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Material Prospection for Dams

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MATERIALS PROSPECTION FOR DAMS

By

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SYNOPSIS

The paper is aimed at analysis the aggregate material that is available in the easy and economical haul of a dam site so that without compromising with the quality and standard strengths of the materials the optimum and economical use of these may be resorted to. Various scientific methods of analysing the strengths of materials have been discussed and in the light of these requirements of Riprap, Rockfill and earthfill dams have been elaborated.

MATERIAL PROSPECTION

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Investigations of construction materials are usually concerned with one of the two questions, namely, is there a sufficient quantity of a specified construction material available within a reasonable haul distance, or the more comprehensive question of what construction materials are available in the area. In considering the construction of a dam, hopefully answering the latter question is the objective of the investigation. The proper selection of the type of dam to be built at a site must include a careful evaluation of the construction materials available. Many times the availability of construction materials determines the type of dam which can economically be considered at a given site.

The importance of thorough construction materials evaluation to the planning and design of a dam is apparent, but it is also critical to the actual construction phase. One of the chief bases for Change Order, disputes between the owner and the contractor, is the availability of sufficient quantity of suitable construction materials. The economic impact of the availability of construction materials, as described in the specifications, must be considered with great care by both the experienced engineer and contractor. Not only should material be available where, when, and as specified, but the physical properties of the material must be described. Also, the borrow area must be as described to the bidders, i.e., access, depth to ground water, ease and depth of excavation and available water disposal area.

It has always been desirable to obtain the construction materials for a dam upstream of the proposed axis, within the reservoir area, because of economics and right-of-way consideration But professional responsibility, and in some cases, legal requirements,demand protection of the environment of the area by avoiding unsightly excavations or rehabilitating them. Therefore, these are factors which must be given serious consideration in locating borrow areas.

The Preliminary Phase

General

One of the most valuable sources of information is the actual production records of construction materials. They are usually available through governmental geologic agencies. These records generally include the total annual production of the various construction materials produced in the area and some description of the various sources. Local highway departments generally have test results and performance records on aggregate, road base materials, and frequently on riprap. It would be a simple solution to the materials problem if an established, proven source had the capability to produce the materials required for the proposed dam construction; however, this is almost never the situation encountered in practice. The chief benefit which can be derived from the study of performance of existing sources is the geologic correlation of the existing borrow areas with possible new borrow sites.

In the remote areas of the world detailed geologic maps, data on existing quarries and borrow areas, and good topographic maps are usually lacking. In these areas aerial photographs and other remote sensing tools are most helpful. However, reconnaissance of the area is the only method of obtaining reliable data. Helicopter reconnaisance is often the least expensive and certainly a most

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effective means.

The preliminary phase of a construction material investigation is generally conducted by an engineering geologist. The effectiveness of this study depends on his experience and how well he is briefed by the project engineer of the requirements. .

The published geologic maps of an area are most useful in locating possible sources of construction materials. These maps show the distribution of various geologic units and the legend generally provides a brief description of each of these units. Potential sources of construction materials may thus be identified and located and further studies planned. There are many types of geologic reports which may provide some useful information to the construction materials investigator. Reports on the general geology of the area usually contain a description of the various construction materials, found there. But even reports on the ground water geology, various mining aspects, petroleum geology, and other geologic data seemingly unrelated to construction materials may provide much useful data.

The preliminary stage of the investigation should include reviewing the geologic data on the area such as the geologic maps and all types of geologic reports, descriptions of existing quarries and borrow areas, their production records, and materials performance histories. Existing quarries and borrow areas, are a great source of data. A review of the production records from each operation, and its geologic description maps and reports, provides information on the characteristics to be expected at other sites. Many governmental agencies, both local and federal, keep records of the quantity of each type of construction material produced, frequently including on estimate of the reserves of each area. Performance histories are also frequently available from these local agencies, Interviews with the various suppliers of construction materials often develop data on problems other have experienced.

