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PREFACE

The management of tailings dams has gained importance in the recent past as they are virtually an integral part of many large scale mining operations. This bulletin on "Tailings Dam Design", the thirtieth in the series of Technical Bulletins brought out by Indian Bureau of Mines with a view to disseminating the available information, deals with the design of tailings dams used for impounding of tailings generated by concentrators for beneficiation of ores/minerals.

The special aspects covered in this bulletin encompass planning, designing, construction and operation of tailings dams. The design procedure for tailings dam has been intertwined with structural and pollution requirements including stability, geological and geotechnical investigations on site, materials used, seepage control and erosion. The details on tailings treatment, effluent transport and area restoration have also been incorporated. Besides, aspects on maintenance of tailings dams for control of seepage, reclamation of water, monitoring contamination of ground water have also been covered.

Some of the prominent tailings dams in metalliferous mines in India are briefly covered with their salient features as part of case studies. The Indian Bureau of Mines thankfully acknowledges the active cooperation extended by the managements of the mining companies which has been very useful in bringing out this Bulletin. The entire presentation of the bulletin is based on published literature, data, inspections/studies of mines carried out by the Indian Bureau of Mines and information obtained through correspondence.

It is hoped that professionals in the mining and allied industry will find it informative and useful.

(O.P. SACHDEVA)
CONTROLLER GENERAL

NAGPUR
DATED : 31 August, 1995

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Chapter - 1
INTRODUCTION

Today, large open pit low grade ore mines handle thousands of tonnes of ores and waste rocks per day. The increased demand for minerals has created several problems for the mining industry including waste disposal and tailings dams. This has given birth to the waste disposal problem. The mine operations confine the waste/tailings in a smaller place with the help of tailings dams erected in such a way so that the entire confinement would be environmentally safe to neighbourhood. This is how the management of tailings dams around the globe has gained the importance.

Tailings are the waste mineral remaining after the valued minerals have been removed from the ore. Typically, the ore is crushed to a fine sand at a concentrator mill and "values" are removed by flotation or chemical processes in the form of "concentrates". The valueless mineral remaining at the "tail" end of the process is referred to as tailings. Tailings are generally in slurry form at the end of processing operation. and for convenience and economy are generally transported as a slurry to the tailings disposal structure, a pond or a dam. It is the function of the tailings impoundment to retain the slurry, during which time the tailings go out of suspension and fall at the bottom of the impoundment. The decant system is used to remove the classified slurry water from the impoundment either for disposal or for reuse or "reclamation" purposes.

The tailing dams are constructed of mill tailings, mine wastes, or earth of rock fill for the retention of tailings slurry or slurry water for reclamation. Tailings dumps are tailings disposal structures constructed by dry or hydraulic fill means but which do not impound significant quantities of water. Both types of structures have long been designed by empirical means with less than satisfactory performance.

The coarse waste material is generally used for dump or dam building, and the fine sludge is impounded for sedimentation and water clarification behind the tailings dam. Large amount of water is used in milling and washing processes. This water cannot be reused or disposed of in most streams without the removal of the suspended solids; therefore, there is a need for settlement ponds and retaining dams.

Tailings dams or dams for the retention of tailing slurries have many features in common with water diversion or retention dams; thus it is natural to start with water dam technology for their design. However, their operational needs are different, as are many of the schedule, construction techniques and mineral characteristics consideration involved with minerals concentration mill tailings disposal. For example, tailings dams are designed to be abandoned and not operated, their construction is usually simultaneous with their operation. Wherever possible they do not cross streams nor do they usually impound water for purposes other than sedimentation and reclamation. Their ultimate purpose is for solid waste disposal, not water retention. It is imperative that the planning, design and operations of waste disposal sites be conducted under the direct supervision of competent engineers. Information collected on tailings dam design has been classified in this publication under chapters on : Disposal of tailings, Planning for tailings dams; Design procedures for tailings dam; Construction, operation and maintenance; Tailings Dam in Indian Mines - case studies; Environmental Aspects of Tailings Disposal. These chapters treat the subject as follows :

Chapter II provides the necessary information for disposal of tailings i.e. methods of transport of tailings from mill to tailings pond in case of slurry and for mine waste disposal by way of trucks, rails, etc. The information is also included on tailings containment, tailings treatments, effluent transport and area restoration.

Chapter III deals with the planning for tailings dams with information on selection of site, facts to be considered, configuration, classification, type of embankment material available/required.

Chapter IV offers ideas on design procedure for tailings dam. It also covers the points to be taken into account for tailings dam such as stability of dam, geotechnical investigations to be carried out, construction material for tailings dam and seepage of the ground.

Chapter V covers construction operations and maintenance of tailings dams. Different types of construction of structures i.e. starter dam, embankment with an impermeable liner, concrete lining, site preparation, construction during operation, are covered. On maintenance of tailings dams information on records, inspections and remedial resources is added.

Chapter VI treats some examples of the tailings dams in India. The available data on the tailings dams at different mines are briefly furnished.

Chapter VII discusses the environmental aspects.

Chapter 2
DISPOSAL OF TAILINGS

(A). METHODS OF DISPOSAL OF TAILINGS

Tailings from beneficiation plants are in most cases, are of slurry which contains particles of ground material mostly consisting of gangue minerals and minor amounts of valuable minerals as suspension in water. Basically two tailings disposal methods are used :

(i) Tailings are discharged directly into the environment.

(ii) Tailings are disposed of into a tailings pond while tailings discharge into river or other water courses are neither desirable nor permissible from ecological point of view; most frequently concentrator tailings are discharged into a specifically designed tailings pond where solids are allowed to settle. Depending upon a number of factors like evaporation, infiltration in the site ground, residual moisture of the tailings supernatant water may be partially or not only discharged into environment.

Other methods include the following :

1) Layered method of tailings disposal

The tailings slurry is deposited in thin layers of uniform thickness, the slope of the layers depending on slurry characteristics. Once a section of the deposit is covered with the desired thickness of fresh tailings, discharge commences in another section and the newly deposited layer is left to settle and dry for a few days. The final configuration is a gently sloping mass of tailings. Advantages are that the tailings are well drained and fully consolidated when the mine is abandoned. On the other hand, it involves expensive site preparation.

2) Thickened tailings disposal

The tailings slurry is thickened prior to discharge from one or more spigotting points within the tailings disposal area and tailings form a cone. The percentage of solids should range from 55 to 75 percent. This method enables a greater storage capacity for a given disposal area but the need to thicken the slurry results in higher operational costs.

3) Tailings disposal behind a dam

The coarse fraction of tailings is usually used to build the dam. The tailings slurry can be discharged from a single point, through a series of spigots from a beader through spray bars or through cyclones for mechanical separation of tailing sands for the dam construction. Where beneficiation process requires too fine a grind of ore, there may not be enough coarse material to build a tailings dam. In such a case, a dam has to be built with borrowed materials with the consequent advantages of the quality of materials being better and that their placement could be controlled which will result in higher cost.

Waste material from a mining operation consists usually of coarse material generated in mine development work. The low grade ore that is excavated in the process of obtaining the richer ore and is not intended to be milled is usually placed in piles/dumps that may or may not be leached to recover some of the metal contained in the ore, and the smaller size material i.e. tailings that remain after the ore is processed through the mill. All the waste materials, both coarse and fine, must be transported to a permanent disposal site as part of mining operation. Tailings disposal methods consist of special preparation for transport (thickening), mode of transport, and the method and procedures employed at the point where the tailings is discharged and comes to final rest or is rehandled and used in embankment construction.

(B). WASTE MATERIAL/TAILINGS TRANSPORT

1. Waste Material

Coarse mine waste is transported primarily by trucks, conveyors and railroads.

a) Trucks : The mined out waste material for short distances is transported by dozer trucks, and by dumpers and trucks for comparatively long distances. The material transported by dumpers and trucks is usually deposited at the angle of repose by end dumping at the edge of a pile which produces steep slopes.

b) Conveyors : These are used to transport the material to the hopper to be trucked or to free discharge at the disposal site. Waste piles constructed in this manner have steep outer slope and may have compacted layers from equipment travel with the possible results of perched water table on the more compact layers.

c) Railroad : Transport of waste material by rail is used for longer distance and not resorted to in India at present.

2. Tailings transport

Tailings are mineral processing solid rejects containing mainly host-barren rocks along with minor amounts of unrecovered or non-recoverable mineral values. Wet concentration techniques usually discard solid particulate materials (tailings) in the form of a slurry. The quantum of tailings produced may be as much as 98 percent of run-of-mine(r.o.m) in case of precious metal ores or sulphide ores, and as low as 5 to 10 percent in case of low value minerals like iron ores. In most cases 50 to 60 percent of tailings are finer than 70 microns and about 10 to 15 percent finer than 2 microns and engineering properties of such material are similar to silt. Slurry concentrations are in the range of 35 to 50 percent solids by weight. The slurry of tailings is transported either after thickening process or by pipe lines or launder with gravity flow. These methods are described below.

(a) Slurry transport

Tailings are frequently slurried in water and transported by either pipe line or launder with gravity flow. The slurry under certain conditions may be discharged into a natural drainage channel and collected at a lower elevation for distribution to a pond area. The system becomes more complicated when gravity flow is not possible, requiring a pump station. Slurry concentrations are in the range of 35 to 50 percent solids by weight.

i) Gravity flow

To avoid cost and problems of pumping, the ideal situation is to have gravity flow from the mill thickeners to the tailings pond for the entire life of the pond. To prevent excessive wear, it is important that the velocity is not too high and to preclude plugging of the line the velocity should not be too low. The flow should be between 1.2 and 1.8 m per second for non-ferrous tails and as high as 3.6 and 4.2 m per second for taconite.

ii) Pumping

When the above mentioned system does not work i.e. gravity flow is not possible then pumps are to be installed for discharging the tailings to the tailings pond.

Centrifugal pumps are common for low-head demands in concentrators where seal water is available and easily controlled. Where several pump stations are required in the pump line, a dump valve should be just ahead of each pump station, with a catch basin to hold the entire contents in case of a power failure.

Centrifugal pumps of abrasive resistant steel or abrasive resistant plastic liner are much simpler to operate and are probably the most popular for tailing slurry pumping.[1]* Different types of pipes used for tailing disposal are steel pipes, wood stave pipes, reinforced concrete pipes, transit pipes, fibre glass pipes and plastic pipes. Wood stave pipes are used in older installations.[2]

(b) Tailings containment/impoundments

Tailings containment must have sufficient dimensions to allow the mine or plant operate during its estimated life time.[1]

The type of tailings containment used is generally determined by seismic activity, water classification, tailings properties and stability foundation conditions, hydrological conditions, tailings distribution and environmental considerations. The tailings containment has other functions than the storage of tailings. It is also used for water classification and sometimes as a water reservoir for the operation of the plant. The site of tailings containment may be forbidden in the vicinity of populated zones or near tourist sites. In selecting the location for tailings impoundments the smaller catchment, the less inflow that has to be by-passed around impoundment or handled through the impoundment and its outlet facilities, is also important. The control of water in a tailings containment is a critical requirement in the overall design necessary to ensure embankment stability. The control of seepage is important to protect the quality of surface and ground water and hence seepage study of the ground of tailing containment is necessary.

