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Production of Sand and Gravel

By
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Production of Sand and Gravel*

By STANTON WALKER†

SYNOPSIS

Production of sand and gravel is discussed under three main groupings: (1) development of deposits, (2) transportation to the plant, and (3) processing. Briefly detailed are prospecting and exploration, excavation, and transporting methods. Described in more detail are processes for washing, classifying, removing deleterious impurities, and crushing oversized materials. A list of 32 selected references completes the report.

INTRODUCTION

Sand and gravel are consolidated granular materials resulting from the natural disintegration of rocks. They generally occur together, variably proportioned in widely available deposits. Their production consists of extraction, transportation to the plant, and processing—the latter generally including washing, screening and otherwise classifying to size, crushing of oversize, and the elimination of deleterious impurities to the extent practicable.

Sand and gravel occur in a wide variety of deposits both above and below water. These deposits may consist of banks, pits, or the beds of streams, lakes or other bodies of water. The banks and pits may extend below the water level. Sand and gravel originate from the weathering of rock and its transportation by water. It may come from material deposited by glaciation or from residual materials broken down in place or from a combination of these. Consequently, mineralogically they are whatever their parent rocks were. The type of the deposit and the nature of the material in it dictates an extremely wide range in methods of production from extraction through final processing.

A first step toward the production of sand and gravel is a detailed exploration of the selected deposit to determine characteristics and quantities of material. The sand and gravel should be examined as to mineral composition, quantity and nature of impurities, soundness, strength, and size and grading. The question of whether or not the material can be economically produced to meet the requirements of applicable specifications is one that can be answered only by sound engineering judgment, based on experience coupled with a careful survey of the deposit and the need for its products.

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This short paper on sand and gravel production permits no more than a brief discussion of fundamental principles. A comprehensive treatment of the subject is impractical except in a work very broad in scope. The literature, while considerable, has not been well correlated. It is hoped, however, that this statement of fundamentals together with references to sources of information will serve a useful purpose.

PROSPECTING AND EXPLORATION

Sand and gravel deposits, by the nature of their occurrence, are evaluated as to quantity and quality only by painstaking exploration. The exploration falls in two parts—a preliminary one to estimate the extent and general nature of the material and, if that is promising, a detailed one which will not only furnish reasonably accurate information as to quantities available, but also as to the quality of the material.

There are a variety of approaches to preliminary exploration. Information available from state topographic, hydrologic, and geological surveys, and from other federal and state government agencies often is of considerable value. Outcroppings, visible deposits under water, and miscellaneous available excavations should be examined. Recent developments in geophysical methods offer promise for rapid preliminary surveys. Resistivity methods, which indicate changes in composition of underground strata by differences in electrical resistance, seem most applicable.

Before any final answer can be secured, exploration methods must be used which provide representative samples. The relative amounts of sand and gravel must be determined and evaluated in the light of market demand and specification requirements. Grading of the material must be examined to determine if specification requirements can be met economically. The nature and amount of deleterious materials and the feasibility of their economical removal must be studied. The problem is complicated by the inherent lack of uniformity of many sand and gravel deposits due to the natural processes by which they were formed.

Exploration methods which permit securing representative samples from land deposits include test pits and trenches, driving of pipes and excavation of material from the pipes by special bucket or other means, earth augers, churn drills, and other procedures for getting a cross section of the material. For underwater deposits, dredges, both pump and ladder, cranes and buckets, draglines, and similar straightforward devices are used. There are no short-cut methods.

There is relatively little literature dealing directly with prospecting and exploration for sand and gravel. In 1932, J. R. Thoenen of the U. S. Bureau of Mines prepared a 50-page discussion of the problems as a whole.[1] He discussed, in somewhat general terms, the occurrence of sand and gravel and the various methods of exploration applicable to different types of deposits. The paper is out of print but should be available in many technical libraries.

A symposium on prospecting was held at the 1950 annual meeting of the National Sand and Gravel Assn. R. Woodward Moore of the Bureau of Public Roads discussed geophysical methods of subsurface exploration and gave a selected list of references to the literature.[2] Experiences of members of the industry with augers, adaptations of well-drilling equipment, resistivity methods, and in underwater exploration are described in references 3, 4, and 5.

General information on prospecting may be found in the Bureau of Reclamation *Concrete Manual,* in the American Institute of Mining Engineers publication, *Industrial Minerals and Rocks,* particularly the chapter on "Sand and Gravel," by Bror Nordberg,[6] and in the American Society for Testing Materials 1948 *Symposium on Mineral Aggregates,* particularly the chapters on "Distribution of Mineral Aggregates," by K. B. Woods,[7] and "Production and Manufacture of Fine and Coarse Aggregates," by N. C. Rockwood.[8]

DEVELOPMENT OF DEPOSITS

Excavation of material from the deposit is the first step in production. For bank and pit deposits above the water level, excavation is ordinarily by power shovel, dragline, drag scraper, or slackline cableway. Earthmoving, tractor-combination machines sometimes are used in shallow deposits. Various methods, including light blasting, are used to break down the face of the pit or bank to make the material more conveniently available for excavation.

Most land deposits are covered by overburden. If it is light and sandy, it may be excavated along with the sand and gravel and removed in the processing plant. If it is heavy, it should be stripped ahead of the excavating operation. The same, or similar, equipment may be used for stripping as for excavation.

Draglines and cableways may also be used to excavate below the water level in wet pits and shallow streams. However, if the nature of the material and the quantity of water permits, it is common practice to use suction dredge pumps. After a pit is opened, the dredge may be used to excavate the above-water material as well, it being broken down into the water by under-cutting, by light blasting, or by other means.

For marine deposits both suction and ladder dredges are used. The suction dredge generally delivers the material directly to the processing plant on land, or it may pump to a sump from which the material is pumped again. Less frequently the material may be pumped to barges in which it is transported to the processing plant.

The ladder dredge is used for deposits which are too consolidated or too coarse for suction dredges and for other reasons which may be dictated by economy of operation. Sometimes ladder dredges deliver the materials direct to barges for transportation to processing plants but, more frequently, except in large wet-pit operations, the processing plant is on the same hull as the dredge.

Excavation is also done with crane and bucket, with dipper dredges and, infrequently, by hydraulic sluicing. Excavation methods and excavating equipment used for production of sand and gravel are those common in the mining field, and are extensively described in the literature. The magazines *Pit and Quarry*[9] and *Rock Products*[10] pay particular attention to sand and gravel production and almost any issue will include descriptions of one or more operations. Another Bureau of Mines publication by Thoenen[11] on developing sand and gravel deposits, written in 1933, deals with excavation from different types of deposits and gives references to descriptions of a number of specific operations.

