USER'S MANUAL

COAL-MINE REFUSE
IN
HIGHWAY EMBANKMENTS

PREPARED FOR
FEDERAL HIGHWAY ADMINISTRATION
Implementation Division

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FOREWORD

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Coal-mine refuse (CMR) is the waste product of mining and processing coal for market. This waste product has commonly been disposed of in large refuse banks. These banks are not only unsightly, but pollute the surrounding air and water.

The successful use of CMR in highway embankment construction has eliminated some of these aesthetic and environmental blights, rehabilitating the once useless land which they infested. The Federal Highway Administration's Implementation Division sponsored the development of this manual to encourage the further use of CMR in highway embankment construction.

The manual is divided into two parts. Part I provides useful background information on CMR. Part II provides guidelines for its use in highway embankment construction. It has primarily been written for individuals and organizations engaged in highway and environmental planning and highway design, materials testing, and construction. While seasoned geotechnical engineers will find some elementary geotechnical data presented, the Federal Highway Administration requested this additional information be provided for agencies and engineers with limited geotechnical experience.

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16. Abstract

This manual provides the information needed to use coarse anthracite and bituminous wastes in highway embankment construction. It has 2 parts. Part 1 contains wide ranging data needed for an understanding of coal-mine refuse (CMR) properties, its origins, and regulations governing its disposal. Case histories of highway embankments with CMR are included. Part 2--the user's portion of the manual--sets forth the procedures to follow from planning through construction of highway embankments with CMR.

The manual will benefit highway and environmental planners, and those engaged in highway design, materials testing, and construction. While geotechnical engineers should be consulted in the design of all highway embankments, the manual contains some elementary geotechnical data for the benefit of those organizations with limited geotechnical skills.

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SECTION 1. INTRODUCTION

Coal mine refuse results from mining processes that extract quantities of non-coal material along with the coal. This non-coal material is processed out of the coal and becomes refuse that must be disposed of, by stockpiling or other means. There are vast quantities of refuse stockpiled throughout the coal fields of the United States. These refuse piles occupy valuable land space and create pollution in the air and water.

The stockpiling and reclamation of refuse has cost mining companies, and, ultimately the public, billions of dollars over the past years. There is a need to take positive approaches in dealing with coal mine refuse, and to consider how this refuse material can be put to use in economically and environmentally beneficial programs. This "Users Manual" documents one such positive approach that can be taken - the utilization of coal refuse as fill in highway embankment.

The development of technology for the use of coal mine refuse as embankment construction material has been underway for many years. Originally, the research efforts were focused primarily on the mining industry, mainly to solve disposal problems. Subsequently, the increasing magnitude of accumulation and availability of the material caused by continuous, and recently, accelerated rates of coal mining, has prompted studies that document the feasibility of using coal mine refuse as an embankment material for many construction projects. The positive results of these studies have resulted in the use of coal refuse in highway embankments. Great Britain has been a forerunner in utilizing coal mine refuse as highway fill. Many highway sections have been built in Great Britain using coal mine refuse as fill material, generally with great success. The success the British have encountered has encouraged the use of coal mine refuse as fill in some highway sections in the United States. This manual exists to further encourage the use of coal mine refuse in highway embankments and to guide such utilization, especially, by highway and construction people who may be unfamiliar with the material.

PURPOSE AND SCOPE

The primary purpose of this manual is to provide guidelines that will help those engaged in the design and construction of highway embankments to use coal mine refuse as a construction material. The manual has been written for use by technicians, professionals and laymen to:

- Provide them with a basic understanding of the production and disposal of coal mine refuse.
- Familiarize them with the physical and chemical characteristics of coal mine refuse.
- Provide them with a thorough understanding of pre-design and environmental considerations.
- Provide them with basic information on design and construction of highway embankments using coal mine refuse.

This manual is not intended to be a substitute for good highway and soils engineering practices. The use of coal mine refuse material in highway embankments can be successfully accomplished by applying standard highway and soils engineering procedures. However, because of the physical and chemical characteristics of coal mine refuse and regulations governing the use of this material, mainly from an environmental viewpoint, special design and construction considerations are required.

This manual encompasses all forms of ANTHRACITE and BITUMINOUS COARSE COAL REFUSE. Coarse coal mine refuse is of plus 28 sieve or greater than 0.5 mm in grain size and results from the initial crushing and separation of the non-coal material from the coal.

This manual does not encompass slurry refuse and lignite refuse. The slurry refuse results from the crushed coal undergoing flotation and frothing methods to remove these finer fraction of refuse (minus 28 sieve). The slurry refuse has different characteristics than the coarse refuse and is not covered in this manual.

The various forms of anthracite and bituminous coarse coal refuse which may be encountered by the user are: Fresh, weathered, and burnt. These forms are explained further in Section 2 of Part I. Differences between the characteristics of these materials are noted when appropriate.

The information contained herein was gathered by an extensive review of all available publications on the subject from both the United States and Great Britain. Individuals from both countries who are experienced with the utilization of coal mine refuse were contacted and interviewed in order to obtain the latest available information.

USE OF THE MANUAL

This manual consists of two parts. The information presented in Part I is directed primarily toward documentation of the suitability of using coal mine refuse as a highway embankment material and at providing a basic understanding of the origin and the physical and chemical characteristics of the material.

Section 2 of Part I describes the environmental and economic problems resulting from the stockpiling of coal mine refuse. Several methods of utilizing coal mine refuse are discussed including basic benefits realized by disposing of coal refuse in highway embankments. The location of the major coal fields of U.S. are presented with a brief discussion of availability of coal mine refuse. The successful methods used by the British to encourage the utilization of coal mine refuse are presented.

Section 3 discusses the coal mining process as it affects the refuse material produced. The basic types of coal mine refuse that will be encountered are described. A description of the history of coal refuse disposal is presented with an aim toward familiarizing the coal refuse user with the variability of refuse between disposal sites and also within the disposal site. Present regulations governing the disposal of coal refuse are outlined with emphasis upon those regulations which will affect the removal of coal mine refuse from the disposal site and subsequent emplacement within a highway embankment.

Section 4 covers the chemical and physical characteristics of coal mine refuse. The descriptions are written to include all types of bituminous and anthracite coarse coal refuse; fresh, weathered, and burnt. Exceptions which may apply to any of these specific refuse types are noted when appropriate. The purpose of this section is to familarize the user with the basic properties of the material and special considerations which may be needed for engineering purposes.

Case histories of highway sections already constructed using coal mine refuse are presented in Section 5. These include highway construction in the U.S. and Great Britain. Two highway sections in the U.S. are covered in detail; one, using bituminous refuse, and the other using anthracite refuse. Case histories of highway construction with coal mine refuse in Great Britain are covered in less detail with emphasis upon the benefits incurred by using this material, and any construction problems encountered.

Part II presents procedures for utilizing coal mine refuse in highway embankments. Section 1 describes pre planning considerations which must be taken into account. These include problems that may be encountered during all phases of pre-construction and construction. The user of refuse should make sure that these problems can be overcome before the design of the highway section is begun.

Section 2 covers the general properties of a refuse pile which will effect the selection of a sampling program. Sampling methods are recommended to fit these conditions with general descriptions of how the various sampling procedures are implemented.

Testing of the chemical and physical properties of coal refuse is covered in Section 3. These testing procedures are presented in a manner to allow the user to tailor the testing program to the specific needs and condition that exist. Recommended specifications are included where pertinent.

Design elements are covered in Section 4. These elements include the grading analysis, selection of areas for refuse placement, typical section development, stability of embankment slopes, and roadside development.

Section 5 describes construction methods to be used in placement of coal refuse in the embankment. General guidelines are presented for foundation preparation, pipe selection and the hauling, spreading, and compaction of refuse. Construction equipment that has proven effective in handling coal refuse is described.

An "Annotated Bibliography" is included at the back of this manual. This bibliography is categorized as follows:

Coal Refuse Utilization and Disposal

Testing and Engineering Properties

Design

Spontaneous Combustion

Survey

Environmental Concern

Miscellaneous

The reader is referred to the bibliography for further information on these specific aspects of the utilization of coal mine refuse.

PART I

SECTION 2. THE PROBLEM

Coal is quickly becoming the major source of energy in the United States. With the present national emphasis on becoming energy independent, coal production is projected to increase greatly over the next 30 years. There are presently bills before Congress to force industry and utilities to change to coal as their major energy source, rather than oil and gas. But, there are problems associated with coal production, and in order for coal to continue to play a major role in supplying our nation's energy needs,the environmental and social damages resulting from its production must be lessened. A typical bituminous refuse bank is pictured in Figure 1. The major problems associated with such dumps are the production of acidic leachates and the run-off of sediment from the surface of the pile and air pollution caused by burning of refuse material within the pile.

An estimated 3 billion tons (2.7 billion metric tons) of bituminous and anthracite coal refuse are presently stockpiled throughout the U.S., with 110 million tons (100 million metric tons) being produced annually.(1) With present preparation techniques, 25 percent of mined coal is rejected as waste and has to be stockpiled.(2) If present projections of coal production are met, the demand for coal will double by 1985, producing over 200 million tons (180 million metric tons) of refuse annually.(3)

The Bureau of Mines did a study of refuse disposal and reclamation costs throughout the U.S..(4) Refuse disposal costs for coal companies

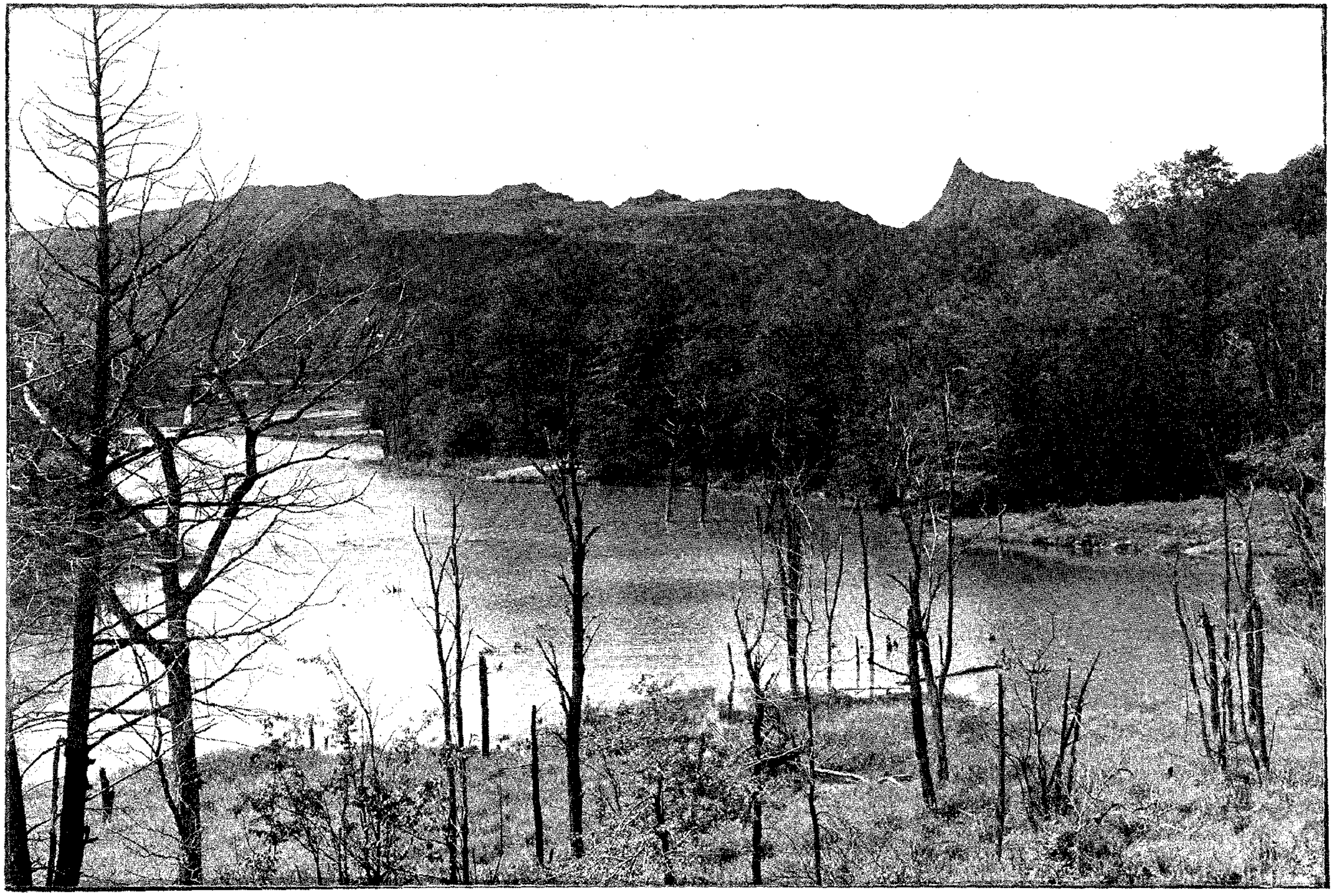


Figure I. A Refuse Bank in Revloc, Pennsylvania.

ranged from 9 to 28 cents per ton-mile for transportation to the dump site. Spreading and compacting of the refuse ranged from 3 to 20 cents per ton. Costs of covering with soil and plants ranged from $750 to $1,646 per acre. The reclamation costs for Pennsylvania refuse sites ranged from $1,800 to $15,000 per acre. It can be seen from these figures that millions of dollars are spent annually on the stockpiling of refuse and the reclamation of abandoned refuse sites.

An obvious solution to many of the economic and environmental problems resulting from coal waste stockpiling is to utilize this material and therefore decrease the quantity requiring storage. It is only recently that concerted efforts have been made in both the U.S. and abroad, to utilize greater quantities of the available refuse. Coal recovery has used the greatest bulk of refuse to this point in the U.S. . Many older banks contain high percentages of coal because early preparation methods were inefficient and only the highest grades of coal were saleable. As much as 60 percent coal recovery has been reported from these older refuse banks.

Another method of utilization that uses great quantities of coal refuse is as fill material for highways. Highway embankments require large quantities of soil and rock material for fill. Substitution of coal refuse for fill would remove large tonnages of unsightly material from the countryside and would alleviate the need to excavate suitable soil and rock material.

The location of refuse banks is perhaps the greatest problem facing utilization of refuse as embankment fill in the U.S.. A University of

Kentucky study determined that the state's refuse is desirable fill material, but that utilization of large quantities was not presently feasible because the majority of refuse banks are located in isolated areas that are not near proposed new highway construction.[5] This is not true of all states. Many of Pennsylvania's refuse banks are located within 2 miles of urban areas.[6] Figure 2 gives the location of the major coal fields of the United States. Refuse can be found in the vicinity of the eastern and most of the midwestern coal fields. The western coal fields have not been extensively mined to the present time and do not contain as large quantities of refuse as the eastern coal fields. The states of Washington, Oregon, and Montana do have sufficient quantities of refuse to cause environmental problems. These states have reported methods of utilizing their sites.[7]

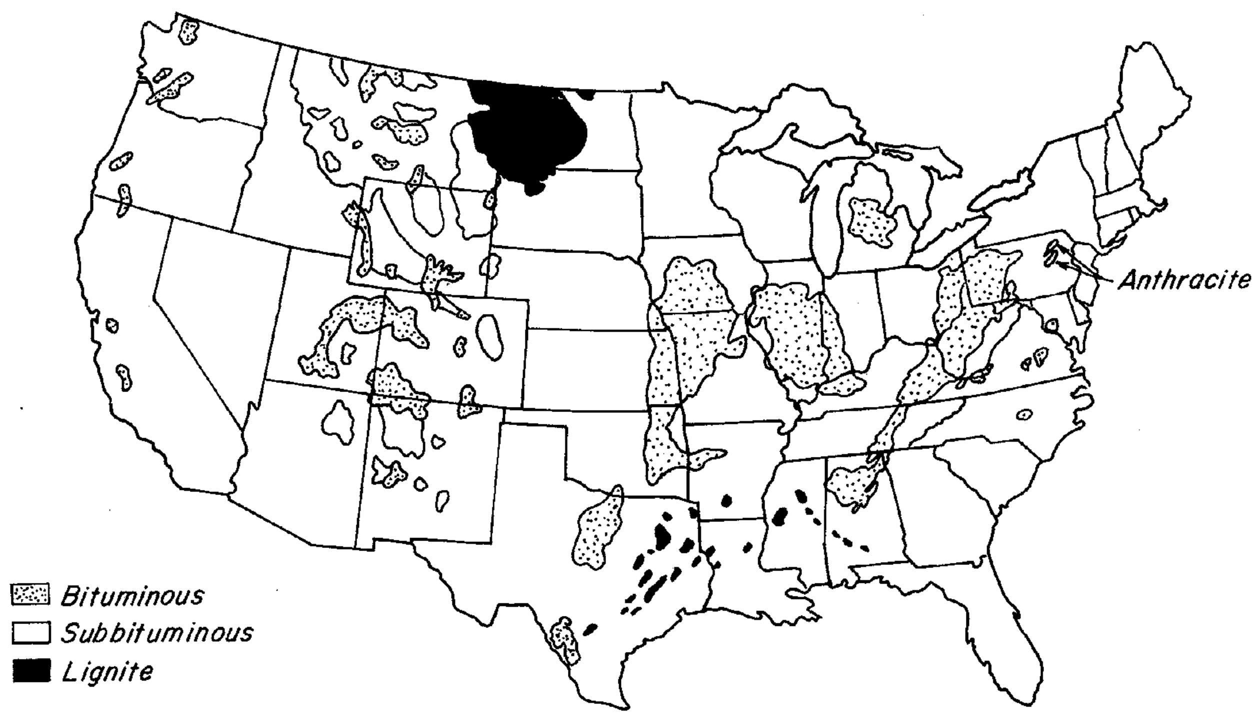


Figure: 2 Main Coal Deposits of the Conterminous United States, Showing the Grade of Coal (U.S. Bureau of Mines).

Great Britain has been a forerunner in the utilization of coal mine refuse in highway embankments. The Ministry of Transport owns most of the refuse sources in Britain. These sources include refuse from all types of mining (eg. sandstone, metal, coal, etc.) and are collectively termed "minestone." The "Minestone Executive" branch of the Ministry of Transport is responsible for the marketing of minestone. They sell the refuse for a royalty. (8)

Since 1968, the British have used millions of tons of coal mine refuse in highway embankments. Highways are not located to favor the use of coal mine refuse. The contractors are required to present two bids (dual tendering); one using any borrow source, and the other using the nearest coal refuse source. The government has the option to pick the higher bid and use the coal mine refuse, if the cost difference is not too great. (9)

A similar method might be employed in the U.S. to encourage the use of coal mine refuse in highway embankments. Communities might be encouraged to subsidize long haulage distances in order to remove the unsightly and environmentally detrimental refuse banks. The removal of this refuse would also free valuable land for use as industrial sites or other community needs.

PART I

SECTION 3. PRODUCTION AND DISPOSAL OF COAL REFUSE

PRODUCTION

Coal is formed from the remains of plants that lived in swampy environments and have undergone the processes of dewatering and compaction to form rock. The major elements found in coal are carbon, hydrogen, and oxygen. Impurities found in coal are sulfur, nitrogen, iron, and various other inorganics (ash). These impurities can be divided into the following classes: (a) impurities which are chemically or structurally a part of the coal, and (b) impurities which can be mechanically removed from the coal. The amount and type of impurities which cannot be economically separated from a particular coal vary greatly and affect its value. The impurities which are separable affect the refuse characteristics.[10]

The rock types associated with bituminous and other soft coals are sedimentary. Those occurring most frequently are sandstone, siltstone, shale, claystone, and limestone. These rock units may grade into each other with a large part of the strata an intermixture of two of these rocks, eg. silty shale. Claystones and shales most commonly surround the coal seam. These rock types are also commonly incorporated within the coal either as discrete bodies or the coal seam may be "split" by a thin bed of sediment. The rock units associated with the coal are commonly high in carbonaceous material evidenced by their black or dark gray color. Iron and sulfur impurities are found in this strata as in the coal, usually in the form of pyrite (FeS_2). Pyrite occurs in many forms, some of which are readily soluble in the presence of air and water to form a sulfuric acid and iron compound. The strata associated with anthracite coal differs from bituminous in that the original sedimentary rocks have undergone intense heat and pressure (metamorphism) to become harder more competent rock units. Slate and quartzites (metamorphic sandstones) are commonly associated with anthracite. The chemical composition of the rocks is not changed greatly and the percentage of impurities in the coals generally remains the same.

A portion of the strata associated with the coal becomes mined with the coal. The coal and associated rock units become the run-of-mine product. With modern mechanization within the mines, especially underground methods, it is more economical to mine the impurities in a split coal seam. Often portions of the surrounding rock must be removed to form stable or level floors and ceilings. Also the floor or ceiling rock may be mined along with a thin coal seam because equipment is used having a fixed thickness of shear (cutting thickness), as with longwall mining.

The refuse resulting from the mining process can be divided into four categories: 1) Processed, 2) Unprocessed, 3) Burnt, and 4) Weathered.

1. Processed coal refuse is a product of the coal cleaning and preparation process which decreases the ash and sulfur content, improves the heating value, and produces a consistent quality coal product. Coal has a lower specific gravity than the associated refuse materials allowing separation of the coarser fractions by heavy-media methods,

resulting in coarse refuse (plus 28 sieve or 0.5 mm size). Flotation and frothing methods are utilized to remove the finer fractions of refuse from the coal, resulting in a slurry of fine coal refuse (minus 28 sieve size). As the cleaning processes are not 100 percent effective, some coal becomes incorporated in the wasted refuse material. Some preparation plants may produce as much as 20,000 tons (18,144 metric tons) of coal per day.(1)

2. Unprocessed refuse material is produced while preparing a mine for operation. Tunnel rock is a product of the initial drilling operations to gain access to the coal seam and contains little or no coal. Other unprocessed mine refuse is produced by a number of mine operations and also contains little coal. The unprocessed refuse materials are commonly placed directly on the refuse banks.(6)

3. Burnt refuse is the product of spontaneous combustion within the refuse pile. The oxidation of pyrite within the refuse gives off heat. Over a period of time the heat builds until the volatile matter within the banks spontaneously ignites. Generally, not enough air is present within the interior for the whole bank to ignite. But rather it will smoulder with the interior heat slowly increasing. Banks are recorded that have been burning for 50 years or more. The burnt refuse has different properties than unburnt and is easily recognized by its red color, giving it the name "red dog."

4. Weathered refuse remains exposed to the atmosphere and undergoes a process of weathering. The most notable change is a breakdown of particle size. The soft shales and claystones are especially

susceptible to breakdown. The soluble pyrites will also oxidize in the presence of atmospheric oxygen and moisture. The refuse exposed at the surface of the pile is most susceptible to weathering. The refuse buried within the pile is less susceptible to weathering and may be relatively fresh even years after its placement. Thomson and Rodin tested refuse at depth in piles up to 50 years old and found that the effects of weathering were only notable to a depth of one meter (3.28 feet).[11]

DISPOSAL METHODS

Methods employed for disposing of coal refuse have changed drastically over the years. Disposal techniques, both past and present, can generally be grouped into two categories: 1. impounding and 2. non-impounding. With the non-impounding disposal method, the refuse is placed in a pile. In the past the refuse was not compacted, but today, regulations require the compaction of the refuse during placement. The non-impounding disposal method does not trap water and is used for coarse refuse alone or for a thickened slurry of fines mixed with coarser refuse, if it can support its own weight. The resulting embankment is a pile which might have numerous configurations depending on the method of transport to the disposal facility. In the past the material was transported by trucks and end-dumped or by aerial trams and dumped along a fixed axis from high elevations. Both methods resulted in the formation of progressing embankment with refuse lying at the angle of repose.

Because the refuse was dumped from some elevation and generally not modified by dozers, the coarser materials tended to collect at the base with the grain size decreasing up-slope. This led to many problems, the most notable being the free circulation of air through the coarser material at the base into the interior of the embankment. This supply of air coupled with the high percentage of volatiles in old piles resulted in frequent occurrences of burning embankments. Regulations covering disposal piles today require the compaction of the refuse during placement. Plans must be approved for abandonment of the pile including the establishment of vegetation on the surface of the pile.

The problems resulting from disposing of refuse in impounding embankments has in the past surpassed those of the non-impounding. The impounding structure is built of the coarse refuse material with the slurry refuse placed behind. Impounding structures can also result from placement of refuse in drainage channels without diversion of the draining waters. In the past, there were no regulations on the construction of these impoundments and subsequently most were built without preceding design considerations to secure stability. Inevitably there were many failures, two of which resulted in significant loss of property and life.

These two failures, one in Great Britain and one in the U.S., led to extensive studies of the design and engineering characteristics of coal refuse. From these studies, regulations were set to guide the safe disposal of refuse. The regulations encompass both the stability of coal refuse piles and embankments and methods to reduce the detrimental environmental effects thereof.

Presently, cooperative programs between the individual state and federal agencies provide for regular inspection of refuse facilities to insure that the coal mine operator is complying with the basic requirements of the law. Air and water pollution stemming from refuse piles and embankments have been decreased as a result of the design and construction regulations. Requirements for compaction during placement of refuse have decreased the amount of air available in the interior of piles and decreased the potential for interior fires. Compaction also decreases leaching through the piles, thus improving water quality. Settling basins are required to trap water draining from refuse piles and embankments. Standards are set by law for the minimum quality of water that can be released into the natural drainage system.

These regulations will also govern the removal of coal refuse from disposal sites for placement within highway embankments. The most recent regulations are contained in Public Law 95-87, "Surface Coal Mining and Reclamation Operations", issued by the Office of Surface Mining, Department of the Interior.[12] The removal of refuse from an existing pile must be approved by the governing state agency and inspectors will most likely visit the site at regular intervals to assure that the removal of the refuse is proceeding without unnecessary further disruption of the environment. Those aspects of Public Law 95-87 which govern the placement of soil cover on the highway embankment using refuse as fill are covered in Part II of this manual.

PART I

SECTION 4. PHYSICAL AND CHEMICAL PROPERTIES

The properties of coal refuse are determined by 1) the characteristics of the coal seam and surrounding lithologies mined, 2) the type of mining process employed, 3) the cleaning process used, and 4) the method of storage or disposal. All these factors account for the great variability of physical and chemical properties found between coal refuse disposal sites. A detailed description of how each of these factors affects the properties of the refuse is beyond the scope of this manual. The importance of such a description is also questionable as it is doubtful that the properties of refuse could be predicted even if all these factors were known. The Department of Civil Engineering of the University of West Virginia has conducted testing to determine the variance in properties of refuse. Findings show the refuse samples vary greatly not only from disposal site to site, but also from source to source within the same refuse disposal site.(13) Even so, the great majority of test results from refuse material have proven that most all sources have physical and chemical properties acceptable and even highly desirable as fill material. The key to economical and efficient use of the refuse material is an understanding of the basic properties of the refuse proposed for use and an awareness that variances may exist within the source area itself. The former can be gained by representative sampling and testing of the refuse site. The latter may not show up in testing and must be watched for during the hauling and construction phase.

The purpose of the following discussion is to familiarize the reader with the physical and chemical properties of coal refuse and the problems or benefits which may be encountered during utilization of the refuse as a fill material. This section is not intended as a substitute for testing of refuse before utilization. Recommended testing procedures and specifications are presented, in Part 2 of this manual. Variances in properties of unburnt, burnt, weathered, anthracite, or bituminous refuse are noted when appropriate.

CHEMICAL PROPERTIES

The chemical properties of coarse coal refuse have proven to be the most problematic over the past years of waste piling the material. Coal mine refuse contains high amounts of coal and pyrite. The oxidation of the pyrite (FeS_2) causes acidic leachates carrying high levels of metals in solution. The oxidation process is an exothermic reaction (heat releasing) and increases the probability of spontaneous combustion of the volatile elements within the refuse piles.

Because these problems are so prevalent with coal refuse piles, investigations were undertaken, especially in Great Britain, and also in the U.S., to determine if these problems were also likely to occur when attempts were made to utilize the coal refuse in bulk fills. These various studies have proven that, with adequate compaction of the refuse material, the atmospheric oxygen needed to oxidize pyrite and to "feed" internal fires is no longer available.

MINERALOGY

Coarse coal refuse is a mixture of roof and floor rock, rock materials incorporated in the coal seam, the coal itself, and the rock originating from shaft and slope cuts. This is the usual order of abundance within the coarse refuse pile. The roof and floor rock are commonly shale or claystone with minor amounts of silty material.

The mineralogy of coarse refuse has not been widely studied. The available data shows clay minerals* to be the predominant constituent. These clays, predominately illite and kaolinite, are the major components of the claystones and shales and are present in minor amounts in siltstones and sandstones.

Some coal seams in Appalachia are directly underlain by a high purity clay which can be economically mined for fire-clay. Table 1 presents

Table 1. Averages of Normative Mineralogy for Eastern and Western Kentucky Coarse and Medium* Refuse.[14]

	Eastern (wt % average of)	Western (wt % average of)
Illite	41.1	28.9
Kaolinite	37.6	26.0
Quartz	14.7	22.6
Pyrite	2.3	7.7
Hematite	1.2	7.2
Calcite	0.3	3.4
Magnesite	0.7	0.5
Apatite	0.3	1.4

*Medium sized refuse results from Deister table preparation processes.

*Clay minerals are not to be confused with clay-sized particles. Coarse refuse is made up mainly of larger than clay-sized particles. As stated, the clay is present in the shales and other rock types and generally does not breakdown to clay-sizes.

the mineralogy of coarse refuse from preparation plants in the eastern and western coal fields of Kentucky.[14] The illite and kaolinite clays are the major constituents with quartz a secondary mineral.

The presence of pyrite (FeS_2) is an indication of the maximum potential acidity of the leachates from the coal piles, although some forms of pyrite are only slightly soluble.

A study of the mineralogy of refuse from a western Pennsylvania coal company preparation plant show the same relative abundance of minerals present as in the Kentucky refuse.[15]

Primary: clays, micas (in anthracite), carbonaceous material.

Often: quartz, pyrite, hematite.

Occasionally: calcite, ankerite, apatite, garnet, rutile, sphene tourmaline, and zircon.

Weathered refuse from old piles was also tested in this Pennsylvania study. The old piles had the same mineral constituents, but also contained varying amounts of burnt refuse and sulfates. The mineralogical range of anthracite refuse has been determined by Spicer and Luckie of Pennsylvania State University. Kaolinite composes as much as 70% of the refuse, with quartz up to 20% and illite, calcite, pyrite and rutile, all less than 10%.[16]

VOLATILE CONTENT AND COMBUSTIBILITY

The volatile content of coal refuse is related to the coal content of the refuse. Coal may be incorporated in the refuse pile by either inadequate preparation and separation processes or it may be present in minor amounts in the rock surrounding the coal seam. Old refuse piles generally have higher volatile contents than fresh or recent piles. Older methods of coal preparation had little mechanization and used mainly hand picking techniques. The volatile content of the refuse also varied with the price of coal in the past.

The volatile content of a refuse pile is, to some extent, a measure of the heating quality of the refuse. It is recommended that refuse of 20% volatile matter or 3,500 BTU per pound (as received basis) be considered first for utilization as an energy source.[17,18] Many old refuse piles can be processed through preparation plants to produce steam coal. Discussions with several preparation plant operators have revealed that reprocessing of old refuse piles has resulted in 50% or more coal recovery. By removing the coal before use, an energy source is utilized. The density of the refuse is increased and its engineering properties improved.

Another reason for decreasing the volatile matter in coal refuse is to reduce the chances of spontaneous combustion within the embankment. The following elements are needed in order for spontaneous combustion to occur:[19]

1. Volatile material; coal and other volatile matter, when present in high percentages, greatly increase the chances for spontaneous combustion.

2. Temperature; the temperature within the refuse pile fluctuates little with ambient temperature. The temperature within a refuse bank is raised by the exothermic reactions of atmospheric oxygen with carbonaceous material and/or pyritic material.

3. Moisture; water (H_2O) is needed for the oxidation of pyrite to sulfates and ferric iron.

4. Atmospheric oxygen; oxygen (O_2) is needed to oxidize pyrite and carbonaceous material. Free movement of oxygen through the pile will allow oxidation to occur, but the heat production will be dissipated. Pockets of air present the best conditions for ignition as the heat is allowed to increase gradually.

The decrease of any of these components within the refuse bank will also decrease the chances of spontaneous combustion. Compaction has proven to be an effective means of decreasing air voids and inhibiting the free movement of water through the refuse bank.

THE OXIDATION AND LEACHING OF PYRITE (FeS_2)

Pyrite is a minor constituent of most coal refuse. The pyrite formed in protected swamps that were the site of accumulation of vegetable material. During the decay of the vegetable matter, organic sulfur was released, combining with the abundant Fe found in terrestrial waters. The resulting pyrite minerals are commonly found in the coal sequence either thinly bedded, in lenses, or finely disseminated throughout the coal and roof rock.

The coal cleaning process efficiently removes the lenses and thin beds of pyrite mined with the coal. The finely disseminated pyrite is difficult to remove from the coal, even with froth-flotation techniques, and is commonly found in the coal product. The pyrite that is removed to the waste pile is exposed to the air and may be partially oxidized.

In order for pyrite to be oxidized continuously, forming acidic leachates, both atmospheric oxygen (O_2) and water (H_2O) must be present. The reaction for the formation of typical acid mine drainage is shown below:

$$FeS_{2(s)} + 3\text{-}3/4 O_2 + 3\text{-}1/2\ H_2O \longrightarrow 2H_2SO_4 + Fe(OH)_3 \downarrow \quad (20)$$

Pyrite + Atmospheric Oxygen + Water ⟶ Sulfuric Acid + Ferric Hydroxide (Yellow Boy)

It can be seen from this reaction that the elimination of significant amounts of free oxygen or water within the embankment will prevent the formation of acid leachates, no matter what the pyrite concentration of the mine refuse. Design of highway embankments, as with any fill material, should be performed so as to channel surface waters into drains, disallowing seepage through the embankment fill. Proper compaction of the fill material will decrease the air voids so that they constitute only a minor amount of the bank and will prevent the free movement of oxygen through the embankment.

SULFATE LEVELS

The iron pyrites present in the coal refuse pile, when exposed to air and water, become oxidized to ferric hydroxides and sulfuric acid. Eventually most of the sulfate ions released by this reaction become the sulfates of calcium, magnesium, sodium and potassium. These sulfate compounds, when placed in contact with concrete structures, can attack the individual components of the concrete and weaken the structure. As with the oxidation of pyrite, water is needed for any attack to occur.

Early sections of highways using refuse for embankment fill were designed with a cautious eye to sulfate attack on concrete. Technical Memorandum (T4/68) [21] was issued by the Ministry of Transport of London in 1968, encouraging the use of unburnt colliery shale, but cautioning that an adequate thickness of sulfate free material must be interposed between the shale and concrete structures. Experimentation by Sherwood and Ryley in 1970 [22] on the attack of concrete by sulfate compounds in refuse, led to the lessening of restrictions on colliery shale use in Great Britain. Their recommendations were adopted by the Ministry of Transport of London and are also adopted in this "User's Manual".

