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Analysis of Geological, Mechanical and Characteristics of Aggregates Used in Tailings Ponds

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Abstract: Increasing social demand, economic developments, consumption fluctuations, urbanization, industrialization, modernization, population growth and technical needs have resulted due toincrease in the production of natural resources throughout the world. However, there is a less importance focused on the environmental regulations. Waste water is one of the environmental problemsthatmining activities may cause. It contains a lot of solid and liquid contaminants.Aggregatesare found among the most abundant ones in natural resources. They are obtained from river basins, sea and lake edges, quarries and industries as by products and waste. During mining activities or terminated mining activities, these materials are used in the creation of stability, impermeability and settlement of tailings dam. In this paper, construction of tailings pond by using aggregates are given in detail together with their classification, particle stability, particle shape, particle size, particle texture, covered in minerals of particle, particle porosity and trending to chemical reactivity of aggregates.

Introduction

Aggregates are defined here as particles of rock, which when brought together in a bound or unbound condition, form part or the whole of an engineering or building structure. Natural sand, gravel and crushed rock aggregates are fundamental materials for the man-made environment and represent a large proportion of the materials used in the construction industry (Smith and Collins, 2001). In addition, aggregates are used during the mining operations and for the termination of mining operations for reclamation purpose.

Aggregates containing sand, gravel or crushed rocksare mainly used for filtering works (land drainage, structure drainage, remedial and stability works, water supply, filtration and purification works and marine works) with specific particle size, grading, strength, durability, shape, texture, porosity, surface coatings and chemical activity (Smith and Collins, 2001). Description and classification of aggregates related on its type, physical characteristics, particle shape, surface texture, color, presence of fines, presence of coatings, extraneous material, petrological composition (monomicitic or polymictic), petrological name, geological age (for sedimentary rocks), petrographicdescription, sample reference, certificate of sampling, source and also identified by petrographic thin section examination, X-ray fluorescence (XRF), X-ray diffraction analysis (XRD), Scanning Electron Microscope (SEM) (Smith and Collis, 2001).

Sedimentary facies plays important role on the color and pattern properties of limestone that its changing has negative effect on the quality of the limestone (Turk et al., 2010).

Nowadays, a number of environmental problems can occur due to the growing industrialization. Thepotential harm is high; the natural balance of the tailings pond formed by the drainage of groundwater or wastewater facilities in the mining activities may cause potential problems. Waste ponds of content in heavy metals (such as lead, mercury and arsenic), the acid or base content (H_2SO_4, such as NaOH and NH_4) status and toxicity are major factors threatening the environment.Therefore, ensuring permeability, stability and settlement conditions of waste ponds is very important for optimum design. Compatible with each of these three elements in the form of implementation, regional geology, the chemical reactivitytendency and strength of the aggregate should be known.

Good filling and ballast (the train route) used as the material aggregates can be used in stability and impermeability. Aggregates are used here for protection. There are three general methods, which are rock fill, riprap method and gabion. As general fill materials would also be excluded, except for purposes of comparison or explanation (Smith and Collins, 2001).

Aggrerate Geology

Rocks are classified as sedimentary, igneous, and metamorphic. Sedimentary rocks especially carbonate rocks such as limestone and dolomite ubiquitously used as aggregates. Limestones are used for aggregates with good strength, low possibility of alkali-silica reaction and reduce the drying shrinkage in concrete (Carlos et al., 2010). Carbonate facies and facies sequences must be defined for evaluation and selection of aggregates for applications.Facies may change vertically or laterally by diversity of fossil content or grain size (Tucker and Wright, 1990). Variations of the color and pattern related to the facies that negatively influences on the quality of the limestone

(Turk et al., 2010). A limestone's classification is often difficult to identify during fieldwork due to the diagenesisbutsome techniques will help us i.e. petrographic thin section observation according to Dunham (1962) and/or Folk (1962) limestone classification, Scanning Electron Microscope (SEM), stable isotope analysis (Morse and Mackenzie, 1990).