The *Pit and Quarry Handbook*[12] includes comprehensive chapters on dredging, stripping, pumping, and excavating pertinent to any consideration of recovery of materials from selected sources. Information of a more general nature will be found in the papers by Nordberg[6] and Rockwood[8] previously cited. There is also much general information, particularly on dredges and pumps, in Taggart's *Handbook of Mineral Dressing.*[13]

TRANSPORTATION TO PLANT

After excavation the material must be taken to the processing plant. Some of the methods of excavation incorporate methods of transportation to the plant—as the suction dredge, the earth mover and, sometimes, the cableway scrapers. For underwater deposits, barges may be used to transport unprocessed material from dredge to plant although more often processing is done on the dredge. When shovels, draglines, or similar equipment are used, independent means must be provided. These include narrow and standard gauge railroads, trucks (of all kinds and up to about 20 cu yd capacity), and belt conveyors. Each method has its place and its economic advantages, depending upon the nature of the deposit.

Transportation from point of excavation to the processing plant is sometimes done in two stages—a "surge pile" being introduced between the two. In the case of a dredge pump operation, material may be pumped to a sump and picked up by a booster pump for transportation to the plant. In the case of a land operation, excavated material may be transported to a storage pile (surge pile) by a selected means and then conveyed from that pile by any other selected means, generally a belt. This intermediate storage serves, among other things, to facilitate maintaining a uniform feed to the plant by divorcing it from complete dependence on the rate of excavation.

The chapter on "Intraplant Transportation" in the *Pit and Quarry Handbook*[12] treats the several methods in considerable detail. Taggart[13] also deals with transportation, including some information on costs, and there is general information in the previously cited works of Nordberg[6] and Rockwood.[8]

PLANT PROCESSING

Plant processing includes washing, screening and otherwise classifiying to size, crushing of oversize, and the reduction of deleterious impurities to the extent practical. Impurities which are soluble or suspendable in water generally can be washed out satisfactorily. Sizing and classifying can be done with considerable accuracy within the limits of the sizes available, although costs are greatly increased if it is necessary to waste much material or if too many or too close separations, particularly in the sand sizes, are required. Deleterious materials may be reduced, but there is a limit beyond which such operations are neither feasible nor economical.

The processing plant essentially is a simple combination of conveyors, screens, crushers, washing and classifying equipment, and storage and loading facilities. Any attempt to illustrate a typical one or to show a typical flow sheet would be misleading. The plant must be tailored to suit the deposit and the market. In the simple case of a land deposit, a plant might consist of the following elements:

1. A hopper, or equivalent, to receive material transported from the deposit or surge pile. Generally this hopper will be covered with a "grizzly" of parallel bars, or equivalent, to screen out boulders too large to be handled by the plant—in most cases a relatively small proportion of casual material.

2. From this receiving hopper the material will pass through a gate, controlled by a "feeder," of which there are numerous designs, to a conveyor on which it is carried to the top of the plant on to the scalping screen. A belt conveyor is generally the most economical. Bucket elevators have been used and are still used but less than in the past. Skip hoists have been used, but sparingly.

3. The scalping screen separates oversize material from the smaller, marketable sizes.

4. Material passing the scalping screen is fed into a battery of screens, either vibrating or revolving, the number, size, and arrangement of which will depend on the sizes and number of sizes to be made. Water from sprays is introduced from the beginning and is applied throughout the screening operation. From these screens the different sizes of gravel will be discharged into bins or on to conveyors for transportation to stockpiles or, in some cases, to crushers and other screens for further processing. The sand passes to classifying and dewatering equipment and from there to bins or stockpiles.

5. The oversize from the scalping screen passes to the crushers—the size, number, and arrangement of which depends upon the quantity and nature of the material to be crushed.

6. Crushed material may be re-elevated to the scalping screen and, hence, through the plant or it may be subjected to an independent screening and sizing operation. Which procedure is used will depend upon whether the crushed material is salable as a separate product or merely represents an economical disposition of oversize. In some cases, the crushed gravel is used

for blending with natural gravel to meet specifications which put a minimum limit on quantity of crushed particles.

Washing

Washing and sizing of sand and gravel are almost always done simultaneously. Water is needed for efficient screening and, of course, is essential to water classification. Accordingly, whether or not washing is needed, water is introduced into the sizing operation if it is available. Dry sizing, involving screening and air separation, has been used in some cases where water is scarce. For sands and gravels containing loosely adhering and readily soluble or suspendable impurities, the minimum amount of water required for sizing is adequate for washing.

However, many sands and gravels contain clay, mud, mudballs, and organic impurities firmly enough attached to require thorough washing and scrubbing. Depending upon circumstances, adequate washing will result from the following, listed (roughly) in order of increasingly difficult conditions: (a) pumping material to the plant; (b) introducing enough water to facilitate screening; (c) providing adequate sprays on vibrating or revolving screens; (d) passing material through special sections of revolving screens in the presence of counter-flowing high-velocity water; (e) same as (d) except that, in effect, the revolving screen is "blinded" (generally called a scrubber) and, perhaps also equipped with abraders in the form of chains or balls; and (f) passing through screws or log washers.

In short, the problem is to grind the sand and gravel together in the presence of adequate water which is replaced frequently enough to carry away the impurities in suspension or in solution. A rough, order-of-magnitude rule is that a minimum of about 10 gal. of water per min is required for each ton of material produced per hr (600 gal. per ton). That is to say, a plant producing 500 tons of sand and gravel per hr (moderately large) would require about 5000 gal. of water per min.

In general, washing presents no insurmountable obstacles, although there are exceptions. Taggart[13] and the *Pit and Quarry Handbook*[12] describe the various processes in considerable detail. Occasionally, organic impurities, as revealed by the colormetric test, are so firmly attached and in such form that they cannot be removed by washing. The damage that they cause, if any, has not been well demonstrated. There is evidence that early strengths may be reduced somewhat but that later strengths are relatively unaffected.

Screening gravel

The efficient use of screens is restricted to the coarser sizes, generally about ¼-in. openings or larger although, infrequently, sizes as small as No. 10- or No. 20-mesh are used. The scalping screen, through which the raw material is introduced to the plant, may be a gravity screen (perhaps only a "grizzly" made of steel bars), a revolving screen, or a vibrating screen. It removes oversize material which is discarded or diverted to a crusher. The undersize from the scalping screen, or from one immediately following it, is then processed through various screens to produce gravel of required sizes and to separate the sand.

Screening of gravel and the crushed oversize presents no special problems. Vibrating screens are used in the vast majority of cases, although revolving screens, either conical or cylindrical, are sometimes indicated because of their aid in cleaning the material. References 12 and 13 (*Pit and Quarry Handbook* and Taggart) previously cited contain excellent information on screens as applied to gravel.

The range in sizes from nominal minima to nominal maxima, together with feasible tolerances for over and undersizes, are well outlined in *Simplified Practice Recommendations for Sizes of Coarse Aggregate* promulgated by the U. S. Department of Commerce.[14] Closer sizes and tolerances are not considered to offer advantages commensurate with the greatly increased cost of processing. The Simplified Practice Recommendations form the basis for grading specifications for coarse aggregate promulgated by the American Society for Testing Materials, the American Assn. of State Highway Officials, many state highway departments, and other authoritative and representative specification-writing bodies.