Generally, coarse coal refuse will contain sulfate levels that are below concentrations harmful to concrete structures. Burnt refuse will be an exception. The increased heat and oxygen available to the refuse during the burning process cause increased oxidation of pyrites and other sulfate minerals.

PHYSICAL PROPERTIES

The physical properties of the refuse selected for fill in embankments should be properly tested and considered by the designer. The physical properties of coal refuse will vary considerably, depending upon the source and preparation method, and will also vary within the refuse site itself. The physical properties or engineering properties of coarse refuse in the coal fields of the U.S. and in Great Britain have been widely studied since the time of the major failures of embankments in the respective countries. The findings of some of the major studies are presented herein.

GRAIN SIZE DISTRIBUTION

The gradation of coarse refuse delivered to the construction site is controlled by the mining and preparation techniques and by the degree of weathering. Generally, coarse refuse is a well-graded material ranging from 3 inches (7.6 millimeters) to less than 0.004 inches (0.01 millimeter), with a maximum of 25 percent passing the 200 mesh sieve.[2] This corresponds to an AASHTO classification of A-1 and A-2.

The typical ranges of gradation for coarse refuse are shown in Figure 3. Coarse refuse is almost always well-graded (poorly sorted). Fraser and Lake of the British Transport and Road Research Laboratory tested burnt refuse and found the same grading for burnt as for unburnt refuse.[23] Testing by the Pennsylvania DOT on bituminous and anthracite

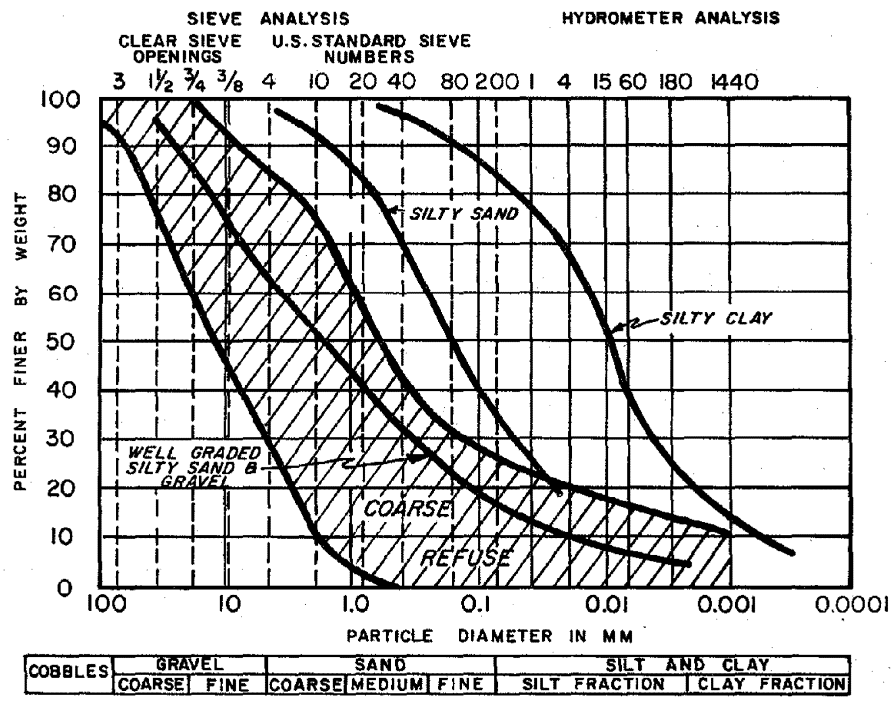


Figure: 3 Typical grain size distribution of coarse coal refuse. (2)

refuse found the anthracite refuse to be coarser grained and less well graded than the bituminous refuse. The anthracite refuse was comparatively deficient in fines.[24]

The grain size of coarse refuse delivered to a refuse pile will change due to surficial weathering. Testing by the British National Coal Board indicates that degradation (size breakdown) starts within a few days, weeks, or months on the surface of the pile, depending on the character of the parent rock. Further testing compared the extent of weathering at depth in spoil heaps ranging in age from recent to about 100 years old. "Visual examination of the spoil material indicated that degradation due to weathering occurs very little, if at all below a depth of about a metre".[25]

Degradation also results from compaction. Appreciable breakdown of the larger particles and an increase in the fine fractions have been documented by experiments on both laboratory and field compacted coarse refuse, burnt and unburnt.[19, 24, 25] The amount of degradation varies depending on the source of the refuse. This breakdown during working of the refuse will affect other physical characteristics and generally facilitates achieving higher densities.

SPECIFIC GRAVITY

The specific gravity of coarse coal refuse is highly variable and generally lower than typical soil with the same gradation. This variability and lower specific gravity are due to the coal content of the refuse. Older inactive refuse piles will generally contain refuse with lower specific gravities than recently produced refuse, due to the inadequacy of the older coal separation processes. Most soils have specific gravities ranging from 2.6 to 2.8. Coarse coal refuse ranges from 1.8 to 2.4.[2] The designer using coal refuse should be aware of the lower specific gravity as it will result in lower densities and higher water content at a given void ratio.

The specific gravity of coarse refuse can be used to predict other properties. Experimentation by Chen[19] has shown excellent correlation to exist between the specific gravity versus heating value or BTU per pound, and specific gravity versus maximum dry density. The correlations derived from Chen's study are shown in Figure 4 and Figure 5.

MOISTURE-DENSITY RELATIONSHIPS

The importance of proper compaction during placement of coarse refuse in highway embankments cannot be overemphasized. Proper compaction will prevent spontaneous combustion and acid leaching by decreasing air voids and permeability. Proper compaction is also needed to insure the maximum bearing capacity.

The compaction tests are based on the principle that for a given energy of compactive effort and a known moisture content, a soil will have a corresponding given density. The moisture-density relationship is determined in the laboratory and used in the field to determine when proper compaction has been achieved.

Coarse coal refuse generally shows good moisture-density relationships with well-defined peaks, although the peak values will vary greatly from source to source. Results of moisture-density relationships tests

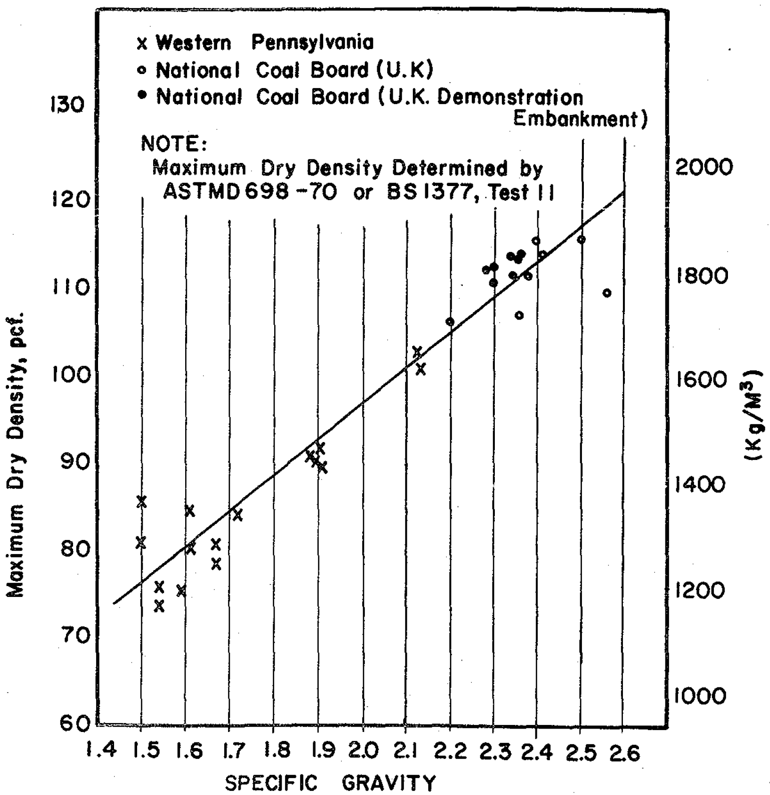


FIGURE 4 Specific Gravity vs Maximum Dry Density Detemined by Standard Proctor (19) (Coarse Refuse)

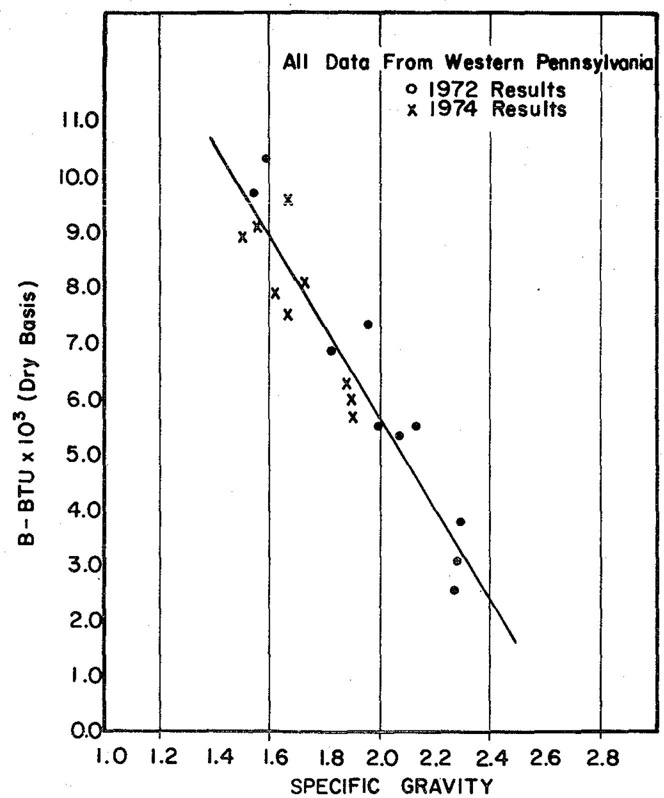


FIGURE 5 Specific Gravity vs. B.T.U. (19) (Coarse Refuse)

show coarse refuse to have low to moderate maximum dry densities from around 85 to 115 pounds per cubic foot. The optimum moisture content varies from a low of about 8 percent to a high value of 22 percent, the lower value corresponding to the higher density.[13,25,26,27] Anthracite refuse will often require a greater compactive effort to achieve desirable densities because of the lack of fines.[24] Testing on burnt refuse achieved maximum dry densities of 110 pounds per cubic foot at 15 percent moisture content when tested with heavy compaction.[23]

FROST SUSCEPTIBILITY

Frost heave in soils is caused by the migration of water upward within the soil to the freezing front, forming an ice lense. Simply speaking, an increase in the amount of silt-sized particles increases the frost susceptibility of the soil. Testing of the frost susceptibility of coal refuse has given various results. Generally frost heave increased with an increase in the amount of fines.[23,28] Burnt refuse tends to be more frost susceptible than unburnt refuse. Unless tests are made to determine the frost susceptibility of the coal refuse to be used, the refuse material should be placed beneath the zone of frost penetration. When properly designed, the embankment fill will be below the zone of frost penetration. Refuse material should be excluded from the sub-base unless the frost susceptiblity is determined.

PLASTICITY

Coarse coal refuse, being predominately granular, is generally defined as a non-plastic, non-cohesive material.[2,10,26] Testing on burnt refuse by the British National Coal Board describes this material as non-plastic.[29]

PERMEABILITY

Coarse coal refuse has poor drainage characteristics when properly compacted, due to the well-graded characteristics. Figure 6 shows the correlation of vertical permeability in coarse refuse plotted as a function of dry density and the percent of Standard Proctor density. (2)

Permeability measurements made on burnt refuse compacted to maximum dry density and optimum moisture content gave results ranging from 1.94 to 0.03 x 10^{-4} cm/sec. and confirmed "...field experience that the finer shales in particular are excellent for protecting soil subgrades from the effect of rain." (23)

SHEAR STRENGTH

The determination of shear strength is usually needed for embankments designed at 20 feet or greater in height or where the embankment is underlain by a poor foundation. Testing on refuse from the U.S. and Great Britain has shown the shear strength to vary from source to source as would be expected. Samples of fresh coarse discard were sampled by Wimpey Laboratories from several collieries, selected to represent the general range of coarse discard being produced throughout Great Britain. Four samples were also taken from existing refuse sites and recompacted. This recompacted material had shear strengths similar to that obtained from the fresh coarse discard. Drained triaxial compression tests were made on 100 mm diameter specimens of the -20mm fraction, compacted at the "as delivered" moisture content and with variable initial density. For zero normal stress, the angle of effective friction, Ø varied from a low of 29 degrees to a high of 38 degrees. The drained shear strength

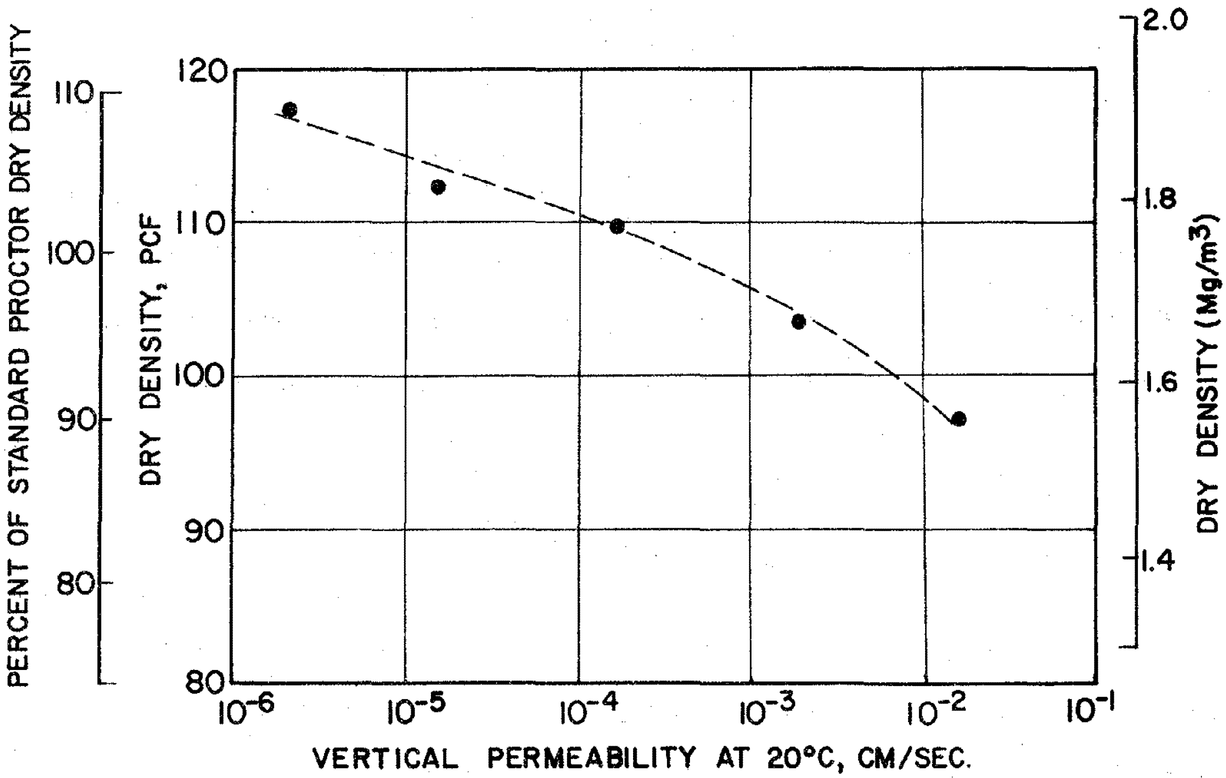


Figure 6 VERTICAL PERMEABILITY - DRY DENSITY RELATIONSHIP FOR COARSE COAL REFUSE.(2)

tended to decrease as the amount of fine fraction (passing the 200 mesh sieve) increased.[25] For refuse types that are poorly graded, compaction increases the amount of fines and facilitates achieving maximum densities.

The effective shear strength parameters reported for coarse coal refuse in the United States show significant variation. The minimum reported values have been: Effective cohesion ($\bar{c}$) at 3.5psi, and the angle of effective internal friction ($\emptyset$) at 28 degrees for old refuse sampled by boring from West Virginia. "But all other data...have a lower bound on the angle of effective internal friction of 33 degrees. Values from 35 to 37 degrees with effective cohesion from 1 to 2 psi seem most typical."[26] The highest effective angle of internal friction reported for coarse refuse is 40.8 degrees.[27] Thomson and Rodin reported a range of effective angles of internal friction from 25 to 42 degrees for British mine refuse.[11] It should be stressed that the designer should not rely upon these figures for designing embankments of coarse refuse. The refuse proposed for borrow should be adequately tested for shear strength.

Testing on anthracite and bituminous refuse from Pennsylvania by the Pennsylvania DOT gave lower angles of internal friction and less cohesion for the anthracite refuse than for the bituminous refuse.[24]

PART I

SECTION 5. CASE HISTORIES

L.R. 1022 - Section J06, U.S. Route 219 Cambria County, Pennsylvania

Prior to 1972 the Pennsylvania Department of Transportation (PennDOT) had been considering using coal mine refuse in the construction of highway embankments. However, it was not until late in 1972 that the use of refuse was given high priority. Secretary of Transportation, Jacob Kassab of PennDOT had requested the Bureau of Materials, Testing and Research to investigate the practicability of using coal mine refuse in construction of highway embankments. The Soils and Geological Engineering division was assigned the research task. As a result of its efforts, the use of coal mine refuse was planned for several projects throughout the state.[24]

Late in 1973, the final design of a section of U.S. Route 219, Cambria County, PA was nearing completion. Phillip E. Butler, P.E., of PennDOT's Bureau of Materials, Testing and Research contacted L. ROBERT KIMBALL & ASSOCIATES, the Consulting Engineers for the project, to inform them that it would be possible to use bituminous coal refuse from the Revloc Dump located near the proposed highway site and owned by Bethlehem Mines Corporation.

Before the coal mine refuse could be used in the embankment, several problems needed to be solved:

1. The refuse dump was located outside the proposed right-of way for construction of the highway.

2. The refuse dump contained sufficient coal to warrant a secondary recovery process.

3. Permission to use the material was required from Bethlehem Mines Corporation.

4. The use of the material would have to be approved by the Pennsylvania Department of Environmental Resources (DER).

5. PennDOT's Bureau of Materials and Testing would need to conduct tests to determine strength and physical characteristics of the material.

The first problem involving the borrow area was resolved by using guidelines established by PennDOT's Legal Bureau pertaining to acquisition of borrow pits off, and not contiguous to highway right-of-way. It was determined that under present law, borrow pits outside the proposed right-of-way could be amicably acquired, but condemnation of off highway borrow pits was not recommended.

A bid proposal would be required to inform bidders that coal mine refuse must be used as borrow and obtained from a designated borrow area. A separate bid item would be required for excavating, hauling and placing of the borrow and restoration of the designed borrow area. Property acquisition and the right to use material would be obtained by PennDOT in accordance with the Federal requirements for designated borrow areas.

Items 2 and 3 were resolved by agreements with Bethlehem Mines Corporation. Bethlehem Mines Corporation granted approval for using the material under three conditions:

1. The designated borrow area should be selected in areas of the dump where the material indicated a low coal content because the corporation had been contacted by another party concerning secondary recovery of coal from the refuse dump.
2. The surface areas disturbed by construction and all work involving the removal of the coal mine refuse would be conducted in accordance with all State and Federal rules and regulations governing coal refuse disposal areas.
3. Any future intended use of the material when the highway is extended north be coordinated with other parties interested in developing the refuse disposal area for an industrial site.[24]

To obtain permission from the Pennsylvania Department of Environmental Resources to use the material, a letter was sent including a sketch of the proposed borrow area, typical sections for use in the embankment and a description of how the material was to be used in the embankment. Upon furnishing a detailed design, the use of the material was approved by DER.

PennDOT's Bureau of Materials tested the refuse material and found that it was suitable for construction and also selected the area of the refuse pile from which the material would be obtained.

DESIGN

SELECTION OF DESIGNATED BORROW AREA

Since final design of the project had progressed to a point where the development of construction plans was approaching completion, it was decided that approximately 200,000 cubic yards (150,000 cubic meters) of coal refuse could be used in the project without delaying the bid-letting schedule. To use more than 200,000 cubic yards (150,000 cubic meters) of refuse would have required a major grade change resulting in considerable delay of the bid schedule. Because of the intended secondary recovery of coal from the refuse pile, it was concluded that more coal refuse could be used in the highway embankment in the proposed northern extensions. The gradeline for the future extension would be raised to accommodate economic use of the material.[24]

An isolated 14 acre (0.06 square kilometers) section of refuse was selected as a designated borrow area (Figure 7). The primary consideration for selecting this area was:

1. Test results indicated that the material was suited for highway embankment construction (See below).
2. The use of this area would not interfere with secondary recovery of the coal operations.
3. The location of the material presented the shortest haul distance to the major embankment sections of the proposed highway.
4. The physical contours of the land were favorable to haul road construction, requiring very little excavation and providing acceptable horizontal and vertical alignments.

TEST RESULTS FROM REVLOC

Sampling at Revloc was accomplished by taking 30 pound pit samples from randon locations and not along traverses. The refuse material at Revloc was well graded with sufficient fines to facilitate compaction.

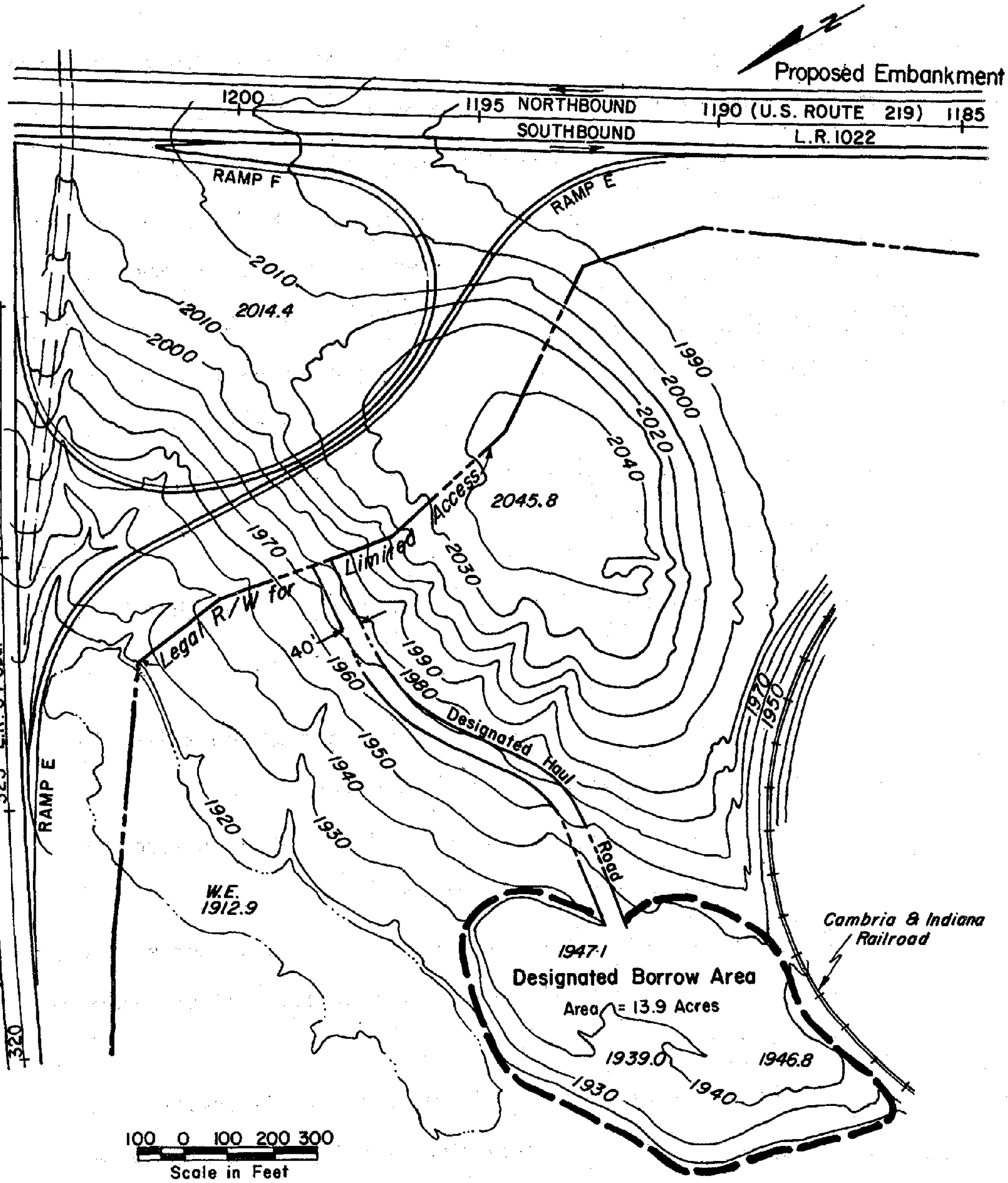


Figure 7. Site Location Map of Designated Borrow Area L.R. 1022, Section J06 (U.S. Route 219)

Figure 8 shows the range of grain size distribution for 40 samples from Revloc.

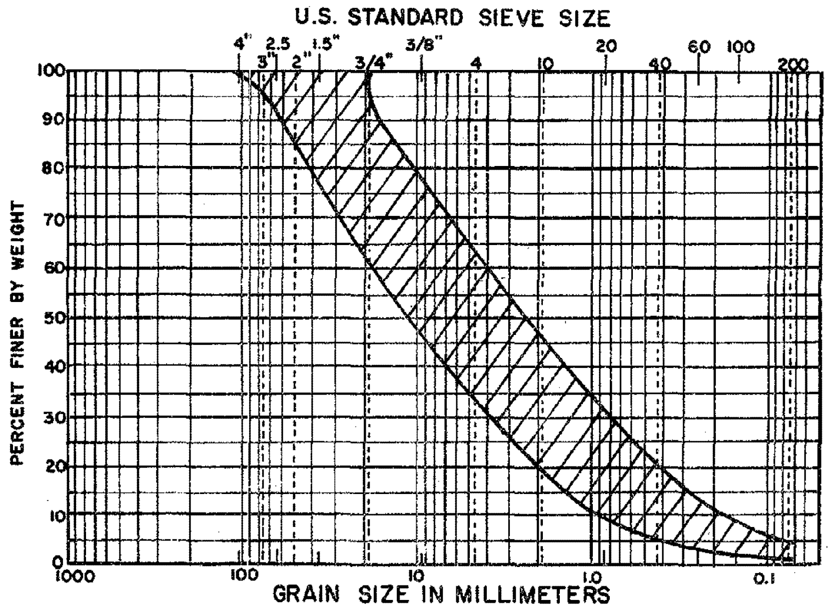


Figure 8. Range of Gradations from Revloc. (29)

The sulfate levels were determined by a water extraction of 21 bituminous samples from Revloc. pH was also determined for these samples. The test methods of the British Standard 1377[30] were followed and are included in Appendix A. Results showed a mean of 0.02% (0.2 g/l) sulfate and a mean pH of 4.5.

The sulfate levels were low and did not call for special considerations for the protection of concrete structures. The pH level was within the range requiring that either special underdrain pipe be used or requiring a buffer zone around the pipe. The latter method of protection was chosen.

Repetitive standard moisture-density tests were run on three (3) samples from Revloc with subsequent grading of the sample after each test. This was done to determine the amount of particle breakdown resulting from hammer impact and to better simulate field conditions of degradation under the dynamic loading of construction compaction equipment. Figure 9a shows the moisture-density data of two tests per sample and (b) shows the grain size distribution of one of the samples as it was originally graded (0) and after the first moisture-density test was completed (1). The breakdown in size was not severe for the refuse tested.

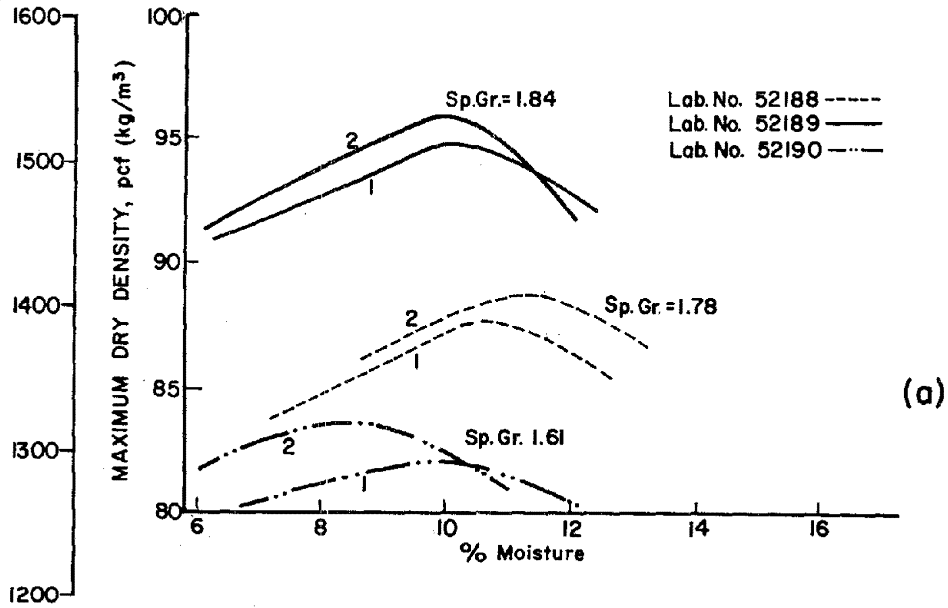
Consolidated, undrained triaxial shear tests were run on 15 samples of bituminous refuse from Revloc. The results as summarized in Table 2, were derived from Mohr's circles. As the material exhibited good strength characteristics and special conditions such as poor foundations or embankments over 25 feet in height, were not present, typical sections provided by PennDOT were used for embankment design.

Table 2. Shear Stress Values of 15 Samples from Revloc Bituminous Refuse.[24]

	ϕ°	c(psi)
Mean $\bar{x}$	39°	8
Range	33° - 42°	0 - 14
Standard Deviation (S)	2.6°	3.2

SELECTION OF LOCATION AND METHOD OF PLACING THE REFUSE IN THE HIGHWAY EMBANKMENT

To satisfy environmental requirements relating to the potential discharge of acidic water runoff and to avoid potential pollution of



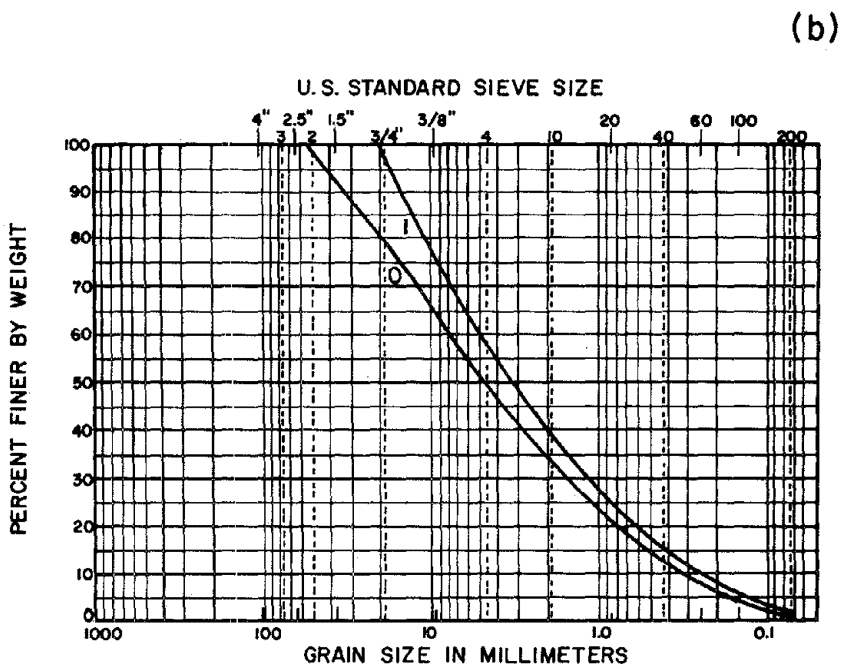


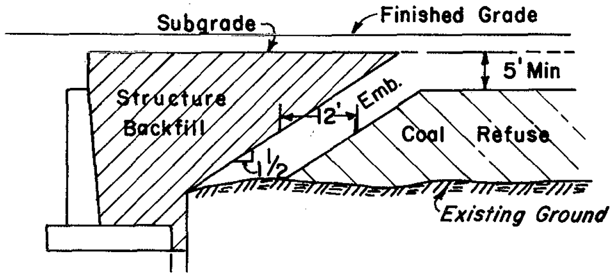
Figure 9. Repetitive Moisture - Density Curves (a) and Gradation of Sample No. 52190 (b) of Refuse from Revloc. (24)

ground water, it was decided to use the coarse refuse to form the core of the embankments. A 12-foot wide (3.7 meter) embankment of natural soil was provided on each side of the embankment. This width was selected for ease of construction and to facilitate use of compaction equipment. All pipes and inlets were protected with a minimum 2-foot (0.6 meter) barrier of natural soil material and no coal refuse was placed within 5-feet (1.5 meter) of the subgrade (Figure 10). This interval was selected to provide sufficient cover over the refuse to reduce the potential of surface water seepage and to ensure that the refuse material was below frost line influence. To prevent discharge of acidic water into the ground water, or embankment section, the refuse placement was selected at a location avoiding wet weather seeps in the foundation.

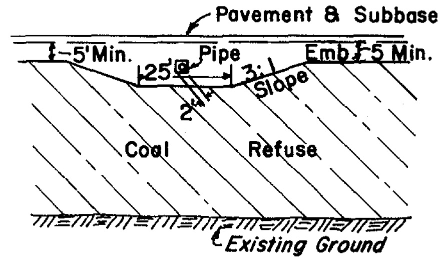
CONSTRUCTION

A haul road to the designated borrow site was constructed according to the design plans. Initial clearing of some debris on top of the refuse area was required. Scrap metal and mine timbers were removed and the top of the pile regraded with a dozer to facilitate traversing the pile with construction equipment.