Aggregates Features

Particle size, grading, strength and durability are the key properties, as these determine permeability, ease of construction, stability and longevity. Particle sizes in filter aggregates can range from fine sands to boulder-sized material. The aggregates are usually placed and compacted in an unbound condition. The completed filter layer or bed will usually need to have the following properties: structural stability (especially if placed in an unconfined situation); durability; high permeability combined with resistance to internal erosion of fines; low frost susceptibility; low susceptibility to salt aggression, chemical attack and solution loss. Physical and chemical breakdown in service may seriously impair the design grading of a filter, adversely affecting its performance. The strength, shape, surface texture and composition of the individual particles will have an important influence on the above properties as will the abrasion resistance and crushing strength of the aggregate since, if these are deficient, it may degrade during placing and compaction (Smith and Collins, 2001).

Grading is fundamental to the design of a filter, detailed consideration of which is beyond the scope of this report. Filters in contact with natural soils or controlled fill material may be designed in accordance with criteria originally was given by Terzaghi and Peck (1967), but current practicefavours the design criteria developed by Sherard and Dunnigan (1985 - 1989) and it was issued as guidelines (U.S. Department of Agriculture 1986). Multi-layered construction will tend to be used for the thicker filter layers. A very wide range of particle sizes, from fine sand up to boulders, might, therefore, be used in different parts of a filter zone. An important requirement is freedom from silt and clay and it is commonly specified that any material passing the 425 µm BS sieve shall be non-plastic when tested in accordance with BS 1377 (British Standards Institutions, Methods of testing soils for engineering purposes). It would also normally have a fine content below 10% (Smith and Collins, 2001).

Aggregate strength, since in the absence of a cementitious binder, the stability and load-bearing properties of a filter rely on the aggregate particles alone, these must be strong enough to prevent breakdown during construction and when in use. Fine-grained materials normally used for filters are generally those which nature has selected as the most durable. Thus, many sands and gravels and fine gravels, are mainly composed of the hard and stable quartz mineral. However, aggregate particles coarser than fine gravel are not usually monomineralic but are composed of rock fragments in which the strength is derived from the interlocking or cementation of individual mineral grains that pay attention to assessment of the strength and abrasion resistance of these aggregates (Smith and Collins, 2001).

Particle durability can be defined as the resistance of the aggregate under its working conditions to cyclic variations in temperature, load, moisture content, freezing and thawing, and chemical environment. It is essential that filter aggregates are durable in the long term and this is particularly important where high strength is not a characteristic of the aggregate. Any breakdown of the constituent particles would increase the fines content of the filter and alter its design grading and efficiency (Smith and Collins, 2001).

Particle shape, is, after grading, as important as strength in a filter aggregate and can be discussed under two main headings. The first relates to whether a particular particle is basically equidimensional in shape or whether it is flaky or elongated. In general, it is desirable for filter aggregates to be essentially equidimensional as this aids the flow distribution through the medium and also facilitates packing of the coarser and fine constituents and improves the effectiveness of the filter. The second important shape characteristic is roundness and again it is better for the filter aggregate to have rounded, as opposed to angular edges to most particles (Smith and Collins, 2001).

Particle texture affects to a lesser extent both the flow of liquid through the filter and the filtration characteristics of the material. A smooth glassy surface is useful from a drainage aspect but not so efficient from a filtration or fines ingress viewpoint, where a rougher surface texture is considered more advantageous (Smith and Collins, 2001).

Some aggregates have a coating that may, or may not, be easily removed during initial processing. Coatings are commonly composed of clay, silt, calcium carbonate, iron oxides, silica or gypsum, but other coatings can occur. Such coatings may vary in thickness and hardness and are, on the whole, undesirable in filter aggregates. They shouldbe removed by scrubbing (Smith and Collins, 2001).

