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.

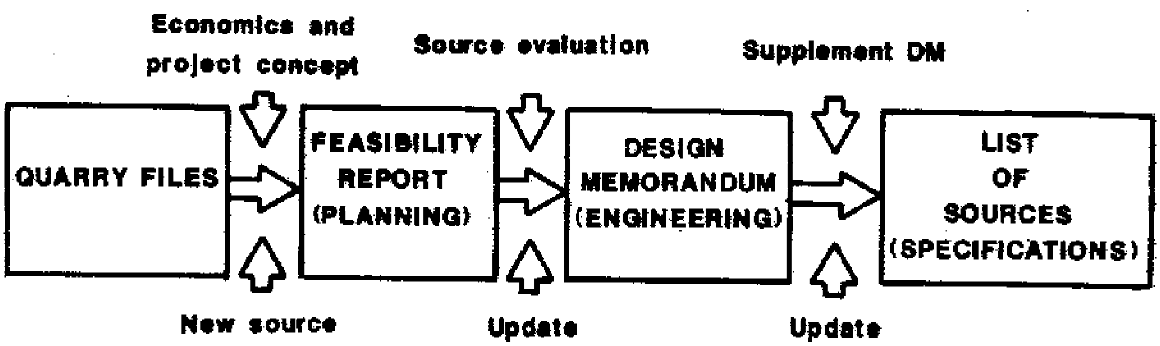

Figure 4-1. Presentation of stone source information in project development

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.