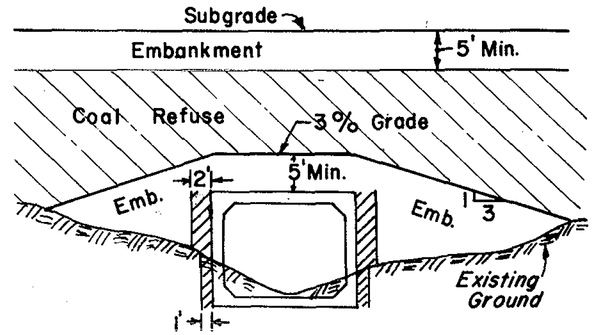
The refuse material was excavated using a D-9 dozer to push Cat 631-13 Scraper pans. The refuse was transported an average haul distance of 0.6 miles (1.0 kilometers) to a thousand foot grading section from station 1180 to station 1190. The 12-foot (3.7 meter) width of natural soil placed on each side of the embankment was constructed using 8-inch (200 millimeter) lifts, forming a boxlike earthen



TYPICAL COAL REFUSE PLACEMENT AT STRUCTURES



*PROFILE VIEW
COAL REFUSE PLACEMENT



TYPICAL COAL REFUSE PLACEMENT AT BOX CULVERTS

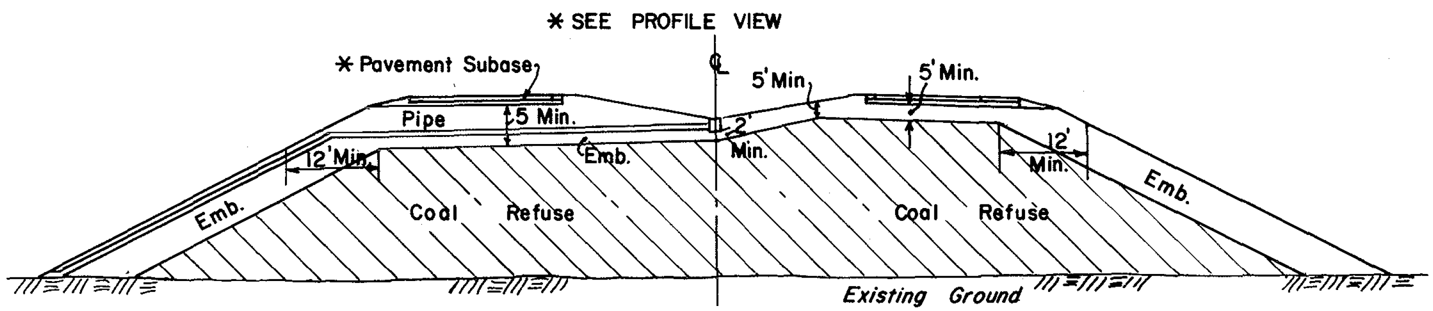


Figure 10. Typical Section of Coal Refuse Placement in Embankments

containment structure, within which the refuse was placed (Figure 10). The material was compacted to 95% of maximum dry density, determined by Standard Proctor, as specified by PennDOT.

The construction continued with the perimeter soil placement preceeding the refuse placement. When the designed height of the embankment was reached, the refuse was covered with natural soil material.

Compaction was achieved using a 210 vibratory roller (Figure 11). Normally two (2) passes by the roller with 50 percent overlay were required to reach maximum density. A water truck was required to control dust and facilitate compaction to achieve maximum density of the material. Approximately 190,631 cubic yards (145,700 cubic meters) of refuse material were placed in a period of eight weeks using six Cat 631-13 scrapers (Figure 12). The scrapers are rated at 21 cubic yards (16 cubic meters) struck and 30 cubic yards (23 cubic meters) heaped. The average load per scraper was estimated at approximately 25 cubic yards (19 cubic meters). The average haul distance was approximately 0.6 miles (1.0 kilometers). Production in moving the material ranged from 110 cubic yards (84 cubic meters) to 125 cubic yards (96 cubic meters) an hour.

The bid price for the "special borrow excavation" was $1.00 per cubic yard. The bids were opened on May 10, 1974. By using the refuse borrow a savings was realized over the price for "common borrow excavation". Common borrow excavation was estimated at $1.25 per cubic yard for the locality at that time.

Figure 11. Compacting of Coarse Coal Refuse using a Bomac Vibratory Compactor, BW 210 with Earthern Containment Structure in Background.

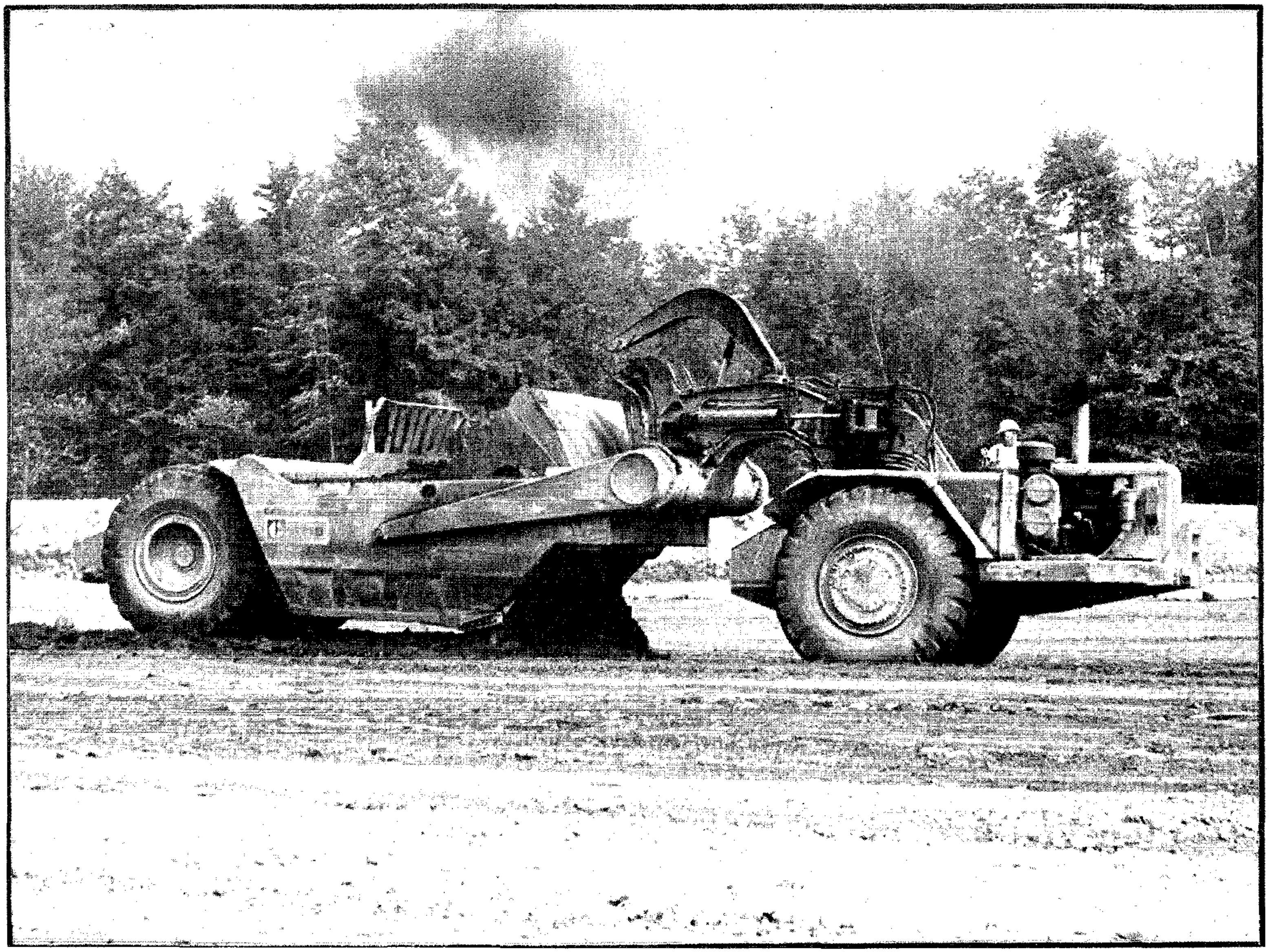


Figure 12. Coarse Coal Refuse being Spread by a Pan-Scraper (Cat 631-13).

POST CONSTRUCTION INTERVIEWS

Post construction interviews were conducted with Mr. Joseph Bondi, Assistant District Engineer, Construction and Mr. Stephen J. Pepoy, Project Engineer, PennDOT District 090, and Mr. Karl Fleming of Central Penn Industries Incorporated, the superintendent on the project for the contractor. The more significant conclusions drawn from these interviews were:

1. Coal refuse is a suitable material to use in highway embankment.
2. The use of refuse material was a definite advantage during wet weather periods. The material could be worked when other areas of the project using natural soil were shut down because soil conditions were too wet to work.
3. During dry periods, dust was a minor problem requiring the constant use of the water truck.
4. The material compacted best when wet and was easily broken down by the compaction equipment to achieve maximum density.
5. The use of the refuse material reduced the amount of maintenance normally required on scraper and dozer blades compared to moving natural earth material.

The completed embankment is shown in Figure 13.

"CROSS VALLEY EXPRESSWAY" LUZERNE COUNTY, PA

The "Cross Valley Expressway" was the first major highway project in the United States to utilize coal mine refuse. As with the previously described U.S. 219, Philip E. Butler, P.E., of PennDOT oversaw the testing and design of the embankment. The following discussion of the

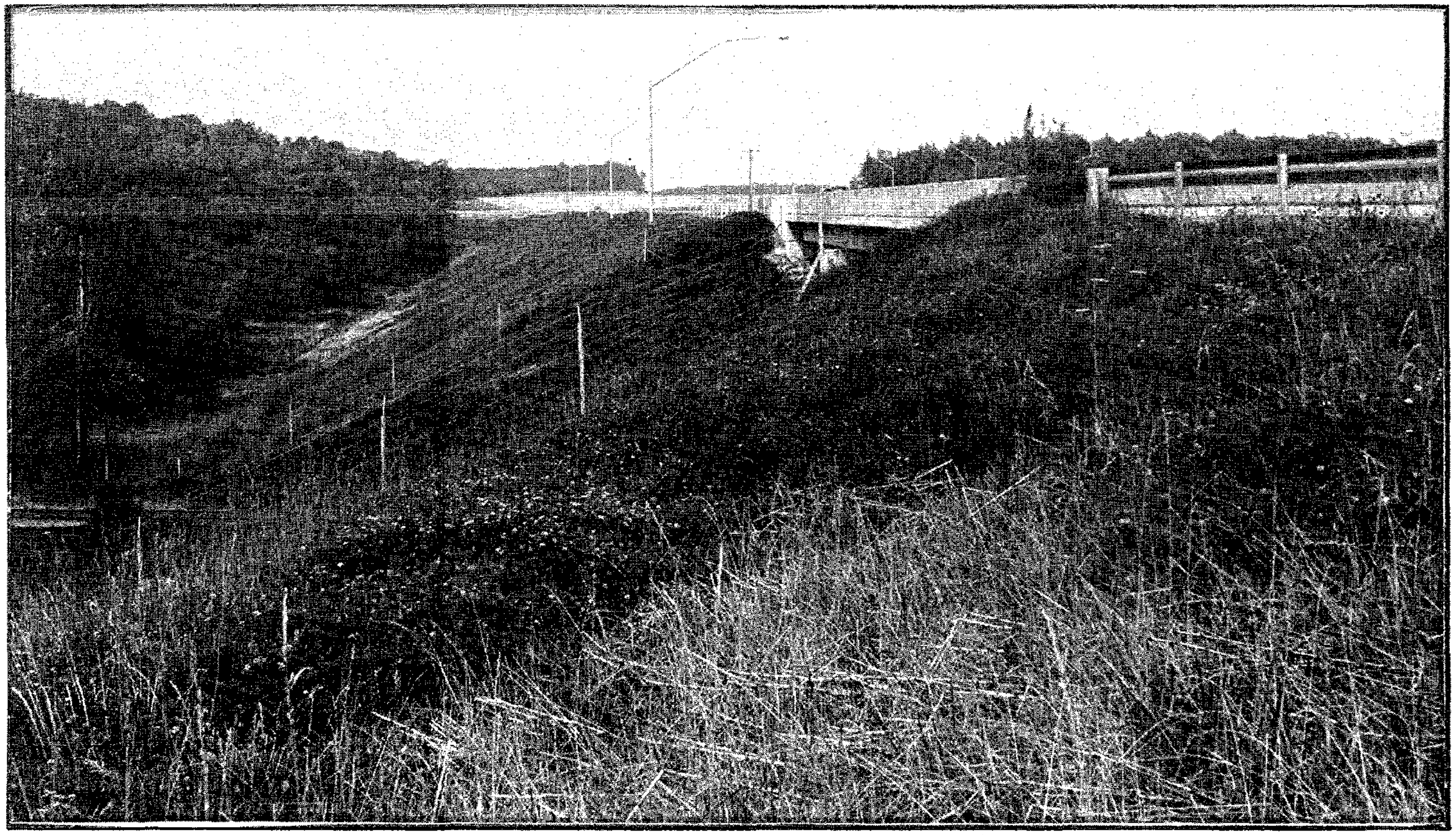


Figure 13. Completed U.S. 219 Embankment with Coarse Coal Refuse as Fill.

"Expressway" is derived from discussions with Mr. Butler and from his publication describing the project.[24] This embankment differs from the previously described project in that refuse from the northern anthracite fields of Pennsylvania was used, with approximately equal portions of burnt and unburnt refuse.

The Expressway is designated as L.R. 1052 and the embankment is Section 2G. It is located between the borough of Forty Fort and Kingston, across the Susquehanna River from Wilkes-Barre, Luzerne County.

> "The embankment is 2,344 feet (714 meters) in length and, with counter berms, reaches a maximum width of about 475 feet (145 meters) and a maximum height of 57 feet (17.5 meters). About 1.5 million cubic yards (1.1 million cubic meters) of both refuse and burned refuse were utilized in the construction of the embankment and counter berms. The refuse came from the Harry E. Breacher bank at Swoyersville, about 2 miles (3.2 killometers) west of the project, and the burned refuse (red dog) was obtained from several locations to the north in the vicinity of West Pittston. Construction began in May, 1973 and was completed in June, 1974."[24]

TEST RESULTS

A random sampling scheme was accomplished at Swoyersville along 300 foot traverses at predetermined locations along the bank and up the side slope. Pit samples weighing 30 pounds were taken at a depth of about 2 feet (600 millimeters). During construction, samples were obtained from the working face in the form of vertical channel samples, where possible.

Seventy-eight (78) samples were tested for grain-size distribution from Swoyersville. The ranges of grain-sizes are shown in Figure 14. This material had a coarse texture of fairly uniform grading. The material had fewer fines and was less well-graded than the bituminous refuse tested from Revloc, PA (See Figure 14). It was assumed from the grain-size distribution of the anthracite refuse, that the attainment of desired densities during construction would require a greater compactive effort than bituminous refuse from Revloc in order to breakdown the particles and provide sufficient fines.

Repetitive standard moisture-density tests were run on the same sample to test these assumptions and determine the amount of particle breakdown during laboratory compaction. Figure 15a gives typical results of one of 15 repetitive compaction tests on the anthracite refuse samples.

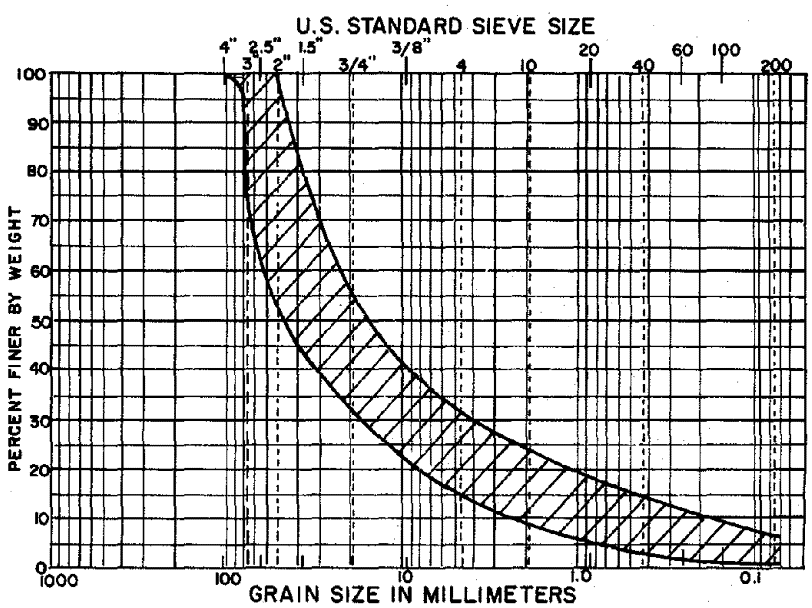
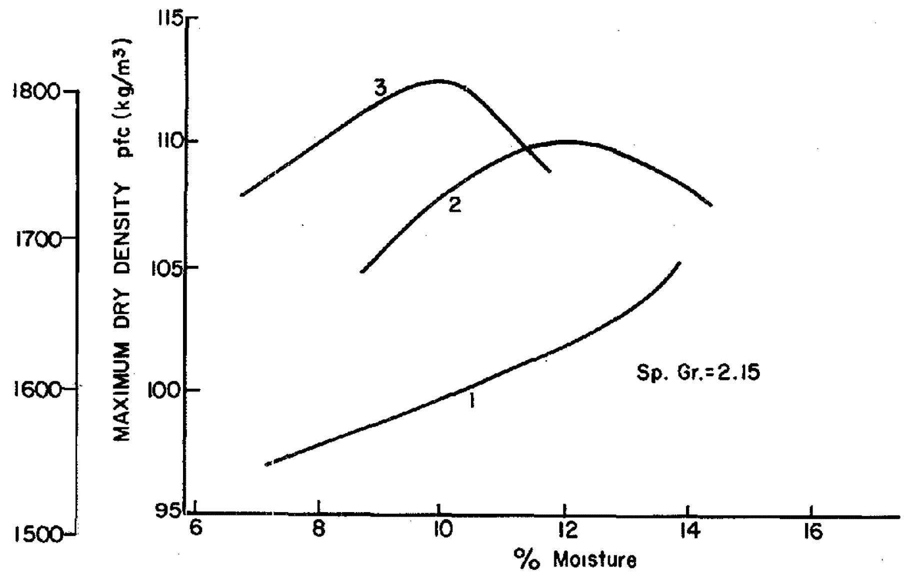


Figure 14. Range of Gradations from Swoyersville (29)



(a)

(b)

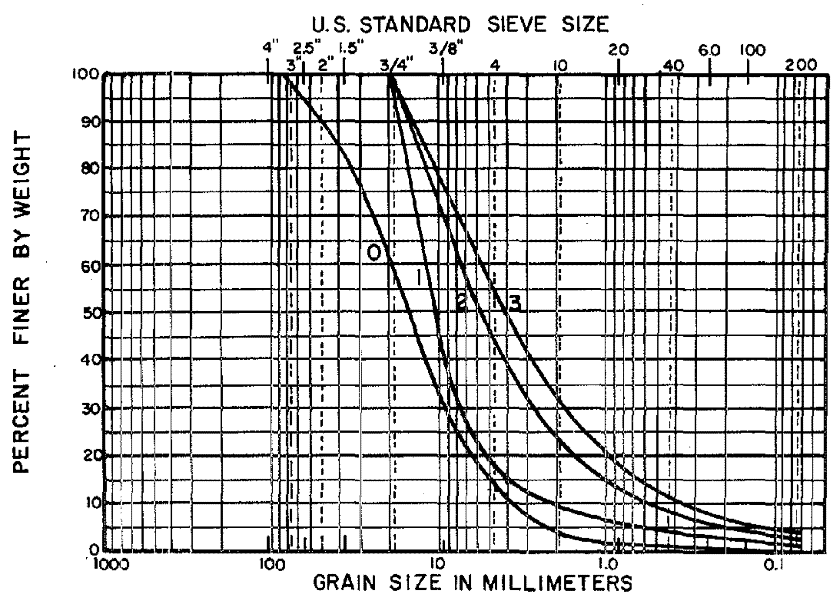


Figure 15. Repetitive Moisture-Density Curves (a) and their Gradations (b) of Refuse from Swoyersville. (24)

Curve 1 is the original moisture-dentity result and curves 2 and 3 are the samples having been tested the second and third times, respectively. These results show rather conclusively improvements of compaction characteristics. Figure 15b shows the grain size distribution of the sample in Figure 14a, with curve 0 representing the original grading of the sample. Curve 1 shows the original test grading and curves 2 and 3, the grading after the first and second moisture-density tests respectively.

Consolidated undrained triaxial shear tests were made on 12 anthracite refuse samples. The results are shown in Table 3 determined by the Mohr failure envelopes. The anthracite samples had lower angles of internal friction and less cohesion than the sample of the Revloc bituminous refuse (See Table 2, page 41).

Table 3. Stress Values for Anthracite Refuse from Swoyersville, PA.[24]

	ϕ°	c(psi)
Mean $\bar{x}$	28°	5
Range	25° - 33°	1 - 10
Standard Deviation $\bar{s}$	2.2°	3.4

SULFATE AND pH

The sulfate and pH levels of the anthracite refuse were determined in accordance with the British Standard 1377:1967. Results of 38 tests gave a mean of 0.03% for sulfate and a mean of 5.2 pH. The sulfate values were very low and indicated no special considerations were needed for effect on concrete structures. The pH values indicated some concern with water quality.

Thirty water samples were obtained from the Cross Valley Expressway embankment over 7 months to check water quality. The samples came from the slope indicator holes in the embankment. The mean value for pH was 6.7 with a range from 6.2 to 7.4 pH.

DESIGN AND CONSTRUCTION

Special consideration was given to slope stability of the refuse embankment because of the existence of a poor foundation. The embankment slopes were designed and constructed on a 2:1 (horizontal:vertical) and the counter berm on 3:1. When considering a foundation shear failure, factors of safety were obtained of 1.35 with the counter berms designed to increase the resistance moment against failure. The slope angle (i) was determined for the case of a planar failure surface and the most critical failure surface intersecting, at its lowest point, the toe of the embankment. The determination of (i) was made by the following equation, where the factor of safety (F) was predetermined, the Ø angle of internal friction was known from $\bar{x}$ (Table 3) and i was desired:

$$i = \arc \tan \left(\frac{\tan \phi}{F} \right)$$

Construction proceeded better than expected. Butler describes the construction:

"The refuse was spread and tracked with D-8 and D-9 bulldozers and compacted with a steeldrum vibratory compactor and steel-drum rollers. The material was easily handled, responded well to preparation and compaction and excellent results were readily apparent. In addition, the contractor was able to work in wet weather and on last conversation

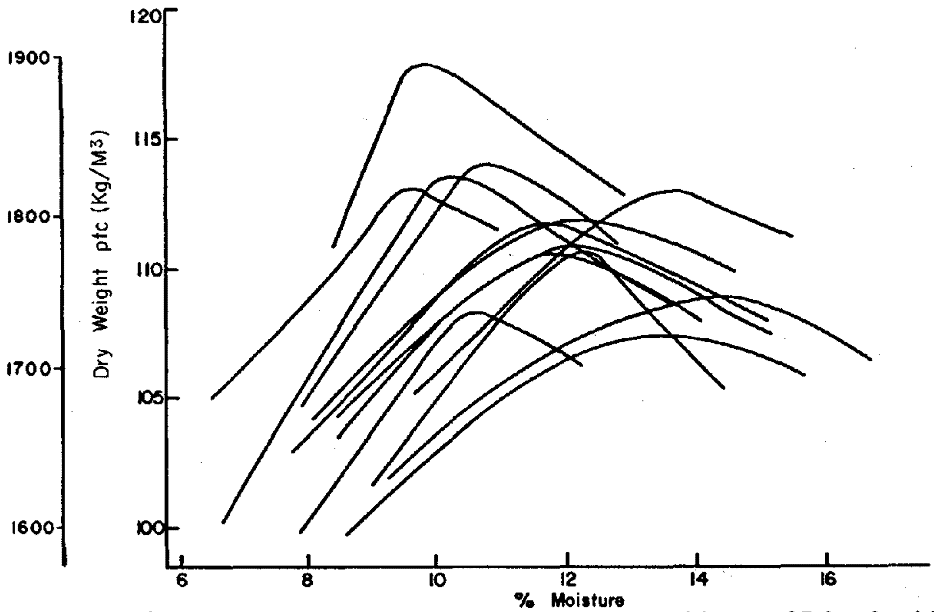


Figure 16 Moisture-Density Curves of Construction Compacted Samples of Refuse from L.R 1052. (24)

Table 4

Summary of Construction Density Measurements and Laboratory Moisture-Density Data (24)

Laboratory Densities	Wet Density lbs./cu. ft.	Moisture lbs./cu. ft.	Dry Density lbs./cu. ft.	% Moisture of Dry Wt.
(N=40)				
$\bar{x}$	122.1	13.5	108.4	12.6
Range	112-128	10-17	102-118	10-15
S	4.05	1.85	3.89	1.85
In-Place Densities				
Wet Wt. + Moisture (N=41)				
$\bar{x}$	126.1	15.3	110.9	13.6
Range	117-130	11-18	102-119	9-16
S	4.21	2.74	4.24	2.67
Wet Wt. Only (N=120)				
$\bar{x}$	122.9	----	----	----
Range	115-131			
S	4.53			

was able to work about 45 days which normally would have been lost due to bad wather."[24]

Table 4 summarizes the construction and laboratory density measurements for the Swoyersville anthracite refuse. Special contract provisions called for compaction to 97 percent of maximum density (from standard moisture-density tests) because of the poor foundation. A layer thickness of 8 inches (200 millimeters) maximum was followed during construction, as required by PennDOT.

The compaction achieved in the embankment is described by Mr. Butler:

> Figure 16 illustrates a range of moisture-density data obtained from 12 samples collected from the embankment after compaction had been completed. These curves resemble the second and third density curves shown in Figure 15a. The mean value of dry density from Figure 16 is 112 lbs/cu.ft with a mean moisture content of 12 percent and ranges from 108 - 118 lbs/cu.ft and 10 - 14 percent, respectively. Comparison with In-Place Densities given in Table 4 would suggest the degradation of samples under hammer impact beyond that achieved during construction, although the data is too limited to have any validity.[24]

Of special interest is the use of nuclear moisture-density gauges. It was believed that the carbon content of the refuse would make the results invalid, but proper air-gap adjustment gave acceptable results.

A 4 foot (1200 millimeter) thick soil cover was placed over the embankment and counter berm slopes. The top of the embankment was covered with 2 feet (600 millimeter) of soil upon which 2 feet (600 millimeter) of burned refuse was placed to provide an access road for the construction of the bridge. The soil cover was mulched and seeded. This thickness of soil cover was placed to:

1. Reduce the chances of erosion
2. Assure a 3 foot minimum for good root growth
3. and, Provide insulation for the interior.

After mulching, the soil was seeded with Crown Vetch (Cornilla varia) a legume which exhibits excellent erosion control and is winter hardy. To date, the vegetation has shown excellent growth and spread.[17]

Thermocouples were placed in the embankment to monitor temperature changes and determine the possibility of spontaneous combustion of the refuse material. The near-surface thermocouples showed temperature variations coinciding with the ambient temperature. The thermocouples monitoring the interior of the embankment showed no rise in temperature and were independent of the ambient temperature.

Mr. Butler drew several conclusions about the compaction of anthracite refuse after his experience at the "Cross Valley Expressway."

a. Although vibratory compactors were used on the expressway, after the material had been prepared by D-9 bulldozers, better compactive results could have been, and were obtained with steel-drum rollers.

b. Increased compactive effort will produce a greater degree of degradation if the effort is dynamic and not vibratory.

c. Improvements in compaction of the anthracite refuse could be realized by the addition of fines. Slurry refuse or pulverized fuel ash (fly ash) could be used to provide these fines.

BLACK FELL-WHITE MARE POOL SPECIAL ROAD IN COUNTY DURHAM, ENGLAND

A trial embankment of approximately 250m (1150 feet) in length and a maximum height of 4.2m (14 feet) was built on the principal road A. 182 in County Durham using unburnt colliery shale. The construction of the embankment is described by R. Richards of the Construction Planning Section of the British Transport and Road Research Laboratory.(32)

Refuse material was selected which was well-graded and had a loss of weight on ignition of 29.3 percent. The material was generally free of post-stone and pit-props and was conveniently situated near the proposed embankment. The maximum dry density averaged 1.874 Mg/m^3 (115 pcf) at an optimum moisture content of 8 percent. Testing for frost susceptibility gave results leading to the conclusion that the material was non-frost susceptible.

The refuse material was spread in 300mm (15 inches) thick lifts and compacted using a Bomag 7.8 Mg double vibrating roller, an 8 - 10 Mg mouth-wheeled roller and 3.75 Mg towed vibrating roller. This achieved a very hard state of compaction. Subsequently, trials were carried out with the Bomag roller to determine the degree to compaction versus number of passes using 200mm (8 inches) lifts with not less than 4 passes by the vibrating roller (See Figure 17).

The construction of the embankment proceeded well even after heavy rain at night, with the exception of an area where no drainage could take place after heavy rain. This trouble was remedied by covering the area with quantities of hot burnt shale.

Field tests gave an average specific gravity of 2.19. The average air void determined was near 9 percent. The British Ministry of Transport requires that a compaction to a maximum of 5 percent air voids be achieved for the material within two (2) feet of formation level. This air void percentage was found difficult to achieve.

OTHER EMBANKMENTS USING UNBURNT REFUSE IN GREAT BRITAIN

From 1968 to 1972, about 9 million cubic meters (12 million cubic yards) of coal refuse material were used in Great Britain for fill in road works and for brick and cement making. A publication by C.K. Fraser of the British Transport and Road Research Laboratory supplied information on the following road sections using unburnt refuse as embankment fill material.[33]

M61 CONTRACT 6

Approximately 230,000 cubic meters (300,000 cubic yards) of unburnt shale were used to form an embankment 3m (10 feet) high. No cladding (clay or soil buffer zone) was used apart from the natural topsoil. The engineer said the material worked well during wet weather.

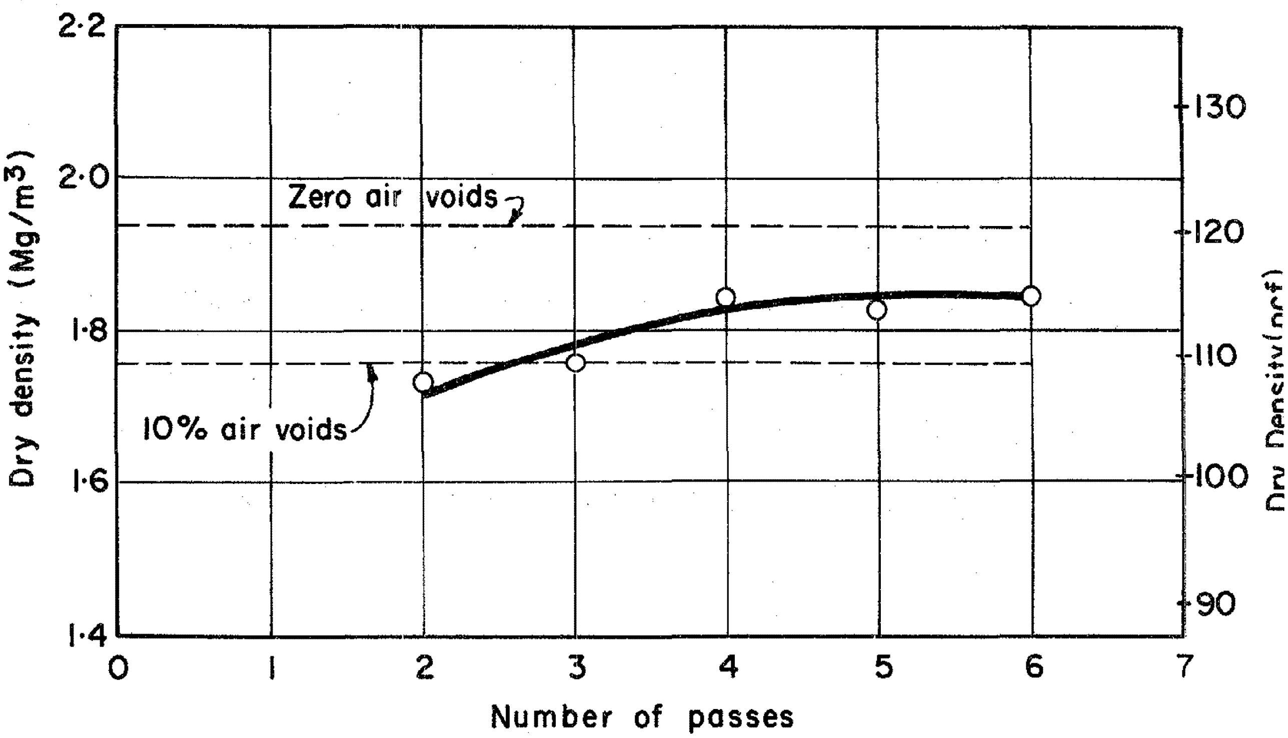


Figure 17 RESULTS OF COMPACTION TESTS WITH BOMAG BW 200 DOUBLE VIBRATING ROLLER ON UNBURNT COLLIERY WASTE. (31)

M61 CONTRACT 7

Approximately 460,000 cubic meters (600,000 cubic yards) were used in the embankment with a maximum height of 4.6m (15 feet). No cladding, apart from the natural topsoil was used. The refuse came from four (4) sites. One site contained refuse with a high clay content which caused some delay of construction during wet weather.

M62 CONTRACT 6

Approximately 277,000 cubic meters (360,000 cubic yards) of unburnt shale were used to form 6.1 meter (20 feet) maximum height embankments. The side and slopes were clad with clay 3 meters (k0 feet) thick and the top was covered with a 40mm (1.6 inch) thick layer of clay. Some difficulty was encountered with slippage in the clay cladding due to surface water running down the shale/clay interface.

PART II USERS MANUAL

INTRODUCTION

The overall goal of Part II is to provide reasonable guidelines and methods of approach to effectively use coal mine refuse in the construction of highway embankments.

Part I of this manual serves as background information pertaining to the use of coal mine refuse in highway embankments. From the background information presented, the following conclusions can be made:

- Coal refuse is a suitable material for construction of highway embankments.
- Case histories of the use of the material provide sufficient evidence that it is a suitable construction material and at the same time that such utilization has an overall benefit to the general public by helping to alleviate adverse environmental effects created, mainly, from abandoned dumps not subject to current disposal regulations.
- Standard highway and soils engineering procedures can be used in solving most problems in dealing with the use of the material.
- Because of environmental restraints and regulatory bodies governing the use of the material, special design considerations and evaluations are required.
- The effective use of this material is governed by principles which

apply to mining, soils engineering, environmental regulations, highway design and construction.

Part II, the User's portion of this manual, provides the framework upon which the strategy for using coal mine refuse for a particular project is built. The basic principles which govern the use of coal refuse are:

- Preplanning
- Sampling of refuse sites
- Testing of refuse materials
- Design elements
- Construction methods

PART II

SECTION 1. PREPLANNING

THE PROBLEM

In the past, some engineers have been reluctant to use the material in construction of highway embankments. This reluctance stems from fears of:

1. Spontaneous combustion of the material,
2. Degradation of the environment, and
3. Lack of knowledge on the physical and chemical properties of the material.

A review of the literature in the course of this study and communications with individuals knowledgeable on the subject, have led to the conclusion that most sources of coarse coal refuse are suitable for embankment construction and are superior in some cases to available soil materials.

An important factor in determining the economic feasibility of using coal mine refuse as construction material is the proximity of potential refuse borrow sources. If a potential borrow source of refuse is near a proposed highway, the use of coal refuse as an embankment material in most cases may prove more economical than excavating deep roadway cuts to maintain earthwork balance. Savings in right-of-way costs, fencing, roadside development and overall excavation costs may be realized.

Since the proximity of potential refuse borrow sources is one of the most important factors in determining the economic use of coal mine refuse in highway embankment construction, every effort should be made, in the very early stages of highway planning, to select proposed routes which would improve the economic feasibility of using the material.

Realizing that there are many factors considered in the selection of a new route for a highway, economics of the proposed construction is generally one of the most important factors, together with social and environmental considerations. Because of the important role that costs of construction play in selecting a proposed route, the economic and environmental benefits realized from the use of coal mine refuse in highway embankments should be subject to a thorough investigation in the route selection process.