The functions of drainage and filtration are not significantly affected by particle porosity which can however, be expected to have a negative correlation with strength and durability. Therefore, the aggregate porosity or a related property such as water absorption, should be measured in order to assess its possible effects on for example, durability, chemical reaction, freeze/thaw or other breakdown mechanisms (Smith and Collins, 2001).

There are generally no specified requirements for chemical inertness or solubility but these should nevertheless be taken into account in relation to the use of the filter media. It is important that the aggregate is not affected by the chemical properties of the liquid to be treated and also that constituents are not leached from the filter medium into the filtrate. The latter is more likely to occur with artificial aggregates, such as slag, than with naturally occurring aggregates. Slag may also be aggressive to concrete and, if used, is generally required to comply with the stability and sulphur content requirements of BS 1047, British Standards Institutions, Specification for air-cooled blastfurnace slag aggregate for use in construction (Smith and Collins, 2001).

Using Aggregates for Waste Water Ponds

As a using for stabilitiy and impermabillity materials aggregate may be applied general aggregate tests. But, use of these aggregates for different purposes, the engineering implementation of tests listed in Table 1 is recommended.

Grading Test is that the rock shall comply with to the defined grading limits after it has been put within the matrix of the rock riprap.

Shape test (flakiness and elongation indices) is examined for two indices. First, the Flakiness index of aggregates is the percentage by weight of particles whose least dimension (thickness) is less than three-fifths (0.6times) of their mean dimension. This test is not applicable to sizes smaller than 6.3mm. Second, the Elongation index of an aggregate is the percentage by weight of particles, whose greatest dimension (length) is greater than nine-fifths (1.8times) their mean dimension.

Relative density (oven dried) test is the ratio of mass of an aggregate to the mass of a volume of water equal to the volume of the aggregate particles, also referred to as the absolute volume of the aggregates. It is also expressed as the ratio of the density of the aggregate particles to the density of water.

Water absorption causes the penetration of a liquid into aggregate particles with resulting increase in particle weight. It is defined as a percentage.Ten percent fines value is a measure of the resistance of aggregate crushing subjected to loading and it is applicable to both weak and strong aggregates. Fine aggregates are defined as those passing 2.36mm sieve. The test aims at looking for the forces required to produce 10% of fine values (i.e. weight of fines aggregates/weight of all aggregates = 10%). This test is very similar to Aggregate Crushing Test in which a standard force 400kN is applied and fine material expressed as a percentage of the original mass, is the aggregate crushing value.

The aggregate crushing value gives a relative measure of the resistance of an aggregate crushing under gradually applied compressiv load. With aggregate crushing value 30 or higher, the result may be anomalous and in such cases the ten percent fines value ought to be determined instead.

Aggregate impact value, the property of a material to resist impact is known as toughness. Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces. The aggregates ought to have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test. The aggregate impact value is a measure of resistance to sudden impact or shock, which may differ from its resistance to gradually applied compressive load.

Aggregate abrasion value, the aggregate used in surface course of the highway pavements are subjected to wearing due to movement of traffic. When vehicles move on the road, the soil particles present between the pneumatic tyres and road surface cause abrasion of road aggregates. The steel rimmed wheels of animal driven vehicles also cause considerable abrasion of the road surface. Therefore, the road aggregates should be hard enough to resist abrasion. Resistance to abrasion of aggregate is determined in laboratory by Los Angeles test machine. The principle of Los Angeles abrasion test is to produce abrasive action by use of standard steel balls, which when mixed with aggregates and rotated in a drum for specific number of revolutions also causes impact on aggregates. The percentage wear of the aggregates due to rubbing with steel balls is determined and is known as Los Angeles Abrasion Value.