The site of the tailings containment must necessarily be dependent on the topographical and geological nature of the available sites. Obviously, that a tailing containment close to the mine or plant concentrator will lend itself to more economical operation and supervision. The best site or sites for an impoundment or tailings containment may be selected only by close cordination among the concerned parties, operating engineers, mine engineers, chemical engineers, geologists, geotechnical engineers, and other specialists.

(c) Tailings treatment

Treatment of effluent before discharge to tailings ponds, one alternative for protecting ground water quality from contamination due to tailings ponds is to perform some chemical or physical treatment of the tailings before discharge to the ponds.

Once it has been determined that treatment is necessary, the approach to selecting a treatment process lies in answering two questions : (1) What are the contaminants or properties of tailings discharge that requires treatment ? and (2) What methods of treatment should be used?

Once the contaminants requiring treatment are identified, the method of treatment may be selected.

Chemical treatment of the tailings can be done at one or more points in the disposal system. The usual locations are immediately before or just after the thickener, just prior to discharge into tailings pond and on the decant site of the tailings pond. For both alkaline and acidic tailings the treatment is, in most cases, a neutralization process. Basic or high pH solutions can be acidified, or in many cases neutralized by carbon dioxide from the atmosphere. Lime or powdered limestone is typically used to correct an acidic condition.

There are cases where radioactive material, cyanide or other harmful materials are present and require special treatment. Barium chloride can be used to reduce radioactive material while chlorine will help rid of the tailings of dangerous amounts of cyanide.

For special cases, ion-exchange can be used to remove heavy metals. Also,

* References listed after chapter VIII

additives may be added to the effluent to reduce or prevent scaling.

List of the contaminants associated with mining and milling waste is given in Table 2.1. To know the toxicity of the tailings a competent toxicologist should be consulted.

Table 2.1 : Potential toxic contaminants associated with mining and milling wastes[1]

Ore category	Solid Waste	Potenial contaminants[2]
Copper	leach heaps and dumps mine drainage tailings	Pyrites Cu, Fe, Mg, Mn, Pb, Sn, Zn, As, pyrites pH,pyrites
Pb,Zn	tailings mine drainage	Pb, Zn, Cl, Cr, As, Cu, Ag, Mn, Sb, pH,pyrites, trace metals,
Hg	mine drainage	pH, pyrites, Ni
U-Ra-Vn (conventional mining method)	Waste rock mine water tailings	Ra, U, Th Ra,U, Th Zn,Ra,U, Th As,pH,NH_3
Sb	tailings	See Pb, Zn
Rare earth metals,Pt,Sn	tailings	See Ti, Zr
Be	tailings	Be, other metals
Au, Ag	tailings	See Cu, Pb, Zn Hg,NaCN
Al	red and brown muds	pH, Mn, Fe, Al
Fe	tailings	pH, Fe
Ti,Zr	tailings	pH, Fe, Ni, Zn
U(in-situ solution mining method)	ore body	pH, U, Ra, gross,NH_3 SO_4,Mn,other dissolved metals,
	surface impoundment	U, Ra, NH_3,pH

NOTES : 1. May not be all-inclusive

2. Metals may exist as either cations or anions.

Source : Development of Systematic Waste disposal plans for metal & non metal mines. A Minerals Research contract report June, 1982. Bureau of Mines - United States Department of the Interior, Minerals Environmental Technology Vol.I of 2 page.431.

(d) Effluent Transport

Handling of decanted liquid from a tailings pond area is usually a simple gravity flow or pumping with the following objectives :

1. Recycling effluent to the plant.
2. Sending the effluent to a special treatment pond.
3. Discharging the effluent to a location for use other than plant process water e.g. agricultural irrigation.
4. Sending the effluent to evaporation ponds.
5. Discharging the effluent into a natural drainage, either with or without treatment.

The liquid decanted may be much less than the total input to the tailing pond area, since liquid entrapment in the tailings, evaporation and seepage all reduce the amount of effluent.

There are three methods of collecting the effluent.

(1) To decant the liquid from the tailings pond to a pump located at the base of the dam. The decantation system offers the advantage of a permanent pump location and is capable of handling a sudden flow of natural drainage. The disadvantages of this system are in the construction costs, and the problems of a decant tower and pipelines beneath the dam.

(2) Pumps are becoming more popular wherever the terrain permits. Their advantages are less construction cost, good water control, good access to pumps and in seismic regions, lesser risk of failure than decant towers or pipes. The disadvantage is that there is no way to get rid of water in case of power failure during a flood freezing during extreme winter weather.

(3) Siphons in tailing ponds should not be used except with a water type dam. Siphons require a low capital investment and operating cost, but cannot give the advantage of pond elevation as barge pumps can.

(e) Area Restoration

Area restoration is necessary to protect human health and the environment by stabilizing the spoil material, eliminating or minimizing the release of waste products to the air or water and to free the site owner of the need to perform major maintenance after the sites become inactive or are abandoned. This requires adequate reliable diversion drainage systems, cover materials and slopes protected from erosion.

Restoration of the waste disposal area has three objectives:

1. Soil stabilization to prevent from wind and water erosion.
2. Pollution control, includes water percolation into the down stream drainage, with special attention to conditions such as radiation from uranium tailings areas.
3. Landscaping of tailing areas so that appearance blends with the surrounding landscape.

Soil stabilization today in most cases is a must and a great deal of efforts have been directed towards this objective.

There are three principal methods to stabilize a tailings area ;

1. Vegetation - the promotion of plant growth.
2. Physical - the covering of tailings area with soil, slag, or other materials.
3. Chemical - the formation of the top crust by the use of chemicals to interact with fine-sized minerals.

Vegetation stabilization should produce a self-perpetuating plant cover. Frequently this involves furrowing or other surface preparation, the planting of the preliminary growth called a nurse crop, fertilizing, and introduction of chemicals to minimize sand movement. A vegetative process may be aided under some conditions by a soil cover, matting and irrigation.

Neutralization of acid soils with limestone and treatment of basic soils with gypsum may prove beneficial. However, tests have indicated that neutralization is frequently not necessary and in some cases may adversely affect plant growth.

This method of stabilization is

preferred as it gives greater permanency and improvement in appearance than other techniques. Vegetation helps to control dust problem, facilitate crop production and also restores wild life habitats.

Physical stabilization is used to protect fine tailings against wind erosion and for providing an attractive habitat for plant growth. The most commonly used material is rock or soil from borrow areas. Mine waste and slag are also used. A physical cover without vegetation will not always produce the aesthetic effect that is demanded. It is usually important that the physical cover be amenable to plant growth.

Chemical stabilization is brought about through the formation of an air and water resistant crust with a thickness of few centimetres. The purpose is to minimize wind and water erosion and to prevent pollution. It is particularly applicable in an arid climate, or with acidic or basic conditions. Because the crust will prevent plant growth, this approach will normally meet full acceptance only where vegetation is either not possible or is not required.

Chapter 3
PLANNING FOR TAILINGS DAM

(A.) SELECTION OF SITE

1. General

Disposal of mine waste/tailings and construction of dam are not profit oriented operations for mine operators, therefore, it is necessary to construct the disposal system in as economical manner as possible and still meet stability and ecological requirements. Because waste generation is directly related to ore production, disposal site selection, construction, operation and waste production rates should be planned concurrently with mine and mill planning as illustrated in the chart. The selection process can vary from a basic problem with few variables to a very complex problem with many and difficult variables to assess. The site selection requires the knowledge and judgement of experts from all disciplines to meet the criterion imposed by economy, embankment stability, public safety and a sound operation. The extent of the site investigation is governed mainly by the following factors :

1. **Dimensions of the dump and of the impounding embankment,**

2. **Site complexity,**

3. **Consequences of possible failures and**

4. **Risks of pollution, atmospheric or water resources.**

If the design height of a dump or impoundment dam is to exceed 10 m, the investigation should comprise, in addition to testing and the assessment of characteristics of the foundations, borrow areas and the mine and industrial waste; the same type of information obtained for a dam covering topography, geology, hydrology, climate and water usage.

2. Maps and Aerial Photographs

These are valuable in making reconnaissance survey of possible sites. Aerial photographs are a source of useful information during planning. The available maps should carry the topography with the location of rivers, streams, dwellings, installations and underground workings. The geological maps should contain delineating the nature, properties and arrangement of different layers or formations, rock outcrops, geological features and seismicity.

3. Proximity of Mill

The location of the disposal site in relation to the mill is of great importance from an economic standpoint. If there are several sites available for tailings dam considering all features as stated earlier, then the selection of the site, at a lower elevation than the mill permits the use of gravity flow for transport of tailings, may be made. The site which is closer to the mill which becomes a definite advantage from the view of lower capital outlay for the tailings.

4. Storage volume

The site for the tailings dam should be selected with dimensions sufficient to allow the mine or plant to operate during its estimated lifetime. The volume of anticipated waste/tailings from underground operations is difficult to estimate accurately. Therefore, tailings dam related to such types of deposit must be designed for higher storage volume than the