In conducting an economic analysis, hauling costs are easily identified. This cost can be determined by using standard earthwork estimating procedures, such as:

1. Production ratio and cycle times.
2. Equipment rental and labor rates.
3. Fuel and oil consumption.

More difficult to determine are the cost benefits realized from using coal refuse in highway embankments resulting from environmental improvements, conservation of land and increased land values. A thorough evaluation of these benefits for each proposed refuse borrow site should be conducted.

Before conducting an evaluation, it is important to understand the adverse effects presented by coal refuse embankments, particularily by abandoned dumps which were deposited prior to current day regulations governing disposal of refuse. Abandoned refuse dumps contribute to the degradation of the environment by polluting water and air, are in some cases only minimally stable, and are in most instances unsightly.

The following is a list of some of the detrimental effects resulting from abandoned coal refuse dumps:

- Sediment run-off occupies storage in reservoirs and fills lakes and ponds
- Uses up productive land
- Destroys aquatic habitat
- Degrades water for consumption uses
- Increases water treatment costs
- Damages water distribution systems
- Generates dusts
- Contributes obnoxious and toxic fumes, if burning.

Obviously, not every abandoned refuse dump will exhibit all the detrimental effects listed above. The use of a refuse borrow site and the subsequent reclamation of the site could help to alleviate some of the adverse effects. For specific projects where coal refuse may be used as an embankment material, the cost benefits gained from environmental improvements may be the deciding factor in determining if it is economical to use the coal refuse material. An economical analysis of environmental benefits may prove fruitful in cases where hauling costs imposed by the use of coal refuse exceed those costs of normal excavation of adjacent borrow sites.

Where proposed highways are located at relatively long distances from refuse sites, funding may be needed to subsidize the haulage. When the refuse proposed for borrow is near urban areas, the community may be persuaded to subsidize the haulage. The long-term benefits realized by the community with removal of refuse banks are:

- Increased land values near the removed refuse site.
- Land previously underlying the bank can be regraded to create industrial sites.
- The alleviation of stream and air pollution in the vicinity of the refuse bank.

Funding may be available in the future from the Office of Surface Mining, Department of the Interior for the removal of refuse banks. This office will allocate the "Abandoned Mine Reclamation Fund (s)" which result from reclamation fees levied upon coal production, as provided by the Office of Surface Mining in the "Proposed Rules for Surface Coal Mining and Reclamation Operations."(12) First priority for allocation of these funds is the removal or reclamation of land disturbances caused by coal mining related activities that are hazardous to public health or safety, such as unstable or polluting refuse embankments.

The ownership of specific refuse banks may be determined by contacting the Department of Environmental Regulation of the state in which the banks are located or by contacting the local U.S. Bureau of Mines office. Most coal companies will not object to the removal of refuse material as long as their coal production is not hindered. Care must be taken to conduct removal activities, and the reclamation of any resulting disturbed lands, in accordance with state and federal regulations governing refuse disposal areas.

Those familiar with the total concept of highway planning know that the choice of a proposed relocation or the location of a new highway is determined in the corridor study stage.

At this time, the choice of the best sites can be encouraged and poor sites discouraged. It is paramount that the contemplated use of coal refuse material, where feasible or applicable, be incorporated in highway planning processes during the corridor study phase. After a corridor study public hearing has been conducted and an approved corridor selected, it would be difficult to change any proposed highway location to accommodate the use of coal refuse in the embankment.

Another reason for introducing the potential use of coal refuse in the earlier stages of planning is that the use of this material in most cases will be the most important factor in establishing the vertical alignment. This is particularily true in the Appalachian Coal fields where the terrain is normally rugged. To use the coal refuse in the embankment sections of the highway it will be necessary to develop the horizontal and vertical alignment to establish an unbalance of earthwork material, creating the need for borrow excavation. Obviously the geometrics of the horizontal and vertical alignments are critical in the decision making of selecting a proposed corridor. These geometrics would be heavily influenced by proposed use of the refuse material. If those responsible for developing the highway are not aware of the intended use of refuse, the designer will study horizontal and vertical alignments which will produce a reasonable earthwork balance between cut and fill sections, requiring the least amount of earthwork, thus eliminating the potential use of coal refuse in the embankment.

PLANNING FOR THE USE OF COAL REFUSE IN A PROPOSED PROJECT

Generally, the development of a proposed highway project progresses through the following stages: 1) corridor study, 2) route selection, 3) preliminary design 4) final design, 5) advertising and bidding, and 6) construction.

The degree of participation by various highway engineering disciplines in these stages is not generally consistent for any given project. Those concerned with the use of coal refuse in a highway embankment (the soils and foundation engineer or geotechnical engineer or the engineering geologist) should be involved during the corridor stage; however, experience indicates that is not always the case; they may or may not be consulted. Normally, their participation increases rapidly once a tentative alignment is selected and geotechnical input is required. This participation generally continues to increase through the preliminary and final design stages and declines through the remaining stages.

In areas where there is a potential for using refuse in a highway embankment, the agency responsible for the development of the highway should assign members of its geotechnical group to the corridor study team. The corridor study stage ultimately results in route selection. At this stage, the geotechnical engineer should collect information concerning the availability of coal refuse as a potential borrow source and should be included with other geotechnical information normally collected at this stage for a proposed highway project.

It is suggested that some limited field exploration be conducted to determine the quantity and quality of refuse available. Visual examination of the material and limited amount of testing for engineering properties should be conducted, using standard highway geotechnical procedures.

Participation at the corridor stage is generally limited to an office review and field reconnaisance with the goal of writing a geotechnical report to provide input for the route selection process.

The office review usually consists of acquisition of information, assembly and review of topographic maps, soil conservation maps and geologic literature.

The intended use of coal refuse in a highway embankment will require collection of geotechnical information from other sources, such as: The United States Bureau of Mines, state mining, solid waste disposal and environmental agencies, mining companies and U.S. Department of Labor-Mine Safety and Health Administration if the proposed refuse borrow site is an active disposal area.

Field reconnaissances generally involves a site walk of the areas under consideration to review conditions in the field concerning all aspects of highway planning.

The preliminary design stage of the development is initiated after a corridor study has been approved. At this stage the location of the project has been determined. If coal refuse is intended to be used in the construction of the embankment, documentation and geotechnical information concerning the use of this material should be included as a supplement to the geotechnical report and follow normal highway procedures for conducting geotechnical investigations and presentation of information. However, the use of coal refuse in a proposed highway embankment will require a more extensive investigation than in a normal highway geotechnical investigation. It is necessary for the geotechnical engineer to become familiar with the use of this material to plan his sampling and testing schedules. The degree and extent of exploration, sampling and testing for any given stage of development of the proposed highway will probably be determined by the agency responsible for designing the proposed facility.

PART II

SECTION 2. SAMPLING OF REFUSE SITES

GENERAL

Before initiating an exploration and sampling program for a proposed refuse borrow site, it is necessary for the geotechnical engineer to become acquainted with the history of the refuse disposal site.

Collecting all available information concerning the development of the refuse pile will provide the engineer with an idea of the variances that may exist within the pile. This information is used to intelligently develop a sampling program to determine the composition of the pile. This is particularly true for older refuse dumps not constructed under current day regulations.

The deposition of coal refuse by mining companies conducted under current regulations is subject to embankment construction procedures similar to those required for highway embankments. From a geotechnical viewpoint, these piles will be much easier to evaluate. Records concerning the material gradation and characteristics are generally available.

No two refuse piles are similar. Many factors influence the composition of the pile and the disposition of the material. Since refuse disposal sites are so unique in character, it would be difficult to develop a step by step procedure in planning an exploration and sampling program. Because of this, it is mandatory that the geotechnical engineer become familiar with the factors of each refuse area to be used that would influence his sampling program. Some of the more significant factors are:

- Age of the pile
- Coal seams mined
- Coal preparation process
- Method of transport
- Configuration and placement at disposal site
- Other variables.

General comments on each of these factors are as follows:

AGE OF THE PILE

- Most older piles have not been subject to processing in coal preparation plants. Therefore these piles have a high coal content.
- High coal content in older piles usually resulted in the piles catching fire and burning to some extent.
- Evidence of burning in some of the older piles is not always visible on the surface. Some older piles may have a hot interior.
- Unburnt portions of the pile may be a valuable energy resource.
- The surface appearance of older piles is not always indicative of the material making up the greater portion of the pile. Flatter slopes are subject to weathering, resulting in finer grain size appearance. Steeper slopes which are subject to erosion appear to have a coarser texture than the general composition of pile.

COAL SEAMS MINED

- The rock formations immediately above and below the coal seam represent a large portion of the material in coal refuse.

- The character of the rock varies from seam to seam and geographically within a single coal seam, depending upon the geologic conditions preceeding and following the deposition of the coal-forming materials.

- Inorganic sedimentary rocks, such as claystone, siltstone, shale, sandstone and occasionally limestone comprise the bulk of the strata in which bituminous coal is contained.

- Anthracite refuse will be composed of metamorphosed sedimentary rocks which are harder in composition than their sedimentary counterparts. (ie. shale - slate; sandstone - quartzite).

- Refuse contained in any given disposal area may have been generated from more than one seam and deposited simultaneously or separately. If the refuse from more than one seam has been deposited separately, composition of rock in certain portions of the pile may vary considerably.

COAL PREPARATION PROCESS

- Normally, coal preparation plants treat two sizes of mined coal separately - coarse coal (plus 28 sieve or 0.5 mm size) and fine coal (minus 28 sieve size).

- The coarse refuse resulting from the preparation plant process generally exhibits a more consistent gradation of refuse particles than non-processed refuse.

- Fine refuse is usually disposed as a slurry pumped to ponds for settling of the solids and clarification of the remaining water. The fine refuse is a poor construction material and is not recommended for use in highway fills.

- Some slurry is partially dewatered at the preparation plant resulting in sludge, then disposed of separately or mixed and placed with the coarse refuse material.

- Records are usually maintained at the plant office containing information relative to material gradation and production rates.

METHOD OF TRANSPORT

- Refuse transport methods vary widely from mine to mine.

- The mode of transportation is usually determined by 1) material gradation 2) production rate, 3) topography and distance to the disposal area, 4) size and configuration of the disposal area.

- The most common methods used for disposal of coarse refuse are 1) trucks and scrapers for short distances 2) conveyers for relatively short distances over moderate terrain 3) continous bucket trams over steep slopes 4) or by combination of the above methods.

CONFIGURATION AND PLACEMENT

- Configuration of the refuse disposal site is usually determined by the mode of transportation and topography of site area.

- Side-hill dumps constructed using trucks that end-dump the refuse material over the outslope tend to segregate the refuse material, resulting in coarser material at the base of the pile and finer material at the top. Tram-dumping results in similar segregation of the material.

- Conical piles usually indicate that the material has been deposited by using a conveyor. This method of disposal results in similar segregation of the material as discussed above.

- Tram-dumped disposal sites usually reach great heights and can be conical in shape or form a long, narrow ridge configuration.

- Since early in 1970 most refuse piles have been constructed using bulldozers to spread and compact the material in level lifts of two feet or less. Scrapers and truck transport are commonly used in areas where terrain is relatively flat and in conjunction with other methods mentioned above to prevent the segregation of material, thus reducing the possibility of spontaneous combustion.

OTHER VARIABLES

- Some coarse refuse disposal site may contain pockets of dried slurry fines, which were pumped into ponds excavated in the coarse refuse.

- Some sections of the coarse refuse disposal area may contain rock from roof falls or shaft and tunnel construction. This is particularly true in the anthracite region. Usually this rock is much larger in size than refuse from the process plant.

- Older refuse piles may contain extraneous material such as: old mine rails, oil and grease cans, wire and cable, timber and lumber, and other discarded items.

An evaluation of these factors will dictate to the geotechnical engineer the course his investigation will follow.

PLANNING THE EXPLORATION AND SAMPLING PROGRAM

After determining the location of the refuse borrow site, quantity of refuse material available and required, and after studying the history of the refuse disposal site, the geotechnical engineer will be required to make many judgements in developing his exploration and sampling program. Those familiar with conducting geotechnical investigations know the main goal of the exploration and sampling program is to collect representative samples of the material to use for testing of engineering properties and to detect any unusual subsurface conditions that may have an effect on the proposed construction. The extent of the program needed to accomplish this goal, when using coal refuse as borrow material, varies considerably for each proposed borrow site. The size and configuration of the refuse pile, quantity of material to be used, variations of the materials and specific site conditions will all have a direct influence on the extent of the exploration and sampling program. Experience indicates that older piles may require more extensive investigations than newer piles. The material in newer piles generally exhibits a more uniform gradation and composition. Older piles usually have the following characteristics which may require a more extensive investigation.

- Refuse material generally is more segregated than in newer piles.
- The older piles generally contain burnt and unburnt materials. A cut through an older pile is pictured in Figure 18 showing the segregation of burnt and unburnt refuse.
- Older piles may be burning even though there is no evidence of burning on the surface, requiring special consideration in extracting the material. These special requirements are discussed in the method of design section of this report (See page 121).

In most instances, it is doubtful that the quantity of available refuse at a proposed borrow site will conveniently equal the amount of borrow material required for any given project. The size of some refuse borrow sites may be massive, requiring that only a portion or portions of the refuse site be used as borrow material. Conversely, the amount of borrow material required for the construction of any given highway project may be greater than the amount of coal refuse available at specific refuse borrow site. In cases where the amount of refuse available exceeds the amount of borrow required, the exploration and sampling program should be developed to satisfy two requirements. The first is to collect sufficient geotechnical information concerning the use of the material for construction of the proposed embankment and the second is to ensure that the unused portion of the refuse site remains in a stable condition. These sites will require a preliminary contour and grading plan depicting the proposed configuration of the unused portion of the refuse site, before developing exploration and sampling program. If the amount of refuse contained at the proposed borrow site is less than the amount of borrow material required to construct a proposed embankment, the exploration and sampling program should be developed to

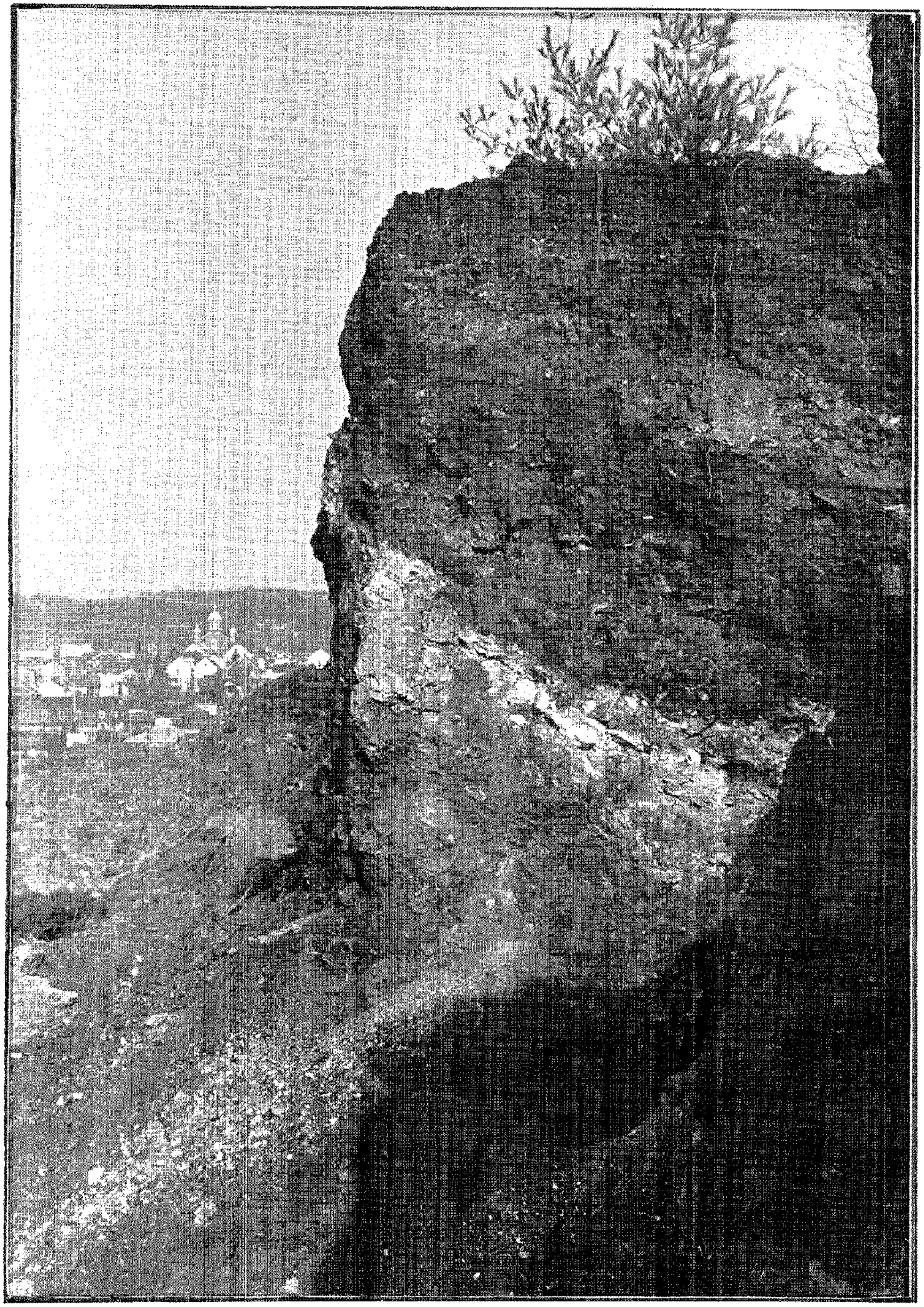


Figure 18. Open Cut Though a 40 Year Old Refuse Pile.
Note Segregation of Burnt Refuse.

thoroughly evaluate the total refuse site.

SAMPLING TECHNIQUES

The primary objective of the sampling program is twofold; first, to collect sufficient information on the physical characteristics of any particular refuse embankment, and second, to obtain samples of that refuse material for visual examination and laboratory testing. It is not possible to state an exact number of samples which must be obtained for any particular refuse pile. The number of samples and exploration sites will be dependent on the size of the pile, the volume of material to be removed and the type of material which is encountered during the exploration and sampling program. Where considerable change in the type of material is noted during the exploration program, it is recommended that a minimum of three to five samples of any one type of refuse material encountered be obtained. This is not to imply that only three to five samples are necessary for a pile which is fairly consistent. Personnel responsible for the exploration and sampling program must keep in mind that one of their primary goals is to obtain sufficient samples for laboratory testing. The testing for any one particular type of material encountered should include as a minimum, classification tests and proctor and/or relative density tests. A more detailed discussion of the testing is presented under the Section 3 - Testing of Refuse Material.

There are several types of conventional exploration and sampling methods which are utilized when testing and sampling coal refuse embankments. These methods include, but are not limited to; test pits, auger borings, soil borings and simple bulk sampling of the exposed surface material. A discussion of each of these methods is presented below with recommendations for utilization in exploring and sampling coal refuse embankments.

It must be kept in mind by the geotechnical engineer that the primary purpose of the exploration and sampling program is not to determine the in-place properties of the refuse material, but rather to obtain information on the potential borrow source for design of an embankment. Therefore, some of the conventional undisturbed sampling methods may not be necessary during sampling of the proposed refuse site.

TEST PITS

The test pit method of exploration and sampling is considered to be the most desirable for this type of project. Utilization of test pits will allow the geotechnical engineer to open up larger exploration holes near the surface of any refuse embankment. This will enable the engineer to obtain bulk samples of the material which may be used as a borrow source, and also give a better means to visually observe the refuse material which lies below the surface. Equipment capabilities and economics dictate the size of test pit which can be excavated. Even so, the utilization of test pits are highly recommended. Where practical, disturbance of the surface of the coal refuse site should be performed to allow deeper excavation of the test pit.

When test pits are utilized, common sampling techniques are recommended. These techinques include logging for changes within the walls of the test pit. The sampling consists essentially of obtaining bag samples or bulk samples of the material at any or many points within the test pit. All samples should be sufficient in size to complete as a minimum: Classification Tests, Proctor or Relative Density Tests, and remolded samples for Consolidation, Triaxial Compression or Direct Shear Tests.

The equipment commonly used today for the test pit exploration sampling includes; backhoes, front end loaders, large and small bulldozers or any type of small excavating equipment, depending on the size and depth at which the test pit is to be excavated. The primary limitation of the test pit is depth. A large conically heaped pile cannot be representatively sampled by test pits, if all of the pile is to be used in the embankment. These limitations can obviously be overcome if economics allow great expenditure during the sampling program. The cost of using test pits vs. utilization of drilling equipment to obtain samples and explore the refuse pile should be considered when the exploration and sampling program is developed.

DRILLING FOR EXPLORATION AND SAMPLING

Conventional rotary drill rigs equipped for soil sampling and exploration can be utilized to explore and sample common refuse embankments. When considering this alternative, the geotechnical engineer must bear in mind that the material to be sampled is a relatively coarse gravel type material. Therefore the type of sampling tools utilized and results obtained will be directly related to the type of material which is to be sampled and explored. Several conventional drilling methods which can be utilized for a refuse embankment are auger borings and soil borings using driven or drilled casing to keep deep holes open for sampling. Further discussion of these alternative methods is presented below.

AUGER BORINGS

Utilization of auger borings will provide two types of information. Where a proposed borrow source is a relatively shallow embankment, auger borings may be used to define the exact depth of refuse within that embankment. This is considered to be the most economical method of determining the exact amount or depth of refuse material in a particular refuse embankment up to a depth of about 50 feet. Auger borings will bring the refuse material to the surface in a disturbed state. A mixing effect is created with depth and determination of a particular material at a specific depth is difficult. This type of sampling allows the engineer only to obtain an idea of the type of material which will be encountered in the refuse embankment. Large bulk samples with depth are generally not practical.

Where auger borings are being considered, they should be used as a supplement to either test pits or soil borings.

SOIL BORINGS

As previously mentioned two types of soil borings are utilized for this type of project. Borings using drilled casing and borings using driven casing are common for many highway exploration and sampling programs.

The common means used by many engineers who have analyzed numerous large refuse embankments is the drilled casing soil boring. These borings are generally drilled with water using a small diameter casing which is 4 or 6 inches (102 or 152mm). Utilization of the casing is necessary to keep the exploration hole open for sampling at depths well below the surface.

Utilization of the method requiring the casing to be driven in the hole is the least desirable of the two soil boring options. The dense nature of some refuse piles will make the driving of casing a difficult operation.

Once a type of soil boring is selected for exploring a particular refuse pile, the sampling operation must be established. Standard sampling techniques such as split spoon sampling and shelby tube sampling are often used in refuse embankments to obtain samples.

The split spoon sample is recommended for exploring a refuse pile as it will give the engineer an indication of the type of material which is being encountered and also allow him to observe any variations in the type of material within the embankment. The split spoon method or standard penetration test (AASHTO T206-74) utilizes a 140 lb. hammer to drive a split barrelled sampler approximately 18 inches (147mm). A large diameter sampler (approximately 3 1/2 inches - 89mm) should be utilized where large particles of refuse are anticipated. A disturbed sample is retrieved which can be used for classification tests. The samples are too small for proctors, relative densities, triaxial or direct shear tests. Continuous split spoon sampling is not always necessary. Utilization of continuous sampling is recommended where changes in material types are expected or where they are encountered during the exploration program.

The shelby tube (AASHTO T207-74) or undisturbed sampling technique, should be used to obtain small bulk samples of relatively undisturbed material. However, as previously discussed it is not absolutely necessary that undisturbed samples of the material be obtained. The primary goal is to obtain sufficient representative samples of the refuse material for the laboratory analysis. Difficulties in utilizing the shelby tube sample are created by the nature of the tube itself. The shelby tube, being a thin walled sampler, has a tendency to collapse when large rocks of refuse material are encountered in the test boring. This will result in efforts expended where no samples are obtained.

To enable the engineer to obtain bulk samples at depth from a refuse pile, it is recommended that an unconventional type of sampling be considered. Since the refuse in the pile will be remolded at the highway construction site it is not necessary to obtain undisturbed samples. To obtain a bulk sample would require a larger thick-walled type tube sampler to be fabricated and utilized. This type of sampling, for example, could include utilization of a 4-inch (102mm) casing section within a 6-inch (152mm) cased hole to either obtain hydraulically pushed samples or samples driven by a hammer. It is also recommended that this type of sampler be fixed with some type of trap door so the samples will be retained in the sampling apparatus and not lost when the sample is extracted.

BULK SAMPLING

Simple bulk sampling can be utilized where the refuse pile to be used for highway embankment is very shallow or very little refuse material is needed. This method would involve simply digging by hand a bag full of refuse on the surface of exposed slopes. This method could be utilized to obtain samples for a preliminary design phase but should not be used to obtain samples for final design parameters. The material at the surface has been exposed to the atmosphere and water and may not be representative of the remaining pile.

FIELD TESTING FOR BURNING REFUSE DUMPS

Old refuse areas with a high percentage of coal and dumps which were constructed with little compaction (end dumped, tram dumped) can sometimes contain burning areas. These burning areas can be very hazardous when cut into by construction equipment. Several explosions of burning refuse areas have occurred resulting in loss of life. During the exploration program, hot areas should be determined if a burning refuse pile is suspected. During the exploratory drilling a maximum reading thermometer can be inserted in a hole until the thermometer has stabilized (generally about 1/2 hour). When the thermometer is removed from the hole it will indicate the maximum temperature reached at that site. By testing the temperature in numerous holes, the extent of the hot area can be determined.

SUMMARY

If should be emphasized that the best method of sampling depends greatly on the size and geometry of the proposed refuse borrow area. In addition the amount of refuse to be used from this borrow source should be considered when determining the type of sampling method. In developing the sampling program, the geotechnical engineer must remember that the primary purpose is to determine the extent of the pile, homogeneity of the pile and extract samples for testing.

PART II

SECTION 3. TESTING OF REFUSE MATERIAL

GENERAL

Testing of refuse materials will be similar to the testing conducted on typical highway soil borrow areas. As with any testing program, the intent is to define engineering characteristics of the borrow material to aid the designer in designing the proposed embankment and in preparing specifications for construction.

PLANNING A TESTING PROGRAM

As previously stated, no two refuse piles are similar in character. Therefore, it is necessary that the designer and geotechnical engineer consider all characteristics of the particular refuse disposal borrow site. Most of the factors that the geotechnical engineer should consider are listed under Section 2 - Sampling of Refuse Sites. This section outlines the numerous factors which change the characteristics of the material. The engineer should consider these factors in addition to all the data obtained from the sampling program. Results of the sampling, and field observations during sampling, may give visual indication of some variations in the character of the refuse pile. These variations will dictate the primary direction the testing program should take.

Once the person responsible for establishing the testing schedule is familiar with all these factors he should determine what initial testing is to be performed to define the basic character of the refuse material. The testing required for this initial phase is generally limited to classification tests, possibly including Atterberg Limits.

The following paragraphs contain a discussion of the particular tests and how they should be applied to the testing of refuse materials. The list of these tests is as follows.

- Classification Tests
- Volatile Contents
- Sulfate Content
- pH
- Specific Gravity
- Proctor Density Tests
- Relative Density Tests
- Shear Tests
- Consolidation Tests
- Bearing Tests
- Special Tests

The test procedures of the American Association of State Highways and Transportation Officials (AASHTO) and American Society for Testing and Materials (ASTM) are recommended when possible because of their wide acceptance and availability. Test procedures not available from these sources are presented in full in the Appendix.

CLASSIFICATION TESTS

At the end of the sampling program, the geotechnical engineer will have to define the basic properties of the entire refuse pile based on either visual observations during the sampling or from testing. The classification test will give more general information than other more specific tests. The classification is based on grain size analysis, hydrometer analysis and Atterberg limits. The grain size analysis consists of shaking the refuse through a stack of wire screens with openings of known sizes. This test will define the amount of gravel and sand size particles in a soil. The test should be conducted in accordance with AASHTO T88-72. If the refuse has an appreciable amount of silt or clay (minus 200 mesh) a hydrometer analysis should be performed. The hydrometer analysis is based upon Stoke's equation for the velocity of a free falling sphere in a solution. This test should also be conducted in accordance with AASHTO T88-72. If the refuse has a significant amount of minus 40 sieve (.425 mm) material, Atterberg limits should be performed. The Atterberg limits consist of two parts: liquid limit and plastic limit. The liquid limit of refuse is the water content at which a soil passes from a plastic to a liquid state. The plastic limit of refuse is the lowest water content at which a soil remains plastic. AASHTO T89-68 and T90-70 should be used as a guide in conducting these tests.

The results of the above three tests are used to classify the refuse according to AASHTO M145-73. This classification system groups together soils with similar engineering properties.

The first classification tests which are conducted for the refuse disposal area should be scheduled to cover any variations noted in the field. These tests will indicate the range of the material which will be encountered within the refuse pile, giving the engineer an indication of grain size and the type of material, i.e. gravel, sand, clay etc. The results of the initial classification tests will give the engineer a basis to schedule the remaining tests. It is not possible to establish a firm requirement on the number of tests that will be necessary for any one particular refuse area. The selection of the number of tests will require engineering judgement. Once the initial testing has been done, the geotechnical engineer can then schedule the additional classification tests as needed and dictated by the characteristics of the particular refuse pile.

The results of classification testing, both preliminary and the total testing done on the pile, should indicate to the engineer the type of material that he will encounter in the borrow area. As previously stated, all refuse areas vary considerably. The soil types will range from gravels down to sandy and silty clays. Therefore the engineer should pay particular attention to variations within the refuse embankment and try to establish a range of gradations for any particular area within the pile or the entire pile itself.

VOLATILE CONTENT

The volatile content of the refuse proposed for use should be determined at the early stages of planning. High volatile contents within the refuse indicate a high coal content. Many refuse piles, especially older ones, are being recycled with as much as 50% coal recovered. Obviously, it would be a waste of an energy source to use refuse with a high coal content as fill material unless some attempt is made beforehand to encourage reprocessing to separate the coal portions. Refuse with a volatile content of 20 percent or greater might allow for economic reprocessing of the pile. Where the refuse has a volatile content of 20 percent or greater, some effort should be made to interest local coal companies or coal processors to further investigate the pile for potential economic reprocessing. The refuse resulting from the reprocessing could still be used as a borrow source and will generally have better engineering characteristics than before reprocessing.

The volatile content of coal refuse should be determined as specified in the ASTM test D3175-73: Volatile Matter Determination.

SULFATE CONTENT

Special consideration should be given to the chemical parameters of coal refuse when using it for embankment fill. The determination of the sulfate levels leached from the refuse material is needed in order to design for the protection of concrete structures. The test procedures for sulfate levels are drawn from the British Standard 1377.[30] These test procedures are presented in full in Appendix A. Two methods of testing are included. The first is a water extraction of sulfates. This test gives an approximation of the levels of sulfate that will be leached by the natural environment. The second test is an acid extraction which will leach higher levels of sulfates from the refuse material. Generally,the sulfate levels from the latter test will be higher than those leached from a natural environment.

The British have done extensive testing on the use of refuse material in roadmaking and the effect released sulfates can have on cemented structures. Sherwood has determined the levels.of sulfates at which sulfate attack on concretes can be detrimental.[22] His recommendations for the use of refuse as bulk fill material have been adopted by the British [33] and are used herein. When using coal refuse as bulk fill no limits need be placed upon the sulfate levels. However, as stated in British specifications, if the sulfate content of the refuse exceeds 2.5 grams per liter sulfate (SO_3) as determined by a water extraction (Test 10 of British Standard 1377), it should not be used within 20 inches (0.5m) of cemented structures or pavement. The buffer zone should be provided by some other fill material not exceeding the above limits of sulfate.

pH

The pH value of the refuse in water should be determined for proper selection of type of underdrain or other drain pipes. Extremely acidic refuse in the embankment will require the use of special compositions or coatings on pipes to avoid deterioration or corrosion of the pipe (See Section 5 - Construction Methods, for pipe selection).

pH - British Standard 1377; Test 11, Method A - This method covers the electrometric determination of pH value of a soil suspension in water. This test is included in its entirety in Appendix A.

SPECIFIC GRAVITY

Testing of specific gravity of the refuse material will give the user an indication of the volatile content and of the maximum densities attainable. Excellent correlations between specific gravity and volatile content and between specific gravity and maximum densities were achieved by Chen (See Figure 4, page 30). Generally, lower specific gravities will result in higher volatile content and lower maximum densities. Specific gravities will be especially useful in checking the validity of widely varying laboratory attained maximum densities.

Specific Gravity - Where a considerable portion of the refuse is retained on the 4.75 mm (No. 4) sieve the AASHTO T85-74 (Specific Gravity of Coarse Aggregate) should be used. When no appreciable portions are retained on the 4.75 mm sieve, AASHTO T100-74 may be used.

PROCTOR DENSITY TESTS

Laboratory moisture density tests will need to be run on the refuse material to determine the compactive effort required in the field to achieve acceptable compaction. The proctor test will determine the maximum density and optimum moisture content of representative refuse samples. Normal geotechnical testing procedures include the utilization of both the standard and modified proctors for potential embankment materials. Judgement of the geotechnical engineer or guidelines developed by the States determines which method is utilized.

The Standard proctor was developed in the 1930's and indicates the maximum density at which a fill material can be compacted at a standard compactive effort. The modified proctor utilizes a larger mold and more compactive effort. The modified proctor was instituted after the development of larger and heavier construction equipment. Results of the proctor density tests give the engineer a method by which he can control the construction of the proposed embankment. This control is exercised through specification limits requiring the embankment be compacted at a certain percentage of proctor density and within a certain moisture, based on the optimum moisture content obtained in the proctor density results. Recommended specifications for percent compaction and maximum density are presented in Section 5 - Construction Methods. Further discussion of both the standard and modified proctor density test procedures is presented below.

STANDARD PROCTOR DENSITY (AASHTO T99-74), - The standard proctor uses a 4 or 6 inch mold. Refuse is placed in the mold in three layers with each layer compacted using 5.5 lb. hammer, falling 12 inches, 25 times. Several of these samples are run, each at a different moisture content. After each sample is run the density and moisture content are determined. A curve is developed depicting moisture content vs. dry density.

MODIFIED PROCTOR DENSITY (AASHTO 180-74) - The modified proctor is similar to the standard proctor, only a 10 lb. hammer is used falling 18 inches. Five layers of refuse are compacted instead of three. Generally the modified proctor results show a higher maximum dry density at a lower moisture content than the standard proctor.