It should be pointed out that processing screens and testing sieves do not have the same clear openings for a given nominal size. Testing sieves have square openings with wire diameter and clear openings conforming to universally accepted specifications.[15] Processing screens may be square, rectangular, round, or of other shape. They may be made of woven wire or perforated plate. The only limitation on size or shape of opening of any processing screen should be that, for the nature of feed, conditions of loading, slope, and capacity, it produces the size required. For example, a 1-in. round opening screen in the plant may produce material which, substantially, has a maximum size of ¾ in. as measured by standard testing sieves where sieving is to "refusal." Similarly, a plant screen with square opening of about ¼ in., or larger, may be used to insure a nominal lower size of about No. 4 as measured by testing sieves.

Classifying sand

Classification of sand as to size presents a major problem in the production of sand and gravel. Sand grading, as it affects concrete quality, is more critical than gravel grading and this is particularly true for the leaner mixes. The separation of sand into different sizes does not represent a straightforward screening operation as in the case of gravel. In general, screens are useful only to separate the sand from the gravel and to make required separations coarser than about a 20-mesh sieve. From that point on, sizing is generally by water classification[16]—although, as pointed out earlier, screens, both wet and dry,[17] and air separators are sometimes used.

In the vast majority of cases the sizing of sand consists only of separating it from the gravel and dewatering it in such a manner as to retain, so far as is feasible, an adequate amount of the finer sizes, generally those finer than a No. 50 sieve. For that purpose there is a wide variety of settling tanks and devices for recovering the sand and leaving the water behind. For example, an inclined screw conveyor in a suitable trough, with an apron overflow at the lower end, is frequently referred to as a screw classifier, a screw washer, or a screw dewaterer. The sand drag, rake classifiers, bowl classifiers, dewatering wheels, and other devices for removing sand from water, with a minimum of turbulence to retain the fines, all accomplish about the same purpose.

Generally, the natural grading of the sand is such that entirely satisfactory results will come from the relatively simple classifying methods referred to. Sometimes, however, for best results more elaborate methods are required. The most authoritative treatments of the general problem of sand classification are by Shaw[16] in his book on sand settling and devices for settling and classifying sand, published by *Rock Products*, and Rockwood[17] in his booklet on screening fine materials, also published by *Rock Products*. Taggart[13] treats hydraulic classification as applied to the mining field in considerable detail. The *Pit and Quarry Handbook*[12] includes a well rounded chapter on "Screens, Classifying and Washing."

The most common difficulty, particularly in water-transported materials, is the absence of fines. In many cases that deficiency has been apparent only and has resulted from inefficient dewatering methods or for other reasons, including loss of fine material during dredging operations. Obviously, if the fines are in the deposit, the solution to their absence in the finished product lies in revising processing methods.

When the fines are not available, the solution is to blend fine materials from other sources (frequently this can best be done at the batching plant) or from crushing larger sizes. Not enough experience has been had with crushing larger sizes for supplying fines to natural sand to permit discussing the problem in specific terms. The tailings from crushers in general, and from impact crushers in particular, have proven helpful. Roll crushers have been used to reduce the smaller sizes of gravel, but not with widespread success. Considerable success has been had with ball mills in grinding sand to finer sizes. Rod mills have been used successfully and economically on some large public works projects where the sand has been derived entirely or principally from the crushing operation.[18]

A common deficiency in the grading of natural sands, particularly those which have been water sorted in nature, is the concentration of an excessive proportion of the grains in the intermediate sizes. It is probably this circumstance which has led to the requirement for excessive fines in concrete sand—in an attempt to overcome, by additional fines, the harshness and tendency to bleed resulting from the high concentrations in the intermediate sizes.

Reducing the proportion of intermediate sizes presents a difficult classifying problem. However, it may be accomplished with varying degrees of success by the addition of fines as already discussed or by the actual elimination of a portion of the excess sizes. The reduction in quantity of intermediate sizes (generally costly in wasted material) can be accomplished by a variety of classification methods which will not be discussed in detail here. Rising current (of water) classification into different sizes represents the most straightforward approach. The collection and recombination of sizes settled at different points in various systems represents another. A classic treatment of the whole problem of sand classification is contained in the book by Edmund Shaw.[16]

Crushing

Gravel is crushed to reduce oversize, sometimes to produce angular particles and, sometimes, as discussed above, to produce the finer sizes of sand. Another reason, discussed subsequently, is to reduce the quantities of soft and friable particles.

Crushers are divided into five general classes: (1) jaw; (2) gyratory, including cone; (3) roll; (4) impact, including hammermills; and (5) various grinding machines, including rod mills. All of them find use in producing sand and gravel.

Jaw and gyratory crushers are most commonly used as primary crushers for sand and gravel. Secondary and later stage crushers are generally of the gyratory or cone type and sometimes are rolls and hammermills. It is difficult to generalize since the problem of crushing depends so much upon the size of product and purpose of crushing.

Where simple size reduction is the objective, first and second stage and sometimes third stage crushers are used. However, frequently, crushing operations are performed for the principal purpose of eliminating soft particles or providing crushed faces. In such cases the objective is to do a maximum of work with a minimum of size reduction. While any crusher lends itself to this type of operation, with suitable regulation of size and amount of feed in relation to crusher opening, the impact type appears to be best fitted for it.

Crushing gravel involves substantially the same problems as for any material in the mining field, and the literature is voluminous. Fred C. Bond and Frank E. Briber[19] presented an informative paper on "Principles of Crushing" at the 1951 annual meeting of the National Sand and Gravel Assn. Taggart[13] gives much information on the several types of crushers. The *Pit and Quarry Handbook*[12] includes a chapter on "Crushing, Grinding and Separating" in which the application of different types of crushers is discussed. There is further voluminous literature available, but that listed should furnish the necessary fundamental information.

Deleterious particles

Among the more vexing problems of sand and gravel production is that presented by deleterious particles occurring as impurities in deposits. It is more pressing for gravel than for sand. In general, if a source does not contain basically suitable material, there is little that can be done about it. While there are methods which can be applied to reduce the quantity of many undesirable particles, there is a quickly reached limit beyond which such processing is neither economical nor practicable.

Particles considered deleterious are generally classified as: soft fragments; thin and friable particles; shale; argillaceous sandstones and limestones; porous and unsound cherts; coated particles; thin and elongated particles; laminated particles; coal; lignite; and other materials depending upon impurities prevalent in the locality. These categories may be further condensed into two general classifications so far as use in concrete is concerned—those particles which break down with little volume change and those which expand considerably and exert a disruptive force.