CHART

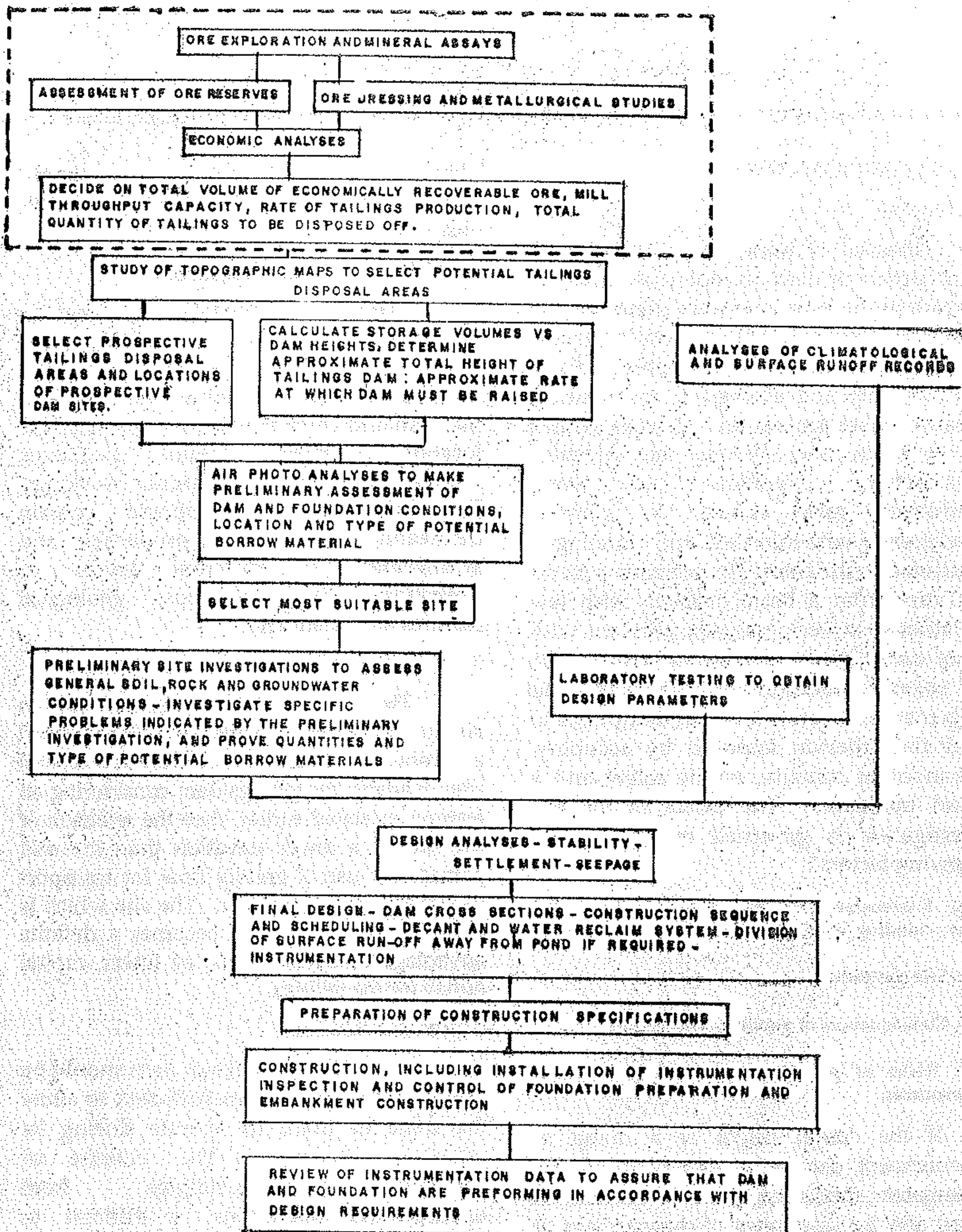


Chart outlining planning and design programme for tailing dam construction

PREPARED BY G. R NITNAWARE STA (Drg.)

planned generation of tailings. The size of the site in relation to the daily tonnage varies with the terrain and whether it is in a wide or narrow mountain valley or in an open and relatively flat plain, but a rough figure of 14 hectares of each 1,000 tonnes of daily capacity is required. In a mountain valley where the annual rise will be rapid for the first 5 to 10 years, careful planning is required to ensure that the discharge tailings dam can be raised sufficiently, quickly to accept all the discharged tailings. The site should be flexible for expansion of the tailing dam with safety.

5. Climatic, Hydrologic and Hydraulic studies

(a) Climatic studies

During the preliminary studies of possible tailings site and dam construction, it is required to have information on climate such as temperature range, rainfall distribution and extremes, rate of evaporation, prevailing wind and precipitation and storm runoff and snowfall where applicable. It is desirable to have a weather station at the site to get the annual precipitation by months, and other climatic data as mentioned above. Cold winter can affect the mode of tailings deposition whereas hot climate evaporation losses will be high inflow from runoff and of minimal amount. If the site is located in a wet climate, the water control structure must be designed to handle relatively large amounts of runoff water with precautions to prevent erosion and pollution.

(b) Hydrological studies

Hydrological studies in planning of tailings dam are important because all waste piles and tailings impoundments are affected by precipitation. It is necessary to determine how much water will flow around, through and over the tailings dam, and to design a system to handle the flows in a safe, economical and environmentally acceptable manner. The amount of surface runoff which enters the tailings disposal can be controlled by site selection. One of the important problems in hydrology is determining of what is likely to occur in the future. From a flood protection point of view, it is useful to know the magnitude of floods that have year frequencies of 1 in 100 or greater. The expression 100 - years-after flood, should not lead one to the wrong conclusion that the flood can happen only once in 100 years. An assessment of the hydrological and runoff data for various locations is performed and a comparison between site conditions is made to aid in selecting a final site for a tailings dam.

(c) Hydraulic studies

Hydraulic computations are used in the design of control measures for the water that enters a disposal site, including the water accompanying the tailings from the mill. In an area with water scarcity, the control structures are usually designed to recycle the maximum amount to the mill. Such water control structures might include seepage intercepter ditches with pumping stations. In areas where water is plentiful, diversion ditches can be used to bypass runoff of flow from the drainage basin above the disposal site.[2] The design of the water control structures must be based on worst possible conditions such as, ultimate height of embankment, maximum phreatic surface and saturated soil. Any structure that releases flow to the downstream channel must be designed to prevent damage to the embankment.

6. Seepage control

An essential step in the planning stage is the assessment of potential seepage through the foundation, abutment and the embankment. The control of seepage is important to protect the quality of surface and groundwater, conserve water, prevent piping and sloughing of material and to maintain the stability of the embankment. Seepage can be difficult and expensive to control; therefore a site should be selected where conditions will minimize the potential for seepage problems. Foundation exploration will identify the location of fractured rock, premeable sands and gravels, thickness and types of soil and depth to groundwater. The collection of this information prior to construction will aid in the design of protective measures to minimize seepage from the tailings pond or to confine leachate from the waste pile. It is not possible to eliminate all seepage through an embankment, but the design should be directed towards seepage control. The principal purpose for controlling seepage in an embankment is to keep the phreatic surface well below the downstream surface of the embankment to preserve its structural integrity. Since tailings embankments are constructed over a long period of time a programme for monitoring the seepage conditions should be established to determine whether the design criteria and assumptions are being met.

7. Provisions for future enlargement

A project is implemented within certain technological or economic conditions which may be modified during the lifetime of the works. It is, therefore, important to ensure in the outset that consistent with sound civil engineering practice, possible changes in the main parameters affecting operations are not overlooked in the site selection.

8. Potential Hazard

The evaluation of the potential hazard of a site is an essential pre-requisite to the design phase for a tailings dam. Hazards pertain to potential loss of human life or property damage in the area downstream of the dam in event of failure or misoperation of the dam. The classification for potential hazards should be in accordance with the following Table - 3.1.

Table 3.1 : Potential Hazard classification

Category	Loss of life (extent of development)	Economic loss (extent of development)
Low	None expected (no permanent structure for human habitation)	Minimal (undeveloped to occasional structures or agriculture)
Significant	Few (no urban developments and no more than a small number of inhabitable structures)	Appreciable (notable agriculture, industry or structures)
High	More than few	Excessive (extensive community, industry or agriculture)

Source : Manual on tailings dams and dumps

Report prepared by M/s G.H.H. Legge, G.L. Herileau, ADM Penman and W.A. Wahler for the ICOLD Committee on Mine & Industrial Tailings Dams and approved by the 50th Executive Meeting Rio de Janeiro, April-May, 1982. Bulletin 45 Page-73.

(B). FACTORS TO BE CONSIDERED

a) Surface

1. GEOLOGY : After the selection of tailings disposal site, information on geology of the site and adjacent areas will dictate the type of design provisions necessary to provide for a stable structure and facility that may be operated without being detrimental to the environment. Knowledge of the regional

geology is necessary to properly log the drillholes and to know the extent of clays, silts and gravels that might underlie the areas. In turn, drillhole logs help in confirming the site geology. Rock types, faults and mineralization, that are necessary in ore delineation are also helpful in choosing the site for tailings dam. The removal of ore underneath an embankment or old underground workings creates a potential for future subsidence, therefore, an alternate site for tailings disposal can be considered.

2. VISUAL INSPECTION OF POTENTIAL SITES : A field inspection of the potential waste disposal sites should be preceded by a thorough study of all available data relating to the topography and geology. Foundation conditions are often revealed or can be inferred from visual inspection of rock out crops, erosional features, and man-made excavations such as rail- road and highway cuts, building excavations, soil pits and rock quarries. The area to be occupied by the tailings and water should be visually examined at this time for existence of poten tial landslides and paths of potential seepage. The possibilities of the mined out areas must be checked.

3. SEISMIC HISTORY : Failure of embankment due to earthquake related motion is an ever-present threat, although a threat is minor in some areas, and major in others. Systematic consideration of the various factors influencing preliminary design must include study of the seismicity of the area. If the planned tailings dam disposal site is in a zone where the probability of major or great earthquake damage is high or the site is located such that a failure would endanger life, construction by the upstream method is not recommended.

b) Below ground

1. GENERAL : For selecting the tailings dam site, some factors are to be considered specially below ground features. Such type of information is very much useful for structural foundation of the tailings dam and this should be studied before the field examinations.

2. VISUAL INSPECTION : A significant portion of the time expended during the visual geologic inspection of the sites will be used inobserving the foundation conditions of the potential sites. Other factors affecting the construction such as wet or boggy areas and steep areas should be noted.

3. SUB-SURFACE EXPLORATION : Sufficient holes should be excavated to give a reasonably clear picture of the foundation upon which the tailings site will be founded. The number and type of holes required will depend on the complexity of the geologic conditions at the site. It is usually advantageous to take a few representative samples during preliminary exploration. During this planning, a few laboratory tests are performed to determine the physical properties of the foundation soil.

C. CONFIGURATION CLASSIFICATION

(1) General :

The methods used in tailings embankment construction to the topography will affect its stability and the amount of work required to develop a water control system. The tailings dam classification system which is based on the local facilities and conditions including topographic condition will be helpful for collecting and recording data in a systematic way.

Figures 1, 2 and 3 present a typical system for the classification of mine and mill waste embankments.

