) times the average stone dimension and/or for an area greater than 1,000 square feet of the structure surface.

NEATLINE TOLERANCES

Material	Above Neatline (inches)	Below Neatline (inches)
Cover Stone, Type "A"	18	6
Underlayer, Type "B"	12	6
Underlayer, Type "C"	12	6
Bedding Material, Type "D"	12	0

NOTE; Add Mattress Stone, Core Stone, and Prepared Limestone if applicable.

The intention is that the work will be built generally to the required elevations, slope, and grade and that the outer surfaces shall be even and shall present a neat appearance. Placed material not meeting these limits shall be removed and/or reworked as directed by the Contracting Officer. Excess material permitted to remain in place the by Contracting Officer will not be paid for.

Figure 8-3. Example technical provisions on tolerances for a finished breakwater. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

e. Reporting. A written report should be prepared each day by the CQC detailing loads or weights of stone both delivered to the site and placed on the slope or structure. Results of visual examination are included, as well as sections surveyed. Samples taken for testing should be identified carefully for eventual correlation with test results developed subsequently. Engineer Form 4056 is useful for presenting stone size gradation. The report is to be furnished to the contracting officer in a timely manner and is preserved as an attachment to a daily QA report.

8-3. Quality Assurance. Quality assurance is performed by the Government in accordance with ER 1180-1-6. Checks, inspections, and tests are made of materials, methods, and the finished feature itself. The purpose is to determine whether the CQC is effective and is meeting the requirements of the contract. Personnel conducting the QA program should be proficient in large-stone inspection and familiar with quarry operations. Engineer Manual 1110-2-1911 contains guidance on rockfill construction control.

a. Inspection and Testing. Visual QA inspections of stone are performed both prior to and after delivery to the jobsite. In addition, physical sampling and testing such as used in CQC are conducted by the Government for QA at about one-tenth the frequency. The purpose is to confirm the validity of CQC results. If the contracting officer suspects that the quality, gradation, or weight of stone being furnished are not consistently as specified, supplemental sampling and testing by the contractor will be required. Selection of samples of the delivered stone and the manner in which the test is performed are as directed by the contracting officer. This additional sampling and testing is performed at the contractor's expense when test results indicate that the material does not meet specified requirements.

b. Reporting. Results of QA are reported daily on or appended to ENG Form 2538 as prescribed in ER 415-1-302 along with the CQC report.

c. Acceptance. The inspection or QA program should be carefully organized and conducted where questions of acceptance of stone material can enter prematurely and present a potential for problems. Acceptance usually needs to be postponed so that material and workmanship remain clearly subject to rejection until measurement for payment. Inspection by divers is sometimes needed to evaluate the acceptability of stone placed under water.

d. Rejection. The contracting officer reserves the right to reject at the source, at the job yard, or finally in the structure throughout the duration of the contract. Stone delivered to the project and then rejected, whether in stockpile or in place in the structure, should be removed from the project site. Stone found deficient at the quarry should be either isolated or disposed or otherwise prevented from mixing with satisfactory stone.

e. Retests. The Government should reserve the right to test or retest any of the stone used on the project at Government expense. A stone feature reworked or formed by replacement of previous, defective stone is to be tested as originally intended at the expense of the contractor.

8-4. Monitoring Stone Production. Although the commercial production of large stone is usually beyond the control of the Government, it is incumbent upon the CE to be aware of practices at the source affecting suitability of material to be delivered to the project. Forewarned in this way, the inspectors can be watchful for specific indications of potential trouble and can circumvent many problems. Pertinent aspects of stone production are reviewed in Appendix B.