REPETITIVE MOISTURE - DENSITY TESTS

Refuse tends to breakdown during both laboratory and field compaction causing an increase in the amount of fines and generally results in higher maximum densities. The performance of a series of repetitive laboratory moisture-density tests on the same sample can give an indication of the breakdown and densities which might be expected in the field. This test has proven to be especially effective when dealing with anthracite refuse. The coarse-grained, uniform nature of anthracite refuse causes some problem with achieving good proctor curves on the initial sample. The breakdown that occurs during compaction increases the amount of fines and results in a curve that is not truly representative of the initial grading. Repetitive proctor tests entail performing a proctor test and then reusing the same material again to see how the maximum density changes. In addition, grain size analyses are performed on the initial (unused) sample and after each proctor test. Mr. Phillip Butler of PennDOT used repetitive standard proctor tests on anthracite refuse from Swoyersville, PA (See Section 5 - Part I, Case Histories). The dry density of the sample and particle size breakdown increased after each test. The highest maximum dry density attained was on the last proctor test run. (Figure15, page 52). The grain size analysis of the last sample at optimum moisture and maximum dry density was assumed to approximate the gradation at which maximum compaction would be achieved in the field. Grain-size analysis and nuclear density determinations were made in the field to assure maximum compaction.[17]

The repetitive proctor testing is recommended when dealing with anthracite refuse. This laboratory test will give the engineer an idea of the amount of effort needed in the field to increase the fines to a point where a high density is achieved. It is also conceivable that some anthracite refuse may not have an increase in the fine fraction after repeated compaction. This would suggest that fines from another source be added to facilitate compaction.

Repetitive proctor tests will not usually be useful for bituminous refuse because the soft nature of the material causes quick breakdown of particle sizes. Repeated proctor tests do not show greatly increased fine fractions or increased maximum densities (Figure 9, page 42).

RELATIVE DENSITY TESTING

An additional tool which the geotechnical engineer should consider when evaluating the refuse embankment is the relative density test. This test is defined by ASTM D-2049-69. The relative density test is usually applied to granular soils such as gravels or sands which have little or no fines. The relative density test is performed in two steps. The first step is to determine the minimum density of the refuse by placing it as loose as possible into a 0.5 ft^3 mold. The mold is weighed and the density is calculated. The second step is to determine the maximum density. This is determined by placing the loose refuse into the mold, adding a surcharge weight and vibrating the mold for eight minutes. The refuse is weighed and its volume measured. The maximum density is calculated. A wet method is sometimes used which usually gives a higher maximum density.

The nature of numerous refuse piles is such that they contain a large percentage of gravel size material. As previously mentioned under the sections describing standard and modified proctor, these tests require that portions of the samples be omitted to enable the test to be completed. The advantage of the relative density test is that it allows determination of minimum and maximum densities of the entire sample including all size fractions. Under normal conditions the refuse pile will contain a certain percentage of material which is minus 4 inch to plus 3/4 inch. This material being of the gravel and rock size cannot be tested using standard or modified proctor methods.

The relative density test applied to coarse coal refuse provides valuable parameters. It will aid the engineer in establishing the minimum density of the refuse material, the maximum density in both a wet and dry condition and enable him to obtain a comparison of his results by utilizing proctor density methods.

Application of results of relative density testing is not similar to applying the results of proctor density testing. Normally in construction a percentage of proctor density is specified. This percentage generally varies from 90 to 100% of the maximum dry density of the material and compacted within a certain range of the optimum moisture content. With relative density testing, standard specifications generally require that the material be placed at or above 70% of relative density. However, a direct percentage of the maximum density is not utilized to derive the percentage of relative density. The formula listed below is utilized to obtain this relationship.

$$\% \text{ Relative Density} = \frac{\gamma_{max}\ (\gamma - \gamma_{min})}{\gamma\ (\gamma_{max} - \gamma_{min})} \times 100$$

Where: γ_{max} = Maximum dry density of the refuse as obtained by laboratory testing

γ_{min} = Minimum dry density of the refuse as obtained by laboratory testing

γ = Dry density cited by the specification or the in-place dry density

If the geotechnical engineer utilizes a relative density test, he should determine the relationship between a specified percent proctor density and a specified percent relative density. For example, he should determine whether 70% relative density is equal to approximately 95% standard proctor or modified proctor density.

It has been our experience with refuse disposal operations, that the relative density test can be a valuable tool to field personnel in charge of controlling construction of a refuse embankment.

SHEAR TESTS

Shear tests (triaxial compression tests or direct shear tests) should be utilized where either a steeper than normal embankment slope is to be used, or poor foundation conditions have been encountered. Under normal highway embankment design conditions, the required embankment slope is such that when refuse material is utilized, the embankment slope will be stable unless there are poor foundation conditions. Therefore, utilization of shear tests is not needed unless other than normal conditions are encountered. For an embankment height in excess of 20 feet from toe to crest, it may be necessary for the designer to obtain some information on the shear strength of the refuse material. For most refuse disposal operations an embankment with 2 to 1 slopes or flatter is considered stable. Should the designer have a slope with a height exceeding 20 feet and an outslope required to be 2:1 or steeper, then shear tests are recommended. The two type of shear tests for refuse are the triaxial compression tests and the direct shear test.

TRIAXIAL COMPRESSION TEST (AASHTO-234-70) - There are several types of triaxial tests but the most usable one for highway embankments is the unconsolidated undrained (Q) test. This test simulates the worst (end of construction) conditions to be expected. A minimum of three refuse specimens are required. The refuse should be remolded to the anticipated field density with the length twice the diameter. Each sample, one at a time, is covered with a rubber membrane and subjected to a different lateral stress. A vertical load is then added until the specimen shears (usually before 15% strain). The peak shear stress is calculated for each specimen. A plot of shear stress vs. normal stress is developed. Two important values are obtained from the plot: cohesion and Ø angle. These are important values for use in stability calculations.

DIRECT SHEAR (AASHTO T236-72) - The direct shear test is usually performed on cohesionless soils. The prepared soil sample is normally 3 inches in diameter and 0.5 to 1.0 inches high. The sample is loaded into the direct shear machine and a load is added to the sample in a vertical direction. The sample is sheared by pulling the sample apart in the horizontal direction. Three samples are sheared each with a different vertical load. Plotting the shear stress vs. the normal stress results in obtaining the cohesion and Ø angle as in the triaxial test. The direct shear test is best applicable whenever there is a small amount of sample or to simulate certain field conditions. There are several direct shear machines which handle 6 inch diameter samples. The direct shear test or the triaxial test are useless for testing coal refuse which has large particles, unless a replacement of the large particles for small ones are made.

CONSOLIDATION TESTS

The consolidation test is used by the geotechnical engineer to simulate how a soil will react to a loading or unloading condition. The test is performed by loading a soil specimen, usually 3 inches in diameter and 1 inch high, into a consolidometer. A load is added to the sample in the vertical direction and the change in height is measured. Additional loads are applied. By plotting the pressure vs the change in height (or void ratio) the consolidation characteristics can be determined. AASHTO T216-74 should be used as a guide in performing the consolidation test.

The consolidation test would only be used if special conditions are anticipated for an embankment using coal refuse. Such special conditions would be if the refuse is very fine or for testing a foundation soil which is soft or thick. Since coarse refuse is generally coarse grained, an embankment constructed out of coarse refuse would consolidate very rapidly. A free draining material generally consolidates as a new load is applied.

BEARING TEST

The California Bearing Ratio is used to evaluate the bearing value of subgrade soils. The results of the testing is used to determine type and thickness of pavement. The test should be performed in accordance with AASHTO T193-72. The test is normally performed on soils that contain only a small portion of material retained on the 3/4 inch sieve. In addition the test procedure calls for removing all the material larger than 3/4 inches and replacing it with material between 3/4 inches and the No. 4 sieve. Some coal refuse contains a high percentage of material over 3/4 inches.

The following figure is presented as a rough prediction of CBR values based on the AASHTO classification. This figure might be used in conjunction with the laboratory derived CBR values to choose an appropriate CBR value for pavement design.

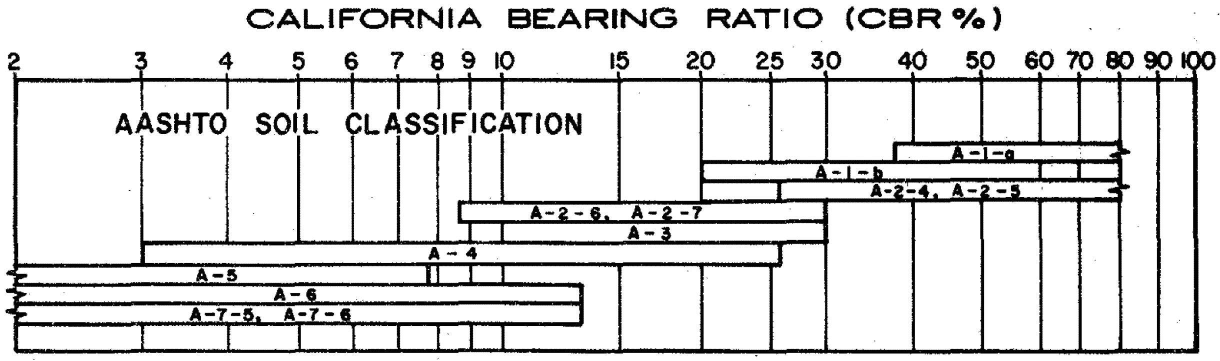


Figure 19. General Relationship between AASHTO Soil Classification and California Bearing Ratio. (34)

SPECIAL TESTS

Under certain design situations, special tests may be required. This is best described by citing two examples. These tests are not normally performed on highway projects.

Expansive Minerals - Certain coal refuse may contain minerals which will expand or swell with contact to moisture. Iron pyrite and certain clays may expand several hundred times their size when exposed to moisture. These would be very critical where the minerals are adjacent to paving, retaining walls or bridge foundations. Microscopes and x-ray diffraction techniques are usually used to determine whether these minerals are present.

Soil Testing - For projects where coal refuse is left exposed at the surface of slopes, special testing will be needed to determine the requirements of the refuse material to produce a soil medium suitable for vegetative growth. Direct seeding of refuse is not recommended by the authors, but, if such a method is used, extensive testing to determine neutralization and nutrient requirements will be needed. Tests would include, but not be limited to; pH, potential acidity, phosphorous demand, lime demand, and potassium demand. The Soil Conservation Service should be contacted for aid in properly preparing the refuse material for seeding.

SUMMARY

In setting up the testing schedule, the geotechnical engineer should keep in mind his goal is to conduct testing sufficient to allow the designer to properly design the embankment. His secondary goal is to obtain sufficient data for the designer to be able to write specifications for construction of the embankment. The geotechnical engineer should not attempt to provide testing which will be used to control the entire embankment construction unless only a small volume of material is utilized. The next section of this discussion deals with the testing necessary to control construction.

CONSTRUCTION CONTROL TESTING

Once the embankment has been designed, it becomes the responsibility of both the contractor and controlling agencies - usually the state or a consultant to see that the embankment is built according to the design and specifications. Because of the variation in refuse material, the best approach is to utilize the testing done for the design only to initiate construction where the refuse material is to be used. Breakdown of the material due to compactive effort should be expected and encouraged. Results of research done by Phillip Butler, P.E. of the PA Department of Transportation using repetitive proctor methods indicate that breakdown of the finer segments of the coarse refuse material, especially with anthracite, can be expected. Mr. Butler encourages this breakdown, as a higher density can be realized during construction with a lower void ratio resulting.[24]

For large projects where a considerable volume of refuse material is to be utilized, it is recommended that proctor densities and relative densities as well as classification tests be conducted throughout the life of the project. Construction controls should be adjusted to reflect any change in the material. This procedure will also allow for reanalysis of the breakdown of the material due to compactive effort and give the contractor an indication of what compactive effort is required to meet the specifications plus allow him to perform a better job within the guidelines.

For a project requiring only a small portion of refuse material to be utilized, the results of the testing performed for design purposes may be all that is necessary to control construction. In this case, utilization of personnel experienced with embankment construction is recommended, as an experienced observer can adequately control construction of a small embankment without utilization of numerous laboratory tests.

During the construction of the refuse embankment several types of tests are performed to determine the in-place density of the coal refuse. They are as follows:

Sand Cone Method (AASHTO T191-61) - A hole is dug at the location of the fill to be tested. The hole is usually about 6 inches in diameter and several inches deep. The material (refuse) is retained weighed, dried, and reweighed. The density apparatus (1 gallon jar, valve, and cone) filled with sand of a known density is placed over the hole. The valve is opened and the sand fills the hole and the cone. The density apparatus is weighed and the sand loss determined. The density of the embankment is calculated from the weight of the removed refuse and volume of the hole.

Rubber-Balloon Method (AASHTO T205-64) - A calibrated vessel is used in this test method for determination of volume. The vessel consists of a glass cylinder with graduations and a rubber balloon at the bottom. An initial reading is made by setting the vessel over the area to be tested and the balloon inflated with the liquid in the cylinder. The level of the liquid is recorded. At this same location the vessel is removed and a small hole is dug and the material is weighed, dried, and weighed again. The vessel is again placed over the hole and another reading is taken by inflating the balloon. The difference in the initial and final readings is the volume of the hole. The density is calculated using the weight of the removed refuse and the volume.

Nuclear Methods (AASHTO T238-73) - There are several types of nuclear density machines and different manufacturers. In general, the total or wet density of the refuse material under the test machine is determined by placing a gamma source and a gamma detector onto, into, or adjacent to the refuse material. The intensity of the radiation detected on a counter is dependent in part to the density of the refuse material. The radiation intensity reading is converted to measured wet density by a suitable calibration curve.

PART II

SECTION 4. DESIGN ELEMENTS

Having ascertained that coal refuse will be used in the construction of a highway embankment for a specific project, the use of this material will be subject to design policies and standards conforming to the agency responsible for development of the proposed highway. Most agencies have prepared design manuals outlining their procedures, criteria and policies. Those concerned with the use of coal refuse in a proposed embankment should be involved in the following elements of the final design work:

- Grading Analysis
- Selection of Areas for Placement of Refuse
- Typical Section Development
- Stability of Embankment Slopes for Special Condition
- Roadside Development
- Borrow Site Evaluation

The first five items can not be developed separately without considering the effects one item has on another.

GRADING ANALYSIS

Once the alignment and gradeline for specific highway project has been established, a preliminary study of earthwork balance will be required to:

- Determine the quantity of available excavation from the proposed roadway cut sections.

- Determine the volume of borrow needed.

It is anticipated that earthwork balance could result in the following conditions, which would determine how the refuse material is placed in the proposed embankment.

- A large quantity of available roadway excavation.
- A moderate quantity or very little roadway excavation.
- An insufficient amount of refuse borrow resulting in the need to use common borrow.

A study of the earthwork balance will indicate to the designer what options he has available to him in determining where the refuse will be placed and how the placement of refuse will be used in developing the typical sections.

SELECTION OF AREAS FOR PLACEMENT OF REFUSE

If the grading of a proposed highway project involves the use of refuse for construction of the entire project and there is no roadway excavation available, the designer's choices for selected placement of material are obviously non existent. However, experience indicates there will usually be some roadway excavation available. The volume of this material available compared to the volume of refuse material to be used for a given project will determine the number of choices open to the designer for selected placement of the refuse. The selected placement of refuse material should be designed to the advantage of the following areas of special concern:

- Reduce the potential contamination of surface and groundwater.
- Enhance the features of roadside development.
- Protect drainage facilities to the extent possible.
- Provide the shortest haul distances.
- Help to alleviate dust control problems.
- Promote stability of the embankments.

If a proposed embankment will be constructed totally of refuse material, special consideration will have to be given to the establishment of a durable vegetative cover, which is discussed in more detail under the roadside development procedures. Placement of the refuse will generally have to conform to the standard typical cross section of the highway agency responsible for developing the proposed highway.

TYPICAL SECTION DEVELOPMENT

Transportation agencies responsible for the design and construction of highways generally have established guidelines for typical roadway cross sections development. Traffic volumes and the design speed of the proposed highway are the major factors used in determining the cross section dimensions and slope configurations. The higher classes of highways, four lanes or more, and some highly traveled two lane facilities are generally constructed using the typical sections for fill areas as shown in Figure 20.

The lower class of highways, based on traffic volumes, are usually constructed using the typical section in embankment areas as shown in Figure 21.

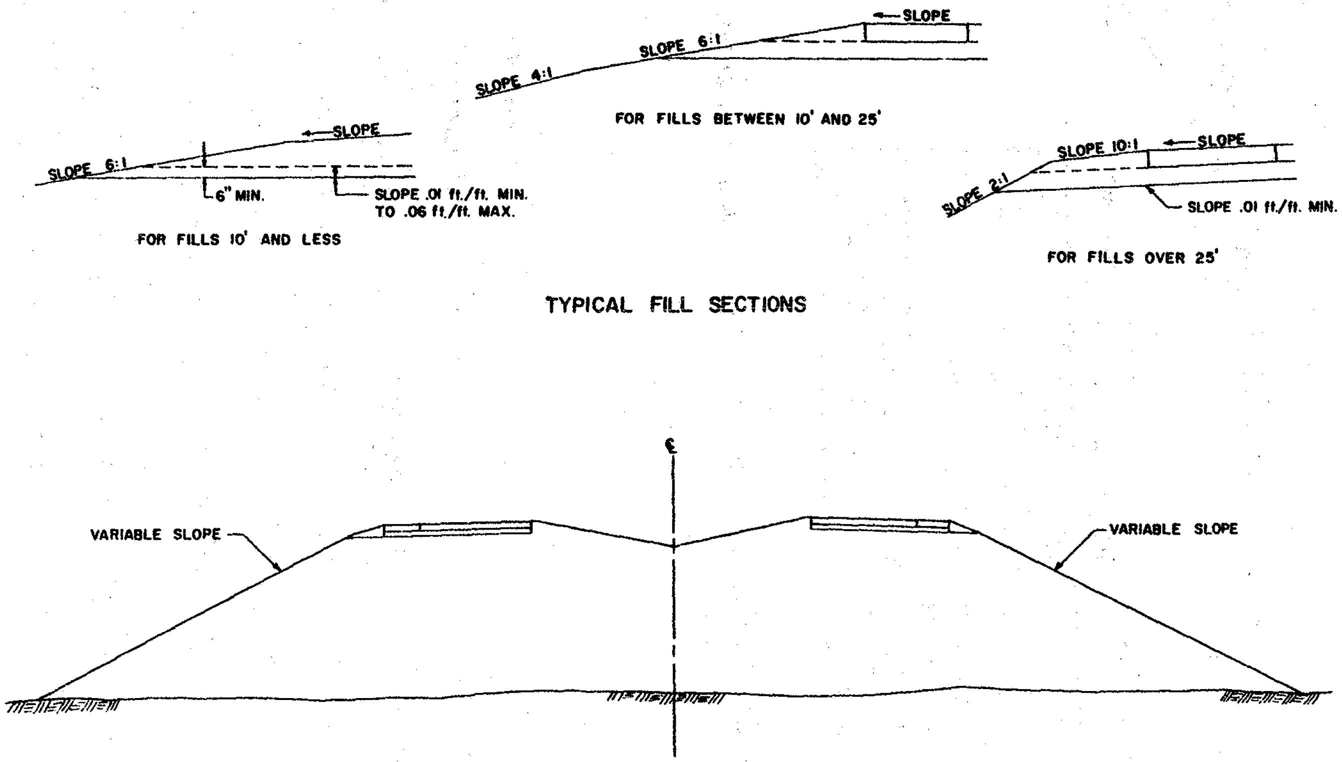
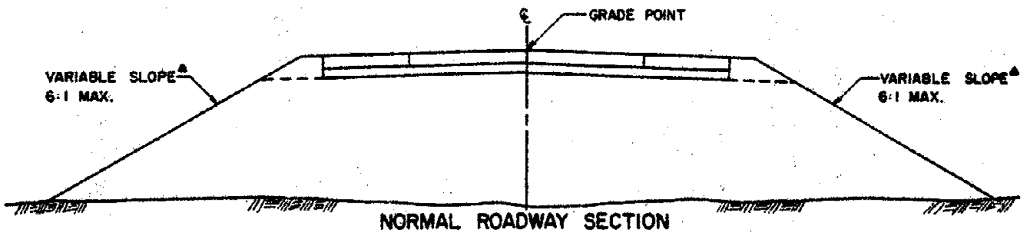


Figure 20. Typical Fill Slopes for Four Lane and Highly Traveled Two Lanes



NORMAL ROADWAY SECTION

	CLASS 3	CLASS 4	CLASS 5
▲	6:1 UP TO 4'* 4:1 4' TO 10'* 2:1 OVER 10'**	4:1 UP TO 10'* 2:1 OVER 10'**	2:1**
* To conserve R/W, steeper slopes will be permitted.			
** When excess material is available, consideration should be given to flattening slopes over 10 feet in height and/or widening fills.			

Figure 21. Typical Fill Slopes for Lower Class Highways.

Responsibility for planning the placement of the refuse material within the confines and conforming to the above typical sections or similar typical sections should be assigned to geotechnical engineers who, by training and experience have adequate design and plan preparation experience to reasonably assure that the most effective use of the material in areas of special concern will be obtained.

Figure 22 illustrates placement of the refuse material where the grading analysis indicates there is sufficient roadway excavation material to totally cover the proposed refuse embankment. The dimensions

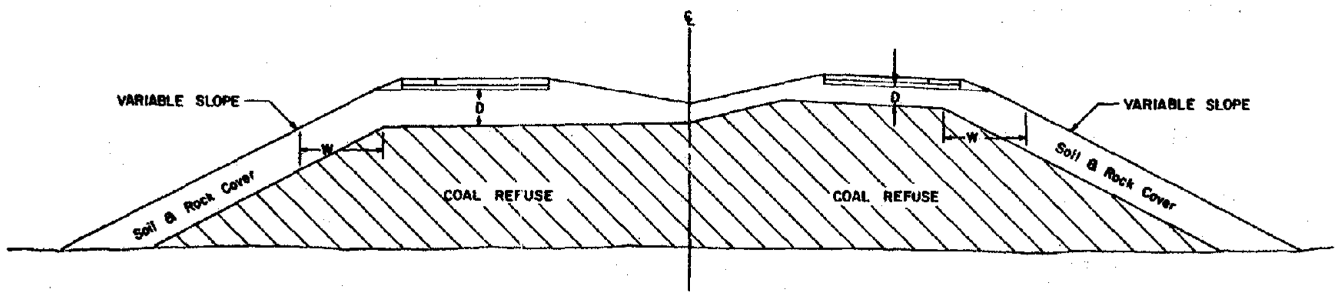


Figure 22. Typical Section of Coal Refuse Placement in Embankments.

dimensions "D" and "W" should be determined by evaluating the earthwork balance and developing trial cross sections compatible with the earthwork between areas for embankment sections for a particular project to cover as much of the refuse material as possible. The advantages of using this method are as follows:

o ENVIRONMENTAL REGULATIONS

This method of placement will satisfy most state and federal environmental regulations pertaining to use and disposal of coal refuse material. Some state environmental regulatory agencies require that all coal refuse be covered with soil to prevent leachate discharges regardless of chemical and physical characteristics of the refuse. The requirements for the depth of the soil cover varies from state to state.

This depth usually ranges from 1 foot to 4 feet. The Department of the Interior, Office of Surface Mining Reclamation and Enforcement (OSM) regulations require that refuse waste banks be covered with a minimum of 4 feet of the best available non-toxic and non-combustible material. OSM defines acid-forming materials as earth materials that contain sulfide minerals or other materials which, if exposed to air, water, or weathering processes will cause acids that may create acid drainage. Acid drainage is defined as water with the pH of less than 6.0. Toxic-forming materials are defined as earth materials or waste, which, if acted upon by air, water, weathering, or microbiological processes, are likely to produce chemical or physical conditions in soils or water that are deterimental to biota or uses of water. Toxic-mine drainage is defined as water that is discharged from active mines and other areas affected by coal mining (refuse sites) and which through chemical action or physical affects is likely to kill, injure or impair biota commonly present in the area that might be exposed to it.

The following are the effluent limitations allowed by the Office of Surface Mining Reclamation and Enforcement to discharge from land affected by coal mining activities.[12]

Effluent Characteristics	Maximum Allowable*	Average of daily values for 30 consecutive discharge days
Fe, total	7.0	3.5
Mn, total	4.0	2.0
Total suspended solids	70.0	35.0
pH	Within range of 6.0 to 9.0	

* All values in mg/l except pH

These effluent limits have been adopted by the OSM in the rules for Permanent Regulatory Program of Surface Mining Reclamation and Enforcement.[12]

o PROMOTE PLANT GROWTH

This method will facilitate establishing a durable vegetative growth and enhance growth. Coal refuse is generally a dark material and has a tendency to absorb heat. The material is generally a relatively free draining material, highly susceptible to water loss and not capable of retaining sufficient moisture to establish an effective plant growth. A combination of these two characteristics usually result in a low survival of plant growth during periods of prolonged dry and hot weather.

o EROSION

The use of this method will help curb erosion. Refuse material is highly susceptible to erosion because of its lighter specific gravity than soil and rock. There has been some success in direct seeding of the refuse material. Most of the success has been in seeding broad flat areas. Most areas to be seeded on a highway project will be on steep slopes.

o WATER POLLUTION ABATEMENT

Placement of soil or clay over the coal refuse will allow runoff of water before it contacts the coal refuse and decrease the potential for creating polluting effluents.

Sediment erosion off the surface will be greatly decreased by this cladding effect and vegetative growth will be enhanced. John Martin of the U.S. EPA tested effluents emitted from refuse banks throughout the eastern and mid-western coal fields. Comparisons between a sample discharging from a covered side of a pile and a sample discharging from the uncovered side of the same pile documented the beneficial effects realized by placing non-toxic soil cover on the refuse. The pH for the covered side was 8.0 and 2.8 for the uncovered side. The iron content of the covered side was only 2.5 mg/l whereas the exposed face yielded 2600 mg/l.[35]

STABILITY OF EMBANKMENT SLOPES
(For Special Conditions)

Where special conditions exist - poor foundation material, slopes greater than 2:1, or where fill height exceeds 20 feet, stability analyses should be considered to assure embankment stability. The test methods necessary to obtain engineering parameters are previously described in Part II, Section 3 - Testing of Refuse Material. These tests include Triaxial Compression Tests and Direct Shear Tests. These tests define the angle of internal friction (Ø) and the cohesion ($\bar{c}$) of the material tested, either refuse or foundation. The unit weight of the material must also be determined. The maximum dry weight as determined by moisture-density tests should be used. The various tests are also described in Part II, Section 3.

The design stability can be determined by a number of different methods. One of the more used and accepted methods is the Simplified Bishop Method. This method may be performed by hand calculations or currently available computer programs. The factor of safety (F) as determined by the Bishop Method should meet the requirements of state transportation agency design criteria.

ROADSIDE DEVELOPMENT

GENERAL

Establishing plant life on an embankment constructed of coal refuse, without the use of soil cover, is usually difficult because the refuse material is generally acidic, not arable and dark in color. Surface temperatures of coal refuse embankments may reach temperatures of 130° F or more. With proper surface preparation, applications of fertilizer and mulches plant life can be established without using any soil covering.

There has been much research conducted involving the direct seeding of refuse material. The problems to be overcome in establishing an effective vegetated growth on any given refuse embankment and the method to be selected in accomplishing this task are subject to many variables, such as: geographic area, climatic conditions, physical and chemical characteristics of the refuse, fertilizer requirements, seed selection, surface preparation, economic feasibility, maintenance cost and environmental regulations. To discuss all the methods available and special requirements of any given refuse embankment in a specific geographical area are not within the scope of this manual. Therefore, only basic information and a brief discussion concerning the direct seeding of refuse embankments is presented in the following portion of this section.

The British have been successful in direct seeding of highway refuse embankments mainly because of favorable physical and chemical characteristics of the refuse and a damp climate not subject to prolonged dry spells. The climate in the British Isles is so conductive to growing grass that England and Ireland are often referred to as "Green" England and "Green" Ireland.

Conditions for growing grass in this country are not as favorable as they are in the British Isles, particularily in the semi-arid west and because of the long and hot summers experienced in the mid-west and Appalachian coal fields. To enjoy the success the British have obtained in the direct seeding of highway refuse embankments, each highway project using this material without the use of soil cover in this country will require a special study. Special consultations with agencies familiar with the methods of establishing growth on refuse embankments are recommended.

Although coal refuse may vary widely in composition and character it does represent a potential soil-making material. Coal refuse waste materials lack organic matter and are low in nitrogen and phosphorous and certain mirco-organisms that make soils a better growth medium. As the original refuse material weathers, breaks down, oxidizes and leaches, conditions for plant growth and survival improve, although it may take many years for this to occur. Unfortunately, environmental regulations and highway construction time frames can not wait for coal refuse embankments to develop into soil material conducive to plant growth. Therefore, the direct seeding refuse embankments will require special treatment in most cases. In planning a roadside development program involving direct seeding of a coal refuse embankment, it will be necessary to overcome the factors and effects of coal refuse properties which restrict plant growth. A list of these properties are:

Factor	Effect
Acidity	Toxic elements in the soil solution.
Compacted surface	Restricted rooting, plant wilting, poor water penetration.
Coarse texture, stony	Low water holding capacity, drought stress, plant damage from loose rock particles.
Dark color	Intolerable temperatures and low available moisture during hot summer months.

The above factors and effects are compounded by the erosive nature of refuse material.

Acidity can be controlled by the use of alkaline additives such as agricultural limestone, to obtain a soil pH compatible with plant growth. For a particular project, the rate of alkaline additives needed to maintain an acceptable pH level is difficult to predict. The pH of treated soil declines with age, as would be expected. Lime and fertilizer applications may be required at periodic intervals long after construction is completed.

Because of the geographic distribution of the major coal fields in this country, the major adverse effect of coal refuse in limiting plant growth common to most sites will be intolerable surface temperatures caused by solar radiation.

Research indicates that coal refuse only reflects 2 to 5% light, compared to 8 to 14% for brown clay. The use of plaster coatings such as developed by the United States Gypsum Company has been successful in establishing an effective plant growth. The benefits realized from the use of plaster sprays are:

- Surface temperatures are lowered. The light reflection of plaster coatings is approximately 72 to 81%.
- The plaster crusts minimize water infiltration, traps waste fines and reduce siltation in rivers and streams.
- Plasters made from natural gypsum are ecologically safe, non-burning and neutral in pH.

The use of fly ash as an additive to the refuse surface has proven beneficial in improving coal refuse embankment soil conditions to sustain grasses and legumes. The use of fly ash catalyzes the soil building process, by neutralizing acid refuse, increasing moisture - holding capacity, increasing pore space volume, reducing erosion by faciliting establishment of an immediate vegetative cover and adding valuable nutrients. Depending on the location and availability of the fly ash, it may be cheaper than the use of soil cover in some instances.

Like fly ash, the use of digested sewege sludge has been successfully used as a soil additive with the same beneficial results.

° SEED SELECTION

If soil cover is used on an embankment constructed of coal refuse material; seeding formulas, limestone additives, fertilizer requirements and mulch applications will be determined by the agency responsible for the development of the highway project. Each state throughout the country has its own seeding specifications and laws regulating purity and germination testing of seeding mixtures.

The use of native soil cover will not require special treatment other than what is required for roadside development of a routine highway construction project for the given location.

The direct seeding of refuse embankments will require special seeding formulas and seed bed preparations, particularily if the refuse material is toxic in nature. Generally the top 6" to 8" of refuse will require alkaline amendments worked into the soil to obtain a pH in the range 5.0 to 7.0.

Each site will require a special study. As stated previously, fly ash and sewage sludge has been used in the reclamation of abandoned refuse dumps with some success. Much of the work is experimental and accomplished by using trial plots. It is recommended that agencies such as the United States Soil Conservation Service, and universities involved with experimental programs involving the direct seeding of refuse embankments be contacted, when soil cover is not comtemplated for a given project.

BORROW SITE EVALUATION

Once it has been determined that a specific refuse site will be used as a borrow source, an evaluation of the pile should be made to determine if special provisions will be required in the specifications for the pile.

These special provisions may have an influence on construction costs. Some of the factors that may influence the cost of using the refuse material are:

- Location of the borrow site in relation to the proposed construction project.
- Configuration of the pile.
- Handling of hot refuse.

A brief discussion of the items to be investigated and how these factors may influence construction costs is presented below.

LOCATION OF THE BORROW SITE

If the proposed refuse borrow site is located near the highway construction project, the design of a haul road may be required. Construction of this road may require the acquisition of a temporary easement through private property.

If the refuse borrow material is to be transported over public roads, the hauling route will need to be carefully selected. Items such as weight restrictions, traffic volumes, horizontal and vertical clearances for the transport equipment or other items which will affect hauling costs should be evaluated. The selected route should be shown in the plans and described in the specifications to enable the contractor to estimate his hauling costs.

CONFIGURATION OF PILE

The configuration of the pile may present the designer with some options to be investigated, particularily if only a partial volume of the refuse material is to be used. Items to be evaluated are:

- Secondary land use
- Environmental benefits
- Restoration of the borrow area.

For proposed refuse borrow sites where only a portion of the pile will be used, the designer should develop a contour grading plan to depict the final configuration of the refuse area. The contour grading plan, depending on site specifics, would be developed to:

- Obtain the best refuse material for construction purposes.
- If practical, reduce the height of the pile to enhance stability and general aesthetics of the unused portion of the refuse site.
- Provide erosion control measures during construction.
- Facilitate restoration of the area - graded to provide a secondary land use, alleviate erosion, deter chemical pollution.

In cases where total use of the refuse site is required, the area formerly occupied by the refuse should be seeded.

The restoration of all refuse sites should be subject to the same considerations as recommended under "Roadside Development" of this section.

HANDLING OF HOT REFUSE

The grading of a hot refuse pile, if not implemented properly, can result in an extremely hazardous situation or result in the ignition of a previously dormant pile. The cost of extinguishing refuse piles can reach major porportions.

Although some piles show no evidence on the surface of burning, burning may still exist, this is particularly true for older piles where the coarse material has accumulated at the base of the pile allowing air movement through the pile.

Excavations at the base of the pile or along the outslope may change the ventilation characteristics of pile and increase the possibilities of spontaneous combustion.

Generally older refuse piles that have burned only on the interior, will contain a layer of unburnt refuse in the upper portion of the pile. Side cutting into the pile will allow the unburned material at the top to slide onto the hotter interior portions and potentially "feed" the fire. Explosions could occur.

The general approach to hot refuse piles is to excavate the refuse material from the top down and not open the side slopes.

General provisions should be incorporated in the specifications, detailing how this material is to be removed. It is further recommended that two publications of the U.S. Bureau of Mines by Myers, et, al, 1966 and Stahl, R.W., 1964, be consulted for further information on burning refuse banks. These papers are included in the "Annotated Bibliography" Appendix B, under Spontaneous Combustion.

When burning piles are suspected, the local office of the United States Bureau of Mines should be consulted.

It is difficult to set a temperature range to define a hot refuse pile. Normally refuse piles will have temperatures higher than natural rock and soil formations. It is not uncommon to find temperatures in the 100 degree range at disposal sites. There are no set rules governing the temperature which is considered to be hot. Some consider refuse in the 200 degree range to be hot. Other signs which will point to a hot pile are a sulfuric smell emitting from the pile and very high concentrations of trace elements present in discharges from the pile. These levels, for Fe and Mn expecially, may reach concentrations in percentages rather than parts per million.

PART II

SECTION 5. CONSTRUCTION METHODS

GENERAL

The purpose of this section is to provide the reader with knowledge of construction considerations associated with the use of coal refuse material in highway embankments. It is not recommended, however, that the general guidelines be used indiscriminately throughout the individual states where coal is produced. Rather, it is recommended that general guidelines offered in this manual be modified and tailored by individual highway agencies to suit their particular specifications and construction policies and procedures.