A non-impounding embankment or waste pile, is an accumulation of typically coarse mine or processing plant waste that is not capable of impounding of or presently retaining water, should be classified as impounding structure. A waste disposal facility may be a combination of two or

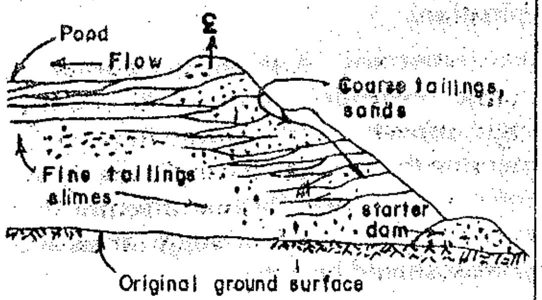
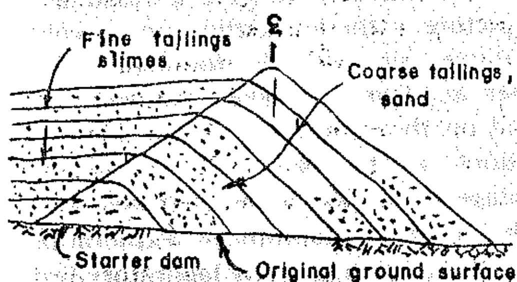
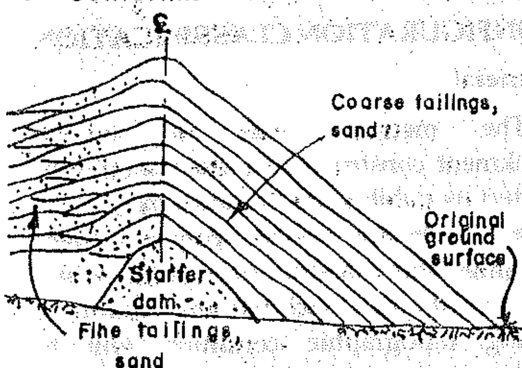
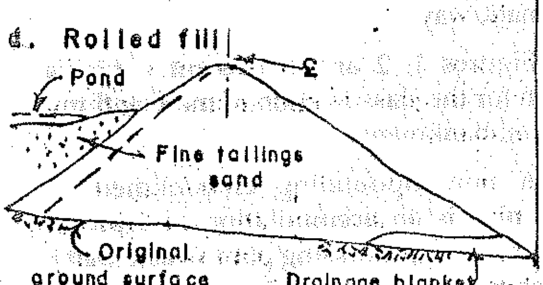
<table>
<tr><th>TYPE</th><th>DESCRIPTION</th></tr>
<tr><td>a. Upstream
</td><td>The embankment is constructed from starter dam in lifts which are placed successively on the previous lift in the upstream direction. The centerline of embankment crest moves in the upstream direction.</td></tr>
<tr><td>b. Downstream
</td><td>The embankment building material is added successively to the down-stream side of the previously placed embankment. The centerline of the crest moves in a downstream direction.</td></tr>
<tr><td>c. Centerline
</td><td>The embankment is raised in steps with the centerline of the crest remaining above the starter dam.</td></tr>
<tr><td>d. Rolled fill
</td><td>The embankment is constructed of compacted borrow material or mine development waste. Zoning of embankment and drainage blanket depends on relative permeability and grain size of tailings and embankment material.</td></tr>
</table>

Figure - I Construction method configuration

PREPARED BY G.R.NITNAWARE STA (Drg.)

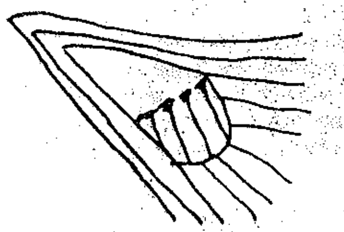
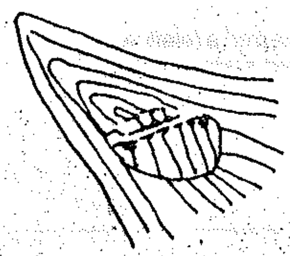
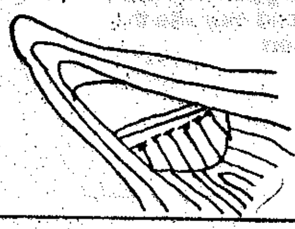
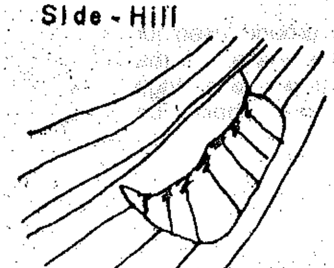
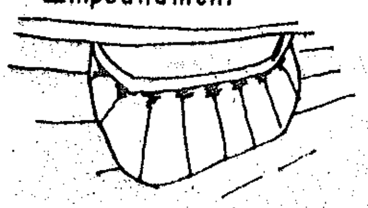
TYPE	DESCRIPTION
a. Valley-Fill 	A mine and/or mill waste embankment which completely fills the valley, extending upstream to the valley head, and is sloped to prevent the impoundment of water.
b. Cross-Valley 	A mine and/or mill waste embankment which crosses a valley, but does not fill up the entire upstream portion of the valley. This type of the embankment must include an outlet system capable of passing flood flows without temporary storage.
c. Cross-Valley Impoundment 	A Cross-Valley embankment which impounds water and/or tailings.
d. Side-Hill 	A mine and/or mill waste pile situated on the side of a hill or valley, below the ridge crest and above the valley bottom. Usually elongated in form and parallel to the valley axis.
e. Side-Hill Impoundment 	A mine and/or mill waste pile located on the side of a hill or valley which impounds water and/or tailings.

Figure - 2 Topographic location configuration

PREPARED BY G.R. NITNAWARE STA(Drg)

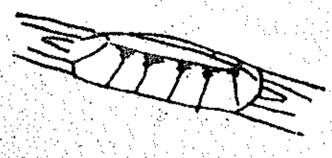
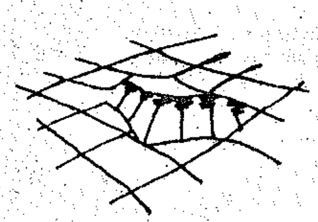
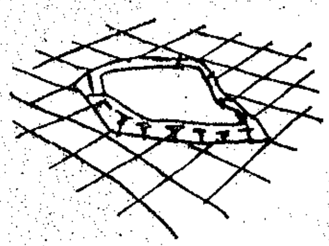
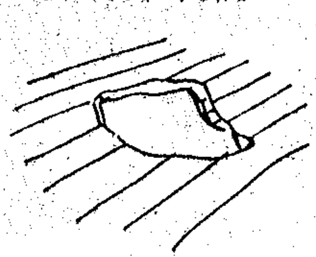
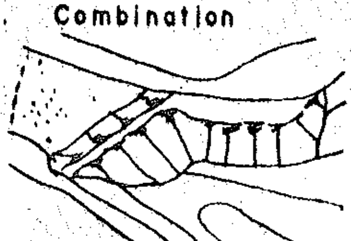
TYPE	DESCRIPTION
f. Ridge 	An embankment of a mine and/or mill waste located on top of a ridge, straddling the crest of the ridge so that the refuse material affects both ridge slopes. These embankments typically evolve into sidehill forms on one or both sides of the ridge.
g. Heaped 	A mine and/or mill waste pile located on a relatively flat, undulating, or slightly inclined surface in the form of a mound or pile.
h. Dyked Pond 	A mine and/or mill waste arranged in the form of an enclosed dyke, located on relatively flat terrain, forming a pond above the original ground surface. On gently sloping terrain, the pond may use the hill as one side of the impoundment.
i. Incised Pond 	An excavation below original ground used for impounding tailings or waste water. If the excavated material forms a continuous ridge around the perimeter, the pond should be classified as a dyked pond.
j. Combination 	Embankments containing any two or more of the basic forms listed above.

Figure - 3 Additional topographic location configuration

PREPARED BY G.R. NITNAWARE STA (Drg.)

more of the basic forms.

2. Construction method configuration :

If tailings are employed for construction, three methods are in common use. They are the upstream method, downstream method and centreline method (refer Figure 1).

i) UPSTREAM METHOD : With the upstream method, an initial starter dam is constructed at the downstream toe. It is most important that this initial dam be sufficiently pervious to pass seepage and that the downstream portion of the dam be designed to resist piping. Tailings are then discharged from the top of the starter dam using spigot or cyclones to develop a dyke composed of the coarser fraction. The centreline of the top of the embankment is shifted towards the pond area as the height of the dam increases. The downstream toe of each subsequent dyke is supported on the top of the pervious dyke with the upstream portion of the dyke placed over finer tailings.

The most common tailings pond is the upstream type with spigotting. It is used if the sand is suitable for dam building, the seismicity risk is relatively low and the dams will not be exceedingly high. Tailings dams of this type are most economical ones. It was used extensively in the past. It is now avoided because of the difficulty of ensuring its stability, particularly under seismic conditions. The basic structures, the starter dam and the decant works are the fastest built and thus are the fastest in operation. If the original material contains sufficient amount of sand fractions and the beach is long, a stable support of the necessary size is easily formed. A disadvantage of this type of tailings dam is that the sections of the support component constructed at later stages will lie on finer granular material, laid during the preceding stages. This material is of lower strength and consolidates slowly. Thus, the stability of this type of embankment is inversely proportional to an increase in height.

ii) DOWNSTREAM METHOD : The dam is built with coarse fraction of tailings. This method would be used only in extremely sensitive seismic areas where this method alone would make a safe embankment. It is somewhat limited in height because of the vast amount of sand needed for each incremental increase. It is more costly because of the mechanical equipment needed to make the flat downstream slope. The operation is more awkward because access to the header pipe is blocked off by the cyclone underflow if the access road is downstream, and blocked off by the cyclone over flow pipe if upstream which is not of the better operating method. This type of embankment offers the greatest stability. In the initial period, it has the disadvantage that the balance between the larger fractions of the supporting part and the small fractions retained by the supporting part is negative i.e. the larger fractions that are to shape the supporting part are insufficient. In the downstream method of construction, the centreline of the top of the dam shifts downstream as the dam is raised. A starter dam is required. The starter dam will usually be constructed of compacted borrow material which contains significant silt and clay sizes. If tailings are to be used during construction, only the coarse fraction must be employed. If the dam is located in a potential earthquake zone and/or will exceed the height of about 15 m the downstream extensions must be compacted. The major disadvantage of the method is a large volume of sand required.

iii) CENTRELINE METHOD : The dam is built with coarse fraction of tailings. The dam centre line is maintained in the same vertical plane as the height increases.

In the centreline method, the crest of the dam is maintained at the same horizontal position as the height of the dam is increased. The dam is raised by spreading and compacting additional coarse tailings on the top, on the upstream shoulder and the downstream slope. Coarse gradation of the tailings is necessary to afford rapid drainage to provide support for construction equipment. The centreline method is a compromise between the upstream and downstream methods because seismically it is better than the upstream and requires much less cyclone underflow than the downstream. It can be designed for easy operation with no interruption in the discharge of tailings provided the area is large and the cyclones produce a sand that has sufficient permeability that the phreatic line is kept well below the surface.

D. TYPE OF EMBANKMENT MATERIAL AVAILABLE/REQUIRED

1. General

For constructing the embankment for tailings the material required need to be used carefully as the tailings dam retained for generation to generation. When the site for the tailings dam is selected, the designer of the tailings dam should plan for using the material for construction of embankment and planning of embankment design should be based on the proper utilization of the various materials in a manner that will produce a structure adequate for the projected needs and stable enough to accommodate planned changes and to remain stable after closure.

2. Tailings

Usually, the most readily available and most economical to use for construction is the material produced at the mill and disposed of as tailings. Physical differences as well as chemical differences exist in tailings for different industries. Special problems which may be created by the type of tailings to be stored must be assessed. During the planning stage, samples of the tailings may not be available for testing, however, some knowledge of the gradation and physical properties should be available for the purpose of design planning. The range of expected gradation can be useful in predicting the total gradation and the percent of the tailings larger than 200 sieve size. Since they may be used as an integral part of the dam, the shear strength, consolidation, permeability, sedimentation and construction characteristics must be determined. Other characteristics like pyrites and acid potential, radioactivity, burning, freezing and thawing, wind erosion, etc. must be assessed.