Evaluation of the Preliminary Investigation

A preliminary evaluation of the construction materials potential of an area should be directed toward providing estimates of the quantities of all the various types of constrction materials available within a specified area. Actual exploration, such as drilling, sampling, and testing, is not performed during this preliminary phase. The evaluation is based on the collection of existing data and reconnaissance of the area. The discussion of each of the types of construction materials follows.

Concrete Aggregate

This is the only material described in this section which has rather well-defined specification.. Most of the concreate aggregate throughout the world comes from stream-channel deposits. Such deposits are subjected to abrasion caused by stream transportation which generally produces well rounded, hard, and frequently clean aggregates. The presence of deleterious materials and poor grading characteristics is an aspect which often requires special attention in evaluating stream deposits.

The physical properties which are most important in the evaluation of potential aggregate sources are:

1. Rock types
2. Degree of weathering soundness
3. Hardness
4. Strength

5. Size and grading
6. Particle shape
7. Coating
8. Organic impurities.

The more acceptable and economical deposits should contain ample material, usually 3 or 4 times the estimated requirements for preliminary evaluation. Ideal deposits should not have large overburden thickness, poor grading characteristics, e.g., gap-grading or too great a percent of fines, high ground water conditions, difficult access and great haul distance.

As noted earlier, performance histories and test results of concrete aggregate sources are frequently available from highway departments. If not, similar information can be obtained by examining various concrete structures, e.g., bridges, highways, etc. where the aggregate sources are known. Potential aggregate reactivity must be considered at this stage and some evaluation of this problem can be made by obtaining data on the type of cement to be used and the admixtures, such as pozzolans, to be used with the aggregates. For example, if low alkali cement was used with the aggregate being considered, the performance records are valid only with the same type of cement. These aggregates could be reactive when used with other types of cement.

Concrete aggregates can be produced by quarrying and crushing rocks. It is expensive but required if natural aggregates are not available within reasonable haul distances. Crushed aggregates produce harsher mixes. To achieve the desired workability, more water is needed; to then maintain a required watercement ratio, more cement is needed. Thus, greater costs are involved. It is especially desirable to try to locate natural deposits of the fine aggragate.

Riprap

Armor stone, natural slope protection, or riprap, is the construction material which may be the most difficult to locate. Riprap is usually natural rock placed on an excavated or constructed slope to act as protection against wave action. Fresh, sound, and massive rock, such as granite, basalt, limestone or quartzite, is frequently used. Specifications for gradation of riprap are usually worded to conform with expected severity of wave action. Usually, riprap should have an unconfined compressive strength greater than 7000 psi, a specific gravity not less than 2.5, and not have a wet-shot test loss greater than 40 percent.

Suitable quantities of a dense, sound riprap in sufficiently large blocks to meet design requirements are frequently not available within a reasonable haul distance of a dam site. Haul distances for riprap have exceeded 150 miles. There are, however, examples of investigation which failed to find suitable riprap sources that were found in the same area by later investigation.

A preliminary study of possible riprap sources should begin with examination of the geologic maps and reports. The geologic description of the materials occuring in the area usually provides the investigator with some suggestion of the rock types which most likely would yield suitable riprap. Field reconnaissance provides more reliable data for preliminary evaluation of the potential riprap sources. For example, rocks which may be likely sources of riprap commonly have bold outcrops and talus slopes which can provide a geologist with some indication of the suitability of the material for riprap. The field examination and the review of the geologic literature should provide adequate data for a preliminary estimate of the volume of rock present, the percent of waste material anticipated, size, distribution and fragment shape, all based on assumed quarrying operations. Each possible source area should contain at least 3 or 4 times the estimated required volume of riprap if it is to be considered worthy of further consideration.

Many rocks are not suitable for riprap. Certain geologic and physical properties are necessary, such as suitable rock type, strength, hardness, and durability, and they must be moderaterly dense. Stratifiction, joining, and fracturing must be considered in estimating the size distribution and fragment shapes developed by quarrying operations. usually, flat, platy fragments are undesirable and specifications require that no one dimension can be more than 3 times any other. These fragments should be quite angular to achieve an interlocking action. Angular fragments will resist displacement better than rounded boulders of comparable size and density. Gradation limits are usually strict and must be considered when estimating the percent of waste which will be produced at each quarry.