The recommended construction procedures presented in this section have been developed as the result of experience gained from using coal mine refuse material in highway embankments in this country and abroad. General guidelines, as presented below, follow specifications similar to those used in the construction of all highway embankments. However, mainly because of potential environmental problems and potential hazardous situations involving burning dumps, the use of coal refuse in highway embankments may require special construction considerations.

FOUNDATION PREPARATION

The use of coal refuse material generally requires no special foundation preparation other than normally required for the construction of highway embankments. The major work items involving foundation preparation are:

- Clearing and Grubbing - Grading operations are not generally started until clearing and grubbing are completed in a given embankment section area. Most highway specifications for clearing call for the removal of weeds, brush, briars, bushes, trees, stumps and other protruding obstructions not designated to remain within the proposed right of way of the highway. Most state specifications pertaining to clearing are rather consistent.

  Grubbing generally consists of the removal of imbedded stumps, root mats, soddy topsoil, and other objectional vegetation beneath the proposed embankment areas to a specific depth below the proposed subgrade or gradeline. Generally the specified depth ranges from 3 to 5 feet below subgrade, calling for grubbing to depth of not less than 8 inches below natural ground. Where the embankment exceeds the above depths, stumps are generally permitted to remain, cut off at ground level or not protruding more than 6 inches above natural ground.

- Wet Areas - If the coal refuse material exhibits a tendency for producing chemical pollution in the form of leachates, placing the material directly over wet areas or springs should be avoided. The limitations for effluent discharges are defined on page 111 of this report. All springs and wet weather seeps should be drained using standard highway procedures, such as tile, underdrain, polymeric coated pipe, or filter blankets consisting of properly sized and graded stone materials. The filter blanket should be constructed at a sufficient thickness to prevent the overlying refuse to come in direct contact with the groundwater in the filter material.

The selection of underdrains or other drain pipes should be compatible with the pH value of the anticipated leachate discharge and or adjacent soil.

Guidelines for pipe selection as listed in the Pennsylvania Department of Transportation Design Manual are shown below: (36)

	pH Values of Water of Soil
pH - 3.5 or less	Stainless Steel, Vitrified Clay, Clay lined Reinforced Cement Concrete Pipe, Coal Tar Epoxy Lined Reinforced Cement Concrete Pipe, Polymeric Coated Corrugated Galvanized Steel Pipe, Coated Aluminum Alloy Pipe.
pH - 3.5 to 5.0	Polymeric Coated Corrugated Galvanized Steel Pipe, Plain Cement Concrete Pipe (24" Maximum), Reinforced Cement Concrete Pipe or Coated Aluminum Alloy Pipe.
pH - 5.0 to 8	Corrugated Galvanized Steel Pipe, Plain Cement Concrete Pipe (24" Maximum), Reinforced Cement Concrete Pipe, or Aluminum Alloy Pipe.
pH - 8 and above	Polymeric Coated Corrugated Galvanized Steel Pipe, Coated Aluminum Alloy Pipe, Reinforced Cement Concrete Pipe or Plain Cement Concrete Pipe (24" Maximum).
High Sulphur Content	Same as 3.5 or less

The above guidelines are generally acceptable to most state highway agencies with some slight variations in pH range and other pipe alternates such as fully coated bituminous corrugated metal pipe.

If the coal refuse is acidic in nature, a pH below 6.0, it is recommended that granular filter blankets be constructed of sandstone material or any durable rock material excepting limestone and sandstone with calcite bonding. Acid discharges of leachate water through limestone filter blankets have a tendency to block the material. Sandstone with calcite bonding agent ($CaCo_3$) will be dissolved by acidic leachates. This same mineral in limestone will result in the breakdown of the rock by acidic water. Acidic water in contact with $CaCo_3$ will also cause precipitation of ferric hydroxides (yellow boy) resulting in clogging of the filter material.

REFUSE MATERIAL HAULING AND DELIVERY

As with most massive earthwork projects, the hauling of coal refuse to a project site will require the selection of the proper equipment. The refuse material can be transported using standard equipment. The length of haul, haulroad grades and access location will govern type of equipment to be used.

If trucks are to be used to transport the refuse material over existing road facilities and through residential or urbanized areas, it is recommended that tarpaulin covers be used to prevent spillage and eliminate potential dust problems.

EMBANKMENT CONSTRUCTION

GENERAL

As with the construction of all highway embankments, the suitability of the coal refuse material has to be determined. Coal refuse is essentially the same material found in rock formations associated with coal seams, which may have undergone a crushing or washing process and sometimes have burned, forming red dog.

Most coal refuse material meets the requirements and specifications as suitable construction material as defined under normal geotechnical testing procedures. In Great Britain, it has become a common practise to use coal refuse in highway construction. There is no reference in their specifications for use of coal refuse material. The material is treated, from a geotechnical viewpoint,as common earth and rock material.

The Pennsylvania Department of Transportation (PennDOT) has used the material without developing a separate set of specifications. The use of the material is subject to the same limitations as other earth and rock materials. Specifications for coal mine refuse fall under the same classification as earth, granular material,shale,and random embankment material. The classifications of these materials are presented below and are an excerpt from PennDOT's Specification, Form 408:[37]

SECTION 206-EMBANKMENT

Classification - For purposes of construction control, the excavation and borrow excavation used in this construction is further classified as follows:

Soil - Soil shall include all earth materials having a maximum size that can be readily placed and compacted in loose 8-inch layers and of which more than 35 percent shall pass the No. 200 sieve. Soil shall have a minimum dry weight density of 95 pounds per cubic foot as determined in accordance with PTM No. 106, Method B and a maximum liquid limit of 65 as determined in accordance with AASHO Designation T 89. The plasticity index, as determined by AASHO Designation T 90 for soils having liquid limits of 41 to 65 inclusive, shall be not less than that determined by the formula - Liquid Limit minus 30.

Granular Material - Granular material shall include all natural or synthetic mineral aggregates having a maximum size that can be readily placed and compacted in loose 8-inch layers and of which 35 percent or less shall pass the No. 200 sieve.

Shale - Shale shall include all rock-like materials formed by the natural consolidation of mud, clay, silt, and fine sand and usually thinly laminated, comparatively soft and easily split, having a maximum size that can be readily placed and compacted in loose 8-inch layers.

Random Material - Random material shall include any combination of the above classifications and may include old concrete, brick, etc., from demolition having a maximum size that can be readily placed and compacted in loose 8-inch layers and which have been approved by the engineer.

Generally coal mine refuse is a granular material and is sometimes nearly void of fines. The requirement that soils shall have a minimum dry weight density of 95 pound per cubic foot as determined by the Standard Proctor test shall not apply to coal mine refuse. Coal refuse, especially bituminous refuse, has a lower specific gravity than usual excavated borrow sources. Because of this, a minimum dry weight density of 85 pounds per cubic foot, determined by Standard Proctor, is recommended for coal refuse.

SPREADING AND SURFACE SLOPES

No special requirements are needed for spreading of coal refuse material. Standard construction specifications governing lift thickness and spreading methods are used. Generally, most states call for loose 8-inch layers.

Vehicular travel transporting and spreading of the refuse using bulldozers results in a similar breakdown of particle size as achieved in the laboratory. Because of this, it is recommended that bituminous and anthracite refuse be spread using bulldozers before rolling operations begin. Most contractors are aware of the advantage of varying the tracking paths of transporting vehicles, over the spread material to enhance compactive effort. This is particularly true when anthracite refuse is used in construction. Vehicular travel will enhance the breakdown of the material, increasing the fine fraction and resulting in a higher density.

During construction, most contractors slope the lift layers to facilitate surface water runoff to maintain a dry working platform on top of the embankment. Some states permit a maximum surface slope on the top fill at a 10 to 1 slope ratio. Surface slopes as steep as these are not recommended when using coal refuse. It is recommended that surface slope should be more gentle to prevent erosion of the material, resulting in an increased pollution potential from sediment. Experience indicates, a slope of approximately 2 to 4 percent is satisfactory. Level slopes should also be avoided. If surface water is not permitted to runoff, severe rutting of the material may occur, resulting in ponding. Ponding of water on acidic refuse will result in the generation acid water.

COMPACTION REQUIREMENTS AND CONSTRUCTION CONTROL

Most state highway agencies require that each layer of an embankment be compacted in a range of 95 to 97 percent of the Standard Proctor determined dry density, except for the top three feet of the embankment. The top three feet of the embankment material is generally required to be compacted to no less than 100 percent of the determined dry density.

In achieving these densities, the compaction of coal mine refuse does present some problems. Literature review of experience indicates that these problems stem from:

- The refuse material has a tendency to breakdown under laboratory and field testing procedures, resulting in a difficulty of correlating laboratory and field testing data. Because of this, repetitive testing both in the field and laboratory may be required.

- With some refuse, particularily anthracite refuse, moisture-density data is difficult to obtain because the coarse fraction is rather uniform in grading and because these is a lack of fines.

Test procedures for density determinations are recommended in Section 3 of Part II. These procedures include laboratory testing of the borrow site and later of the in-place embankment fill. On site in-place density tests include sand-cone and nuclear density methods. As previously stated the laboratory density determinations should be used in conjunction with the on-site density determination to ensure that proper compaction is achieved. When the refuse is too coarse to satisfactorily use these methods, the compaction must be based on the judgement of the engineer in the field; mainly based on nonmovement of the material under the compaction equipment. PennDOT has set forth roller requirements in their specifications. Their requirements are as follows:

- Three-wheel power rollers shall have an unballasted load of not less than 300 pounds per linear inch of tread of rear wheels and shall have a manufacturer's certified metal weight of not less than 10 tons.
- Tandem power-driven rollers shall have a ballasted load of not less than 330 pounds per linear inch of tread of drive roll and shall have a manufacturer's certified metal weight of not less than 10 tons.
- Tandem power-driven rollers shall have a load of not less than 120 pounds per linear inch of tread of drive roll and shall have a manufacturer's certified metal weight of not less than 5 tons nor more than 8 tons, or not less than 8 tons nor more than 10 tons.
- Trench-type rollers shall develop a minimum of 300 pounds pressure per inch-width of compaction roll.
- Pneumatic-tired rollers used to compact soils, subbases, and base courses may be either single or multiple-axle type and shall be equipped with pneumatic tires of equal size and diameter on any one axle. All tires shall be uniformly inflated so that air pressure shall not vary more than 5 pounds per square inch. The rollers shall be of sufficient weight and dimensions that, when loaded, will cause the pneumatic-tired wheels to exert a ground

pressure of not less than 300 pounds per inch of width of tread as measured on a hard surface.

- Tamping rollers shall have an operating weight of not less than 250 pounds per square inch of cross-sectional area on each tamping foot, face, or end.

- Vibratory rollers shall be of an approved self propelled type. The roller shall have the necessary frequency and amplitude to achieve required density without objectionable undulations, material pickup or other surface defects. The vibrator drive shall automatically stop when the roller changes direction or stops.

- Other compaction equipment may be used, if the equipment is designed for and capable of accomplishing compaction and consolidation at least equivalent to the capabilities specified above.

The British have long recognized the problems associated with using moisture-density laboratory and field data to control compaction. They no longer rely on this method as the only method for determining compaction. Their specifications for compaction control have been developed, over the years, by specifying the number of passes required for a particular type of roller at given weights and at varying lift thicknesses for: cohesive soils, well graded granular and dry cohesive soils and uniformly graded materials. An excerpt from their specifications is presented in Table 5.

Table 5. British Compaction Requirements

D = Maximum depth of compacted layer (mm)
N = Minimum number of passes

Type of compaction plant	Category	Cohesive soils		Well graded granular and dry cohesive soils		Uniformly graded material	
	Mass per metre width of roll:	D	N	D	N	D	N
Smooth-wheeled roller	over 2100 kg up to 2700 kg	125	8	125	10	125	10*
	over 2700 kg up to 5400 kg	125	6	125	8	125	8*
	over 5400 kg	150	4	150	8	unsuitable	
Grid roller	over 2700 kg up to 5400 kg	150	10	unsuitable		150	10
	over 5400 kg up to 8000 kg	150	8	125	12	unsuitable	
	over 8000 kg	150	4	150	12	unsuitabla	
Tamping roller	over 4000 kg	225	4	150	12	250	4
Pneumatic-tyred roller	Mass per wheel						
	over 1000 kg up to 1500 kg	125	6	unsuitable		150	10*
	over 1500 kg up to 2000 kg	150	5	unsuitable		unsuitable	
	over 2000 kg up to 2500 kg	175	4	125	12	unsuitable	
	over 2500 kg up to 4000 kg	225	4	125	10	unsuitable	
	over 4000 kg up to 6000 kg	300	4	125	10	unsuitable	
	over 6000 kg up to 8000 kg	350	4	150	8	unsuitable	
	over 8000 kg up to 12000 kg	400	4	150	8	unsuitable	
	over 12000 kg	450	4	175	6	unsuitable	
Vibrating roller	Mass per metre width of a vibrating roll						
	over 270 kg up to 450 kg	unsuitable		75	16	150	16
	over 450 kg up to 700 kg	unsuitable		75	12	150	12
	over 700 kg up to 1300 kg	100	12	125	12	150	6
	over 1300 kg up to 1800 kg	125	8	150	8	200	10*
	over 1800 kg up to 2300 kg	150	4	150	4	225	12*
	over 2300 kg up to 2900 kg	175	4	175	4	250	10*
	over 2900 kg up to 3600 kg	200	4	200	4	275	8*
	over 3600 kg up to 4300 kg	225	4	225	4	300	8*
	over 4300 kg up to 5000 kg	250	4	250	4	300	6*
	over 5000 kg	275	4	275	4	300	4*

*Towed Roller

A review of the British roller specifications indicates, as one would expect, the use of heavier rollers permits greater lift thicknesses and requires less passes. The above specifications, further reveal that cohesive soils and well graded granular and dry cohesive soils are more readily compacted using thinner lifts and generally require less compactive effort than uniformly graded material.

When using coal mine refuse in a highway embankment, achieving the maximum compactive effort is more critical than in routine construction projects. Adequate compaction is needed to assure reduction in air voids throughout the embankment and to eliminate the problem of potential spontaneous combustion. Because of variations in composition of the physical and chemical characteristic of coal mine refuse, the choice of test methods in controlling compaction are not always clear and requires engineering judgement.

Some refuse, particularly anthracite refuse containing fissile shales or other friable material, is more subject to a breakdown of individual grain particles under impact testing and loading imposed by compaction equipment than the more typical soil materials associated with routine highway construction. The degradation of the individual refuse particles under testing and field compaction conditions is not considered to be as critical for bituminous coal mine refuse as the breakdown of anthracite material. The use of bulldozers to spread anthracite refuse will facilitate the breakdown of the material. Mr. Phillip Butler, based on his experience with the compaction of anthracite refuse, states that vibratory equipment alone will not produce satisfactory compaction. While working with Pennsylvania anthracite refuse, he found that the material was satisfactorily compacted using D-9 bulldozers for preparation and vibratory compaction equipment for final compaction. He also found that better compaction was achieved using a steel-padded drum roller to compact the refuse.[24]

Satisfactory compaction of bituminous refuse material should be no problem and a variety of compaction equipment may be used, depending on availability. It has been the authors experience, though, that the use of sheepsfoot roller (Tamping Roller) is not particularly effective for bituminous refuse as it tends to push the material rather than create loading and breakdown.

TEST STRIPS

Everyone interviewed, experienced in the use of coal refuse in the construction of highway embankments, agreed that one of the best methods of controlling compaction is to establish a test section embankment. This method is more applicable when the use of large quantities of refuse is anticipated over extensive construction areas. It is much easier for a field engineer to control the compaction of a smaller section of embankment by conventional geotechnical methods.

The purpose of a test fill is to determine the best and most practical methods of placing the coarse refuse under given specific site conditions for each individual project.

If a large amount of coal refuse is to be used on a project or if high embankments or unusual conditions are expected, development of a test fill should be considered. The purpose of the test fill is to determine the best and most practical method of placing the coarse refuse under job conditions. The most applicable methods of constructing the embankment may be determined before actual embankment construction begins by varying the placement procedures, exercising strict control over a relatively small volume of the area, and maintaining complete and accurate records of tests. The field density tests made of the test fill will provide the necessary information for establishing construction control methods that are consistent with the design requirements.

The test fill can be made before final design or after the contractor has been selected. The fill is made at an appropriate location at the construction site. It is important for the engineer or agency to have adequate personnel present to witness the placing of the refuse and to conduct sufficient testing. The test fill is built by changing the variables until a satisfactory procedure is developed. Some of the variables affecting embankment construction which may be adjusted and analyzed during the development of the test fill are:

- Borrow sources
- Gradation and specific gravity of borrow material
- Moisture content of fill
- Thickness of layers
- Equipment (roller) characteristics
- Number of roller passes
- Condition of surface layers after rolling

The test fill is constructed by adjusting each of the variables one at a time. Sufficient density tests are performed after each variable change to determine the effect on the density of the embankment. The test fill is analyzed by comparing what effect changing each variable has on the density of the fill. The combination of variables which produced the most economical and practical fill with the desired minimum density.

After the placing conditions and procedures have been determined from the test fill, construction can proceed. It is important that the contractors operations adhere to the conditions set forth in the specifications and recommendations made by the field engineer. Construction of the entire embankment can be thought of as a test section. Complete records on the construction of the embankment must be maintained so that the most efficient methods may be perfected.

COMPACTION DURING INCLEMENT WEATHER

It was pointed out by nearly all those interviewed that, one of the most significant advantages of using coal refuse material for constructing highway embankments was that the material could be used in construction during wet periods and winter months as long as temperatures remain warm enough to prevent frost penetration of the material. In many instances, the refuse material is used to build construction roads to provide access during wet periods.

Under present laws governing coal refuse disposal areas, coal operators are faced with the task of spreading and compacting refuse as part of their daily operations, in all types of weather, and are reportedly successful if:

1. The top of embankment is sloped gently to prevent ponding of water and
2. Vehicular movement is planned using a tracking scheme to facilitate compaction and prevent rutting.

Selective placement of refuse during freezing periods can be accomplished if the material consists mainly of rock. In many instances, stockpiled refuse material has a higher <u>in-situ</u> temperature than excavated natural soils. This reduces the effects of frost penetration. Caution should be used during freezing weather to ensure that no frozen material is incorporated into the embankments or that the refuse is not placed over frozen surfaces.

SUBGRADE AND FROST SUSCEPTIBILITY

The frost susceptibility of coal mine refuse is difficult to determine. Generally, the fine grained materials, those containing high percentages of silt and clay, are most frost susceptible. These fines,especially silt sized particle, allow the capillary movement of water upwards into the frost zone, causing ice lenses to form. These ice lenses create a differential pavement support and result in pavement failure.

Obviously other conditions such as high water tables, and groundwater seepage, contribute to pavement failures. However, these problems are not unique in routine highway construction. Usual design procedures that address these potential problems should also be used when dealing with coal mine refuse. To protect against abnormally high moisture content in the subgrade, drainage swales can be placed adjacent to the pavement, supplemented by underdrains placed to drain the subbase material and control seepage water. Also, the material placed in the portion of the embankment which is above the frost line should be non-frost susceptible.

The difficulty of predicting frost susceptibility of coal mine refuse comes as a result of the great variances which exist within the pile itself and also from the breakdown of grain size during compaction. Granted, the grain size determination of a refuse sample will determine the relative frost susceptibility of that sample. The problem lies in determining if that sample or even multiple samples adequately depict the material that will form the top portions of the embankment. Construction control may be adequate to assure that the original refuse incorporated into the subgrade is non-frost susceptible, but the grain size will be changed by compaction. The upper portion of the embankment is usually compacted to 100% of the maximum density as determined by Standard Proctor. This compaction effort greatly increases the amount of fines and also increases the frost susceptibility. Laboratory testing has not proven capable of adequately predicting the amount of breakdown that will occur from a given field compactive effort.

Another factor which discourages the placement of coal refuse within the zone of frost penetration is that the properties of the refuse are not known under long-term, freeze-thaw conditions. Some refuse is highly susceptible to weathering and significant grain size breakdown may occur with a freeze-thaw type of weathering.

Visual examination of the proposed refuse borrow area will give some idea of the amount of degradation which results from the seasonal changes in weather conditions. However, if fresh refuse is used in an embankment, the change in grain size would be difficult to predict.

Because of the many unknowns pertaining to changes in the physical characteristics of coal refuse under compaction pavements and long term freeze-thaw conditions, it is not recommended that coal refuse be used in the top portion of the embankment in geographic areas where frost is an important consideration in the design of a pavement structure, unless the refuse material is a high quality construction material, mainly exhibiting durable traits such as possesed by a hard sandstone or limestone.

In areas where frost is not an important consideration, other factors such as pavement depth may permit the use of the material in the subgrade. To achieve structural strength of the pavement, pavement and base and subbase courses may be of sufficient depth to where frost heave is no longer an important consideration.

DUST CONTROL

As with most earth moving projects, dust is a problem during dry construction periods.

During spreading, hauling and compaction operations, dust is easily controlled by continued use of a water truck. Haul areas where repetitive vehicular traffic is required are partically susceptible to dust generation. These areas normally require the extensive use of a water truck. It is recommended that the top of the refuse normally be kept in a moist condition.

If possible, it is recommended that soil cover operations should be conducted simultaneously with the placement of refuse to reduce exposure of refuse embankment surfaces.

Dust control when using coal refuse is generally more critical than when using common borrow in a construction project because of the relatively light specific gravity and the black color of the refuse. The lighter black dust is more easily suspended and settles less readily than other dust types.

Generally dust can easily be controlled at the construction site as recommended above. The borrow sites may present particular dust control problems under certain specific site conditions. The extent of the problem is subject to many variations such as: the height of the pile, proximity of residential areas, direction of prevailing winds, presense or lack of vegetative cover and the temperature of the pile.

Hot or warm refuse borrow areas will generate more dust than common borrow areas because of the lack of moisture content in the pile. When the hot refuse is disturbed by construction equipment, the heat from the pile causes the dust particles to rise more rapidly and in greater numbers than when using common borrow or cooler refuse areas. In most cases the removal of hot refuse material will require continuous spraying during the extraction and transporting operations.

SOIL COVER

The advantages of using soil cover has been thoroughly discussed in previous sections of this manual. The only disadvantages in using soil cover may be the cost of obtaining suitable soil cover and the instability presented by covering steep slopes with a thin veneer of soil. These stability problems are usually confined and pertain to the problem of maintaining the soil cover on the outslope of the embankment and not necessarily the stability of main portion of the embankment.

For those projects where sufficient soil material is available, recommended design procedures in Section 4, Part II of this manual should prove sufficient to prevent the problems of instability of the soil cover from occuring.

General recommendations for using soil cover are presented below:

- A thin veneer of soil cover should prove sufficient in areas where roadside development calls for grassed areas. It is recommended that a thin veneer soil cover should be limited to areas where the embankment is constructed at a slope rate of three horizontally to one vertically (3:1) or flatter. These slope rates will facilitate spreading of the soil cover and seeding operations.

- On slopes steeper than 3:1, a thin veneer of soil cover (one foot minimum) is difficult to construct and often is subject to sliding. On the steeper slopes, it is recommended that the width of the soil cover be sufficient in width to accommodate compaction equipment enabling the soil cover area to be constructed from the toe of the embankment. This width should be determined by construction sequence. If the soil cover is to be constructed at the same rate as the embankment, a four foot width should prove sufficient. If the embankments are constructed at different time intervals, it is recommended that an eight foot width or greater should be used.

- In interchange areas where special plantings are proposed, the thickness of the soil cover should be governed by the root system of the proposed plants, if toxic refuse material is involved. Usually a four (4) foot depth of natural soil will prove sufficient.

RECOMMENDATIONS

Currently, highway planners have very little information available concerning suitable refuse borrow sources. Because of this, it is recommended that an inventory of suitable sources of available refuse material be conducted on a regional or state basis, or at a minimum, all sources of refuse material within a given radius of a proposed project be identified during the "Corridor Location Study" phase of a project. It is important that the potential use of refuse material be indentified in the earlier planning stages of the project so that designers can make adjustments in gradelines to place the project in "borrow".

Since most highway projects are seldom conveniently adjacent to an available source of refuse material, it is recommended that cost of using the material be investigated during the earlier planning stages. The economic analysis should consider improved land use and environmental benefits derived from using the material. If the economic analysis indicates that it is feasible to use the refuse material, a dual bidding system could be used in seeking construction bids. This system would permit two bids; 1) using any source of borrow, 2) using the nearest refuse source. Using this method, additional costs, if any, incurred by using the refuse could be funded separately.

For all projects where it is obvious from an economic and construction standpoint that it is feasible to use the refuse material, every effort should be made to incorporate the refuse material in the highway embankments.

Once it has been established that a source of suitable refuse material is in the vicinity of highway construction, the following information has to be evaluated:

1. Ownership and availability of the refuse material must be determined.
2. The earthwork balance on the project should be determined. The grade line for any proposed project could be adjusted to use the refuse material, reducing the amount of excavation required for a project and calling for borrow excavation of refuse site.
3. Special provisions should be incorporated into the plans to provide legal access to the material.

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LIST OF ABBREVIATIONS

AASHTO
American Association of State Highways and Transportation Officials

ASTM
American Society for Testing and Materials

BCR
Bituminous Coal Research

BTU
British thermal unit

CMR
coal mine refuse

DER
Department of Environmental Regulation

E.P.A.
Environmental Protection Agency

IITRI
Illinois Institute of Technology Research Institute

IMMR
Institute for Mining and Minerals Research - University of Kentucky

K_g
Kilogram

m^3
cubic meter (metre - British spelling)

MESA
Mining Enforcement and Safety Administration

M_g
Megagram

NCA
National Coal Association

NCB
National Coal Board - Great Britain

NTIS
National Technical Information Services

ORES
Office of Research and Engineering Services - University of Kentucky

PennDOT
Pennsylvania Department of Transportation

TRRL
Transport and Road Research Laboratory - Great Britain

U.S.B.O.M.
United States Bureau of Mines

GLOSSARY

acid mine drainage - An extremely acidic, iron-sulfate rich drainage that forms under natural conditions when water, as rainfall, percolates through coal seams, coal storage piles, refuse piles or the like and reacts with the pyrite in the presence of oxygen to form the acidic drainage.

anthracite - A hard coal of high rank exhibiting high luster, low content of volatile matter and little moisture.

atmospheric oxygen - Oxygen which is not chemically bonded to any substance but itself (O_2).

bitiminous - The middle rank of coal, softer and more moisture than anthracite and exhibiting volatile matter contents of 15% to over 30%.

carbonaceous material - Any material containing carbon, usually referring to bone (a mixture of shale and coal).

coal preparation - A mechanical procedure which will clean or reduce the size of coal particles so that they are more suitable for their intended use.

coarse coal refuse - That material remaining after the coal has been cleaned, consisting of noncoal materials and any coal that has remained attached to non-coal materials. The size range is anything greater than 28 mesh (0.025 in.).

degradation - The physical break down of particles to smaller sizes.

exothermic reaction - A chemical process characterized by the evolution of heat.

fine coal refuse (slurry) - That part of the refuse that is smaller than 28 mesh (0.025 in.), usually removed from the coal preparation plant in a suspension of coal, refuse and a liquid medium.

leachate - A solution produced when a liquid, such as water, percolates through a material and removes some of that material so that the effluent contains dissolved and suspended solids.

lignite - A brownish-black, soft coal containing a great deal of moisture (more than 40%). The vegetable matter has not been altered much past the peat stage.

poorly sorted - A reference to grain-size distribution in which the particles have not been separated into groups of similar sizes.

run-of-mine coal - The coal as it comes directly from the mine with any extraneous material still included.

spontaneous combustion - A process whereby the heat evolved in the oxidation of a substance, coal in this case, is not dissipated but remains in the substance to further increase the rate of oxidation so that eventually the kindling temperature of the substance is reached.

volatile content - Thermal decomposition products which are formed and liberated from coal, as vapor when the coal is heated under rigidly specified conditions.

weathered refuse - That part of the refuse that has undergone oxidation and degradation.

well-graded - Denotes a soil with a wide range in grain size and substantial amounts of all intermediate particle sizes.

APPENDIX A - TEST METHODS

Determination of pH of Coal Refuse

This method of determination of the pH of coal refuse has been drawn from:

Methods of Test for Soils for Civil Engineering Purposes, British Standard Institution, London, British Standard 1377, April, 1975.

3.4 Test 11. Determination of the pH value

3.4.1 Test 11(A). Standard method (electrometric)

3.4.1.1 *General.* This method covers the electrometric determination of the pH value of a soil suspension (see Notes 1 and 2).

3.4.1.2 *Apparatus.* The following apparatus is required.

(1) A pH meter fitted with a glass electrode and a calomel reference electrode and covering the range pH 3.0 to pH 10.0. The scale shall be readable and accurate to 0.05 pH units.
(2) A balance readable and accurate to 0.001 g.
(3) Three 100 ml glass beakers with cover glasses and stirring rods.
(4) Two 500 ml volumetric flasks.
(5) A wash bottle, preferably made of plastics, containing distilled water.
(6) A 3.35 mm BS test sieve.
(7) A pestle and mortar or suitable mechanical pulverizer.

3.4.1.3 *Reagents.* The following reagents are required. They shall be of recognized analytical reagent quality.

(1) *Buffer solution, pH 4.0.* Dissolve 5.106 g of potassium hydrogen phthalate in distilled water and dilute to 500 ml with distilled water. Alternatively, a proprietary buffer solution of pH 4.0 may be used.
(2) *Buffer solution, pH 9.2.* Dissolve 9.54 g of sodium tetraborate (borax) in distilled water and dilute to 500 ml. Alternatively, a proprietary buffer solution of pH 9.2 may be used.
(3) *Potassium chloride.* Saturated solution (for maintenance of calomel electrode).

3.4.1.4 *Procedure.* The procedure is as follows.

(1) The bulk sample obtained as described in the procedure for the preparation of disturbed samples for testing (see 1.5) shall after air drying be crushed to pass through a 3.35 mm BS test sieve. The material passing the 3.35 mm BS test sieve shall then be divided by successive divisions to produce a sample weighing 30 g to 35 g.
(2) 30 g of soil obtained as described in (1) shall be weighed into a 100 ml beaker. 75 ml of distilled water shall be added to it. The suspension shall be stirred for a few minutes, the beaker then covered with a cover glass and allowed to stand for several hours, preferably overnight. It shall be stirred again immediately before testing.
(3) The pH meter shall be calibrated by means of the standard buffer solutions following the procedure recommended by the manufacturer.
(4) The electrode shall be washed with distilled water and then immersed in the soil suspension. Two or three readings of the pH of the soil suspension shall be made with brief stirrings in between each reading. These readings should agree to within ± 0.05 pH units (see Note 3).
(5) The electrodes shall be removed from the suspension and washed with distilled water. The calibration of the pH meter shall then be checked against one of the standard buffer solutions. If the instrument is out of adjustment by more than 0.05 pH units it shall be set to the correct adjustment and the procedure given in (4) shall be repeated until consistent readings are obtained.
(6) When not in use, the electrodes shall be left standing in a beaker of distilled water.

*See Form L, Appendix B.

3.4.1.5 *Reporting of results.* The pH value of the soil suspension shall be reported to the nearest 0.1 pH unit. It shall be reported that the electrometric method was used.

Notes on Test 11(A)

NOTE 1. The pH value of a soil suspension varies with the ratio of soil to water, an increase in dilution causing an increase in pH. Above a ratio of soil to water of 1 to 2, the effect is not marked and The Soil Reaction Committee of the International Society of Soil Science have recommended a soil to water ratio of 1 to 2.5.

NOTE 2. The pH value of a sample of ground water can be measured in a similar manner to that used for a soil suspension.

NOTE 3. The pH readings of the soil suspension should reach a constant value in about 1 min. No readings should be taken until the pH meter has reached equilibrium.

Sulfate Content of Coal Refuse

The determination of the sulfate content of coal refuse has been drawn from:

Methods of Test for Soils for Civil Engineering Purposes, British Standard Institution, London, British Standard 1377, April, 1975.

3.2 Test 9. Determination of the total sulphate content of soil

3.2.1 **General.** This method describes a procedure for the determination of the acid soluble sulphate content of natural soil, which includes all naturally occurring sulphates apart from negligible rarities. The results obtained give the sulphate content at the time of sampling only, as the sulphate content is subject to seasonal fluctuations.

3.2.2 **Apparatus.** The following apparatus is required.

(1) A thermostatically controlled drying oven capable of maintaining a temperature of 75 °C to 80 °C. (The normal drying oven can usually be adjusted to cover this range as well as the range 105 °C to 110 °C.
(2) A balance readable and accurate to 0.001 g.
(3) A glass weighing bottle, approximately 25 mm in diameter, 50 mm high and fitted with a ground glass stopper.
(4) Two conical beakers of 500 ml capacity, and cover glasses to fit.
(5) A glass filter funnel about 100 mm diameter.
(6) A porcelain or silica crucible 35 mm in diameter and 40 mm in height, or preferably, a porous porcelain or silica filter and ignition crucible, 35 mm in diameter and 40 mm in height, with a suitable Gooch funnel and rubber cone.
(7) A suitable means of igniting the precipitate, preferably an electric muffle furnace, capable of reaching and maintaining 800 °C.
(8) A desiccator (a convenient size is one 200 mm to 250 mm in diameter) containing anhydrous silica gel.
(9) Filter papers. Whatman No. 541, 110 mm diameter, and Whatman No. 44 or Barcham Green No. 800.
(10) 2 mm and 425 µm BS test sieves with receivers.
(11) Sample dividers of the multiple-slot type (riffle boxes) similar to those shown in Fig. 3, having widths of opening of 7 mm and 15 mm.
(12) A pestle and mortar or a suitable mechanical pulverizer.
(13) A source of vacuum, e.g. good filter pump.
(14) Two glass rods about 150 mm to 200 mm long and 3 mm to 5 mm in diameter.
(15) A wash bottle, preferably made of plastics, containing distilled water.
(16) A length of rubber tubing to fit vacuum pump and filter flask.

3.2.3 **Reagents.** The following reagents are required. They shall be of recognized analytical reagent quality.

(1) *Barium chloride, 5 % solution.* Dissolve 50 g of barium chloride in 1 litre of distilled water.
(2) *Dilute hydrochloric acid.* Dilute 100 ml of concentrated hydrochloric acid (relative density 1.18) to 1 litre with distilled water.
(3) *Dilute ammonia solution.* Dilute 500 ml of ammonia (relative density 0.880) to 1 litre with distilled water.
(4) Litmus paper (blue).
(5) *Silver nitrate, 5 % solution.* Dissolve 0.5 g of silver nitrate in 10 ml of distilled water.
(6) *Bromine water.* Shake 6 ml of liquid bromine with 500 ml of distilled water.

3.2.4 **Procedure**

3.2.4.1 *Preparation of soil sample for analysis.* The bulk sample obtained as described in the procedure for the preparation of disturbed samples for testing (see 1.5) shall be dried in the oven at a temperature not exceeding 80 °C (see Note 1) and cooled. It shall then be weighed to the nearest 0.1 % of its original mass and the mass (m_1) recorded. It shall then be sieved on a 2 mm BS test sieve and all particles other than stones (see Note 2) crushed to pass through the sieve. The stones may be rejected and the mass of material passing the test sieve (m_2) shall be recorded to the nearest 0.1 % of its total mass. Through these and all subsequent operations care shall be taken to ensure that there is no loss of fines.