Various attempts have been made to develop processing methods for reducing the quantity of these deleterious particles with only moderately encouraging results. It is self-evident that processing to separate selected types of particles from the parent gravel must depend on differences in strength and hardness, or in weight, or, to a limited extent, in size and appearance, or a combination of these.

Very soft particles, such as mud balls and some loosely consolidated conglomerates, may be removed, or reduced in quantity satisfactorily by processing through log washers or scrubbers. At least one example can be cited of a deposit with the sand and gravel completely embedded in clay, where the high content of sticky clay is removed satisfactorily by log washers. Numerous examples of fairly satisfactory removal of mud balls and the like by scrubbers of various types can be cited. In general, only the simplest of scrubbers are used in the industry.

Particles such as those just discussed, while soft, do not fall in the category of those commonly identified as soft. The common category suggests separation by differences in hardness, which has led to the use of various types of impact crushers and "soft stone eliminators.". These have been used with varying success depending upon the material being processed. Their use introduces additional problems: (a) Inevitably, a bottle neck in the flow sheet is produced; (b) What shall be done with the crushed soft materials? Shall they be permitted to go into the sand? In many cases that probably would not be harmful but in others it might; (c) The quantity of soft materials cannot be reduced satisfactorily without, at the same time, breaking up considerable quantities of good materials; (d) Equipment maintenance costs are generally high.

Separation on the basis of weight found little application in the gravel industry until recently. Some simple jigs have been used to separate coal, lignite, and sticks. References to the use of jigs for removal of shale and soft stone are in the literature. Taggart[13] describes various types of jigs in some detail. Jigs require a greater difference in weight than generally exists between the parent gravel and the material which it is wished to remove, except for such materials as coal and sticks where they may be used quite effectively.

Heavy-media separation (*i.e.*, sink-float), developed in the mining industry within the past 15 years, has proven successful for making separation of materials differing in specific gravity. It is claimed that a range in specific gravity of as little as 0.02 makes separation feasible and that for a range of 0.05, separation can be made quite readily.

In principle the process consists of floating out the lightweight material on a heavy "liquid" which is formed by suspension of heavy materials such as magnetite, galena, or ferrosilicon in water. Quartz sand suspensions have been used for cleaning coal for many years—the Chance process. The maximum specific gravity obtainable with sand, according to Taggart,[13] is only about 1.8, which, of course, would not be applicable to aggregate processing. Again according to Taggart,[13] magnetite will provide suspensions of specific gravities up to 2.55 and galena and ferrosilicon up to about 3.3 for normal working conditions.

Modern heavy-media processes employing ferrosilicon, galena, or magnetite have been used quite widely in processing low-grade iron ore, cleaning coal, and concentrating zinc, feldspar, magnetite, manganese, and other ores.[20,21,22,23] Cases of its use in processing gravel are, as yet, relatively few. The earliest was described in the April, 1949, issue of *The Engineering Journal* (the journal of the Engineering Institute of Canada),[24] the December, 1949, issue of *Pit and Quarry*,[25] the February, 1950, issue of *Rock Products*,[26] and the December, 1951, issue of *Civil Engineering*.[27] Those articles describe separation of gravel for use in the construction of airport runways at Rivers, Manitoba, Canada. The gravel contained considerable quantities of shale and rotten granite and it is said that a satisfactory separation was made at an estimated operating cost of about 10 cents per cu yd. It appears that this figure does not include plant "write-off" or any royalty payments.

Heavy-media installations have been made in at least three commercial gravel operations and these have apparently accomplished their intended purpose of removing objectionable lightweight constituents. Obviously, economy and the nature and amount of deleterious substances will limit to relatively few the plants which can advantageously employ heavy-media processing. Discussions of the application of that process will be found in references 28, 29, and 30.

The efficacy of hand-picked methods should not be overlooked. "Belt-pickers" are familiar in the industry. Commonly, no more special provision is made than to provide a place for a man to stand or sit where he can reach the moving belt. Sometimes a picking table, in the form of a widened and slowed-down section of belt, is provided. More elaborate devices are available, but not commonly used in sand and gravel processing. A good job can be done in the removal of certain impurities, (clay, chert, and large pieces of rotten stone) by alert workmen.

MISCELLANEOUS

It should be clear from the preceding that, although only relatively simple processes are involved, the production of sand and gravel involves possibilities for so many approaches and combinations of approaches as to become a complex subject. In anything less than a comprehensive and voluminous treatise, only the most general aspects of the problems can be touched upon. There are a number of subjects deserving discussion which are not readily classified and which will be discussed briefly in this "catch-all" miscellaneous section.

Breakage in handling

Handling and stockpiling can result in a great deal of undoing of the plant processing. Breakage and segregation may result in significant changes in grading.

Gravels are heavy materials and any handling results in breakage. Accordingly, after screening, care should be taken to minimize the impact due to falling to the extent practical. Excessively high drops should be avoided. Where it is unavoidable that the conveyor discharge is at considerable height above the point of deposit, breakage can be minimized by the use of rock ladders[31] or other means of interrupting the free drop. Sometimes breakage due to handling is enough that rescreening and rinsing are required. It is not uncommon to rescreen and rinse gravel as it is loaded into cars and other conveyances. The best practice, however, is to handle the material so that this additional processing will not be required.

Stockpiling

Segregation is a problem of particular importance with gravel. Sand is not free from it but, since it is generally being handled moist, little segregation is likely to take place. The importance of segregation of gravel is diminished as the sizes are more closely graded. It is very difficult, almost impossible, to handle "long" gradings (No. 4 to 2 in. for example) without objectionable segregation while with short gradings (½ to 1 in. for example) segregation which takes place may be relatively unimportant.

Aggregates should be handled in stockpiles and bins in a manner to minimize segregation of sizes. "Recommended Practice for Measuring, Mixing and Placing Concrete (ACI 614-42)"[32] contains some valuable suggestions for handling materials. Reference should also be made to the Bureau of Reclamation's *Concrete Manual* and to the *Pit and Quarry Handbook*[12] chapter on "Open Storage and Reclamation."

Reclaiming

Material in stockpiles must be reclaimed for transportation to point of use. There are numerous types of portable loaders for this purpose[12] and conventional cranes are adaptable. Stockpiling over a tunnel with reclaiming by belt offers many advantages including that of the ready blending of different sizes of materials.

Disposal of slimes

Spent wash water generally contains considerable quantities of clay and other fine material in suspension. Frequently circumstances, including stream pollution regulations, make the disposal of this material a problem—that of settling out the solids before disposing of the water or disposing of the suspension in such a manner as to be unobjectionable.

This problem only recently has become a prominent one in the sand and gravel industry, brought about by increasing attention to stream pollution. The best procedures for handling it have not as yet been worked out. It is mentioned here as something which the designer of plant and appurtenances should have in mind. Settling ponds and filters appear to represent the most direct approach. Re-using the clarified wash water frequently represents an economy.