Most igneous rock types can be suitable for riprap. Only the more massive metamorphic rocks, such as meta-volcanic rocks, gneiss, and massive schists, are generally acceptable. The platy slates, phyllites, and fissile schists may be acceptable. Many sedimentary rocks are not suitable; however, massive or thickbedded limestone and well-cemented sandstone may be acceptable.

Rockfill

Requirements for materials for rockfill dams are similar to those for riprap, but perhaps not quite so demanding. The rocks must still be strong, hard, durable, and relatively dense, but the gradation limitations are much less restrictive. Hence, the percent of waste is much less for rockfill. The need for angular shaped fragments is usually much less important, although flat or platy fragments are undesirable.

Suitable rockfill materials should be sufficiently hard and durable to resist major changes in gradation during hauling, stock piling, and placement. The materials used especially in the outer portions of the upstream and downstream slopes must be capable of resisting weathering. Another important aspect of the study of rockfill sources which differs from the evaluation of riprap sources which differs from the evaluation of riprap sources is the haul distance. A riprap source may be economical, although it is many miles from the axis; a rockfill source must be within a few miles of the site. The large quantities usually required for a rockfill dam indicate the economic need for a short haul distance. Environmental considerations suggest that a borrow area ideally should be in the area to be inundated by the reservoir.

Earthfill Materials

The preliminary evaluation of the earthfill materials which may be suitable for dam construction should be directed to providing an accurate estimate of the quantities and description of materials available. The designer has a wide range of embankment designs which he can consider. The concept of having the earthfill materials investigation directed toward developing specific quantities of pervious and impervious materials is generally not valid in the preliminary phase of the project. Many capable earth-dam engineers feel that a safe dam can be built with almost any earth materials. If good description of the mateials available in an area is provided to the designer early in the planning stage, he can begin to evaluate the most desirable combinations to use for his design. During the second phase of materials investigation, the exploration can be directed towards evaluation of the potential for specific materials.

In evaluating potential embankment sources, the haul distance, access, estimated stripping and waste, location of ground water in the potential borrow area, and the moisture content of the materials must be considered in addition to the physical properties of the materials. A desirable borrow area would contain: relatively uniform materials, free of organic matter; a reasonable thick deposit of borrow material overlain with a minimum thickness of overburden; ground water deep enough not to interfere with excavations.

Materials for the stability section or pervious zone usually are sandy materials with good shear strenght and are free-draining, relative to the core of impervious section materials. Good core materials contain sufficient fines to be relatively impermeable when compacted in the embankment. If the material contains sufficient granular materials, it should provide some shear strength and make it more workable.

A random-fill or homogenous section design is frequently considered when the more readily available materials are neither clearly pervious nor impervious. The material for drains usually involves limited volumes and hence can be processed materials.

As stated earlier, the objective of the construction materials investigation is to locate and describe as accurately as possible the depth, aereal extent and physical properties of the various types of materials Occurring within reasonable haul distance of the site.

The Secondary Phase

After the preliminary phase of the exploration for construction materials is completed, and the evaluation is presented in a report, new requirements for the construction materials are established. These new requirements are guides for the secondary phase of the construction materials investigation. The objective of this phase of the materials is to meet the probable requirements for the types of dams being considered for final planning.

This stage includes preliminary drilling, sampling, and testing of the most promising sources in order to establish that adequate quantities of suitable materials are available. It is usual to locate approximately 2 or 3 times the actual volume of material needed for the dam construction.

A more complete and thorough investigation of existing geologic data, existing quarries and borrow areas, their test results, performance records and production data is required at this time. An additional reconnaissance of the area should also be completed at this stage of the investigation.

Remote-sensing methods ranging from black and white photography to line scanning devices, such as thermal infra-red or side-looking radar (SLAR), and satellite imagery may be employed to good advantage at this stage, especially in remote areas. These methods should provide a basis for further study of the more promising sources. Aerial photographs have been used in the search for engineering construction materials over the last few decades, using black and white stereo photographs. Within the present decade, technology has advanced to include other complementary remote sensing tools; namely SLAR, thermal infra-red scanning, color infra-red photography, and satellite multispectral imagery.