The soundness ($MgSO_4$) test determines an aggregate'sresistance to disintegration by weathering and in particular, freeze-thaw cycles. Aggregates that are durable (resistant to weathering) are less likely to degrade in the field and cause premature hot mix asphalt(HMA) pavement distress and potentially, failure. The soundness test repeatedly submerges an aggregate sample in a sodium sulfate or magnesium sulfate solution. This process causes salt crystals to form in the aggregate's water permeable pores. The formation of these crystals creates internal forces that apply pressure on aggregate pores and tend to break the aggregate. After a specified number of submerging and drying repetitions, the aggregate is sieved to determine the percent loss of material.

Deleterious substances in aggregate, organic impurities interfere with the hydration reaction.Organic matter is mostly found in sand and consists usually of products of decay of vegetable matter (mainly tannic acid and its derivatives).Organic matter may removed from sand by washing. In order to determine the organic content of aggregate, colorimetric test is recommended. However, this test does not confirm the adverse effect of the organic impurity, because high organic content does necessarily mean that the aggregate is not fit for use in concrete. Clay present on the surface of the aggregate particles in the coating form interferes with the bond between aggregate and the cement paste, adversely affecting the strength and durability of concrete. Other fine materials, which may be present in aggregate, are silt (2 to 60 μm) and crusher dust. Silt and dust, owing to their fineness, increase the surface area and therefore, increase the amount of water necessary to wet all the particles in the mix. In view of above, it is necessary to control the amountof sand from seashore or dredged from the sea or a river estuary, as well as desert sand contains salt. Coarse aggregate dredged from sea also contains salt. Salts coming through aggregates cause reinforcement corrosion and also absorb moisture from the air and cause efflorescenceof clay, silt and fine dust in aggregate. Following are the two broad types of unsound particles found in aggregates. Materials fail to maintain their integrity. Materials lead to disruptive expansion on freezing or even on exposure to water. Unsound particles, if present in large quantities (over 2 to 5% of the mass of the aggregate), these particles may adversely affect the strength of concrete and should certainly not be permitted in concrete, which is exposed to abrasion. Shale and other particles of low density are regarded as unsound. Clay lumps, wood and coal, included in aggregate are also regarded as unsound.

The procedure of petrographic analysis outlines the method to be employed in the petrographic analysis of fine aggregate. Unlike the petrographic analysis of coarse aggregate, this method does not provide a petrographic number. The procedure appraises the quality of the fine aggregate. Firstly, the method determines amounts of silicate and carbonate rock types. Secondly, the amount of deleterious material including, for example, shale, mica and chart, is recorded. The latter is required so as to assess the potential for problems, such as lack of freeze-thraw durability and alkali-aggregate reaction.

Table 1 Proposed test for assessment of filter aggregates (modified from Smith and Collins, 2001).

Categories of Test	Tests	Suggested guideline
Physical Properties	Grading	Design test only
	Shape (flakiness and elongation indices)	Not more than 30
	Relative density (oven dried)	No less than 2.5
	Water absorption	Not more than 3% by weight
Mechanical Properties	10% fines value	Not less than 100 kN
	Aggregate crushing value	Not more than 30
	Aggregate impact value	Not more than 30
	Aggregate abrasion value	Not more than 20
	Los Angeles abrasion value	Not more than 40
Durability Properties	Soundness ($MgSO_4$)	Not more than 12% lost
	Deleterious substances	To be assessed after examination
	Petrographic analysis	

To use in tailings ponds aggregates, mineral filler (<63 µm.), Thin (63 . µm. to 4 mm.), container (4 mm. to 31.5 mm.), ballast (31.5 mm to 70 mm) and large (70 mm to 1.3 m.) are examined in five groups.

Mineral fillers have worn this uniform structure by the physical and chemical processes are a very fine grained more resistant to degradation. They ensure very good impermeability. Coarse aggregates can hold mineral filler. Therefore, coarse aggregates fullfil very effective impermeability function like mineral fillers.

Ballast and large granular aggregates, resistance to wear on the physical and chemical processes may be low. Therefore, the geological origin of these aggregates and Table 1 values should be considered in the selection. These size aggregates are used to ensure the stability and settlement of the tailings ponds.