APPENDIX A

REFERENCES

1. ER 415-1-302, Inspection and Work Records.

2. ER 1105-2-10, Planning Programs.

3. ER 1110-1-2005, Compilation of Concrete Aggregate and Stone Riprap Test Data.

4. ER 1110-2-1150, Engineering After Feasibility Studies.

5. ER 1110-2-1200, Plans and Specifications.

6. ER 1110-2-1925, Field Control Data for Earth and Rockfill Dams.

7. ER 1180-1-6, Construction Quality Management.

8. Federal Acquisition Regulation.

9. EM 385-1-1, General Safety Requirements.

10. EM 1110-1-1802, Geophysical Explorations.

11. EM 1110-1-1804, Geotechnical Investigations.

12. EM 1110-2-38, Environmental Quality in Design for Civil Works Projects.

13. EM 1110-2-1601, Hydraulic Design of Flood Control Channels.

14. EM 1110-2-1602, Hydraulic Design of Reservoir Outlet Works.

15. EM 1110-2-1603, Hydraulic Design of Spillways.

16. EM 1110-2-1902, Stability of Earth and Rockfill Dams.

17. EM 1110-2-1910, Inspection of Earthwork Construction.

18. EM 1110-2-1911, Construction Control for Earth and Rockfill Dams.

19. EM 1110-2-1913, Design and Construction of Levees.

20. EM 1110-2-2000, Standard Practice for Concrete.

21. EM 1110-2-2300, Earth and Rockfill Dams, General Design and Construction Considerations.

22. EM 1110-2-2904, Design of Breakwaters and Jetties.

23. EM 1110-2-3800, Systematic Drilling and Blasting for Surface Excavations.

24. CE-1201, Guide Specifications, Subsurface Drilling, Sampling, and Testing.

25. CE-1308, Guide Specifications, Stone Protection (Slopes and Channels).

26. Evaluation of Quality and Performance of Stone as Riprap or Armor, U.S. Army Engineer Waterways Experiment Station, TR GL-81-8, by R. J. Lutton, B. J. Houston, and J. B. Warriner, 1981. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

27. Handbook for Concrete and Cement (with quarterly supplements), U.S. Army Engineer Waterways Experiment Station. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

28. Rock Testing Handbook, U.S. Army Engineer Waterways Experiment Station. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

29. National Bureau of Standards, Specification, Tolerances, and other Technical Requirements for Weighing and Measuring Devices, NBS Handbook 44. Available from Superintendent of Documents, US Government Printing Office, Washington, DC. 20402.

30. American Society for Testing and Materials, Annual Book of ASTM Standards, Vol 4, Construction. Available from American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103.

APPENDIX B

STONE PRODUCTION

B-1. General. Interest and concern with practices at the source during production of project stone may be useful in more than one way. The producer's quality control program is bound to be sensitized by an awareness of close scrutiny and evaluation of methods and products of the source. Corps overviewing usually is passive and in that case must carefully avoid any direct influence that might later be perceived as having been a direction or recommendation or an acceptance or rejection of material. Observations at the source of materials by CE personnel may also constitute an extension of their quality assurance program.

B-2. Blasting. The size and gradation of quarry stone are generally recognized as being influenced by the blasting pattern. The influence may be conspicuous in massive rocks but subordinate to geological structure in bedded or highly fractured or foliated rocks. The effects and interactions are extremely complex and not practically amenable to explanation by theory or sophisticated model. Such tools should be avoided in favor of using first-hand experience and observation. Table B-1 illustrates the divergence among blasting methods for different purposes.

Table B-1. Blasting Methods for Various Purposes

Type	Diameter in.	Hole Depth ft	Pattern ft by ft	Rows	Charge* lb	Powder Factor lb/cu yd	Rock
Aggregate Production**	6	50	18 by 16	1	6,500	1.1	Limestone
Massive Excavation	3	18	7.5 by 7.5	6	8,500	1.5	Sandstone
Structural Excavation	3.5	15	10 by 8	5	3,400	0.5	Limestone
Armor-Stone Production	3	8	5 by 3	1	20	0.3	Limestone

* Mostly ammonium nitrate/fuel oil (ANFO) or similar agent.
** With armor stone as byproduct.

a. Aggregate.