In the event of an insufficient volume of sand can be produced to construct an embankment of the required density, permeability and stability, the embankment must be constructed of material from borrow or from usable mine waste.

3. Mine Development Waste

Although soils and waters found in engineering water retaining dams are usually chemically neutral such is often not the case with mining and industrial wastes. Waste material excavated for mine development purposes or to be excavated during mining activities is a mine development waste material.Their composition varies according to the nature and conditions of the operation and they are prone to change over a period of time. The wastes may have soluble toxic salts.

In copper, lead, zinc and iron mines, the wastes may have a high sulphur content, particularly iron. These are heavier than the silicious elements and settle at a faster rate. As they become oxidized, they may form hard crusts preventing or limiting the drainage. Therefore, the sufficient samples of the mine development wastes are to be tested to determine the stability for use of construction, classification, gradation and shear test.

Mine waste material that will not deteriorate and is proven suitable for construction, can be used in starter dam and to supplement tailings materials in construction of the main embankment. However, investigation methods require the use of techniques different from those in civil engineering, specially in the fields of chemistry and mineralogy.

4. Borrow Materials

Use of borrow materials for constructing the tailings dam is made when

a) tailings are of fine grind,

b) the rate of rise of the tailings is excessive with respect to the filling time of each successive stage in the construction, and

c) for other practical reasons.

Prior to the selection of a specific site, a few exploration holes need be placed in various potential borrow areas from where the borrow material can be excavated. Therefore, during the early phase of planning, sufficient exploration, sampling and testing of potential borrow materials should be made to locate and classify enough material for construction of the starter dam. When disposal facility plans call for the entire embankment to be constructed by borrow materials, a much greater volume of material must be explored, sampled and tested.

Borrow material can be used only when the tailings are not used due to fine grind and mine waste rock cannot be used as the mine is located far away and transportation of waste material is not economical.

Chapter-4
DESIGN PROCEDURE FOR TAILINGS DAM

A. GENERAL

Successful design of the tailings dam is largely dependent on a thorough evaluation of the foundation. Disposal of tailings, and using the water from milling process, demands that the foundation evaluation satisfies both structural and pollution requirements.

The objective of the design phase is to produce a design and specifications for construction of a tailings dam which will stabilise through the operational years and remain stable for an indefinite period after rehabilitation following termination of operations. The resulting waste facility should be adequate for all disposal requirements and be economical to operate and maintain during the life of the tailing facility.

To certain extent, the procedural steps will be the similar to the procedures followed during the planning for embankments in the earlier chapter. However, the procedural steps during the design of tailings dam are notably more thorough and more detailed.

B. STABILITY

1. GENERAL : There are a variety of conditions of stability ranging from a small area of an embankment with an incipient failure to a massive slide. Many of the signs of the stability are associated with the relationship of the embankment to the surface or subsurface water. It is also important to recognize the minor condition of stability which not corrected can progressively lead to a massive failure when an embankment is placed under increasing stress such as increased load, rising pond water level, rising phreatic surface, and heavy precipitation, or sudden shock during an earthquake. Depending on other circumstances, any one of these causes of stability may not cause a failure of dam but creates a condition of instability if combined with another one or more which may result in a major failure.

2. OVERLY STEEP SLOPES : Overly steep slopes can be the result of impoundment construction or severe erosion or these may be the remaining slopes exposed by partial failure and movement of down slope material. Overly steep slopes may remain stable for long periods of time as long as no change is introduced into the state of equilibrium. However, when a change occurs such as additional downstream movement, increase in moisture content due to precipitation or rising phreatic surface, a failure is certainly to occur. Therefore, existing conditions of overly steep slopes should be corrected and the design and construction of steep, inherently unstable/steep slopes should be avoided.

Compaction and drainage have considerable influence on stability and hence on the gradient of the down stream slopes. For example, if a slope in loose saturated sand having a friction angle of 30 degrees has a minimum safety factor of 1.3, the computed down stream slope is 13 degree (4.2:1). If the sand is compacted the friction angle increases to 38 degrees, the corresponding slope angle is 18.5 degrees (3.1). If the slope is drained the phreatic water surface is lowered to the level of the toe, the slope angle for a safety factor of 1.3 becomes 31 degrees (1.7 : 1). These calculations do not include allowance for seismic forces. However, the steepest permissible embankment slope depends on the shear strength of the fill and/or the foundation soil or rock, the unit weight of the material, the height of the embankment and the distribution of water pressure.

3. HIGH WATER LEVEL : Except in case where an embankment is designed to specifically operate with a high water surface in contact with the upstream face, design should provide for keeping the water surface as low as possible by adequately designed drains and planned method of operation and construction to prevent saturation of the embankment. Therefore, preliminary investigations should cover all possible sites preferably at a lower elevation.

4. A RAPID RISE OF WATER LEVEL : A rapid rise in the water level may be so sudden as to make it impossible for the designed drains to handle the increased flow. Even if the drain capacity is large enough to handle the increase in flow, the permeability of the path of flow may not be adequate to permit increased flow to reach the drains. The rapid rise in water level would place water against the upper part of the tailings dam which is usually at a lower density than material at lower levels in the embankment due to less consolidation and compaction. Consequently, water against a low density fill can lead to rapid saturation and piping which can cause collapse leading to loss of free-board and probable over-topping. Therefore, condition must be made during design and construction to avoid a rapid rise in water level by provisions for bypassing, pumping or safe storage increase in volume of water affecting the site.

5. HIGH PHREATIC SURFACE : A high phreatic surface reflects an inadequate drainage condition in an embankment. The pre-water pressure below the phreatic surface reduces the shear strength of the soil mass. Design considerations should provide for maintaining the phreatic surface at a low level.

6. SEEPAGE OR PIPING : No dam of any significant size is completely seepage free. Seepage along the perimeter of decant and culvert pipes can cause severe problems, therefore, the design should incorporate measures, such as the use of cutoff collars and seep rings to prevent seepage problem.

In tailings dam the purpose is often to design to permit a controlled amount of seepage to flow into drainage system and keep the phreatic time from rising to a level that would be detrimental to embankment stability. Foundation resistance to attack by both water and leachate should be established.

7. LOW EMBANKMENT DENSITY: Improper or inconsistent compaction or placement procedure, and wide variation in placement moisture are causes of low density embankment. The undesirable results of low density are many and include reduction in shear strength, increased permeability, excessive consolidation and differential settlement. All of these may be conditions leading to eventual failure of an embankment.

8. WEAK FOUNDATION : Numerous embankment failures have been caused by foundations that were not competent enough to support the embankments superimposed on them. Adequate foundation exploration programmes are carried out to provide sufficient data to identify weak conditions in the foundations. During the design phase remedial procedures are analysed to determine the most economically satisfactory method to be specified to correct the deficiencies. The method may range from embankment section modification to complete removal of the weak material in the foundation.

The successful design of a tailings dam is largely dependent on thorough evaluation of the foundation. The foundation evaluation should satisfy both structural and pollution requirements. The foundation must have adequate strength to support trends of the embankment and the hydraulic structure included in the embankment.

9. DIFFERENTIAL SETTLEMENT : Uneven settlement may be caused by improper compaction. However, the most common cause is improper foundation preparation--either from a failure to recognize and treat weak areas or failure to specialy trimming or excavation to eliminate or to substantially reduce major, start breaks in the topography along the alignment of the proposed embankment.

10. CHANGES IN PHYSICAL PROPERTIES : Though not common cause of instability in tailings embankments, changes in the physical properties of the material in the embankments can occur, primarily on the exposed downstream slope.Freezing in addition to physical and chemical weathering may produce an impervious crust on a surface that is intended to be pervious and free draining. Chemical leaching, either through normal weathering processes or through planned leaching to extract metals, may create cavities in an embankment and reduce the strength of the remaining material in the embankment.

11. LIQUEFACTION : The conclusive studies indicated that sands with a relative density of less than 60 percent are susceptible to liquefaction and sands with a relative density of 60 percent or slightly greater have only a marginal stability against liquefaction. The design should take organisation of large volume of water and slimes.

12. COLLAPSE OF STRUCTURE : Collapse of an intake structure to a decant pipe would impair the ability to control the water surface and the embankment could overtop during a period of high inflow. A collapsed decant pipe would prevent control or the water surface, and could create a path for piping under the dam and lead to eventual failure of the embankment. Adequately designed structures to support the anticipated ultimate load, specific instructions for proper installation, followed by proper installation during construction will reduce such failure.

13. EXTENDED DEPOSITION OF TAILINGS : Continued deposition of tailings at one location along an embankment can produce an undesirable increase in the saturation level resulting in a decrease in the stability. Design provisions cannot provide safeguards against all types of detrimental operational procedures without costly over design. Therefore, adherence to proper operational procedures is essential to prevent development of critical conditions in adequately designed structures. Facilities should be provided to permit shifting of deposition to points distant enough to reduce the rise in the phreatic surface which may occur due to continuous extensive deposition.

C. GEOTECHNICAL INVESTIGATIONS

1. General : Information relating to foundation conditions and natural materials available for construction is essential for design of a tailings dam. Preliminary investigations are normally made during the planning phase with all the available collected data.

2. An Investigation Programme : The geological investigation required may be summarised as follows :

i) geological and geotechnical reconnaissance on the site,

ii) in-situ tests,

iii) laboratory tests and

iv) data from similar sites.

I) GEOLOGICAL AND GEOTECHNICAL RECONNAISSANCE ON THE SITE : The site inspections by a geologist and a geotechnical engineer permit them to define and set the investigation programmes which in their opinion are necessary by pits, and trenches. All natural anomalies like artesian phenomena, smelling clays or artificial ones like mining works are searched for and identified.

ii) IN-SITU TESTS : In-situ tests as below are carried out partly at least during the drilling programme.

a) The installation of piezometers to measure existing pressure at different times of the year, before and after rainfall seasons,

b) In some materials, carrying out water tests at various depths during drilling to determine soil and rock permeabilities by injection or preferably by extraction of water, with control piezometers located at various distances away from the pumping well.

c) In-situ testing in boreholes permetrometers or pressure meters vane tester to give strength and deformation parameters of the natural soil,

d) Measurement of in-situ density with sand or with membrane densimeter.

The drilling programme should include deep bores to check on mineral deposits that might lie below the proposed site, the extraction of which could affect future stability. The foundation holes supplemented to the planning phase drilling, should be drilled a minimum of 1.5 m into firm rock to ascertain that a firm foundation has been reached especially if large boulders are expected in the foundation above the bedrock.

iii) LABORATORY TESTS : Laboratory tests are to measure the characteristics like chemical analysis, strength and deformation characteristics. Sufficient test data are necessary to permit determination of representative strength values and physical characteristics of the foundation and construction materials to be involved in the dam embankment and disposal site. Laboratory tests may also be performed on samples previously subjected to accelerated pre-ageing. Such tests do not give in most of the cases the expected final strength to be considered in the stability calculations.

iv) DATA FROM SIMILAR SITE : While there is similarity between certain aspects of water retaining and tailings dams, the specific design requirements for the latter requires specialized knowledge of experienced engineers in this field.