Taken from another thought, there are basically two types of sand filter. First, filters are characterized by slow filtration rates, using fine sand and requiring infrequent cleaning. Second, rapid filters are coarser operating at higher filtration rates and requiring frequent cleaning. The action of a filter bed in removing fine suspended matter is complex and not yet fully understood, being a combination of straining, physical forces, which determine the transport of particles towards and on to the sand grains, and surface forces, which hold the suspended particles to the grains. In slow sand filters, the bed usually comprises of 0.6 m. to 1.2 m. of fine sand supported by layers of graded gravel 0.2 m. to 0.3 m. thick. Rapid filters usually comprise of 0.6 m. to 0.8 m. of coarse sand supported on several layers of fine to coarse gravel to give a total bed thickness of 1.0 m. to 1.3 m. (Fig.1). The sand should be hard, abrasion resistant and free from contaminants. It should not lose more than 2% by weight after immersion for 24 hours in 20% hydrochloric acid at 20 ^{o}Cboth rounded and angular grains may be used, but they should not be flaky. Filter sand is normally obtained from natural sand deposits by sieving, although crushed fines produced from rocks aremainly quartz minerals. The gravel or coarse layer in a filter system has several functions. It supports the sand, permits the filtered water to move freely towards the underdrain and, in the case of a rapid filter, and facilitates a uniform flow distribution. The coarse material should be clean, hard, durable, and free from flat, flaky or elongated particles (Smith and Collins, 2001).

Fig.1Settle of filter aggregate (Tibbett, 2015).

Landfill Applications Using Aggregate for Arrangement of Tailings Ponds

Landfilling is the most economical and environmentally admitted method of solid waste isolation. Implementation of waste reduction, recycling, and transformation technologies has decreased landfill. Landfill for Solid Waste Disposal remains an important component of an integrated solid waste management strategy (Tchobanoglous, 1993). Landfilling unit is a discrete area of land or excavation that receives household waste and that is not considered a land application unit, surface impoundment and injection well, or waste pile, etc. In addition to household waste, a unit may receive commercial waste, non-hazardous solid waste from industrial facilities with nonhazardous sludges and sewage sludge from wastewater treatment plants (US Environmental Protection Agency, 1993; Environmental Research Foundation, 2009). Tailing pond components are shown in Figure 2.

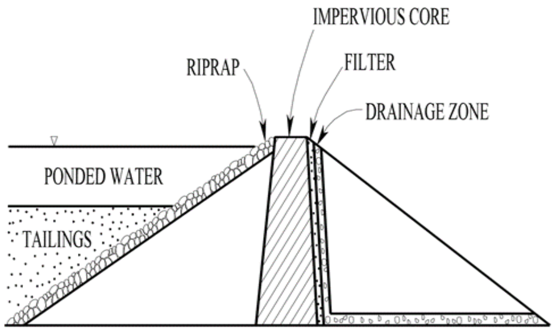

Fig2Systematic tailing pond pomponents (Environmental Protection Agency, 2003).

Sequential raising upstream embankment of tailing pond is shown in Figure 3.Sequential raising centerline embankment of tailing pond is shown in Figure 4.Sequential raising downstream embankment of tailing pond is shown in Figure 5.

Release of pore water during tailings consolidation is the main source of potential contaminant release to the receiving environment. Thus, the tailings storage facilities (TSF) design must provide the most effective means for allowing this fluid to be expelled, while ensuring significant capture of the contaminated water.

Consolidation calculations indicate that the fine nature of the tailings will lead to a relatively slow rate of consolidation. Therefore, the proposed design includes a high permeability consolidation seepage collection layer installed at the base of the facility.