The material passing the 2 mm BS test sieve shall be divided by successive riffling through the 15 mm divider to produce a sample weighing approximately 100 g. This sample shall then be pulverized so that it passes the 425 µm BS test sieve. The sample shall be subdivided by riffling through the 7 mm divider until a sample weighing approximately 10 g is obtained. Throughout this and any subsequent operation the material available for any division shall be mixed thoroughly and precautions shall be taken to avoid segregation during riffling. The sample shall be placed in the glass weighing bottle and dried at a temperature not less than 75 °C and not more than 80 °C. The sample shall be deemed to be dry when the differences in successive weighings, carried out at intervals of 4 h, do not exceed 0.1 % of the original mass of the sample. Drying overnight is usually sufficient.

3.2.4.2 *Preparation of the acid extract.* The weighing bottle containing the dried soil shall be removed from the oven, cooled in the desiccator and weighed to the nearest 0.001 g. A sample, about 2 g, (see Note 3) shall then be transferred to a 500 ml beaker, the weighing bottle reweighed and the mass of soil (m_3) shall be calculated by difference. 200 ml of 10 % hydrochloric acid shall be added, care being taken if effervescence occurs to ensure that no material is lost. The beaker shall be covered with a clock glass and the contents boiled gently for 4 min to 5 min. The underside of the clock glass shall be rinsed back into the beaker and 3 ml of bromine water added whilst the solution continues to boil. Ammonia solution shall be added slowly (preferably from a burette) with constant stirring to the boiling solution until the sesquioxides are precipitated and the liquid smells slightly of ammonia. The suspension shall be filtered through an 110 mm hardened filter paper (Whatman No. 541) into a conical 500 ml beaker. When the original beaker has been drained and when filtration has stopped, the filter paper and contents shall be removed carefully from the funnel and transferred back to the same beaker. 20 ml of 10 % hydrochloric acid shall be added to the beaker and the mixture stirred until all the sesquioxides have gone into solution (more acid may be required if an undue excess of ammonia was added or the sesquioxide content is high but the acid used should be kept to a minimum). The filter paper shall then be removed and washed with water until all traces of yellow colouration have disappeared. These washings shall be collected in the beaker and when the washing is completed the filter paper shall be rejected and the contents of the beaker brought to the boil. Ammonia solution shall be added as before to reprecipitate the sesquioxides and the contents of the beaker filtered through a Whatman No. 541 filter paper into the conical beaker containing the washings from the first precipitation.

3.2.4.3 *Analysis of the acid extract.* The extract shall be tested with litmus and made slightly acid by the addition of hydrochloric acid. It shall then be brought to boiling point and 25 ml of 5 % barium chloride solution shall be added drop by drop with stirring of the solution. The covered solution shall be kept hot but not boiling for at least 1 h.

The suspension shall be allowed to settle and a few drops of the barium chloride solution shall be added to the supernatant liquid to ensure complete precipitation of the barium sulphate. If precipitation is incomplete more barium chloride solution shall be added until no further sulphate is precipitated. The solution shall again be kept hot but not boiling for about 1 h.

The precipitate of barium sulphate shall be transferred with extreme care to a previously ignited and weighed porous porcelain filter and ignition crucible using suction. Alternatively, the precipitate shall be transferred with extreme care to a suitable filter paper (Whatman No. 44 or Barcham Green No. 800) in the glass funnel and filtered. In either case the precipitate shall be washed several times with hot distilled water until the washings are free from chloride as indicated by an absence of turbidity when a drop is tested with the solution of silver nitrate. If a porous porcelain filter and ignition crucible is used it shall be removed from the filter flask and dried at 105 °C to 110 °C for approximately 30 min and the temperature gradually raised to 800 °C either in an electric muffle furnace or by other suitable means until no further loss in mass occurs, 15 min at 800 °C should suffice (see Note 4). The crucible shall be cooled in a desiccator and weighed to the nearest 0.001 g. The mass of the precipitate (m_4) shall be calculated from the increase in mass of the crucible.

If the precipitate is filtered through a filter paper, the filter paper and precipitate shall be transferred to a previously ignited and weighed porcelain or silica crucible, dried slowly and ignited. If an electric muffle furnace is used, the crucible and contents shall be placed in it at room temperature and the temperature shall be raised gradually to red heat (800 °C). If a bunsen or other burner is used, the filter paper and precipitate shall first be dried slowly over a small flame, care being taken to char the filter paper slowly rather than to allow it to inflame, otherwise some of the precipitate may be lost. Ignition for about 15 min at red head should be sufficient in all cases. The crucible and contents, when cool shall be moistened with a few drops of concentrated hydrochloric acid followed by a few drops of concentrated sulphuric acid, brought to constant mass by ignition for 15 min and then cooled in a desiccator for 30 min (see Note 5). The mass of the precipitate obtained (m_4) is calculated from the increase in mass (to the nearest 0.001 g) of the crucible.

3.2.5 **Calculations***. The percentage of sulphate (as SO_3) present in the original soil sample shall be calculated from the equation:

$$\text{Percentage of } SO_3 = \frac{34.3 m_2 \; m_4}{m_1 \; m_3}$$

where

m_1 is the mass of sample before sieving (g);
m_2 is the mass of sample passing a 2 mm BS test sieve (g);
m_3 is the mass of soil used (g)
m_4 is the mass of ignited precipitate (g);

3.2.6 **Reporting of results.** The sulphate content of the soil shall be reported to the nearest 0.01 % (as SO_3) of the original oven dry soil mass (see Note 6).

Notes on Test 9

NOTE 1. Soils containing sulphates in the form of gypsum lose water of crystallization if heated above the specified temperature.
NOTE 2. It is assumed that any material retained on the 2 mm BS test sieve will not contain sulphates. This is generally true but certain soils may contain lumps of gypsum larger than 2 mm diameter and in such cases the gypsum should be removed by hand, crushed to pass a 2 mm BS test sieve and incorporated in the fraction passing the sieve.
NOTE 3. *Mass of sample.* The mass of sample to use depends on the amount of sulphate present. Ideally a mass of soil should be chosen that will produce a precipitate of barium sulphate weighing approximately 0.2 g.
NOTE 4. If a rapid estimation of sulphate is required and a furnace is not available, the crucible may be dried in an oven at 105 °C to 110 °C until no further loss in mass occurs (one hour is usually sufficient). The result in this case will usually be less accurate than that obtained by ignition of the crucible.
NOTE 5. *Treatment with acids after ignition.* During the ignition some of the barium sulphate precipitate may be reduced to sulphide by the carbon of the filter paper. The addition of a few drops of hydrochloric acid converts any sulphide to the chloride and further treatment with a little sulphuric acid reprecipitates barium sulphate. Any excess acid is driven off in a subsequent ignition. The effect may be ignored for most practical purposes.
NOTE 6. In cases where the sulphate content exceeds 0.5 % it is suggested that as an additional test the water soluble sulphate content should be determined by the method given in Test 10. (See also Note 1 of Test 10.)

3.3 Test 10. Determination of the sulphate content of ground water and of aqueous soil extracts

3.3.1 **General.** This method describes the determination of the sulphate content of a 1 to 1 soil-water extract (see Note 1) and the sulphate content of ground water. The method cannot be used if the soil or the ground water contains chloride, nitrate or phosphate ions (see Note 2).

3.3.2 **Apparatus.** The following apparatus is required.

(1) A thermostatically controlled drying oven capable of maintaining a temperature of 75 °C to 80 °C. (The normal drying oven can usually be adjusted to cover this range as well as the range 105 °C to 110 °C.)
(2) A balance readable and accurate to 0.001 g.
(3) A glass weighing bottle, approximately 35 mm in diameter, 70 mm high and fitted with a ground glass stopper.
(4) A mechanical shaker or stirrer capable of keeping 50 g of soil in continuous suspension in 50 ml of water.
(5) An extraction bottle of approximately 100 ml capacity (see Note 3).
(6) A Büchner funnel about 100 mm diameter.
(7) A filter flask of about 500 ml capacity to take the funnel.
(8) A glass tube about 400 mm long and 10 mm diameter fitted with a swan-neck outlet as shown in Fig. 16.
(9) A constant head device, as shown in Fig. 17 (optional). This may conveniently be made from a 500 ml round bottomed flask.
(10) Two 500 ml conical beakers and one 250 ml beaker.
(11) A 50 ml burette.
(12) A desiccator (a convenient size is one 200 mm to 250 mm in diameter containing anhydrous silica gel.
(13) Filter papers (Whatman Nos. 44 and 50 or Barcham Green Nos. 800 and 975 are suitable).
(14) 2mm and 425 µm BS test sieves with receivers.
(15) Sample dividers of the multiple-slot type (riffle boxes) similar to those shown in Fig. 3, having widths of opening of 7 mm and 15 mm.
(16) A pestle and mortar or a suitable mechanical pulverizer.
(17) A source of vacuum, e.g. a good filter pump.
(18) A 50 ml and a 25 ml pipette.
(19) Two glass rods about 150 mm to 200 mm long and 3 mm to 5 mm in diameter.
(20) A wash bottle, preferably made of plastics, containing distilled water.
(21) A length of rubber tubing to fit the vacuum pump and the filter flask.
(22) A 75 mm diameter watch glass.

*See Form K, Appendix B.

3.3.3 Reagents. The following reagents are required. They shall be of recognized analytical reagent quality.

(1) A strongly acidic cationic exchange resin such as Zeo-Karb 225 or Amberlite IR-120.

(2) Hydrochloric acid, approximately 4N. Dilute 360 ml of concentrated hydrochloric acid (relative density 1.18) to 1 litre with distilled water.

(3) Sodium hydroxide solution, approximately 0.1N. Dissolve 2 g of sodium hydroxide in 500 ml of distilled water. The exact normality of this solution shall be determined by titration with standard acid, and the solution shall be kept in an airtight plastics container.

(4) *Indicator.* An indicator solution, e.g. screened methyl orange, which gives a distinct colour change in the range pH 4 to pH 5.

(5) *Silver nitrate solution.* Dissolve 0.5 g of silver nitrate in 100 ml distilled water. The solution shall be stored in an amber coloured glass container.

(6) *Nitric acid, approximately N.* Dilute 15 ml of concentrated nitric acid (relative density 1.42) to 100 ml with distilled water.

3.3.4 Procedure

3.3.4.1 *Preparation of soil sample for analysis.* The bulk sample obtained as described in the procedure for the preparation of disturbed samples for testing (see 1.5) shall be dried in the oven at a temperature not exceeding 80 °C (see Note 4) and cooled. It shall then be weighed to the nearest 0.1 % of its original mass and the mass recorded (m_1). It shall then be sieved on a 2 mm BS test sieve and all particles other than stones (see Note 5) crushed to pass through the sieve. The stones may be rejected. The mass of material passing the test sieve (m_2) shall be recorded to the nearest 0.1 % of its total mass. Through these and all subsequent operations care shall be taken to ensure that there is no loss of fines.

The material passing the 2 mm BS test sieve shall then be divided by successive riffling through the 7 mm divider to produce a sample weighing approximately 60 g. This sample shall then be pulverized so that it passes the 425 µm BS test sieve. Throughout this and any subsequent operation, the material available for any division shall be mixed thoroughly and precautions shall be taken to avoid segregation during riffling. The sample shall be placed in the glass weighing bottle and dried at a temperature not less than 75 °C and not more than 80 °C. The sample shall be deemed to be dry when the difference in successive weighings, carried out at intervals of 4 h, does not exceed 0.1 % of the original mass of sample. Drying overnight is usually sufficient.

3.3.4.2 *Preparation of the ion-exchange column.* A quantity of ion exchange resin sufficient to half fill the column shall be emptied into a beaker and stirred with water. The suspension of resin in water shall then be emptied into the column so that when the resin has settled there is approximately 20 mm depth of water above the resin when the surplus water has drained away (see Fig. 16).

The ion-exchange resin shall be activated by leaching with 100 ml of the 4N hydrochloric acid followed by washing with distilled water. If the constant head device (see Fig. 17) is available the acid shall be placed in the device, the stopper replaced and the apparatus left until the acid has passed through the column. The constant head device shall then be rinsed and filled with distilled water and the water left to percolate through until the liquid coming from the column gives no turbidity when tested with about 1 ml of the silver nitrate solution acidified with a few drops of nitric acid. If no constant head device is available the acid and water shall be added to the column in increments taking care not to add further liquid until each increment has drained away.

The ion-exchange resin shall be regenerated in the manner described above after it has been used for four consecutive determinations.

3.3.4.3 *Preparation of the water extract.* The weighing bottle containing the dried soil shall be removed from the oven, and cooled in the desiccator. A sample weighing 50.00 g shall be weighed onto a watch glass and then transferred to a clean and dry extraction bottle. Exactly 50 ml of distilled water shall be added to the extraction bottle which shall then be stoppered tightly, placed in the shaker and agitated for 30 min. The soil suspension shall then be filtered into a clean and dry flask through a suitable filter paper, e.g. Whatman No. 50 or Barcham Green No. 975, or the Büchner funnel (see Note 3). It is essential that no additional water is added at any stage and it is not required that the soil remaining on the filter paper shall be washed.

3.3.4.4 *Preparation of the ground water sample.* At least 500 ml of ground water shall be collected (see Note 6) in a clean bottle and filtered through a suitable filter paper, e.g. Whatman No. 44 or Barcham Green No. 800.

3.3.4.5 *Determination of the sulphate content of the soil-water extract or the ground water by the ion-exchange method* (see Note 7). Exactly 25 ml of the water extract or 100 ml of the ground water sample shall be transferred to a 250 ml beaker. The contents of the beaker shall then, if necessary, be diluted to 100 ml and then gently boiled for 5 min, taking care that no liquid is lost during this process, and left to cool. The solution shall then be passed through the ion-exchange column and the column rinsed with two 75 ml increments of distilled water. The solution and washings shall be collected in a 500 ml conical beaker placed under the outlet of the exchange column. Indicator shall be added to the contents of the conical beaker to impart sufficient colour for the detection of the end-point, when the solution is titrated against the standardized sodium hydroxide solution. The volume of sodium hydroxide solution required to neutralize the test solution shall be noted to the nearest 0.05 ml (V).

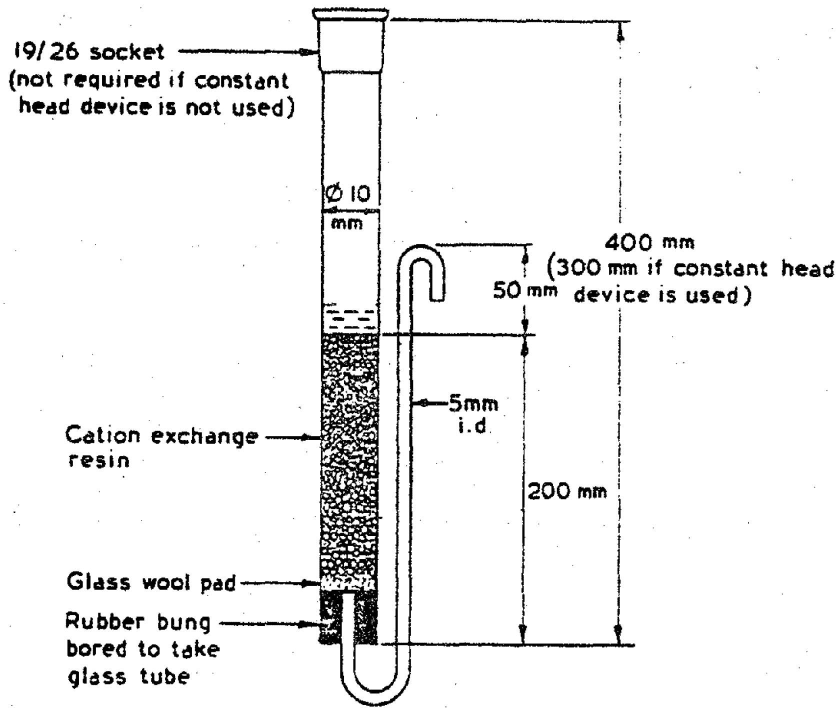

Fig. 16. Ion-exchange column for sulphate terminations

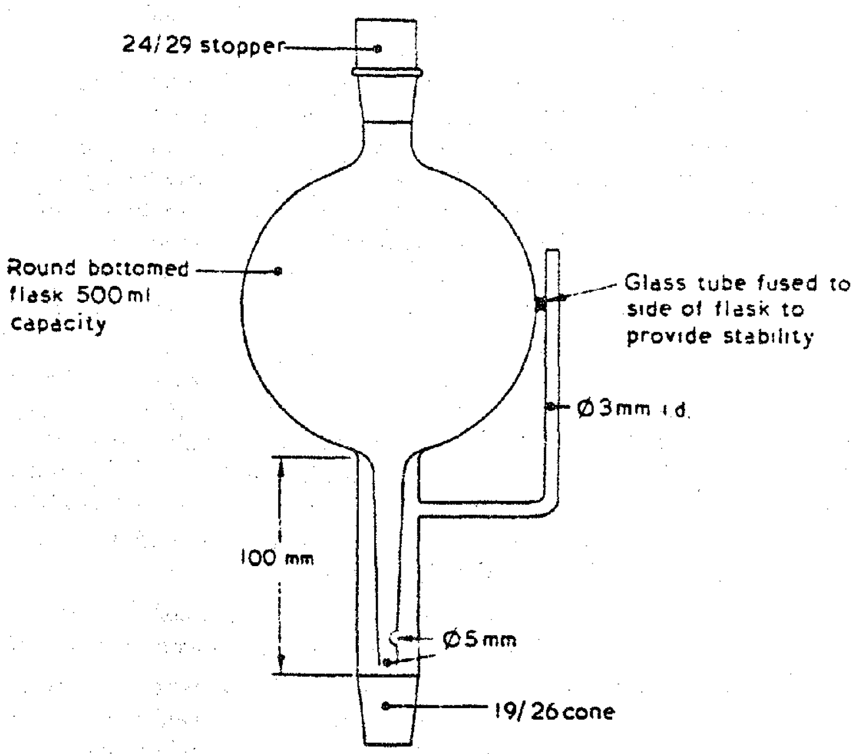

Fig. 17. Constant head device for use with ion-exchange column

3.3.5 **Calculations***. The percentage of sulphate (as SO_3) present in the soil-water extract or ground water shall be calculated from the equations:

(1) Soil-water extract

$SO_3 = 1.6\,nV$ g/litre
or $160\,nV$ parts per 100000

(2) Ground water

$SO_3 = 0.4\,nV$ g/litre

where

n = normality of sodium hydroxide solution;
V = volume of sodium hudroxide solution (ml).

3.3.6 **Reporting of results**. The sulphate content of the soil-water extract and the ground water shall be reported to the nearest 0.01 g/litre.

The percentage of material removed from the soil sample shall also be reported.

Notes on Test 10

NOTE 1. If the sulphate present in the soil is predominantly the calcium salt the total sulphate content as determined by Test 9 is likely to give a misleading and pessimistic impression of the danger to concrete or cement-stabilized material arising from the presence of sulphates. In cases where the total sulphate exceeds 0.5 % it is suggested that the water soluble sulphate content of a 1 to 1 soil-water extract should be determined. If calcium sulphate is the only sulphate salt present its low solubility will ensure that the sulphate content of the aqueous extract does not exceed 1.2 g/litre (120 parts per 100 000). Sulphate contents in excess of this figure in the soil-water extract or in the ground water as determined in this test therefore indicate the presence of other and more harmful sulphate salts. For further information on this subject consult Building Research Station Digest 90 'Concrete in sulphate-bearing soils and ground waters', HMSO, London: 1968.

NOTE 2. In Great Britain these anions may occur to a depth of 1 m in cultivated soils but they are not likely to be found in other soils. If there is reason to believe that they are present a textbook of qualitative analytical chemistry should be consulted for descriptions of simple chemical tests that are available for determining their presence.

If the presence of other anions precludes the use of the ion-exchange method the sulphate content of the soil-water extract and of the ground water can be determined gravimetrically as described in 3.2.4.3 of Test 9.

NOTE 3. If a centrifuge is available it will probably prove more convenient to use a centrifuge tube for the extraction. The suspension can then be centrifuged instead of filtered and 25 ml of the clear supernatant liquid used for analysis.

NOTE 4. Soils containing sulphates in the form of gypsum lose water of crystallization if heated above the specified temperature.

NOTE 5. It is assumed that any material retained on the 2 mm BS test sieve will not contain sulphates. This is generally true but certain soils may contain lumps of gypsum larger than 2 mm diameter and in such cases the gypsum should be removed by hand, crushed to pass a 2 mm BS test sieve and incorporated in the fraction passing the 2 mm BS test sieve.

NOTE 6. Methods for obtaining samples of ground water are given in the publication referred to in Note 1.

NOTE 7. The ion-exchange method is recommended as it is quicker and easier to carry out. However, the method given in 3.2.4.3 may also be used. If the latter method is used care should be taken to ensure that the water extract or ground water sample is made acid to litmus with hydrochloric acid before proceeding.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

The following annotated bibliography contains references on the utilization of coal mine refuse in highway embankments. It is broken into seven categories.

Several categories are subdivided into those papers most specific to the subject - Section A, and papers of a more general nature - Section B.

When a single reference is listed under more than one category, key words, which precede the narrative, identify the other categories where the reference may be found. In general, the narrative for a multiple listed reference is oriented toward the category under which it is listed.

Some of the references included in the Annotated Bibliography may be obtained from the following addresses. Other references may be obtained by writing to the nearest major college library.

Appalachian Regional Commission
1666 Connecticut Avenue
Washington, D.C. 20235

British Library
Lending Division
Boston Spa
United Kingdom

Envo Publishing Company, Inc.
P.O. Box 2326
Lehigh Valley, Pennsylvania 18001

Illinois Institute of Technology Research
Institute (IITRI)
P.O. Box 4963
Chicago, Illinois 60680

Librarian-Transport and Road Research Laboratory
Ministry of Transport
Old Wokington Road
Crowthorne, Berkshire
United Kingdom

National Coal Association and Bituminous Coal Association
(NCA/BCR) Publications
National Coal Association
The Coal Building
1130 Seventeenth Street, N.W.
Washington, D.C. 20036

National Coal Board
Hobart House
Grosvenor Place
London, England S.W.1

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Ohio River Valley Soils Seminar
Engineering Continuing Education
University of Kentucky
Lexington, Kentucky 40506

ORES Publications
College of Engineering
University of Kentucky
Lexington, Kentucky 40506
(606) 257-2843

1. COAL REFUSE UTILIZATION AND DISPOSAL

The papers presented in this category deal with different methods of coal waste utilization and disposal, including in highway embankments.

Section A

Collins, R.J., Availability of Mining Wastes and their Potential for use as Highway Material, Volume III - Annotated Bibliography, U.S. Department of Transportation, Federal Highway Administration, Offices of Research and Development, Washington, D.C., FHWA - RD-76-108, May, 1976, 47pp.

Coal Refuse Utilization: This study includes 80 of the most pertinent references on the availability of mining and metallurgical wastes and assessment of their potential for use in various aspects of highway construction. The study was conducted by reviewing the domestic and foreign literature pertaining to their production and use of these waste materials. Emphasis was given to those references which present the findings of research on the engineering properties and the field performance of specific waste materials.

Maneval, D.R., "Recent Foreign and Domestic Experience in Coal Refuse Utilization" 1st Symposium on Mine and Preparation Plant Refuse Disposal, NCA/BCR, 1974, pp. 256-262.

Coal Refuse Utilization: The utilization of coal refuse by the US and GB, expecially as highway construction material, is discussed. The University of Kentucky has carried out typical soil mechanics classification tests on coal refuse. These tests showed the characteristics of coal refuse to differ somewhat from soils and rocks typically used in embankments. With an understanding of these differences the refuse may still be used successfully as fill material. Problems may arise from frost susceptibility. The low permeability of coal refuse may allow its use as a cover for sanitary landfills. Coal refuse is being studied for use as "coal concrete" and as a lightweight aggregate.

A case history of the refuse bank at Revloc, PA is included. The refuse bank is undergoing reprocessing whereby as much as 40 percent of the material is recovered as saleable coal. PennDOT found the secondary refuse pile to have excellent compaction characteristics suitable for use as fill material.

Maneval, D.R., "Coal Refuse Utilization Prospects: An Update of Recent Work," Second Symposium on Coal Preparation, National Coal Association/Bituminous Coal Research (NCA/BCR), 1976, pp. 184-198.

Coal Refuse Utilization: Describes the utilization of coal refuse by the United States and Great Britain especially as highway construction. Acceptable limits of physical parameter for CMR when utilized as embankment fill are given as determined in Germany and the United Kingdom. CMR as lightweight aggregate and in the manufacture of bricks is discussed briefly. Possible cooperative programs between the coal industry and government to encourage the utilization of coal waste are discussed.

Michael Baker Jr., Inc., Investigation of Mining Related Pollution Reduction Activities & Economic Incentives in the Monongahela River Basin, Prepared for Appalachian Regional Commission Contract No. 72-89/RPC-707, April 1975.

Utilization of Coal Refuse and Engineering Properties: The objective of this study is to develop or discover feasible economic incentives for coal mine operators and others to undertake environmental improvement activities on:

1) existing mining operations to reduce operation and restoration expenses; and
2) abandoned mines to recover expenses with a profit. Included was a task to investigate the prospects of utilizing coal waste as a source of construction material for embankments and fills. Other forms of coal waste utilization are also focused on.

A laboratory investigation of the engineering properties of bituminous coal mine refuse is included.

Tanfield, D.A., "Disposal and Utilization of Colliery Spoils," National Coal Board, London. date unknown.

Utilization: The source, disposal methods, and both established and possible utilization methods of colliery spoil are discussed. The use of burnt and unburnt spoil as aggregate and as fill is included. The potential uses of burnt spoil includes as pre-concrete blocks, anti-skid material, and as road sub-base or fill. Potential uses of unburnt spoil included are; cement stabilized sub-base, as pre-cast concrete blocks and as river bed fill.

Tanfield, D.A.,"Utilization of coal mining residuals in the United Kingdom,"UNDP/WHO Project Conference - Management & Disposal of Industrial Solid Wastes, Mining Residuals and Sludges, National Coal Board, 1972.

Utilization and Design: Describes the utilization of colliery spoil both burnt and unburnt in road construction, brick making, as fill for flood proven areas, lighweight aggregate, and in agriculture. Special problems of using burnt and unburnt spoil as road fill are discussed such as the placement of spoil near concrete, the potential for spontaneous combustion, and workability during wet weather.

University of Kentucky - Research Foundation, Feasibility Study of Utilization of Coal Mine Refuse, Estell County, Kentucky, Prepared for Bluegrass Area Development District, under Contract with Appalachian Regional Commission, Contract No. 74-217 KY-3685-74-1-302B-0607, August 1976.

Physical & Chemical Characteristics & Utilization: A preliminary study establishing the physical & chemical characteristics of coal mine refuse from Eastern Kentucky bituminous coal for evaluation of product potential. A marketability effort has also been made on products of consideration. Utilization as highway embankment fill is not considered as a prime market because of the lack of major highway construction in the area.

An introduction to refuse testing is included along with the results of Physical (soils) Properties Analysis and a characterization of materials.

Section B

Berhman, S., "National Coal Board Colliery Shales - Some Technical & Environmental Considerations in their Development and Use," Planning & Transport Research & Computation Co., Ltd., London, England, July 1974, pp. 229 - 236.

Utilization: Colliery Shale's (burnt & unburnt) characteristics are identified. Current uses of these range from screened burnt shale or running tracks and tennis courts through road uses such as fill, land reclamation, and sea-river defenses. Other uses include various hard standing areas such as pathways, car parks etc, as well as low and medium strength masonry blocks. Work is in progress on the use of heat-treated minestone as an aggregate.

Charmbury, H.B.,"Utilization of Pennsylvania Anthracite Refuse,"in Proceedings. First Kentucky Coal Refuse Disposal and Utilization Seminar, Institute for Mining and Minerals Research, 1976. pp. 13-17

Coal Refuse Utilization: Describes various utilization projects for anthracite refuse, including reprocessing for energy, stowing in underground mines, element extraction, and as building material. Incinerated refuse was found to be satisfactory as a substitute for anti skid surfacing and as a soilless medium for growing plants.

Dorr-Oliver Incorporated, Operation Red Dog, Office of Research and Development, Report No. 42, Dept. of the Int. Washington D.C., 1969.

Coal Refuse Utilization (Burnt): Presents the results of bench scale fluid-bed combustion of anthracite breaker refuse for removal of carbon and sulfur from solid residue. The calcined refuse was tested for use in highway construction and brickmaking. Highway construction utilization includes bases, subbase, and embankment material.

Doyle, F.S. and Chen, C. Y., Utilization of Coal Mine Refuse: Presented to Environments Quality Board, Penna. Dept. of Environmental Resources, at Public Hearing or Coal Refuse Disposal Regulations, November 15, 1972, 16 pp.

Coal Refuse Utilization: This paper discusses some of the ways in which coal refuse may be utilized. It also discusses the past and present usage of coal in G.B. especially as embankment fill. Includes examples of the former. Discusses the engineering properties of coal refuse as embankment material (no specific data). Further information on usage is given as fill material for flood areas and utilization as power plant fuel.

Geer, M.D., "Disposal of Solid Wastes from Coal Mining in Washington, Oregon, and Montana," U.S. Bureau of Mines, Information Circular 8430, 1969, 39 pp.

SEE SURVEY.

Coal Refuse Survey and Utilization: Bureau of Mines surveyed the solid wastes; amounts, characteristics, and conditions - both economic and environmental factors. Coal Mine refuse as highway fill and ceramic raw material. Also includes red-dog.

Glover, Gordan, Coal Mine Refuse Disposal in Great Britain, Department of Environmental Resources of Commonwealth of Pennsylvania, Special Research Report SR-81, 1971, 48 pp.

Coal Refuse Disposal and Utilization and Properties: Summarizes the problem of mining refuse in Great Britain and the utilization of the waste. Includes a section on coal refuse embankment stability and the mechanical properties of Great Britain's coal refuse. Utilization includes general statements on coal recovery, manufacture of bricks, and as an aggregate and landfill.

Gutt, W, Nixon, P.J., Smith, M.A., Harrison, W.H. and Russell, A.D., A Survey of the Locations, Disposal, and Prospective Uses of the Major Industrial By-Products and Waste Materials, Building Research Establishment, Building Research Station, Garston Watford, 1974, 81 pp.

Utilization & Survey: Covers 8 different waste materials including colliery spoil. The location of spoil piles on the island are given and magnitude. Possible uses include as fill material (burnt and unburnt), aggregate, skid resistant roadstone and brickmaking.

Luckie, P.T., Peters, J.W., and Spicer, T.S., Evaluation of Anthracite Refuse as A Highway Construction Material, The Penn State University, M.I. Exp. Station SR-57, 1966, 66 pp.

Coal Refuse Utilization: Summarizes the usefulness of raw and beneficiated anthracite refuse for use in PA highway construction. Includes specification for highway materials and construction (both AASHO Road and Test Reports and Commonwealth of PA Dept. of Highways Specification (1960)) and the ability of anthracite refuse to meet these specifications.

Miller, R.C. and Collins, R.J., Waste Materials as Potential Replacements for Highway Aggregates. Valley Forge Laboratories Inc., Devon, PA, 1976.

Waste Utilization - A survey of the feasibility of utilizing wastes as aggregate material. Covers 34 types of waste, including coal refuse, fly ash, and boiler slag. Anthracite refuse ranks with high potential for utilization.

Moulton, Anderson, Hussain, & Seals, 1974.
SEE TESTING (A)

Coal Refuse Testing and Utilization: Describes the properties of and utilization of coal refuse as a base for a parking lot. Four refuse sources in West Virginia were chosen for analysis of physical and chemical properties. Three areas were monitored over parking lot with refuse and fly ash; refuse and fly ash with 15% lime; and refuse alone, as sub-base material. The results of these tests are given.

Moulton, L.K., Ras, S.K., and Seals, R.K. "The Use of Coal Associated Wastes in the Construction and Stabilization of Refuse Landfills", in New Horizons in Construction Materials, Hsai-Yang Fang, Ed. Envo Publishing Company, Inc. Lehigh, PA, 1976, pp. 53-66.

Coal Refuse Utilization: The use of coal associated wastes as cover materials for refuse landfills is proposed. The results of laboratory & field studies are presented and discussed. It is concluded that there are definite advantages to the use of coal wastes as landfill cover, in haul roads, and in landfill stabilization, as long as the unique properties of these materials are recognized and controlled.

National Coal Board, Spoil Heaps and Lagoons - Technical Handbook, Second Draft, September 1970.
SEE DESIGN
Coal Refuse Disposal: The aim of this handbook is to amplify the technical aspects of work on colliery tips dealt with in the TIPS - Codes and Rules. Reissued later in a more permanent printed form.

National Coal Board, TIPS - Codes and Rules, First Draft, 1971.
SEE DESIGN
Refuse Disposal Regulations and Design Specifications: Presents the regulations on colliery tips and their application in Great Britain, particularly those relating to technical matters and to inspections and reports.

Sherwood, P.T., 1974.
SEE TESTING (B)
Testing & Utilization: Describes in general terms the potential uses of mining and industry wastes.

Spicer, T.S. and Luckie, P.T., "Operation Anthracite Refuse" in Proceedings of the 2nd Mineral Waste Utilization Symposium, the U.S.B.M. and IIT Research Institute, Chicago, Illinois, March, 1970.

Coal Refuse Utilization: Describes "Operation Anthracite Refuse," a research assault seeking to establish approaches and capabilities for utilizing and/or disposing of anthracite refuse by determining the characteristics, methods of beneficiation, and economic values of current and in situ refuse. Covers the initial phase of the "Operation". A number of related usages are discussed.

A survey of the 4 major anthracite fields of PA shows that over 1 billion tons of refuse remain above ground. A breakdown of the type of material in the banks (ie, breaker refuses, silt etc) is presented by anthracite fields.

Thomson, G.M. and Rodin, S., 1972
SEE TESTING
Coal Refuse Characteristics and Disposal: This paper sets out the general background and scale of engineering properties and the new technical standards of tip construction in England.

Urban Services Group Inc., 1976.
SEE SURVEY
Coal Refuse Survey & Utilization: This paper discusses the potential usage of Pennsylvania anthracite refuse as cement raw material, Highway anti-skid base, roadbase material, black top surface, patching material and road shoulder material, and for extraction of element oxides.

Wilmoth, R.C. and Scott, R.B, "Use of Coal Mine Refuse and Fly Ash as a Road Base Material," Proceedings, Coal and the Environment Technology Conf., Mining Pollution Control Branch, Louisville, KY October 1974, 16 pp.
Coal Waste Utilization, Environmental Aspect: Coal Mine Refuse and Fly Ash were mixed to form road base material. The leachates from the road were monitored for 10 months to determine if the leachate was detrimental to the environment. Coal Refuse alone was determined to be an unsuitable road base material because of the poor quality of the effluent. The pH dropped from 7 to 3 and acidity increased to nearly 500 mg/l. The leachates from mixtures of fly ash and refuse with and without lime were not environmentally hazardous.