(1) Most large commercial quarries produce aggregate as their primary product, and any large-stone material is a subordinate by-product. The same is true for quarries producing flux for iron ore reduction. This imbalance must be appreciated when considering an aggregate or flux-stone quarry as a source of large stone. The production and stockpiling of large stone usually is constrained rigidly by the production of the primary product. Occasionally, a separate operation for large stone is established within the quarry.

(2) An example blasting pattern for aggregate is given in Table B-1. Since crushing is a part of the processing of aggregate, most patterns are designed to fragment heavily. This universally suspected preference for heavy fragmentation leads to the widespread pessimism about the quality of large stone by-produced from aggregate or flux-stone quarries. Cracks from blasting may remain hidden in outwardly solid stone until aggravated by environmental processes after placement. This potential for delayed problems can sometimes be recognized by carefully scrutinizing large-stone material in the quarry, but the evidence is seldom clear-cut.

b. Construction Excavation. The emphasis in construction blasting is on maintaining a production rate toward meeting a construction schedule. There also should be an important concern with avoiding damage to adjacent structures and excavated rock surfaces, a concern that would ordinarily favor light shooting and the survival of undamaged large stone. However, incidental production of oversized pieces interferes with equipment operations and is normally avoided. Despite the apparent difference in the representative patterns in Table B-1, construction blasting achieves about the same results as quarrying for aggregate. The yield of large stones is low. See EM 1110-2-3800 for details of construction blasting.

c. Large-Stone Special. Small-scale quarrying specifically for high yield of large stone is sometimes feasible where geological structure such as bedding makes a massive ledge accessible and workable. Elsewhere, strong intact rock combined with very widely spaced irregular jointing may be suited to production of large stone, but even there, the yields seldom exceed 15 percent. The blasting pattern for large stone often positions light charges of low velocity (commonly ANFO) at intervals of a few feet parallel to the face. Black powder, with very low velocity and causing lesser impact on the rock, is sometimes recommended to minimize cracking in commercial quarries, but the use of black powder is prohibited at Corps projects according to EM-385-1-1.

d. Coyote. Coyote blasting is sometimes used to produce rock fill and larger stone because of its economy and speed. Charges measured in tons are detonated simultaneously at one or a few points in a tunnel to produce total stone needs. Application of this method should be considered with restraint. The poor control of effects may lead to damage of material and even the ruination of a source. Coyote blasting may yield an excessive amount of fines and dust, and these may have to be removed by extensive processing. Even oversize stone may result and have to be broken by secondary methods or otherwise removed.

B-3. Processing. Some processing is usually necessary to achieve the stone size distribution required in the specifications. Processing usually involves the removal of oversize and undersize material at the minimum but may also involve sophisticated means of separating stone pieces into classes by size.

a. Quarry-Run. Quarry-run stone is supplied directly from the source with little or no processing. Stone size is controlled partially by modifying blast size and pattern. The terminology is not universally defined; consequently, it is important that quarry-run stone and similar material such as spalls should be carefully defined as far as hidden size requirements likely to involve processing. Quarry-run rock is used in large volumes for constructing some rockfill dams and as stone protection in lieu of graded riprap.

b. Picking. Large stone is often separated from blasted rock by mechanically picking and setting aside or accumulating into a stockpile. This method of producing large stone is favored by some aggregate operations, since it tends to reduce the need for secondary shooting of oversize rock. Stockpiles are slow to assemble and may be exhausted unexpectedly under heavy volume demand. On the other hand, such stockpiles are usually dependable for intermittent or relatively small-volume jobs.

c. Grizzlying. The simplicity and ruggedness of grizzlies make them the primary element of stone processing at most quarries. They also are used extensively in construction excavation. Grizzlies functioning alone or in sets accomplish basic processing as indicated below.

(1) Removes fines.

(2) Removes oversize.