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Title No. 51-7

Production of Sand and Gravel*

By STANTON WALKER†

SYNOPSIS

Production of sand and gravel is discussed under three main groupings: (1) development of deposits, (2) transportation to the plant, and (3) processing. Briefly detailed are prospecting and exploration, excavation, and transporting methods. Described in more detail are processes for washing, classifying, removing deleterious impurities, and crushing oversized materials. A list of 32 selected references completes the report.

INTRODUCTION

Sand and gravel are consolidated granular materials resulting from the natural disintegration of rocks. They generally occur together, variably proportioned in widely available deposits. Their production consists of extraction, transportation to the plant, and processing—the latter generally including washing, screening and otherwise classifying to size, crushing of oversize, and the elimination of deleterious impurities to the extent practicable.

Sand and gravel occur in a wide variety of deposits both above and below water. These deposits may consist of banks, pits, or the beds of streams, lakes or other bodies of water. The banks and pits may extend below the water level. Sand and gravel originate from the weathering of rock and its transportation by water. It may come from material deposited by glaciation or from residual materials broken down in place or from a combination of these. Consequently, mineralogically they are whatever their parent rocks were. The type of the deposit and the nature of the material in it dictates an extremely wide range in methods of production from extraction through final processing.

A first step toward the production of sand and gravel is a detailed exploration of the selected deposit to determine characteristics and quantities of material. The sand and gravel should be examined as to mineral composition, quantity and nature of impurities, soundness, strength, and size and grading. The question of whether or not the material can be economically produced to meet the requirements of applicable specifications is one that can be answered only by sound engineering judgment, based on experience coupled with a careful survey of the deposit and the need for its products.

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This short paper on sand and gravel production permits no more than a brief discussion of fundamental principles. A comprehensive treatment of the subject is impractical except in a work very broad in scope. The literature, while considerable, has not been well correlated. It is hoped, however, that this statement of fundamentals together with references to sources of information will serve a useful purpose.

PROSPECTING AND EXPLORATION

Sand and gravel deposits, by the nature of their occurrence, are evaluated as to quantity and quality only by painstaking exploration. The exploration falls in two parts—a preliminary one to estimate the extent and general nature of the material and, if that is promising, a detailed one which will not only furnish reasonably accurate information as to quantities available, but also as to the quality of the material.

There are a variety of approaches to preliminary exploration. Information available from state topographic, hydrologic, and geological surveys, and from other federal and state government agencies often is of considerable value. Outcroppings, visible deposits under water, and miscellaneous available excavations should be examined. Recent developments in geophysical methods offer promise for rapid preliminary surveys. Resistivity methods, which indicate changes in composition of underground strata by differences in electrical resistance, seem most applicable.

Before any final answer can be secured, exploration methods must be used which provide representative samples. The relative amounts of sand and gravel must be determined and evaluated in the light of market demand and specification requirements. Grading of the material must be examined to determine if specification requirements can be met economically. The nature and amount of deleterious materials and the feasibility of their economical removal must be studied. The problem is complicated by the inherent lack of uniformity of many sand and gravel deposits due to the natural processes by which they were formed.

Exploration methods which permit securing representative samples from land deposits include test pits and trenches, driving of pipes and excavation of material from the pipes by special bucket or other means, earth augers, churn drills, and other procedures for getting a cross section of the material. For underwater deposits, dredges, both pump and ladder, cranes and buckets, draglines, and similar straightforward devices are used. There are no short-cut methods.

There is relatively little literature dealing directly with prospecting and exploration for sand and gravel. In 1932, J. R. Thoenen of the U. S. Bureau of Mines prepared a 50-page discussion of the problems as a whole.[1] He discussed, in somewhat general terms, the occurrence of sand and gravel and the various methods of exploration applicable to different types of deposits. The paper is out of print but should be available in many technical libraries.

A symposium on prospecting was held at the 1950 annual meeting of the National Sand and Gravel Assn. R. Woodward Moore of the Bureau of Public Roads discussed geophysical methods of subsurface exploration and gave a selected list of references to the literature.[2] Experiences of members of the industry with augers, adaptations of well-drilling equipment, resistivity methods, and in underwater exploration are described in references 3, 4, and 5.

General information on prospecting may be found in the Bureau of Reclamation *Concrete Manual*, in the American Institute of Mining Engineers publication, *Industrial Minerals and Rocks*, particularly the chapter on "Sand and Gravel," by Bror Nordberg,[6] and in the American Society for Testing Materials 1948 *Symposium on Mineral Aggregates*, particularly the chapters on "Distribution of Mineral Aggregates," by K. B. Woods,[7] and "Production and Manufacture of Fine and Coarse Aggregates," by N. C. Rockwood.[8]

DEVELOPMENT OF DEPOSITS

Excavation of material from the deposit is the first step in production. For bank and pit deposits above the water level, excavation is ordinarily by power shovel, dragline, drag scraper, or slackline cableway. Earthmoving, tractor-combination machines sometimes are used in shallow deposits. Various methods, including light blasting, are used to break down the face of the pit or bank to make the material more conveniently available for excavation.

Most land deposits are covered by overburden. If it is light and sandy, it may be excavated along with the sand and gravel and removed in the processing plant. If it is heavy, it should be stripped ahead of the excavating operation. The same, or similar, equipment may be used for stripping as for excavation.

Draglines and cableways may also be used to excavate below the water level in wet pits and shallow streams. However, if the nature of the material and the quantity of water permits, it is common practice to use suction dredge pumps. After a pit is opened, the dredge may be used to excavate the above-water material as well, it being broken down into the water by under-cutting, by light blasting, or by other means.

For marine deposits both suction and ladder dredges are used. The suction dredge generally delivers the material directly to the processing plant on land, or it may pump to a sump from which the material is pumped again. Less frequently the material may be pumped to barges in which it is transported to the processing plant.

The ladder dredge is used for deposits which are too consolidated or too coarse for suction dredges and for other reasons which may be dictated by economy of operation. Sometimes ladder dredges deliver the materials direct to barges for transportation to processing plants but, more frequently, except in large wet-pit operations, the processing plant is on the same hull as the dredge.

Excavation is also done with crane and bucket, with dipper dredges and, infrequently, by hydraulic sluicing. Excavation methods and excavating equipment used for production of sand and gravel are those common in the mining field, and are extensively described in the literature. The magazines *Pit and Quarry*[9] and *Rock Products*[10] pay particular attention to sand and gravel production and almost any issue will include descriptions of one or more operations. Another Bureau of Mines publication by Thoenen[11] on developing sand and gravel deposits, written in 1933, deals with excavation from different types of deposits and gives references to descriptions of a number of specific operations.