2. TESTING AND ENGINEERING PROPERTIES

This section presents papers giving testing procedures for the determination of physical & chemical properties of coal refuse and the result of tests on engineering properties of coal refuse is the U.S. and abroad.

Section A

Almes, R.G., and Butail, Ame, P.E.,"Coal Refuse: Its Behavior Related to the Design and Operation of Coal Refuse Disposal Facilities," in Ohio River Valley Soil Seminar: Shales and Mine Wastes Geotechnical Properties, Design and Construction, 1976, pp. 8, 1-9

Physical Properties and Miscellaneous: This paper addresses some of the geotechnical parameters that have been measured for establishing design criteria for safe disposal of the coal refuse product and summarizes experiences and recommendations related to operational practices most suited to its behavior; including transportation methods and placement.

Coal refuse products are classified as:
Mine Rock: greater than 3 inches in diameter
Coarse Coal Refuse: Minus 2 inches to +28 mesh
Fine Coal Refuse: Minus 28 mesh
Coarse coal refuse is generally non-plastic with great variations in specific gravity due to coal content. In situ dry densities usually range from 85 to 105 pcf. The permeability of coarse refuse ranges from 10^{-2} to 10^{-5} cm/sec and is dependent upon the particle size distribution as well as density. The effective angle of internal friction (Ø) varies from 33° to 39°.

Methods of transportation for coarse refuse which are considered excellent are off-highway trucks, scrapers, aerial tramways, and gravity chutes.

Bishop, C.S., and Rose, J.G.,"Physical and Engineering Characteristics of Coal Preparation Plant Refuse," in Proceedings of the Seventh Ohio River Valley Soils Seminar on Shale and Mine Wastes: Geotechnical Properties, Design and Construction, October 1976, pp 4, 1-11.

Coal Refuse Testing & Characteristics: Laboratory and field testing was performed on coal refuse from Kentucky. Field sampling and testing consisted of both disturbed sampling and in-situ shear strength testing of weathered refuse. Laboratory testing consisted of typical soil classification tests along with moisture-density, bearing ratio, permeability, and triaxial testing of compacted specimens.

Bishop, C.S., and Rose, J.G., cont.

Significant variations from typical values for soils were noted. Specific gravities ranged from 1.77 to 2.58. The materials are classified as either SC or SM (Unified System). Dry unit weights varied from 81 pcf to 115 pcf. The effective angle of shearing resistance, $\bar{\emptyset}$, ranged from 29 to 34 degrees, consistently lower than for those soils with similar classifications. Results of tests on disturbed samples from other refuse sites in Kentucky indicate that a wide variability exists between plants due to characteristics of the coal seam being mined, preparation processes used, and disposal methods practiced.

Results of this project indicate that coal refuse can be used successfully as a construction material when the engineering properties are known and considered in design. Due to variability in coal refuse, detailed investigations of the engineering properties should be carried out.

Bishop, C.S., and Simon, N.R.,"Selected Soil Mechanics Properties of KY Coal Preparation Plant Refuse," in <u>2nd KY Coal Refuse Disposal and Utilization Seminar</u>, editor Jerry G. Rose, Institute for Mining and Minerals Research, Univ. of Kentucky, Lexington, 1976, p. 61-67.

<u>Specification</u>: Applies commonly used laboratory tests to the refuse to determine physical and chemical engineering characteristics in order to evaluate disposal techniques and determine if the refuse is suitable for other uses. 23 coal preparation plants were sampled from eastern and western Kentucky coal field.

Results of the testing program showed coal refuse to vary greatly from plant to plant. The refuse had lower dry densities than those of similarly classified soils but this correlated with its lower specific gravity and does not mean the refuse cannot be adequately compacted. Where greater than ten percent of the material is smaller than 0.02 mm frost heave might present a problem.

Busch, R.A., Backer, R.R., and Atkins, L.A., Physical Property Data on Coal Waste Embankment Materials. U.S. Bureau of Mines Bu Mines, RI 7964, NTIS PB-240 022. 1974,142 pp.

Coal Refuse Physical Data: Samples of coal refuse from 8 preparation plants in West Virginia were tested for their engineering properties. This paper includes extensive physical property data aimed at determining coal waste embankment stability.

The values of shear strength, permeability, and grain size distribution for the various samples were quite uniform. Specific gravities and densities of the samples varied considerably. Some of the field density tests indicated high degree of compaction but others were extremely low. It appears that an effort of density control in the field is needed to produce a waste pile with uniform high density.

Butler, Philip E. P.E.,"Utilization of Coal Mine Refuse in the Construction of Highway Embankments." 1st Symposium on Mine and Preparation Plant Refuse Disposal. NCA-BCR, 1974, pp 237-255.

Coal Refuse Testing and Design:
The test results of anthracite refuse from Swoyersville, PA and bituminous refuse from Revloc, PA are compared. The bituminous refuse was better graded and contained more fines than the anthracite refuse. During construction less degradation will be required to achieve desired densities for the bituminous refuse, and, therefore compaction will require less effort than the anthracite refuse. The results of consolidated, undrained triaxial shear tests on 12 samples of bituminous refuse and 15 samples of anthracite refuse showed, surprisingly, that the bituminous refuse had slightly higher values of friction angle (Ø) and higher cohesion (c) than the anthracite refuse.

The Cross Valley Expressway embankment was sampled over 7 months to determine water quality from slope indicator holes. The mean value of pH was 6.7 with a range of 6.2 to 7.4 pH. It is recommended that loss on ignition tests be run on refuse before utilization to determine if coal exists in marketable levels. Banks containing 15% coal are considered economically attractive to coal contractors.

Three design cases are presented for determining the stability of slopes in embankments.

Chen, C.Y. Investigation and Statistical Analysis of Geotechnical Properties of Coal Mine Refuse, Ph. D. Dissertation submitted to the School of Engineering, University of Pittsburgh, Pittsburgh, PA, 1976.

Physical & Chemical Properties & Testing Procedures: A set of guidelines, based on the findings of the study, were formulated to ensure a proper utilization of coal refuse in engineering construction and to assist the mining industry in implementation of an economically and environmentally acceptable disposal method.

Based on the results of this study the following recommendations (in part) on the use of coal refuse in engineering construction were made:

1. There is a relationship between degradation and decrease in shear strength; therefore the excessive compaction of refuse material should be avoided.
2. Coal refuse with a heating value of more than 3500 BTU/lb and/or volatile matter of more than 19% could be used in blends with higher grade coal for energy sources and should have the coal content reduced before put to other use.
3. Proper compaction is the most important factor in reducing the potential of combustion. The main body of an embankment should be compacted to 95% to 97% compaction of Standard Proctor. The three (3) foot shell, top and sides, should be compacted to 100% compaction of the Standard Proctor.
4. The refuse should be well graded with a minimum particle size of less than 3 inches
5. If the requirements of 2, 3 and 4 are met, generally a layer of soil cover with sufficient thickness required for vegetation is necessary. In all cases, surface seals must be kept intact.
6. The air void ratio is inversely proportional to the degree of compaction and is readily determinable from the results of the compaction tests. The permeability can be controlled by varying the degree of compaction.

Chen, C.Y., Elnagger, H.A. and Brelen, A.G.R., "Degradation and the Relationship Between Shear Strength and Various Index Properties of Coal Refuse," in New Horizons in Construction Material, Vol. 1 Hsai-Yang Fang, Ed., Envo Publishing Co., Inc., Lehigh, PA 1976, pp 41-52.

Testing Procedures & Changes due to Degradation. The degradation characteristic and its effect on the shear strength of coal refuse are studied. The recent studies in G.B. have indicated the mechanical breakdown during placement of the material is likely to have been the predominant cause of degradation and that the physio chemical changes by weathering are significant only on the surface of the pile. This paper describes the effect of such degradation on shear strength of coarse refuse and also presents established relationships between shear strength and various index properties.

Elnagger, H.A., Chen, C.Y., and Bullen, A.G.R., "Combustion Potential in the Utilization of Bituminous Coal Refuse in Geotechnical Construction", in New Horizons in Construction Materials, Hsai-Yang Fang, ed., Envo Publishing Company, Inc., Lehigh, PA, 1976 pp 27-40.

Testing Procedures: This paper critically evaluates and assesses various engineering properties and performance records of the British Cortonwood demonstration embankment. The engineering properties were then determined for the Appalachian coal refuse obtained from 23 refuse banks throughout the Monongahela River basin. Based on these investigations, guidelines are provided to eliminate or minimize the potential of combustion for the utilization of bituminous coal refuse in geotechnical construction.

Fraser, C.K. and Lake, J.R., "A Laboratory Investigation of the Physical and Chemical Properties of Burnt Colliery Shale," Road Research Laboratory, Ministry of Transport, Crowthorne, Report, LR 125, 1967, 11pp.

Testing & Properties: Burnt Colliery Shale was sampled on the basis of color occurring as stratification in banks. Moisture content, particle-size distribution, specific gravity, water absorption, permeability, B.S. Compaction, CBR, and front susceptibility were measured. Results showed the shales to be suitable for road fills and sub-basis below the zone of freezing. A problem could be encountered when using the "maximum air voids" concept in compaction because of variations in specific gravity. The addition of cement was required to reduce the volume - change under freezing conditions.

Fredland, J. Ward, and Sawyer, S.G., "Experience in Field and Laboratory Compaction Testing in Coarse Coal Mine Waste," in Second Symposium on Coal Preparation. NCA/BCR, 1976, pp. 160-174.

Coal Refuse Testing: Testing of coarse coal refuse in Pennsylvania including field densities, compaction, and material indices.

In place density measurements were made for various field compaction conditions at three coal refuse sites in western Pennsylvania. The measurements were made by the sand-cone method and by a nuclear moisture density gauge. The latter method produced consistently higher results due to hydrogen containing material. For a lift thickness of 6 inches and one pass with a scraper, the average dry density achieved was 95.6 PCF, at an average water content of 5 percent. Increasing the number of passes to five, achieved an average dry density of 107.4 PCF, with an average water content of 6.5 percent. It was found that the density decreased with depth within a compacted layer. With 2 passes of a scraper on a 1.5 foot layer the average density dropped from >115 PCF at the top of the lift to <90 PCF at the bottom. Comparison of field and laboratory density values shows that whenever the number of passes in increased to five, the density achieved represents 103 percent of the maximum density from the Standard test and 94 percent of the maximum density from the Modified test.

Kettle, R.J., and Williams, R.I.T., "Frost Heave and Heaving Pressure Measurements in Colliery Shales," reprinted from Canadian Geotechnical Journal, Vol, 13, No. 2, 1976, pp. 127-128.

Testing Methods and Properties: Tests were performed on specimens of unbound & cement stabilized colliery shale, both burnt and unburnt. Higher heaving pressures were measured for shales containing higher amounts of fine material. All burnt shales were frost susceptible. Generally cement stabilization does not decrease heaving pressures except for those shales containing large amounts of fine grains.

Lawrence, J.A. Some Properties of South Wales Colliery Discards. Colliery Guardian, June, 1972.

Coal Refuse - Properties: Paper gives details of the important properties, chemical and physical, of discards from collieries in S. Wales coalfields. Discusses their behavior when placed "en masse" in the form of tips.

Michael Baker Jr., Inc., 1975.
SEE UTILIZATION (A)

Utilization of Coal Refuse & Engineering Properties: Physical and chemical tests were performed on coal refuse focusing on engineering properties and potential for acid drainage.

Moulton, L.K., Anderson, D.A., Hussain, S.M., and Seals, R.K., "Coal Mine Refuse: An Engineering Material," 1st Symposium on Mine and Preparation Plant Refuse Disposal, National Coal Association, 1974, pp 1-25.

SEE UTILIZATION(B)

Coal Refuse Testing & Utilization: Laboratory studies of coal refuse from West Virginia are presented. Both fresh and old refuse are tested for soil properties. Moisture density data and plate bearing test are given for coal refuse used as a base for a parking lot one year after construction.

Moulton, et. al., cont.

Soil identification tests were run on coal mine refuse samples selected to be representative of refuse produced in the north central and north western part of W VA. Both "fresh" and "old" refuse were sampled. The basic properties of the refuse varied markedly, not only from source to source and with degrees of weathering, but also from sample to sample within a single source. Permeabilities ranged from 5×10^{-2} to 5×10^{-7} cm/sec, with the weathered refuse generally having the lower values. The effective angles of internal friction ranged from 27.0 degrees to 40.8 degress.

National Coal Board, Application of British Standard 1377: 1967 to the Testing of Colliery Spoil, Technical Memorandum Issued on Soil Mechanics Testing by the Joint Working Party, May, 1971.

Testing of Spoil for Construction Uses: Focuses on properties important to disposal in colliery tips (spoil embankments). Includes methods for determination of pH, moisture content, liquid & plastic limits, specific gravity, particle size, dry density both in the lab and on site, and sulphate content.

Peters, Spicer, & Lovell
SEE SURVEY

Coal Refuse Survey & Testing: This paper presents the results of testing on the four major Pennsylvania anthracite fields'' refuse deposits.

Sherwood, P.T., The Use of Waste and Low-grade Materials in Road Construction, 2. Colliery Shale, Dept. of the Environment, TRRL Laboratory Report 649, Crowthorne Berkshire, 1975, 18 pp.

Coal Refuse Testing and Design: The use of coal refuse and low grade waste materials in highway construction is discussed. The results of physical and chemical testing on burnt and unburnt colliery shales is presented. Tests on colliery shale show most of them meet requirements for fill material. The possibility of frost susceptibility and attack on concrete structures by sulphates must be considered in the design. Unburnt shales also meet the requirements on sub-base material w/the aforementioned limitations. Burnt colliery shales are generally more frost-susceptible than unburnt and are therefore not used as sub-base within 450 mm (18 inches) of the surface. Colliery shales stabilized with cement may be used as base material.

Sherwood, 1975, cont.

The Appendix contains methods for testing colliery shale as a roadmaking material. Generally the tests included in BS (British Standard) 1377: 1974 are considered to be suitable for the testing of colliery shale. Those tests found not to be suitable to testing colliery shale are:

Moisture content: sand bath method
alcohol method
Particle size by dry-sieving
Organic matter content
In-situ density testing

Sherwood, P.T. and Ryley, M.D., The Effects of Sulphates in Colliery Shale on its Use for Roadmaking, RRL Report LR 324, Crowthorne, Berkshire, 1970.

Coal Refuse - Sulfur Content: Describes the results of investigations made to find the effect on cemented products of sulphides in colliery shale. The results show that burnt colliery shale can be used as an unbound sub-base without risk of attack to adjacent concrete and cement-bound materials if the sulphate concentration $\leq$2g. sulphate as (SO_3) per liter. These limits are too restricted for shale used as bulk fill.

Thomson, G.M. and Rodin, S.,"Colliery Spoil Tips - After Aberfan," The Institution of Civil Engineer, London, 1972

Coal Refuse Characteristics & Disposal: After the disaster at Aberfan, the NCB required additional tips to be treated as civil engineering earthworks. This paper sets out the general background and scale of the civil engineering problems and the new technical standards of tips construction. Also discussed is the physical properties of tip materials. It gives the general ranges of particular size distribution, density of coarse discard, the effect of weathering on chemical composition, shear strength and particle size distribution.

Test procedures followed those of BS(British Standard) 1377:1967 but is was found necessary to avoid the breakdown, mainly of coarse particles, which occurs when dried spoil is re-wetted. A detailed investigation of a 50 year old spoil heap showed no evidence of progressive chemical or physical weathering within the body of the heap. Weathering was significant only to a depth of about 1m. Shear strengths of old refuse from shallow depths and from the central portions of old heaps did not vary significantly.

Transport and Road Research Laboratory, Technical Memorandum 114/74
SEE DESIGN

Design and Sulphate Testing: This memo gives specifications for sulfate concentrations of coal refuse adjacent to cement products and general requirements for compaction and sealing of coal refuse in highway embankments.

University of Kentucky, 1976.

SEE UTILIZATION (A)

Utilization and Physical and Chemical Characteristics: An introduction to refuse testing is presented along with the results of physical (soils) properties analyses and a characterization of refuse materials.

Wimpey Laboratory, LTD, Review of Research on Properties of Spoil Tip Materials, prep. for National Coal Board, Laboratory. Reference Number S/7307, 1972.

Coal Refuse Properties: The interrelation and significance of the physical & chemical properties of colliery discard is discussed with respect to spoil heaps and lagoons. The research projects included 1) the physical & mineralogical properties of coarse discard 2) The reliability of standard sampling and laboratory testing 3) temperature in coarse discard placed in thin layers 4) physical properties of lagoon deposits 5) design of lagoon banks 6) stability of spoil heaps & lagoon banks.

Section B

Busch, R.A., Backer, R.R., Atkins, L.A. and Kealy, C.D., Physical Property Data on Fine Coal Refuse, U.S. Dept. of the Int. Bureau of Mines, Report of Investigation 8062, NTIS-PB-245 841. 1975, 40 pp.

Coal Ash Utilization and Properties: Engineering properties of coal ash are studied along with chemical properties and utilization as a mineral extraction.

Department of the Environment, Scottish Development Department, 1976.

SEE DESIGN

Design & Specifications: Gives design requirements for road and bridge works in G.B. Some testing procedures are included; sampling and testing of structural components, concrete, paving and fill materials.

Glover, Gordon, 1971.
SEE DISPOSAL & UTILIZATION (B)

Coal Refuse Disposal and Utilization and Properties: Describes the physical properties of coal refuse important to embankment stability.

Rose, T.G., Robl, T.L., and Bland, A.E., 1976. "Composition and Properties of Refuse From KY Coal Preparation Plants" in Proceedings of the 5th Mineral Waste Utilization Symposium, U.S. Bureau of Mines and IIT Research Institute, Chicago, Illinois, April 13-14, 1976, pp. 122-131.

Chemical Characteristics of Coal Refuse: Coal refuse samples were taken from 23 prep. plants in KY and evaluated for potential analyses, and slow/quick firing tests. Mineralogy was also determined. Uses studied include fuel sources, lightweight aggregate, and structural clay.

Sherwood, P.T., The Use of Waste and Low Grade Materials in Road Construction: 1. Guide to Materials Available, Transport & Road Research Lab, Crowthorne, England, TRRL LR 647, 1974, 16 pp.

Testing & Utilization: Describes the use of Waste materials, including colliery shale in road construction: i.e. base, sub-base, and fill material. Describes the tests required to determine the suitability to meet specification requirements in England. Includes a useful bibliography.

3. DESIGN

Those papers are presented which give design techniques or specifications for using coal refuse in highway embankments.

Section A

Annen, Gunther and Stalmann, Volker, "Washery Discard in Dike and Embankment Construction", from Gluckauf, 4r, 105, No. 26, 25th Des., 1969, pp. 1336-1343, by National Coal Board, Translating and Interpreting Branch, TRANS. A. 2794/AL.

Design Utilization: Describes the properties of colliery discard which affect the stability and design of dikes and embankments. The composition of washery discard from 2 localities is described along with the disintegration and swelling of washery discard containing clay, its behavior under compaction, the shear strength, and permeability.

Butler, P.E, 1974

SEE TESTING (A)

Coal Refuse Testing & Embankment Design: The construction procedures of the Cross Valley Expressway embankment utilizing anthracite refuse are detailed. The refuse material was easily handled and responded well to preparation and compaction. The contractor was able to work in wet weather. Special construction specifications required densities of 97% of maximum determined by Standard Proctor and a layer thickness of 8 inches maximum. Special contract provisions required the material placed in the counter berms to be compacted to a minimum wet-density of 120 lb per cu. ft. Three cases are given whereby the design and stability of embankment slopes may be determined. Other coal refuse highway embankment projects in Pennsylvania are briefly discussed.

Department of the Environment, Scottish Development Department, Welsh Office, Specification for Road and Bridge Works, Her Majesty's Stationary Office, Crown, 1976, 194 pp.

Design & Specifications: Specifications are given for the construction of highway embankments. "Suitable" and "Unsuitable" fill material is defined. The fill material should be deposited in horizontal layers not exceeding 450 mm (17.7 inches) loose depth. The method of achieving acceptable compaction of the fill material is determined by the type of compaction plant used and its mass per metre width of roll, type of soil, and maximum depth of compacted layer, these defining the number of passes required. A table is included with compaction requirements. Any fill material used within 500 mm (19.7 inches) of concrete structures or cement bound materials shall have a soluble sulphate content not exceeding 2.5 g per litre when tested in accordance with Test 10 of BS 1377.

Fraser, C.K., 1974. The Use of Unburnt Colliery Shale in Road Construction, Transport & Road Research Laboratory, Berkshire, Supplementary Report 20 UC, 1974, 8 pp.

Utilization Design reviews the use of unburnt colliery shale as mass-fill for road embankments since the issue of Technical Memorandum T4/68. It summarizes data and observations obtained from engineers who have used the material during the past years.

In general all the engineers contacted considered that unburnt colliery shale formed sound embankments and provided excellent fill material with advantages over most soils particularly during periods of inclement weather.

National Coal Board, Spoil Heaps and Lagoons - Technical Handbook, Second Draft, September 1970.

Coal Refuse Disposal: The aim of this handbook is to amplify the technical aspects of work in colliery tips as dealt with in the TIPS - Codes and Rules. Reissued later in a more permanent printed form.

National Coal Board, TIPS - Codes and Rules, First Draft, 1971.

Refuse Disposal Regulations and Design Specifications
Presents the regulations of colliery tips and their application in Great Britain, particularly those relating to technical matters and to inspections and reports.

Sherwood, P.T., 1974

SEE TESTING (A)

Coal Refuse Testing & Design: Apart from spontaneous combustion, which is no longer considered to be a problem , the other possible limitations on the use of refuse as a fill material are the sulphate content and frost-susceptibility. Where refuse is used as bulk fill no limitations are imposed on sulphate levels. If the refuse is within 0.5m (20 inches) of concrete structures, the sulphate content of a 1:1 refuse: water extract should not exceed 2g sulphate (as SO_3)/litre. The method of determining sulphate content is given in the appendix of this report. Frost susceptible materials cannot be used within 450 mm of the road surface. Most unburnt refuse is non-susceptible but where the refuse is present within the frost zone the frost-susceptibility should be to determine. Compaction requirements when used as fill material are presented for different types of compaction plants.

Tanfield, D.A., 1972

SEE UTILIZATION

Utilization and Design: Colliery spoil has proven to be a very good wet weather material except for those containing high percentages of fines. It is common in the UK to include a barrier section of clay or crushed rock between colliery shale and concrete to avoid attack by sulphates. In some cases the sulphate contents are so low that no barrier is considered necessary.

Transport and Road Research Laboratory, The Use Of Colliery Shale as Filling Material in Embankments. Technical Memorandum No. H4/74 (Superseding Tech. Memo. T4/68)

Design and Testing: Presents the results of the trial period for utilization of colliery shale in road embankments. It is stated that colliery shale is a suitable material for embankment fill and that combustion is not a problem. Specifications are given for limits of soluble sulphates when stabilized with cement. Appendices describe tests for determination of the total and soluble sulphate content.

4. SPONTANEOUS COMBUSTION

This section presents papers which deal with methods of extinguishing **culm bank** fires and methods of prevention.

Flegal, R.C. and Gahr, N.J., Summary of Demonstration Methods for Extinguishing Culm Bank Fires, U.S. Environment Protection Agency, Office of Air and Water Programs, 1973.

Extinguishment of Burning: Sealing, grouting, and mechanical, hydraulic methods of extinguishing burning coal refuse banks were evaluated through 15 demonstration grants in three states of the Appalachian region of U.S. Both effectiveness and unit cost were evaluated. Mechanical - hydraulic were the most successful procedures used in terms of effectiveness and economy.

Isaac, A.S. "An Instrumented Demonstration Embankment at Cortonwood Colliery Final Report," National Coal Board; Coal Research Establishment - Mineral Products Section, Report No MP 13, 1972.

Spontaneous Combustion: A demonstration embankment in which the temperature of the spoil could be monitored continuously was constructed to publicize the use of minestone as fill material and to confirm the widely held view that the risk of spontaneous combustion was remote when minestone was compacted to Ministry of Transport specifications. There have been no increases in temperature from spontaneous heating during the two year monitoring period and the small fluctuations in temperature which have been observed, appeared to be associated with changes in the ambient temperature.

McNay, 1971
SEE SURVEY

Coal Refuse Survey and Burning: A survey throughout the nation was made of burning culm banks. The effects (social and health) are discussed and methods of extinguishment and prevention are presented.

Myers, J.W., Pfeiffer, J.J., Murphy, E.W., and Griffith, F.E., Ignition and Control of Burning of Coal Mine Refuse. U.S.B.M. RI 6758. 1966, 24 pp.

Coal Refuse Combustion: Description of laboratory experiments showing that air permeates segregated refuse more readily than non-segregated and that air permeability is higher in coarse than fine size refuse. Capping of refuse piles with a layer of fine refuse facilitates quenching of fires.

Stahl, R.W., 1964.
SEE SURVEY

Survey of Burning Coal Banks: Methods of extinguishing and preventing refuse - bank fires are described.

5. SURVEY

This presents those papers which give locations of existing coal refuse piles.

Geer, 1969
SEE UTILIZATION

Coal Refuse Utilization & Survey A survey of the solid wastes from coal (amounts, characteristics, and conditions) in Washington, Oregon, and Montana

Gutt, W., 1974

SEE UTILILIZATION B

Utilization & Survey: A map of existing colliery spoil banks in Great Britain is included w/the magnitude of spoil estimated for different areas.

MacCartney, J.C. and Whaite, R.H., Penn-Anthracite Refuse. A Survey of Solid Waste from Mining & Preparation, U.S. BOM IC 840-9, 1969, 77 pp., $1.25.

Survey: The B.O.M. surveyed 863 banks containing over 910 million cubic yards of material. The large majority are near incorporated communities with 27 burning

McNay, L.M., Coal Refuse Fires, an Environmental Hazard. U.S.B.M. IC 8515, 1971, 50 pp.

Coal Refuse: Survey and Burning: The U.S.B.M. located and examined 292 burning coal refuse banks throughout the nation's coal producing regions in 1968. Methods of extinguishing fires are discussed and an approach to eliminating future occurrence of these fires is presented (out of print)

Peters, J.W., Spicer, T.S. and Lovell, H.L., A Survey of the Location, Magnitude, Characteristics, and Potential Uses of Pennsylvania Refuse, Coal, Research Board of the Commonwealth of PA, Special Research Report SR-67, 1968.

Coal Refuse; Survey and Utilization: Includes the location and magnitude of culm banks from the anthracite region of northeastern PA. It presents the results of testing from samples of each of the four (4) major anthracite fields. Focuses on the recovery of quality coal from the culm banks.

Stahl, R.W., Survey of Burning Coal - Mine Refuse Banks, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1964, 39pp.

Survey of Burning Coal Banks: This study presents the results of an effort to survey the burning coal refuse piles of the U.S. The burning banks are located by state, county, and nearest town. The size of the bank is given along with the status of the bank - active or inactive, and the status of the fire - smouldering or burning rapidly. These characteristics were tabulated for 495 banks. Means of controlling refuse fires are reviewed focusing on the compaction and sealing method which has proved most satisfactory. Methods for preventing refuse - bank fires by proper construction of banks are described.

Urban Services Group, Inc. Survey of Mining Refuse Uses in Northeastern Pennsylvania, Submitted to: The Economic Development Council of Northeastern Pennsylvania, December, 1976, 45 pp.

Coal Refuse Survey & Utilization: A survey of refuse from anthracite cleaning & strip mining operations in Northeastern Pennsylvania. Gives general locations of coal refuse banks and past and future utilization.

Wobber, F.J., Wier, C.F., Leshendok, Charles, and Beeman, William. "Survey of Coal Refuse Banks and Slurry Ponds for the Indiana State Legislature Using Aerial and Orbital Inventory Techniques," in First Symposium on Mine and Preparation Pland Refuse Disposal, National Coal Association and Bituminous Coal Research, Inc., October, 1974, p. 64-77.

Survey. The Indiana Geological Survey and other state and Federal agencies cooperated to prepare an accurate inventory of coal refuse sites throughout Indiana using ERTS-1 satellite and high altitude aircraft imagery. Tabulations of over 200 coal refuse sites give site acreages, capsulated descriptions of site conditions, and cost of reclamation summarized on two 1:250,000 scale Coal Refuse Inventory Maps.

6. ENVIRONMENTAL CONCERNS

Special problems which may arise with the utilization of coal refuse are presented.

Section A

Adams, L.M., Capp, J.P., and Eisentrout, E., "Reclamation of Acidic Coal-Mine Spoil with Fly Ash," Bureau of Mine Report of Investigation 7504, April 1971, 9 pp.

Coal Refuse Reclamation: Experiments in reclaiming acidic surface mined coal lands with raw fly ash from bituminous coal fired plants were conducted at 2 sites in W. VA. Plots of both sites were treated with varying tonnages of fly ash and were planted with a variety of grasses, legumes, trees and shrubs. Greatest promise of growth under harsh soil conditions was shown by Kentucky 31 Fescue, rye, and red top grasses, and birdsfoot trefoil, a legume. Survival of trees and shrubs was negligible. Addition of fly ash to the spoil increased the pH to a range tolerable to some plants, improved soil texture, and increased available water of the resulting mixture.

Brundage, R.S."Depth of Soil Covering Refuse (GOB) vs. Quality of Vegetation",1st Symposium on Mine and Preparation Plant Refuse Disposal - NCA-BCR, 1974, 183-185.

Revegetation: Details a method for covering refuse piles with soil and subsequent planting in order to eliminate detrimental effects of the gob piles on the environment.

Twelve to eighteen inches of soil cover on refuse banks was found sufficient to support good quality vegetative growth. The quality of vegetation did not increase with increased soil thickness. No increased improvement in water quality was achieved by placing greater thicknesses of soil cover.

Coalgate, J.L., Akers, D.J., and Frum, R.W."Gob Pile Stabilization, Reclamation, and Utilization,"Prepared for: Office of Coal Research, Dept. of the Interior, Research and Development Report No. 75, 1973.

Refuse Reclamation, Disposal and Utilization: Presents the problems resulting from gob piles, ie. water and air pollution, embankment instability, etc., and presents methods of control. The author explores the current methods of utilization and disposal and recovery of fuels, methods of stowing, as building materials. Includes an extensive bibliography.

Kosowski, Z.V., Control of Mine Drainage from Coal Mine Mineral Waste: Part II - Pollution Abatement and Monitoring, Prepared for U.S. E.P.A. Office of Research and Monitoring, Project No. 14010 DOH, EPA-$2 - 73-230, May, 1973.

Coal Refuse Pile - Reclamation: A refuse pile was monitored for acid drainage. Comparisons were made between unreclaimed pile and piles covered with 1, 2, and 3 feet of soil. No significant differences were measured in acid production between the reclaimed piles but the acid production was reduced +91% from the unreclaimed rate. The costs for reclaiming with 1, 2 and 3 feet of soil respectively was determined to be $6,100, $8,000, and $9,800 per acre.

Mine Safety Appliances Research Corporation, Mine Refuse Pile Coverings to Reduce Water Percolation, Summary Report to Commonwealth of PA Environmental Resources Administration, MSAR Job B - 900211, Project No. CR-78, March 24, 1971.

Sealing Refuse Piles: Evaluates materials as potential mine refuse pile covers. Five candidate materials were selected for testing based on their properties, material costs and estimated labor costs. Their weathering characteristics were evaluated over a 15 month test period.

Ramsey, John P."Control of Acid Pollution from Coal Refuse Piles and Slurry Lagoons." Coal Mine Drainage Research Symposium, 3rd Proceeding: Bituminous Coal Research, Inc., Monroeville, PA, 1970, pp. 138-144.

Sealing & Reclamation: Covers the use of agriculture limestone to raise pH of CMR soils. Limestone is used as a replacement for topsoil.

Sorrell, S.T.,"Establishing Vegetation on Acidic Coal Refuse Materials without Use of Topsoil Cover." 1st Symposium on Mine and Preparation Plant Refuse Disposal NCA-BCR., 1974, pp. 228-236.

Revegetation: Details effective revegetation of refuse pile without the use of topsoil cover. Agricultural limestone is used to treat the spoil.

U.S. Bureau of Mines, Methods and Cost of Coal Refuse Disposal and Reclamation, U.S. Department of the Interior. Information Circular: 8576, 1973, 36 pp.

Refuse Reclamation: An investigation of nine (9) reclamation projects of mining companies and six (6) projects of the Commonwealth of PA were investigated. Provides information on the procedures, costs, and results obtained from reclamation projects of bituminous coal-waste disposal areas. GPO Catalogue No. 128.27: 8576 Stock No. 2404-01289. 70¢.

7. MISCELLANEOUS

Almes & Butail, 1976.

SEE TESTING & SPECIFICATION:

Physical Properties & Transportation - A description of various transportation methods for coal refuse are evaluated econocially.

Falkie, Thomas V., Economic Aspects of Solid Wastes from Mining, in American Society for Engineering Education. Annual Conference, Lobbock, Texas. July, 1972.

Economic Aspects: Problems resulting from mine wastes are catagorized as:

1. Safety problems resulting from stabilities or embankments
2. Conservation problems where wastes contain valuable mineral commodities
3. Land use where the land has economic value and/or presents an eyesore and pollution problems
4. Air pollution emitting from stockpiled wastes as dust, radioactive, or burning materials
5. Water pollution problems resulting from drainage off the surface of wastes and internally.

These problems are discussed in detail for Pennsylvania antracite refuse and Florida phosphate waste. Proposed solutions to these problems include reclamation of waste piles or, where possible, utilization of the waste material.

Kraus, Allen, Local Government Involvement in Coal Refuse Utilization in First KY Coal Refuse Disposal & Utilization Seminar, Jerry G. Rose ed. Institute for Mining & Minerals Research, Univ. of KY, Lexington, May 1975, pp 34-35.

Incentive for Utilization: Various steps which local governments may take to control the placement of coal refuse are detailed with the aim of encouraging future utilization. Through zoning, local governments could regulate land use activities or specifically prohibit the placement of refuse on the preparation plant property. Disposal areas could be selected where the refuse could be utilized as fill to build up future industrial, recreational, or other site preparation processes. A comprehensive plan should be proposed based on extensive research, analysis and projection.

Leonard, J.W. and Lawrence, W.F., Waste Coal Reclamation, 1972, in Investigation of Mining Related Pollution Reduction Activities and Economic Incentives in the Monongahela River Basin, by Michael Baker, Inc. Beaver, Pennsylvania 15009, distributed by Appalachian Regional Commission, April 1975, pp V-18-28.

Economic & Social Aspects of Coal Refuse Storage: This paper presents a brief history of refuse banks and some resulting environmental problems. Utilization of existing refuse piles is encouraged, especially for extraction of coal. Testing on randomly selected refuse banks in the Monongahela River drainage basin showed many banks contain greater than 19 percent volatile matter and/or greater than 3500 BTU heating values.

The determination of the ownership of abandoned refuse piles is often difficult. The individual municipality's laws must be checked to determine ownership or responsibility. Names and addresses of agencies to contact in order to determine the ownership or responsibility of refuse banks are listed.

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