(3) Classifies into two or more classes of specified size range.

d. Screening. Screening is basic to producing aggregate and similarly sized products and often gives some by-product large-stone classes also. The plant normally combines several vibrating screens and grizzlies with belt conveyors, bins, and surge piles. The size ranges of classes are varied in order to meet specifications of a job or jobs. Riprap and larger sizes are ordinarily removed well ahead of screening, but coarse classes from screening plants have been used for core stone within retention dikes and for interior zones in rockfill embankments.

B-4. Scheduling. The limitations imposed by the scale, methods, and principal product from blasting and processing frequently impact on the availability of material on schedule.

a. Direct Ship. Those large-stone products that can be hauled directly from the blasting face to the project present the least problem in meeting a construction schedule. The rate is increased by upscaling the quarry operation or construction excavation.

b. Stockpiling. Stockpiling of large stone is advantageous and often necessary as a contingency against interruptions at the source. Stockpiles may be located at the source or at or near the project. Stone available in a stockpile may be considered in terms of days of placement operation. When stockpiled stone is down to a few days of placement, there will be an urgency to replenishment. Figure B-1 shows technical provisions prepared for a large jetty project to avoid confusion and problems incidental to handling and stockpiling.

c. Curing Stone.

(1) In some regions and for some rock types, it is considered necessary to stockpile large stone through a curing period. Curing allows large stone

3. STOCKPILES OF STONE.

3.1 General. Separate stockpiles for each type armor and underlayer stone, each gradation of blanket stone and leveling stone shall be maintained at each quarry, intermediate transfer points, and at the worksite. Every stone of the armor and underlayer stone larger than 1,000 pounds shall be marked at the quarry with a distinctive marking, unique for each type armor or underlayer size gradation. The marking shall be placed on at least three (3) different sides of a stone.

3.2 Stone Breakage. Stones which are broken during shipment to the work site or during placement shall be reweighed and may be reassigned to a new armor/underlayer type provided they meet the weight criteria for any one type stone. Stones broken in placement shall be removed from the structure and returned to the stockpile area to accomplish the reweighing.

Figure B-1. Example technical provisions for stockpiling armor stone. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

to stabilize before placement and occasionally circumvents deterioration problems dramatically. A period of 90 days is sufficient for drying and possible stress relief and case-hardening effects to occur. However, stone buried in large stockpiles may need longer periods. Past experience can usually establish whether curing is critical. Where the question has not been clearly resolved, provisions may be considered for inclusion in the specifications for curing, unless the contractor can provide evidence that curing is unnecessary.

(2) It has also been found that some large stone fractures detrimentally when quarried in cold weather. The mechanism is a freezing of pore water. Figure B-2 shows a technical provision addressing the problem.

B-5. Dimension Stone. Dimension stone quarries are ideal sources of large stone for construction since they normally produce joint-free blocks of durable rock as a raw material for processing into monuments and facing for buildings. Light blasting is used in some operations while others use wire sawing systems. Keep in mind, however, that the large stone available for construction is generally the waste or reject excluded from the principal production and accordingly may be of somewhat lesser quality.

B-6. Boulder Accumulations. Boulders and natural stone blocks are useful forms of large stone where they can be concentrated economically. Since these stones have already experienced aggressive geomorphic processes in the past, they are likely to be very durable in construction applications.

a. Field Stone. Field stones naturally distributed on the ground surface over the source deposit have been used extensively for slope protection in the northern Great Plains, Hawaii, and elsewhere. Such material is

All stone shall be delivered to the jobsite during the period 15 April to 15 September except as follows: stone delivered later than 15 September shall have been quarried prior to 15 September. Stone quarried after 15 September will not be considered for acceptance until after the following 15 April. These restrictions may be waived for igneous or metamorphic rock or other rock with a history showing conclusively that the stone is durable irrespective of the time of year that it was quarried.

NOTE: Date for quarrying and delivery of stone may be varied at the discretion of the District's Geotechnical Branch.