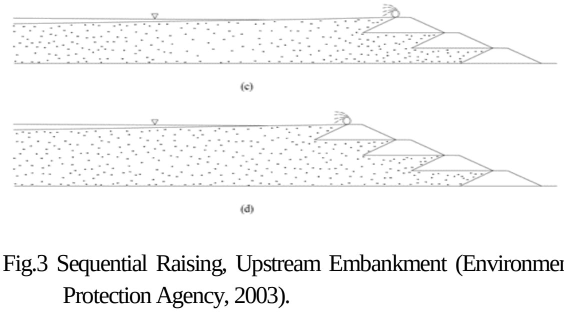

Fig.3 Sequential Raising, Upstream Embankment (Environmental Protection Agency, 2003).

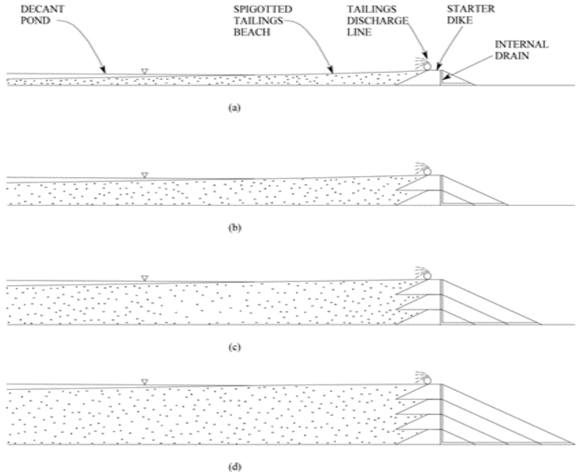

Fig. 4 Sequential raising, centerline embankment (Environmental Protection Agency, 2003).

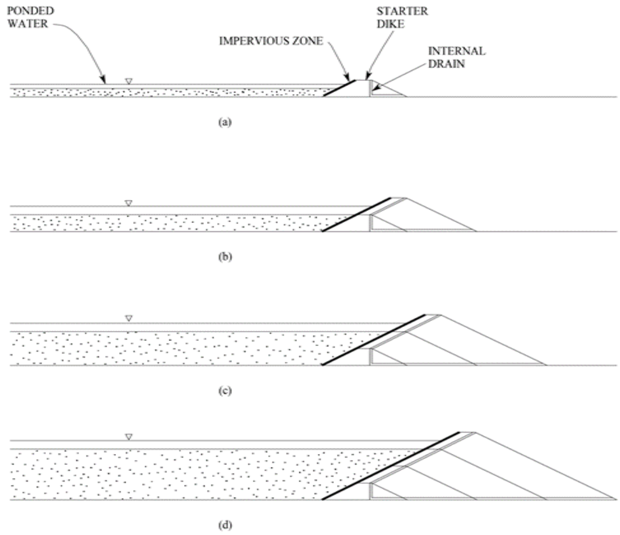

Fig. 5 Sequential raising, centerline embankment (Environmental Protection Agency, 2003).

This drainage layer is designed to allow for active collection and pumping of the pore water released from the base and partially at the sides of the tailings mass during consolidation. To enhance tailings drainage and to prevent the expelled pore water from entering the environment, an active pumping system will be installed (Hore and Duppnow, 2015).Detailed section of the underdrainage layer is shown in Figure 6.

Soil structural stability plays an important role for environmental protection. It is named as primary soil particles held with each other by cohesive forces, secondary particles and organic matter form soil aggregates. Stability of an aggregate is its ability to resist stresses such as tillage, swelling, drying and shrinking processes and fast wetting by meteoric water, which cause aggregate disintegration. Structural stability is the same meaning with aggregate stability, especially in cases, where the stress to which the soil is exposed arises from wetting under different conditions (Kay and Angers, 1999; Glinski and et. al., 2011).