The *Pit and Quarry Handbook*[12] includes comprehensive chapters on dredging, stripping, pumping, and excavating pertinent to any consideration of recovery of materials from selected sources. Information of a more general nature will be found in the papers by Nordberg[6] and Rockwood[8] previously cited. There is also much general information, particularly on dredges and pumps, in Taggart's *Handbook of Mineral Dressing*.[13]

TRANSPORTATION TO PLANT

After excavation the material must be taken to the processing plant. Some of the methods of excavation incorporate methods of transportation to the plant—as the suction dredge, the earth mover and, sometimes, the cableway scrapers. For underwater deposits, barges may be used to transport unprocessed material from dredge to plant although more often processing is done on the dredge. When shovels, draglines, or similar equipment are used, independent means must be provided. These include narrow and standard gauge railroads, trucks (of all kinds and up to about 20 cu yd capacity), and belt conveyors. Each method has its place and its economic advantages, depending upon the nature of the deposit.

Transportation from point of excavation to the processing plant is sometimes done in two stages—a "surge pile" being introduced between the two. In the case of a dredge pump operation, material may be pumped to a sump and picked up by a booster pump for transportation to the plant. In the case of a land operation, excavated material may be transported to a storage pile (surge pile) by a selected means and then conveyed from that pile by any other selected means, generally a belt. This intermediate storage serves, among other things, to facilitate maintaining a uniform feed to the plant by divorcing it from complete dependence on the rate of excavation.

The chapter on "Intraplant Transportation" in the *Pit and Quarry Handbook*[12] treats the several methods in considerable detail. Taggart[13] also deals with transportation, including some information on costs, and there is general information in the previously cited works of Nordberg[6] and Rockwood.[8]

PLANT PROCESSING

Plant processing includes washing, screening and otherwise classifying to size, crushing of oversize, and the reduction of deleterious impurities to the extent practical. Impurities which are soluble or suspendable in water generally can be washed out satisfactorily. Sizing and classifying can be done with considerable accuracy within the limits of the sizes available, although costs are greatly increased if it is necessary to waste much material or if too many or too close separations, particularly in the sand sizes, are required. Deleterious materials may be reduced, but there is a limit beyond which such operations are neither feasible nor economical.

The processing plant essentially is a simple combination of conveyors, screens, crushers, washing and classifying equipment, and storage and loading facilities. Any attempt to illustrate a typical one or to show a typical flow sheet would be misleading. The plant must be tailored to suit the deposit and the market. In the simple case of a land deposit, a plant might consist of the following elements:

1. A hopper, or equivalent, to receive material transported from the deposit or surge pile. Generally this hopper will be covered with a "grizzly" of parallel bars, or equivalent, to screen out boulders too large to be handled by the plant—in most cases a relatively small proportion of casual material.

2. From this receiving hopper the material will pass through a gate, controlled by a "feeder," of which there are numerous designs, to a conveyor on which it is carried to the top of the plant on to the scalping screen. A belt conveyor is generally the most economical. Bucket elevators have been used and are still used but less than in the past. Skip hoists have been used, but sparingly.

3. The scalping screen separates oversize material from the smaller, marketable sizes.

4. Material passing the scalping screen is fed into a battery of screens, either vibrating or revolving, the number, size, and arrangement of which will depend on the sizes and number of sizes to be made. Water from sprays is introduced from the beginning and is applied throughout the screening operation. From these screens the different sizes of gravel will be discharged into bins or on to conveyors for transportation to stockpiles or, in some cases, to crushers and other screens for further processing. The sand passes to classifying and dewatering equipment and from there to bins or stockpiles.

5. The oversize from the scalping screen passes to the crushers—the size, number, and arrangement of which depends upon the quantity and nature of the material to be crushed.

6. Crushed material may be re-elevated to the scalping screen and, hence, through the plant or it may be subjected to an independent screening and sizing operation. Which procedure is used will depend upon whether the crushed material is salable as a separate product or merely represents an economical disposition of oversize. In some cases, the crushed gravel is used

for blending with natural gravel to meet specifications which put a minimum limit on quantity of crushed particles.

Washing

Washing and sizing of sand and gravel are almost always done simultaneously. Water is needed for efficient screening and, of course, is essential to water classification. Accordingly, whether or not washing is needed, water is introduced into the sizing operation if it is available. Dry sizing, involving screening and air separation, has been used in some cases where water is scarce. For sands and gravels containing loosely adhering and readily soluble or suspendable impurities, the minimum amount of water required for sizing is adequate for washing.

However, many sands and gravels contain clay, mud, mudballs, and organic impurities firmly enough attached to require thorough washing and scrubbing. Depending upon circumstances, adequate washing will result from the following, listed (roughly) in order of increasingly difficult conditions: (a) pumping material to the plant; (b) introducing enough water to facilitate screening; (c) providing adequate sprays on vibrating or revolving screens; (d) passing material through special sections of revolving screens in the presence of counter-flowing high-velocity water; (e) same as (d) except that, in effect, the revolving screen is "blinded" (generally called a scrubber) and, perhaps also equipped with abraders in the form of chains or balls; and (f) passing through screws or log washers.

In short, the problem is to grind the sand and gravel together in the presence of adequate water which is replaced frequently enough to carry away the impurities in suspension or in solution. A rough, order-of-magnitude rule is that a minimum of about 10 gal. of water per min is required for each ton of material produced per hr (600 gal. per ton). That is to say, a plant producing 500 tons of sand and gravel per hr (moderately large) would require about 5000 gal. of water per min.

In general, washing presents no insurmountable obstacles, although there are exceptions. Taggart[13] and the *Pit and Quarry Handbook*[12] describe the various processes in considerable detail. Occasionally, organic impurities, as revealed by the colormetric test, are so firmly attached and in such form that they cannot be removed by washing. The damage that they cause, if any, has not been well demonstrated. There is evidence that early strengths may be reduced somewhat but that later strengths are relatively unaffected.

Screening gravel

The efficient use of screens is restricted to the coarser sizes, generally about ¼-in. openings or larger although, infrequently, sizes as small as No. 10- or No. 20-mesh are used. The scalping screen, through which the raw material is introduced to the plant, may be a gravity screen (perhaps only a "grizzly" made of steel bars), a revolving screen, or a vibrating screen. It removes oversize material which is discarded or diverted to a crusher. The undersize from the scalping screen, or from one immediately following it, is then processed through various screens to produce gravel of required sizes and to separate the sand.

Screening of gravel and the crushed oversize presents no special problems. Vibrating screens are used in the vast majority of cases, although revolving screens, either conical or cylindrical, are sometimes indicated because of their aid in cleaning the material. References 12 and 13 (*Pit and Quarry Handbook* and Taggart) previously cited contain excellent information on screens as applied to gravel.

The range in sizes from nominal minima to nominal maxima, together with feasible tolerances for over and undersizes, are well outlined in *Simplified Practice Recommendations for Sizes of Coarse Aggregate* promulgated by the U. S. Department of Commerce.[14] Closer sizes and tolerances are not considered to offer advantages commensurate with the greatly increased cost of processing. The Simplified Practice Recommendations form the basis for grading specifications for coarse aggregate promulgated by the American Society for Testing Materials, the American Assn. of State Highway Officials, many state highway departments, and other authoritative and representative specification-writing bodies.