Figure B-2. Example technical provision against deterioration from insufficient curing of stone. (Not intended for direct use; this example only illustrates how technical data are ultimately presented in contract language)

particularly attractive to contractors where it has been collected by man, as in the clearing of fields for agriculture.

b. Oversize. Boulders are sometimes available where they have been removed in an early stage of processing for sand and gravel. Construction sites in alluvial or glacial strata may also have accumulations of large stone as oversize.

c. Talus. Deposits containing large stone result naturally from local erosion in mountainous areas and along rock canyon walls. Talus is perhaps most useful, but deposits from colluvial and rock glacier activity are other possibilities. The clean surface of a talus deposit may be deceptive in regard to gradation since soil typically fills some of the open space at depth and processing may be needed.

APPENDIX C

MEASUREMENT FOR PAYMENT

C-1. General. Large-stone materials acceptably placed on breakwaters and similar structures are usually measured for payment by the ton as determined by certified scale or by carrier displacement. Partial payment is sometimes made at the time of delivery of stone. Material placed beyond the tolerance limits specified for each zone or stone feature are measured and excluded from payment. The method of determining the quantity of materials placed beyond tolerance limits follows generally that in paragraph 8-2d. on check surveys. This appendix is not intended for application to most rockfill embankments.

C-2. Barge Delivery.

a. Gauges.

(1) The vessel or barge (carrier) for stone delivery is fitted by the contractor at his own expense with gauges or other facilities for accurately determining displacement. Six gauges graduated to 0.1 ft or other suitable units should be placed near the ends and midpoints of both sides.

(2) Gauges are attached solidly to the hull. Gauges located inside need provisions for the free passage of the outside water to a vertical tube and for convenient measurement within the tube. Outside gauges on wooden hulls should be protected by fenders or recessed into the planking. On steel hulls, the gauge marks may be placed directly on the outside plates and identified by punch marks. The zero mark is below water when the carrier lies trim, light, and free from water. The contracting officer should be notified a minimum of 5 days prior to installation and be given the opportunity to be present.

b. Gauging Tables.

(1) A gauging table is prepared by an accredited agent satisfactory to the contracting officer. The table shows the cargo weight in tons for each linear unit of draft. If the lines of the carrier are such that displacement in cubic feet for each measured unit of draft can be accurately calculated, the gauging table is based upon 62.4 lb/cu ft in fresh water and 64 lb/cu ft in salt water.

(2) If the shape of the carrier is such as to render impracticable the preparation of the table according to the method in (1) above, the weight corresponding to each unit of draft is determined by actually loading stone of known weight. All weights thus obtained should be entered in the table for use in subsequent gauging. Alterations made in a carrier which will affect the accuracy of the gauging table necessitate the carrier be remeasured and a new table prepared.

c. Reading Gauges.

(1) Gauges should be read before and after unloading. The difference in tonnage calculated from displacements loaded and empty is the net stone weight. The draft should be determined from the average of all six readings.

The contracting officer should have the opportunity to be present at all draft readings.

(2) All measurements for determining gauging tables and for calculating loads should be made in still water close to the work. The contractor should be required to place the carrier where such measurement can be accurately made.

d. Uniform Loading. The carriers should be so loaded as to cause uniform submergence. The average increase in draft on the middle gauges, as a result of the load, should not differ by more than 0.5 ft, and that between any bow gauge and any stern gauge should not differ by more than 1.5 ft. Otherwise, the contractor should trim the carrier by shifting stone until this limit is reached. If, however, the carriers used by the contractor cannot be loaded as prescribed above, and yet can be calibrated accurately for displacement under varying loads, another method of determining displacement may be used where approved by the contracting officer.

e. Variations. Stone carriers should be free of leaks such as may render accurate gauging difficult. The hold of each carrier should be inspected for leakage and adequate pumping facilities should be provided so that water accumulating in the hold can be removed before each gauging. Lightening by pumping or through transfer of crews or supplies should not be permitted while stone is being discharged. Should any lightening become necessary, the unloading of stone should be suspended and the load marks should be taken in such manner as to ensure the Government against loss from that cause.