The geotechnical investigations should be followed, classified and presented by an experienced observer, capable of modifying the investigations programme to adapt them to the conditions found on the site.

Besides, geotechnical investigations, geophysical investigations like seismic survey and resistivity survey are necessary to be carried out.

3. Detailed site geology :

A report containing all of the foundation and borrow explorations displayed in cross-section along with detailed descriptions of the soil and rock formations at the dam site should be compiled for design use. The report should include geologic plan showing all known faults at the site and surrounding area and should also contain all available permeability, groundwater and seismicity data.

D. CONSTRUCTION MATERIALS

1. General : Construction of a tailings dam involves use of material from required excavation mill tailings or from borrowed materials. Required excavation includes mine development waste, road and other constructions. Borrowed materials are obtained from borrow area excavation and are used to supplement materials from required excavation for construction of a dam. However, as the heights of the tailings dam increase, the stability of the embankments is often inadequate, therefore greater attention must be paid to the strength parameters associated with the present day mill tailings as well as the construction procedures, the design configuration of embankment and the internal seepage control drains included in the structure. Anticipated use of mine waste and tailings is dependent upon whether or not the physical characteristics of these materials meet the requirements of the retaining embankment regarding permeability and strength. Tailings segregation by cycloning and borrowing the construction materials has increased the cost of tailings dam.

2. Types of materials

(a) MINE WASTE : Mine waste is generated by mine development work and may consist of soil and rock or a mixture of both. Gradation of the mine waste may range from a predominantly minus 200 sieve size (clay and silt) to rock material of cobble and boulder size. Prior to extensive use of waste material for construction purposes, appropriate soil test should be made on representative samples to determine strength values of the material. The material sizes may range from medium sized sand to fine silt. The finer fraction is unsuitable for dam construction.

Coarse grained soils are larger than the number 200 sieve size (74 microns) and they are further divided as follows :

Gravel	Size
Coarse	7.5 cm to 2.5 cm.
Medium	2.5 cm to 9 mm.
Fine	9 mm to 0.25 mm.
	(50 percent or more of the coarse fraction passes the No.4 sieve)

Sand	Size
Coarse	2.0 to 0.6 mm
Medium	0.6 to 0.2 mm
Fine	0.2 to 0.06 mm

Fine grained soils are those of which 50 percent or more pass the number 200 sieve and with the following sub-divisions :

Silt	Size
Coarse	0.6 to 0.02 mm
Medium	0.02 to 0.006 mm
Fine	0.006 to 0.002 mm

Clay	Size
Coarse	2.0 to 0.6 microns
Medium	0.6 to 0.2 microns
Colloids	0.2 to 0.0 microns

In addition, the material should be tested for its durability when subjected to contact with tailings fluids. Waste material when used in construction, should be assigned the lowest strength value as determined by testing. The test result may not indicate the final strength values that may be reached, therefore, material displaying poor durability should not be used in critical ores.

Permeability of mine waste must be ascertained to estimate the amount of seepage, potential of piping and if necessary, methods of control. The method and sequence of construction must be developed and the availability of the mine waste to meet the construction schedule must also be assessed.

(b) TAILINGS : Mill tailings are a product of milling and any subsequent processing of ore. Generally, metal mine tailings include material mineralogically similar to that of corresponding parent ore materials. It should be remembered that tailings being man made, the materials are much more uniform in their characteristics than are most natural deposits. Chemical properties and special properties such as radioactivity, the grain size distribution or gradation of the tailings is an important property in determining the utility of the material in the construction.

Tailings slurries are usually transported from the mill to the tailings pond by pipeline or flume. For size separation, two methods i.e. by spigotting and cycloning are in common use. In the spigotting method, the slurry on the surface of the tailings pond forms a gently sloping beach where the coarsest fraction is deposited progressively towards the centre of the disposal area. In the second method of cycloning, the separation is to use cyclones. The resulting gradation usually provides a sand from 10 to 20 percent particle sizes passing the no. 200 sieve. This will depend on the initial grind gradation, size of cyclones and rate of cycloning. If a coarser gradation is required for special purposes, double cycloning will further reduce the fines contents.

Tests are required to determine the permeability and shear strength of the tailings that will be used in the dam. These tests must be performed at various moisture and density conditions. If the dam will be very large it is recommended that the shear strength be determined under dynamic load conditions.

The tailings resulting from a concentrating process consist of uniform, sand-sized grains with a rather small span of sizes (Fig. 4)

(c) BORROW MATERIALS : Materials other than tailings and mine waste that have to be obtained from a natural source are usually excavated from a nearby borrow area. Soils available may range from fine grained silts and clays to sand, gravel and cobbles. An ideal situation would be to have an ample supply of all types of borrow materials. A good knowledge of the availability of borrow materials is necessary so that the designer can produce a design that will utilize available materials and still fulfill criteria established for the construction.

It is necessary to use borrow materials located near the dam site. If possible these should be obtained from the reservoir area since this will increase the reservoir storage capacity. Laboratory testing of the borrow materials samples is required to determine the shear strength, stress-strain relationship, compressibility, grain size and permeability.

E. SEEPAGE CONTROL

1. General

All seepage through a tailings embankment cannot be eliminated. Therefore, the design should include adequate filters and drains to control seepage. Tailings embankments are usually constructed in stages continuing through the size of the mine. Often changes in the orebody and milling processes will result in changes in the tailings disposal system. Thus the original design or for the seepage control must be flexible and capable of adjustment to incorporate the changes. The seepage will depend upon the permeability of the materials and elevation difference between the pond surface and the point of emergence of the seep age. Since the difference in elevation increases with deposition of tailings and impervious barriers cannot be placed after construction, therefore, it is imperative that seepage control be incorporated into the design.

The rate of seepage through the embankment or foundation can be estimated from the equation.

$$q = (h)^{nf/nd}$$

Where q = the rate of seepage per unit length of embankment,

nf= number of flow paths,

nd= number of equipotential drops

and

h = difference in piezometric elevation between the water in the pond and the location of seepage exit.

The values of nf and nd are obtained from the flow net. If zones of variable permeability occur they must be taken into account in the development of the flow net.

The seepage water constitutes containment and therefore the value of seepage must be determined to evaluate the effluence on adjacent land and water sources. If potential contamination is above allowable limits the design must incorporate procedures to prevent leakage, to maintain it within tolerable limits and or remove the contaminants.

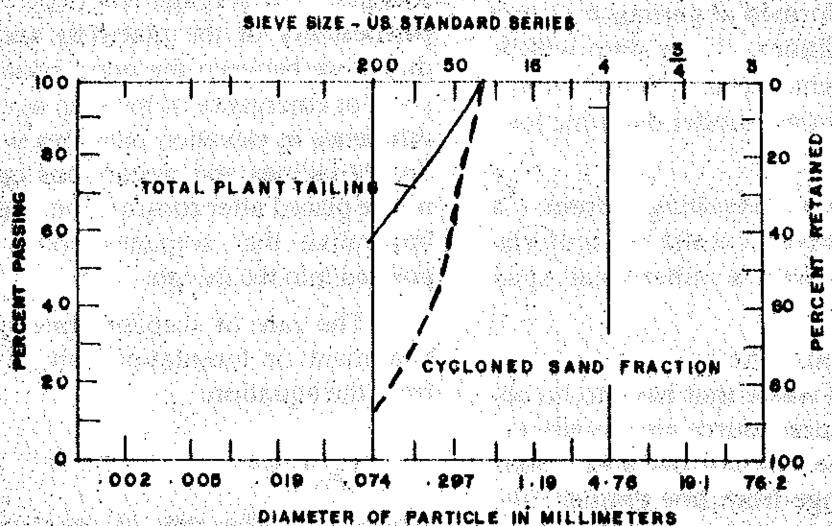


Figure - 4 Uniformity of sized grains with minimal span of grain sizes.

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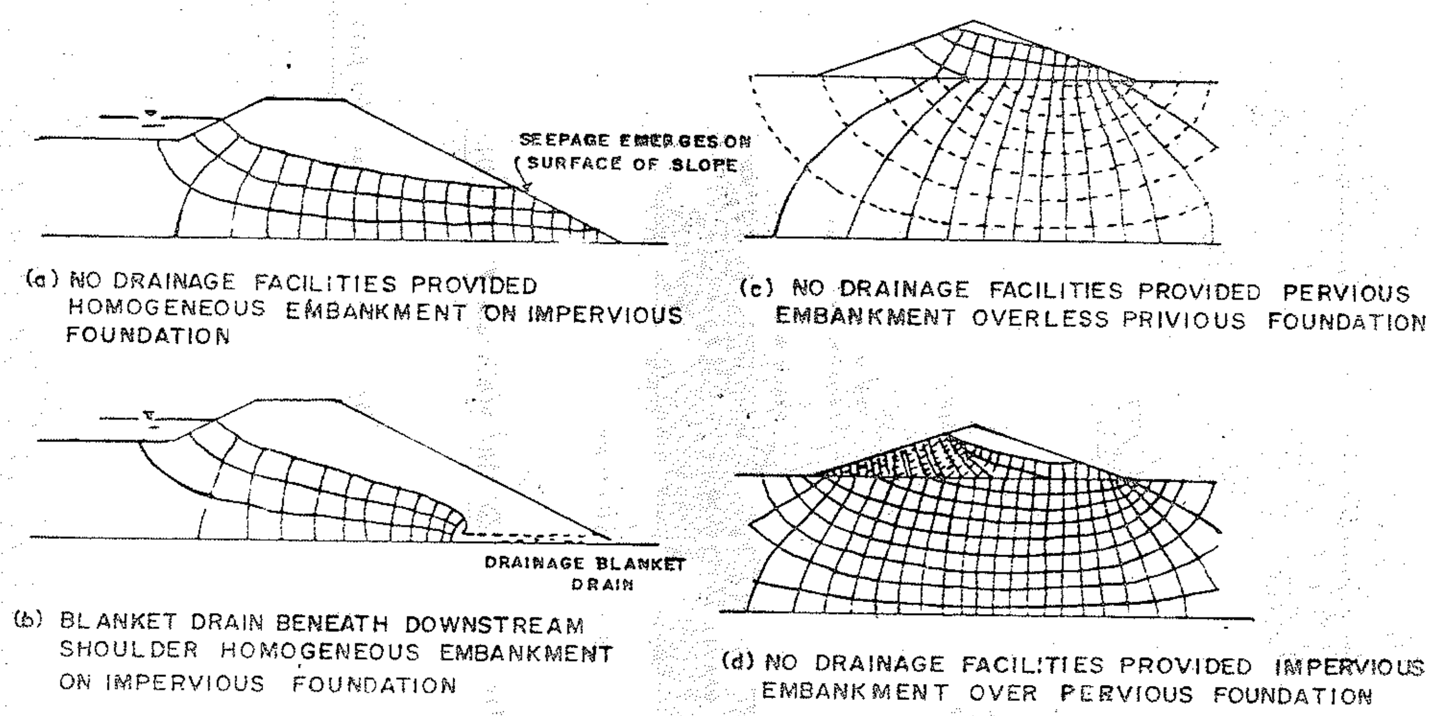

Figure-5 Typical seepage flow nets.