It should be pointed out that processing screens and testing sieves do not have the same clear openings for a given nominal size. Testing sieves have square openings with wire diameter and clear openings conforming to universally accepted specifications.[15] Processing screens may be square, rectangular, round, or of other shape. They may be made of woven wire or perforated plate. The only limitation on size or shape of opening of any processing screen should be that, for the nature of feed, conditions of loading, slope, and capacity, it produces the size required. For example, a 1-in. round opening screen in the plant may produce material which, substantially, has a maximum size of ¾ in. as measured by standard testing sieves where sieving is to "refusal." Similarly, a plant screen with square opening of about ¼ in., or larger, may be used to insure a nominal lower size of about No. 4 as measured by testing sieves.

Classifying sand

Classification of sand as to size presents a major problem in the production of sand and gravel. Sand grading, as it affects concrete quality, is more critical than gravel grading and this is particularly true for the leaner mixes. The separation of sand into different sizes does not represent a straightforward screening operation as in the case of gravel. In general, screens are useful only to separate the sand from the gravel and to make required separations coarser than about a 20-mesh sieve. From that point on, sizing is generally by water classification[16]—although, as pointed out earlier, screens, both wet and dry,[17] and air separators are sometimes used.

In the vast majority of cases the sizing of sand consists only of separating it from the gravel and dewatering it in such a manner as to retain, so far as is feasible, an adequate amount of the finer sizes, generally those finer than a No. 50 sieve. For that purpose there is a wide variety of settling tanks and devices for recovering the sand and leaving the water behind. For example, an inclined screw conveyor in a suitable trough, with an apron overflow at the lower end, is frequently referred to as a screw classifier, a screw washer, or a screw dewaterer. The sand drag, rake classifiers, bowl classifiers, dewatering wheels, and other devices for removing sand from water, with a minimum of turbulence to retain the fines, all accomplish about the same purpose.

Generally, the natural grading of the sand is such that entirely satisfactory results will come from the relatively simple classifying methods referred to. Sometimes, however, for best results more elaborate methods are required. The most authoritative treatments of the general problem of sand classification are by Shaw[16] in his book on sand settling and devices for settling and classifying sand, published by *Rock Products*, and Rockwood[17] in his booklet on screening fine materials, also published by *Rock Products*. Taggart[13] treats hydraulic classification as applied to the mining field in considerable detail. The *Pit and Quarry Handbook*[12] includes a well rounded chapter on "Screens, Classifying and Washing."

The most common difficulty, particularly in water-transported materials, is the absence of fines. In many cases that deficiency has been apparent only and has resulted from inefficient dewatering methods or for other reasons, including loss of fine material during dredging operations. Obviously, if the fines are in the deposit, the solution to their absence in the finished product lies in revising processing methods.

When the fines are not available, the solution is to blend fine materials, from other sources (frequently this can best be done at the batching plant) or from crushing larger sizes. Not enough experience has been had with crushing larger sizes for supplying fines to natural sand to permit discussing the problem in specific terms. The tailings from crushers in general, and from impact crushers in particular, have proven helpful. Roll crushers have been used to reduce the smaller sizes of gravel, but not with widespread success. Considerable success has been had with ball mills in grinding sand to finer sizes. Rod mills have been used successfully and economically on some large public works projects where the sand has been derived entirely or principally from the crushing operation.[18]

A common deficiency in the grading of natural sands, particularly those which have been water sorted in nature, is the concentration of an excessive proportion of the grains in the intermediate sizes. It is probably this circumstance which has led to the requirement for excessive fines in concrete sand—in an attempt to overcome, by additional fines, the harshness and tendency to bleed resulting from the high concentrations in the intermediate sizes.

Reducing the proportion of intermediate sizes presents a difficult classifying problem. However, it may be accomplished with varying degrees of success by the addition of fines as already discussed or by the actual elimination of a portion of the excess sizes. The reduction in quantity of intermediate sizes (generally costly in wasted material) can be accomplished by a variety of classification methods which will not be discussed in detail here. Rising current (of water) classification into different sizes represents the most straightforward approach. The collection and recombination of sizes settled at different points in various systems represents another. A classic treatment of the whole problem of sand classification is contained in the book by Edmund Shaw.[16]

Crushing

Gravel is crushed to reduce oversize, sometimes to produce angular particles and, sometimes, as discussed above, to produce the finer sizes of sand. Another reason, discussed subsequently, is to reduce the quantities of soft and friable particles.

Crushers are divided into five general classes: (1) jaw; (2) gyratory, including cone; (3) roll; (4) impact, including hammermills; and (5) various grinding machines, including rod mills. All of them find use in producing sand and gravel.

Jaw and gyratory crushers are most commonly used as primary crushers for sand and gravel. Secondary and later stage crushers are generally of the gyratory or cone type and sometimes are rolls and hammermills. It is difficult to generalize since the problem of crushing depends so much upon the size of product and purpose of crushing.

Where simple size reduction is the objective, first and second stage and sometimes third stage crushers are used. However, frequently, crushing operations are performed for the principal purpose of eliminating soft particles or providing crushed faces. In such cases the objective is to do a maximum of work with a minimum of size reduction. While any crusher lends itself to this type of operation, with suitable regulation of size and amount of feed in relation to crusher opening, the impact type appears to be best fitted for it.

Crushing gravel involves substantially the same problems as for any material in the mining field, and the literature is voluminous. Fred C. Bond and Frank E. Briber[19] presented an informative paper on "Principles of Crushing" at the 1951 annual meeting of the National Sand and Gravel Assn. Taggart[13] gives much information on the several types of crushers. The *Pit and Quarry Handbook*[12] includes a chapter on "Crushing, Grinding and Separating" in which the application of different types of crushers is discussed. There is further voluminous literature available, but that listed should furnish the necessary fundamental information.

Deleterious particles

Among the more vexing problems of sand and gravel production is that presented by deleterious particles occurring as impurities in deposits. It is more pressing for gravel than for sand. In general, if a source does not contain basically suitable material, there is little that can be done about it. While there are methods which can be applied to reduce the quantity of many undesirable particles, there is a quickly reached limit beyond which such processing is neither economical nor practicable.

Particles considered deleterious are generally classified as: soft fragments; thin and friable particles; shale; argillaceous sandstones and limestones; porous and unsound cherts; coated particles; thin and elongated particles; laminated particles; coal; lignite; and other materials depending upon impurities prevalent in the locality. These categories may be further condensed into two general classifications so far as use in concrete is concerned—those particles which break down with little volume change and those which expand considerably and exert a disruptive force.