C-3. Truck Delivery.

a. Scales.

(1) Stone material delivered by truck should be weighed and certified on weigh bills provided by the contractor at the jobsite. Guidance on scales including tolerances for under-registration and over-registration is found in NBS Handbook 44 (item 30). Load capacity marked on the scale by the manufacturer should be observed. The portion of the load in excess of this nominal scale capacity should not be considered for payment.

(2) The accuracy of the scale should be checked frequently. When a state scale inspector is not immediately available for checking, the contractor, at his own expense, secures a check from a local official sealer of weights and measures, or the contracting officer may allow checking with truckloads weighed on other scales which bear an official seal placed in the current calendar year.

b. Weighing. The total weight of a load should be in a single draft rather than being determined by adding results obtained by separately weighing each end of the truck or trailer except that a coupled combination may be weighed without uncoupling under the following conditions:

(1) Released brakes.

(2) Relaxed drawbar with no tension or compression.

(3) Straight approach in the same level plane as the scale platform.

(4) Paved approaches at least 50 ft in each direction with a seal coat or higher type surfacing.

(5) Large approaches of sufficient width and length to ensure level positioning of vehicles.

c. Documentation. The documentation for platform or surge-bin scale weights includes time and date and truck identification such as license plate number for each truckload. A sequential ticket number is also needed and may conveniently be preprinted on the ticket or weigh bill. Required records of weight are gross weight, tare weight, and net weight. Tare weight should be measured at least twice a day on the same scales. Most scales provide automatic printout of results directly on the ticket or weigh bill. Printout systems should be interlocked to allow printing only when the scale has come to a complete rest. Weigh bills should be certified with signature by the scale operator, attesting to the correctness of weights and other information shown. The Government should reserve the right to inspect periodically the weighing operations at the scales.

d. Onsite Storage. Engineer Regulation 1110-2-1200 describes appropriate provisions in the specifications for safe storage of and partial payment for materials (that is, large stone) delivered on the site. See precautions for handling and stockpiling various classes of stone in Figure B-1.

C-4. Verifying Weight Measurements.

a. Measurements and calculations from which gauging tables, truck weights, and stone tonnages are determined should be open to verification by the contractor and should be subject to the approval of the contracting officer. The contractor should be invited to be present or represented by an authorized agent during the measuring of trucks or carriers. When the empty truck or carrier is measured or remeasured, a record of the allowed measurement should be sent to the contractor. If the contractor protests within 5 days, the carrier or truck should be remeasured with the contractor present or represented by an accredited agent. In this way, an agreement is possible on the contested measurements.

b. The contractor should also be informed of the weight of each load of stone as it is determined. Failure to protest within 5 days is equivalent to expressing satisfaction with the measurements and weights determined by the contracting officer.

C-5. Excess Material. All stone in place permitted by the contracting officer to remain outside the limits and tolerances are normally deducted from the quantity to be paid.

a. Calculation. Volume of excess stone is computed using the average area of excess above or below the tolerance line for two successive cross sections, multiplied by the distance between the cross sections. The volume computed for each type of stone should be converted to weight using the design stone unit weight and percent voids among stones. Stone which has been delivered to the site but lost or wasted or otherwise not properly incorporated into the final required work must be documented in order to avoid payment or to recover any prior partial payment.

b. Measurement. The contractor should coordinate excess volume surveys with the contracting officer for appropriate timing. The survey work and measurements are done by a joint team of Government and contractor, but volume computations are done by the Government alone. Elevations and soundings are typically taken along sections perpendicular to the axis of the structure and 25 ft apart, with the readings at 10-ft intervals and at breaks in the slope. Other section and reading intervals may be used if deemed appropriate by the contracting officer.