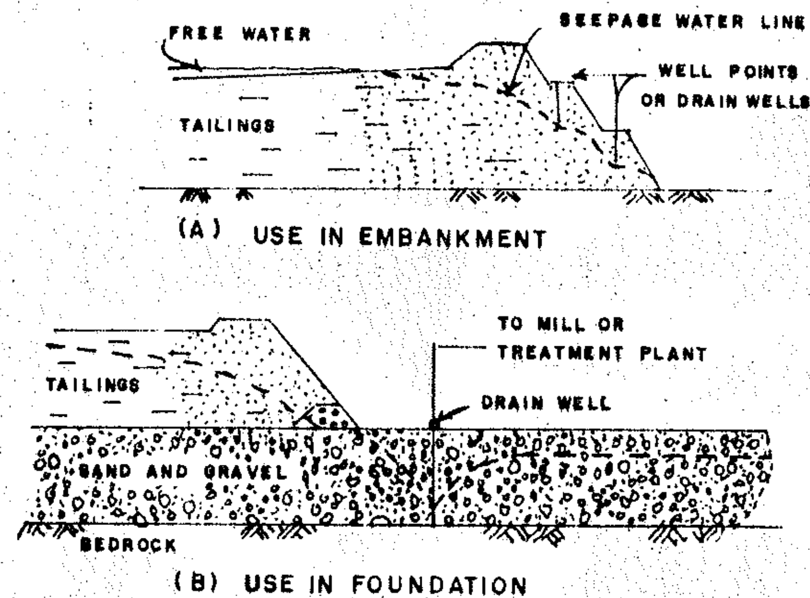

Figure - 6 Drain well construction

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2. Seepage Control Processes

Seepage control is based on two fundamental processes, viz.

i) those that reduce seepage quantity by restricting seepage flow, and

ii) those that use drainage methods to discharge the seepage without the danger of piping material or build up of a high phreatic surface.

Since the location of the phreatic surface is dependent upon permeability pervious tailings embankment is commmonly used to promote drainage, lower the phreatic surface and maintain a stable embankment. A relatively impervious tailings embankment must be used where it is necessary to reduce the amount of water leaving the component as seepage to protect water quality.

The drainage system of large embankment should be separated into several distinct parts to allow the discharge to be measured separately thus narrowing down the location of any change of conditions. An adequately designed drainage system must be based upon the estimated seepage flow rate. The most common method of estimating seepage rates is the use of flow nets. Typical flow nets are shown in Fig. 5. If the volume of seepage is expected to be moderate to heavy, blanket drains are preferred. If the potential seepage is small strip drain comprising pervious drain material may be sufficient. Blanket drains or strip drains are placed prior to placement of the dam embankment. The thickness of the drains should never be less than 30 cm thick and should preferably be at least 1 m thick.

When the tailings are radioactive or the tailings contain toxic material, it becomes necessary to limit seepage into the embankment to the minimum so as to prevent contaminated water adverse to environment.

3. Drainage wells

Drainage wells can also be used in controlling seepage outflow. These wells can be installed in the embankment as shown in Fig. 6. Drain wells can also be used to control water flow in the foundation by intercepting seepage water coming from the tailings structure as shown in Fig. 6 (B). In order to effectively control foundation seepage, a line of injection wells could be installed immediately down stream from the time of drain wells to form hydraulic barrier.

The coarse tailings are cohesionless and very suspectible to the erosion action of the water and seepage flow. This is why great attention must be paid to the protection of the tailings by the filters at any place where erosion and piping could appear. Wind and rain cannot be controlled. Therefore surface erosion is a problems, special control or construction methods may be considered while planning of the design of tailings dam.

Chapter-5

CONSTRUCTION, OPERATION AND MAINTENANCE

A. GENERAL

During the design phase, decisions are made based on the expected gradation of the mill tailings. A design should be selected on the guidelines contained in the previous chapters about consideration of prevention of water pollution, proper handling of the tailings, stability of the embankment, seepage control, drainage flow, ground water infiltration, height of the embankment and reclamation of the site.

The engineer who plans and designs any tailings dam must assess the sequence, timings, method of placement and stability control programme during construction to ensure that the requirements of practicability and economics are met. Competent engineering supervision should always be specified for construction of the starter dam and periodic essentiality inspections by a stability specialist.

The classification for size based on the height of the dam and storage capacity should be in accordance with the Table 5.1. Size classification may be determined by either storage or height or whichever gives the larger size.

Table 5.1 : Size classification Impoundments

Category	Storage capacity (cu.m.)	Height (m.)
i)Small	1,233,500-61,700	12 & 7.6
ii)Intermediate	1,233,500-61,700	12 & 30.5
iii)Large	61,700	30.5

(Source : Manual on tailings dams and dumps. Report prepared by M/s G.H.H. Legge, G.L.Heriteau, ADM Penman and W.A.Wahler for the ICOLD Committee on Mine and Industrial Tailings Dams and approved by the 50th Executive Meeting, Rio De Janerio, April, 1982, Bulletin -45, Page 71).

The cost of compaction will depend on the equipment used. Cohesionless sands, sandy gravels or fine rock are most effectively compacted using vibrating drum or heavy pneumatic rollers. Cohesive clays, silt-clays are most effectively compacted using grid or sheep foot roller. The thickness of the layers of cohesive soil should not exceed about 45 cm for effective compaction and for non-cohesive soils, about 60 cm.

Field tests must be made during construction to ensure that the design densities are obtained. Records should be kept on all tests results. When test results indicate non-compliance with specifications, corrective measures should be implemented immediately. This may consist of removal and recompaction of material, applying additional compaction, adding water or drying out material.

Regular sampling and testing of all the construction materials is recommended throughout the development of the disposal facility. This provides records for future evaluation of material performance and for regulating agencies. Most important material sampling and testing during construction increases assurance that the work is being done in compliance with design requirements.

B. INITIAL CONSTRUCTION

1. General

During the planning and design phases, foundation and borrow explorations and testing of sampled materials will provide information to determine the source of materials for the embankment construction and the necessary foundation preparation required for construction. The extent and type of foundation preparation required will vary considerably and will depend upon the height of the dam. If the dam is to be high dam (over 30 m in height) more extensive preparation will be required than for a lower dam. Unsatisfactory materials such as organic materials, loose material, weak, highly compressible material, pockets of pervious sand, gravel and cobbles and boulders, etc. should be removed.

2. Starter Dam

After determining the use of the material for construction of the tailings dam, the method to be adopted for tailings pond/impoundment is confirmed. If tailings are employed for construction, three methods are in common use. They are viz., upstream method, downstream method and centreline method, and depending upon the adoption out of these methods a type of starter dam i.e. pervious or impervious starter dam can be constructed accordingly.

Adequate compaction, correct moisture content and use of proper construction material are commonly recognised standards that must be attained and consistently maintained during the entire construction phase. Successful construction depends on the adequacy of the site preparation and the quality the construction embodied in the starter dam.

While serving its purpose as a starter dam it must also perform as a barrier against migration of tailings through it, must be an effective barrier against undue seepage and must also be capable of resisting the bull pressure of supersaturated tailings.

a) PERVIOUS STARTER DAM : Stripping of all organic and unsatisfactory foundation material and the removal of all material that would create an unstable foundation is required. Pervious material inherent in the foundation should be excavated if the permeability of the material is great enough to create a piping problem under the dam.

Although a pervious embankment is designed to permit seepage through the embankment, the designed permeability is obtained by prudent use of gradation qualities of the material during the design phase and is not obtained by permitting placement of material at low density during construction. Therefore, sandy and gravelly mixtures should be placed at 95 percent of proctor maximum density and clean sand and gravels should be placed at 65 to 70 percent relative density with the lower valve recommended for use in low seismicity areas. The clean granular materials, containing less than 10 percent of materials passing the 200 sieve size can be satisfactorily compacted by vibratory or rubber tyred rollers. Materials more than 10 percent passing the 200 sieve size, when compacted create relatively impervious embankment and should not be used in pervious dams or in pervious zones of a zoned embankment. Proper placement can be obtained by ascertaining that placement moisture content is correct, and an adequate number of roller passes are made with the proper equipment. Construction of a designed pervious dam requires no less adherence to established construction procedures than the con struction of an impervious dam keeping in mind that a much higher tailings dam will be resting on the starter dam.

b. IMPERVIOUS STARTER DAM : During the planning and design phases, if the downstream method of construction was selected or explorations have established the availability of only impervious material, an impervious starter dam should be built. After the required foundation preparations have been made, construction of the required embankment can be started. Construction of the embankment should be to 95 percent of proctor maximum density which can be readily attained by maintaining the proper near optimum placement moisture, making a sufficient number of roller passes limiting the thickness of the loose material so that the roller teeth will penetrate to the pervious placed layer, and using construction equipment capable of producing the required results. As with the construction of a pervious starter dam, supervision of con struction should be supervised by experienced engineers in the construction of dam embankments.

3. Embankment with an Impermeable Liner

It is important to realize that an unstable structure cannot be made stable by the addition of lining system. Any structure such as inlet pipes, decants and headwalls should be completed prior to placement of the liner.To accomplish the design intention, an impermeable liner must be properly constructed or installed. No less important is the high quality workmanship required during construction and/or installation of the liner.

(a) CLAY : The effectiveness of a compacted clay liner is dependent upon the impervious qualities of the construction material, thickness of the liner and quality of construction. Compaction should be done by sheep foot roller with tamping feet long enough to penetrate to the imperviously compacted layer and create a bending action between the lower layer and the layer being compacted. The thickness of the layer of loose material should be limited to ensure penetration and the weight of the roller should be adequate to satisfactorily compact the liner material to a minimum of 95 per-cent of proctor maximum density. Placement moisture of the material should be near optimum and a sufficient number of density and moisture tests should be made and records should be kept of the test data including the location of the tests.

(b) CONCRETE LINING : Concrete lining has been extensively used to line for tailings dams that are compactible with the concrete.

(c) SOIL CEMENT : The construction of the soil-cement lining can be accomplished by road construction equipment and paving or embankment placement methods. Soil cement for small projects can be mixed in place, however, on large projects, the soil, cement and water are mixed at a central plant. Accurate calibration of the plant prior to construction is essential besides periodic rechecks of the calibration are also required.

Compaction of the soil-cement can be done by sheep foot rollers, steel-wheel rollers or pneumatic-tyre rollers. All permanently bonded surfaces should be kept moist for 7 days to permit proper curing.