Various attempts have been made to develop processing methods for reducing the quantity of these deleterious particles with only moderately encouraging results. It is self-evident that processing to separate selected types of particles from the parent gravel must depend on differences in strength and hardness, or in weight, or, to a limited extent, in size and appearance, or a combination of these.

Very soft particles, such as mud balls and some loosely consolidated conglomerates, may be removed, or reduced in quantity satisfactorily by processing through log washers or scrubbers. At least one example can be cited of a deposit with the sand and gravel completely embedded in clay, where the high content of sticky clay is removed satisfactorily by log washers. Numerous examples of fairly satisfactory removal of mud balls and the like by scrubbers of various types can be cited. In general, only the simplest of scrubbers are used in the industry.

Particles such as those just discussed, while soft, do not fall in the category of those commonly identified as soft. The common category suggests separation by differences in hardness, which has led to the use of various types of impact crushers and "soft stone eliminators." These have been used with varying success depending upon the material being processed. Their use introduces additional problems: (a) Inevitably, a bottle neck in the flow sheet is produced; (b) What shall be done with the crushed soft materials? Shall they be permitted to go into the sand? In many cases that probably would not be harmful but in others it might; (c) The quantity of soft materials cannot be reduced satisfactorily without, at the same time, breaking up considerable quantities of good materials; (d) Equipment maintenance costs are generally high.

Separation on the basis of weight found little application in the gravel industry until recently. Some simple jigs have been used to separate coal, lignite, and sticks. References to the use of jigs for removal of shale and soft stone are in the literature. Taggart[13] describes various types of jigs in some detail. Jigs require a greater difference in weight than generally exists between the parent gravel and the material which it is wished to remove, except for such materials as coal and sticks where they may be used quite effectively.

Heavy-media separation (*i.e.*, sink-float), developed in the mining industry within the past 15 years, has proven successful for making separation of materials differing in specific gravity. It is claimed that a range in specific gravity of as little as 0.02 makes separation feasible and that for a range of 0.05, separation can be made quite readily.

In principle the process consists of floating out the lightweight material on a heavy "liquid" which is formed by suspension of heavy materials such as magnetite, galena, or ferrosilicon in water. Quartz sand suspensions have been used for cleaning coal for many years—the Chance process. The maximum specific gravity obtainable with sand, according to Taggart,[13] is only about 1.8, which, of course, would not be applicable to aggregate processing. Again according to Taggart,[13] magnetite will provide suspensions of specific gravities up to 2.55 and galena and ferrosilicon up to about 3.3 for normal working conditions.

Modern heavy-media processes employing ferrosilicon, galena, or magnetite have been used quite widely in processing low-grade iron ore, cleaning coal, and concentrating zinc, feldspar, magnetite, manganese, and other ores.[20,21,22,23] Cases of its use in processing gravel are, as yet, relatively few. The earliest was described in the April, 1949, issue of *The Engineering Journal* (the journal of the Engineering Institute of Canada),[24] the December, 1949, issue of *Pit and Quarry*,[25] the February, 1950, issue of *Rock Products*,[26] and the December, 1951, issue of *Civil Engineering*.[27] These articles describe separation of gravel for use in the construction of airport runways at Rivers, Manitoba, Canada. The gravel contained considerable quantities of shale and rotten granite and it is said that a satisfactory separation was made at an estimated operating cost of about 10 cents per cu yd. It appears that this figure does not include plant "write-off" or any royalty payments.

Heavy-media installations have been made in at least three commercial gravel operations and these have apparently accomplished their intended purpose of removing objectionable lightweight constituents. Obviously, economy and the nature and amount of deleterious substances will limit to relatively few the plants which can advantageously employ heavy-media processing. Discussions of the application of that process will be found in references 28, 29, and 30.

The efficacy of hand-picked methods should not be overlooked. "Belt-pickers" are familiar in the industry. Commonly, no more special provision is made than to provide a place for a man to stand or sit where he can reach the moving belt. Sometimes a picking table, in the form of a widened and slowed-down section of belt, is provided. More elaborate devices are available, but not commonly used in sand and gravel processing. A good job can be done in the removal of certain impurities, (clay, chert, and large pieces of rotten stone) by alert workmen.

MISCELLANEOUS

It should be clear from the preceding that, although only relatively simple processes are involved, the production of sand and gravel involves possibilities for so many approaches and combinations of approaches as to become a complex subject. In anything less than a comprehensive and voluminous treatise, only the most general aspects of the problems can be touched upon. There are a number of subjects deserving discussion which are not readily classified and which will be discussed briefly in this "catch-all" miscellaneous section.

Breakage in handling

Handling and stockpiling can result in a great deal of undoing of the plant processing. Breakage and segregation may result in significant changes in grading.

Gravels are heavy materials and any handling results in breakage. Accordingly, after screening, care should be taken to minimize the impact due to falling to the extent practical. Excessively high drops should be avoided. Where it is unavoidable that the conveyor discharge is at considerable height above the point of deposit, breakage can be minimized by the use of rock ladders[31] or other means of interrupting the free drop. Sometimes breakage due to handling is enough that rescreening and rinsing are required. It is not uncommon to rescreen and rinse gravel as it is loaded into cars and other conveyances. The best practice, however, is to handle the material so that this additional processing will not be required.

Stockpiling

Segregation is a problem of particular importance with gravel. Sand is not free from it but, since it is generally being handled moist, little segregation is likely to take place. The importance of segregation of gravel is diminished as the sizes are more closely graded. It is very difficult, almost impossible, to handle "long" gradings (No. 4 to 2 in. for example) without objectionable segregation while with short gradings (½ to 1 in. for example) segregation which takes place may be relatively unimportant.

Aggregates should be handled in stockpiles and bins in a manner to minimize segregation of sizes. "Recommended Practice for Measuring, Mixing and Placing Concrete (ACI 614-42)"[32] contains some valuable suggestions for handling materials. Reference should also be made to the Bureau of Reclamation's *Concrete Manual* and to the *Pit and Quarry Handbook*[12] chapter on "Open Storage and Reclamation."

Reclaiming

Material in stockpiles must be reclaimed for transportation to point of use. There are numerous types of portable loaders for this purpose[12] and conventional cranes are adaptable. Stockpiling over a tunnel with reclaiming by belt offers many advantages including that of the ready blending of different sizes of materials.

Disposal of slimes

Spent wash water generally contains considerable quantities of clay and other fine material in suspension. Frequently circumstances, including stream pollution regulations, make the disposal of this material a problem—that of settling out the solids before disposing of the water or disposing of the suspension in such a manner as to be unobjectionable.

This problem only recently has become a prominent one in the sand and gravel industry, brought about by increasing attention to stream pollution. The best procedures for handling it have not as yet been worked out. It is mentioned here as something which the designer of plant and appurtenances should have in mind. Settling ponds and filters appear to represent the most direct approach. Re-using the clarified wash water frequently represents an economy.

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