U.S. Army Corps of Engineers' studies in the Mekong Delta and other studies in the Missi-ssipi Delta show colour infrared photography to be superior to black and white photography for identification of reaches, abandoned channels, and point bars. The tonal contrast between land vegetation water boundaries accounts for this superiority. These land forms are all good sources of engineering materials in the deltaic environment.

Whereas colour infra-red photography records reflected solar radiation, the tones on thermal infrared imagery are a result of temperature differences caused by varied emissivities of materials on the surface. The normal infra-red can be useful in mapping areas of shallow ground water. These maps may also provide suggested source areas for construction materials where shallow aquifers are burried river channels or thick glacial deposits.

For regional construction materials inventories, satellite and radar imagery are useful because of their synoptic coverage. Regional structural and landform features can be seen more readily on small scale imagery than on larger scale air photos, which allows for prediction of the types of materials that will be encountered.

Radar provides its own illumination and is not dependent on weather conditions. For example, in Darien Province, Panama, where photography had been unsuccessful because of ever-present cloud and impenetrable vegetation, radar studies showed that it is possible to differentiate alluvial deposits of sand and gravel from bedrock.

Landsat imagery has worldwide coverage and is often the only readily available source of imagery for remote areas. The standard data products include black and white prints in four wavelength bands for color composites, all of which can be interpreted in much the same way as aerial black and white or color infrared photos, but allowing for the small scale involved. The regional viewpoint makes it possible to predict possible materials location.

At this stage of investigation, field studies including geologic mapping or the checking of existing geologic maps, should be completed for the more promising areas. Limited sampling of selected areas and preliminary testing will provide more reliable data on the area. New estimates of the volume of materials available in the area should be based on the additional data collected since the initial reconnaissance.

A review with planners, designers, estimators, and construction specialists is appropriate at this time. These reviews out questions, new approaches, and suggestions which should be incorporated in the final exploration for the construction materials Frequently, this review provides the basis for narrowing the scope of the study and permits the investigator to concentrate his efforts on the more probable types of materials to be used for the project.

Final Exploration

The objective of the final exploration program is to confirm the location of adequate quantities of suitable materials for an evaluation of the specific sources of construction materials.

Large diameter, bucket auger drilling is probably the most efficient method of exploring for unconsolidated construction material. Trenching and test pits excavated by backhoe are also very efficient methods of exploring unconsolidated deposits. All of these methods permit accurate, detailed logging. Logging of these holes should be accopmlished by a capable specialist. They should record the usual geologic and soils descriptions, and their observations are of great impotance during drilling and sampling; for example, notes on organic materials, moisture content, water levels, degree of cementation and uniformity of the materials. Samples of the materials should be obtained in sufficient quantities for testing. These methods of exploration also provide data on the methods of excavation most suitable for material, depth of over burden, thickness and uniformity of the material and depth to ground water. Geophysical methods such as seismic and electrical resistivity are not usually needed in exploring these materials as the bucket auger is economical and the drilling is completed so quickly; however, in many areas the geophysical methods may be used effectively to provide some data on the borrow areas, e.g. water table, depth to consolidated rock etc.

Aggregate exploration is usually accomplished with dozer, backhoe or clamshell or where equipment is scarce and labour is not expensive, by hand excavated test pits using cassions or timber and lagging. The methods of exploration may vary locally, but the location and distribution of the test excavations must be designed to determine accurately the uniformity, quality and quantity of the deposit. Sampling is quite critical at this stage and it is necessary that representative grading be obtained. Instructions such as found in ASTM standards must be followed in detail.

Special consideration must be given to zones occurring below tthe water table and smapling techniques developed to assure that fines are not lost during the sampling.