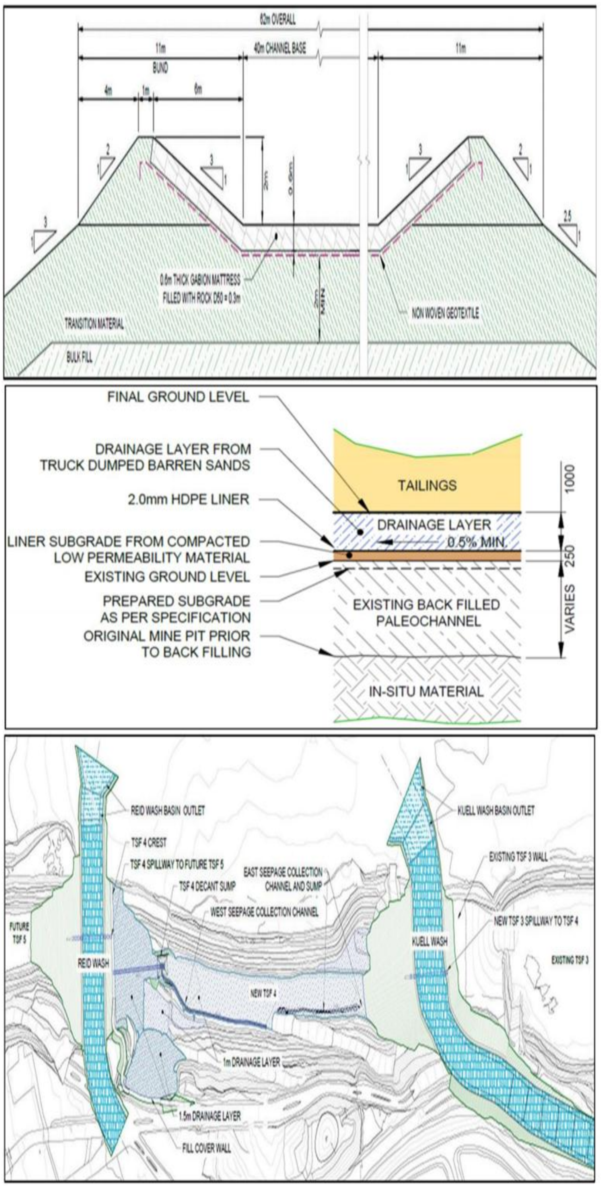

Fig.6 Section of the underdrainage detailing (modified from HoreandDuppnow, 2015).

Aggregate breakdown by water can steam from a variety of physical and physicochemical mechanisms. There are four main mechanisms: First, slaking owing to compression of entrapped air during (fast) wetting (Panabokke and Quirk, 1957),second, breakdown (microcraking) by differential swelling during (fast) wetting (Kheyrabi and Monnier, 1968); third, breakdown (mechanical) by impact of raindrops (McIntyre, 1958), and fourth, physicochemical dispersion because of osmotic stress upon wetting with low electrolyte water. These mechanisms differ in the type of energy included aggregate disruption (Emerson, 1967). For instance, swelling can overcome attractive pressures in the magnitude of MPa (Rengasamy and Olsson, 1991), whereas slaking and impact of raindrops can overcome attractive pressures in the range of kPa only (Rengasamy and Sumner, 1998).In addition, various mechanisms may differ in the size distribution of the disrupted products (Farres, 1980; Chan and Mullins, 1994), and in the type of soil properties affecting the mechanism (LeBissonnais, 1996).

Conclussion

Aggregates are useful for different environmental regulations in soil and water areas. Especially, sedimentary origin rocks such as limestone and dolomite are optimum materials for production of filter aggregates.

Environmental researchers expected that the properties required for filter aggregates are influenced by the highly diverse objectives for which they might be used. In other situations, the shape and size of the filter aggregates, their operating conditions (including the physical and chemical environment), and making a general specification is sometimes impossible. The predominant requirement are for durability, settlement, impermeability and measured stability, which will usually have to be stated from a wide range of physical, chemical and geological properties. This might ask for a substantial degree of decision and experience on the part of the engineer.

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