Potential aggregate reactivity must be carefully evaluated during this final phase of aggregate exploration. If significant quantities of potentially reactive materials may be present, the planning and design engineers must be alerted to the problem. There are several possible methods of slou-tion, e.g., low alkali cement, pozzolans or finding another aggregate source which contains non-reactive aggregates. The following is a partial list of materials which are frequently reactive:

1. Siliceous minerals such as cherts, opal, chalcedony.
2. Certain rhyolites, andesites.
3. Tuffaceous rocks.
4. Zeolites.
5. some phyllites.

Explorations for riprap and rockfill is usually based on careful geologic mapping, diamond core drilling, geophysical logging, geophysical surveys and test blasting. The geologic mapping should stress rock type, jointing, fracturing, weathering, overburden thickness and detailed description of representative outcrops. Core drilling should be used to provide representative coverage of the potential quarry site. The drilling should enable the geologist to "prove" a volume of rock equal to twice that required for the dam. This estimate should not include waste rock in this volume. Geologic log should have detailed lithology descriptions and should describe fracturing, jointing, core lengths and degree of weathering.

Electrical resistivity, sonic, density and other types of geophysical logging can be helpful in estimating the degree of fracturing and the density and modulus of elasticity can be calculated. While these geophysically determined values may not be precise, they are very accurate for a relative determination and are reliable in a qualitative sense.

Geophysical survery, especially seismic refraction surveys can provide good information on the bulk properties of the rock. For example, if the P-Wave velocities are less than 10,000 ft/sec, the rock is suspect and requires considerable further investigation. If the rock velocities exceed 12,000 ft/sec a more optimistic view of the quarry potential is indicated. Small test blast can provide considerable data on the quarry site. In addition to information of the quality of the rock, the test blast should provide data on estimated drilling and blasting costs.

An evaluation of the physical properties of rock samples may be obtained by laboratory tests. Unconfined compression test, hardness, absorption, specific gravity, freezing and thawing determinations, and the wet-shot tests are used to make such evaluations. The following chart may be used in evaluating the suitability of rock for riprap and rockfill materials.

LABORATORY TEST RESULTS

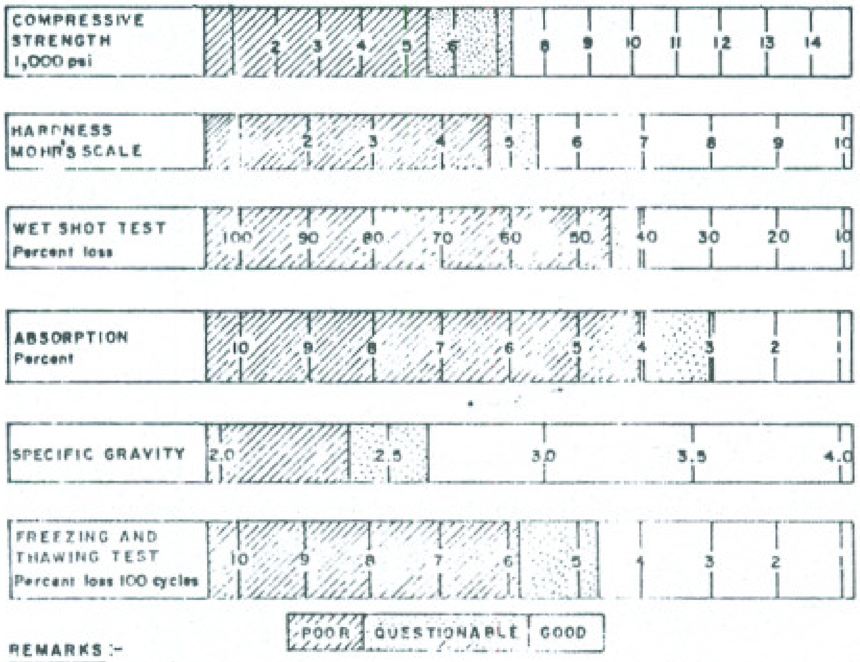
RIPRAP SUITABILITY

Project ____________________

Job No. __________ Date __________

Sample Description ____________________

Source ____________________



REMARKS :-

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FIG: I STANDARD FORM FOR EVALUATING RIPRAP SUITABILITY.