4. Site Preparation

Some of the main items of work that must be performed to prepare the site for the construction of tailings dam are as follows :

(a) FOUNDATION STRIPPING : Even the lowest embankments usually require a minimal amount of stripping to remove organic material, shrubs and small trees from the area to be occupied by the embankment. Depth of stripping will vary according to site conditions but will usually extend to the depth of the top soil. Stripping is normally accomplished by bulldozers, self-propelled scrappers.

(b) FOUNDATION EXCAVATION : The requirement for removing materi al below the depth of normal stripping is classed as foundation excavation. Such excavation is usually required to remove unde sirable material such as organic matter, loose material, pockets of pervious material and muck.

If the stripping or foundation excavation exposes the bed rock, the rock surface should be cleaned and inspected for open cracks, fissures, fault planes and jointing that may require grouting or surface sealing to prevent piping. For impoundment designed to retain fluids and restricted seepage into the foundation, care should be taken to avoid removing any in place soil that is acting as a natural blanket from any foundation area that may be exposed to the impounded fluid. A thorough foundation investigation may be required to establish that the natural blanket material will not pipe into immediately underlying fractured rock or pervious soils. If the embankment has an upstream pervious zone, removal of natural material blanket under the pervious zone should be avoided unless a positive cut-off is to be constructed under the embankment.

(c) CUT-OFF TRENCH EXCAVATION : When an embankment is located on a shallow, relatively pervious alluvium ground, a cut-off trench should be constructed to control the seepage. The trench is normally excavated with 1 : 1 side slopes and with minimum bottom width of 6 m to accommodate the normally used equipment. The trench excavation is extended to an underlying impervious soil stratum or to bedrock.

Ground water may be encountered in the cut-off trench excavation and dewatering may be required. Seepage removal is necessary to prepare the trench for backfilling with impervious fill material.

(d) DECANT PIPE AND INTAKE STRUCTURES : Decant pipes are usually located on the floor of the empoundment and pass under the dam to discharge the decanted water into a holding pond for treatment or to be pumped back to the concentrator water storage pond. The pipe is subjected to the weight of the overlying tailings and water, and an adequate foundation for the pipe is necessary to prevent differential settlement of the line which, if excessive can rupture the pipe and cause complete failure of the decant system. If the pipe is located on a soil foundation, excavation or preparation should provide a foundation that consolidation tests have confirmed to be adequate for the planned superimposed load. Intake lower structure should be placed on rock foundation or on adequately compacted fill that will support the structure without settling. If the decant pipe is to be placed on a foundation of bedrock then top soil, loose soil and loose rock should be removed from the alignment and 15 cm of bedding placed to assure a firm support to prevent differential settlement and cracking which can result in leaking of the tailings into the decant causes subsequent failure. Foundations for intake structures constructed up the side slope of the impounding reservoir should also be prepared in such a manner.

(e) DRAINS : Part of the preparation of a site for embankment construction is the locating and construction of drains. A relatively impervious starter dam would require drainage on the upstream side. Further more, the use of a pervious starter dam does not preclude the need for drains, since a pervious starter dam could substantially decrease in permeability and without a backup drainage system the phreatic line could rise.

The minimum thickness of drain and filter material must be established by design criteria but the ultimate thickness will vary depending upon whether the filter is placed by hand or through equipment.

Steeply inclined drains, chimney drains and/or filters should be wide enough to accommodate the equipment to be used for construction. To counteract the contamination that occurs during construction, even-hand placed sloping drains and filters should be less than one metre thick. Hand placed filters around pipe drains should be at least 15 cm thick.

Good construction practice should also be followed with fabric filters even though they have factory controlled uniformity in tensile strength and are simpler to install. The fabric should be placed within the trench in such a manner so as to obtain a high soil-to-fabric contact area and as wrinkle free as possible.

1. *Blanket drains* : All depressions in the area to be occupied by the blanket drain should be drained of standing water, filled with blanket material, compacted and the surface smoothed and graded to slope downstream. The surface upon which the blanket filter material and blanket is to be placed should be compacted so that only minimum amount of pervious material will be wasted by becoming embedded into subgrade. All pervious material should be placed in a manner so as to prevent segregation. The filter layer should be evenly and properly compacted. To assure that adequate compaction (70 percent relative density) has been obtained, relative density tests should be made in the material at regular intervals.

2. *Strip drains* : Strip drains are the same as blanket drains except that they are narrow strips of drain material used in lieu of blanket drain. The scarcity of suitable drain blanket material or high cost of blanket material may dictate the use of strip drains. The locations and placement of the drains should be reaffirmed after the foundation has been exposed by stripping and foundation excavation in order to maximize the effectiveness of the drains.

3. *Pipe Drains* : Pipe drains normally consist of perforated pipe placed in a narrow trench and surrounded by a two-layer filter with the material in contact with the pipe being of sufficient particle size to material size so that material will not enter or clog the perforations in metal pipe or the joint openings in clay or concrete tile. Open join pipes should be properly aligned and well bedded in the filter material to prevent movement that would open the joints excessively. All drain pipes must have adequate strength to withstand the imposed load (Fig. 7).

The portion of the drain that lies underneath the starter dam should not be perforated and should not be fitted with cut-off (seepage) collars. Special care in compacting backfill should include the entire area delimited by the cut-off collars. Pipe drains should not be installed under a tailings embankment which has a compressible foundation subject to differential settlements that may cause the pipe to open at the joints or break as these failures could cause interval erosion.

4. *Finger drains* : Finger drains are usually narrow in width and may only be slightly wider than a pipe drain installation. Finger drains may be placed in a trench similar to trench drains or placed on the foundation surface. To be effective, the drains must be carefully installed to keep the coarse water-carrying core of the finger drain from being exclusively infiltrated by the surrounding finer pervious filter and base material. Finger drains should be protected from vehicular and equipment travel by constructing protective pads over the drains at equipment crossings and by restricting crossing traffic to these locations until sufficient embankment is built up above the drains. Finger drains in the foundation should not be used to drain seepage flowing over a wide area but should be restricted to provide drainage of limited areas such as an active spring in a localized area of the abutment or foundation.

5. Materials

For initial construction, usually two types of material are available i.e. mine development waste and borrow materials.

(a) MINE DEVELOPMENT WASTE : Waste material may consist of soil or rock material or a mixture of both. Development waste is often an economical source of embankment construction material. In the situation where considerable development waste is to be excavated before actual mining, the waste may be placed directly in the initial construction of embankment. Proper utilization of the waste will be dependent upon the type of material produced and the properties of the material as indicated by the test results.

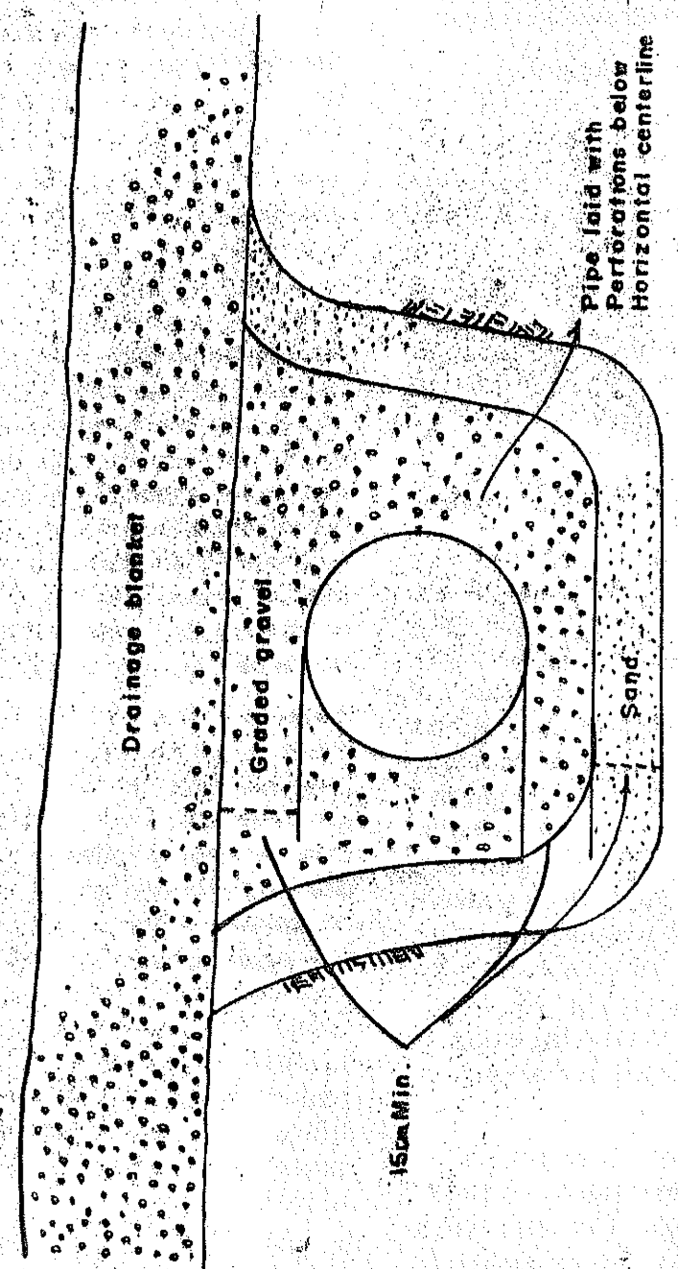

Figure-7 Pipe drain

(b) BORROW MATERIALS : The use of borrow materials is usually stipulated in the waste embankment design due to unavailability of other suitable sources of material either because of timing or the unsuitability of available mine development waste materials. Borrow materials are generally used to construct starter dam or water storage dams.

6. Factors Affecting Embankment Construction :

After the embankment site has been prepared, initial embankment construction usually involves constructions of a starter dam built with materials other than tailings by the use of construction equipment. As the requirement for more stable equipment increases more tailing embankments will be raised incrementally by the use of conventional dam building equipment and compaction technique.

Some of the factors affecting embankment constructions are :

(a) TYPE OF MATERIAL : The type or classification of material used for construction (clay, silt, clayee sand, silty sand, sand gravel, cobbels and rock) will govern the selection of the type of compaction equipment to be used and the location within the embankment where the material should be placed. This location is determined during design. For example coarse material is generally placed outside and the impervious material interior in a zoned embankment; however, when utilizing tailings for construction the coarser sand is segregated to the downstream side and is used to raise the embankment and the finer material and slimes are directed upstream.

(b) TYPE OF COMPACTION : Compaction is usually accomplished by impact, vibration or a combination of both. The compaction equipment commonly used in embankment construction which includes, crawler tractor, grid roller, pneumatic tyred roller, scrapers, sheep foot rollers and vibrating plate compactor. Pneumatic-tyred rollers provide good compaction of cohessionless soils including sands and gravels. Pneumatic tyred rollers should not be used in materials where deep rutting occurs or laminated layers result from the smooth surfaces created between layers by rubber-tyres.

There is no equipment suited best for the various soil types, but generally sheepfoot rollers are preferred for cohesive soils where bonding between layers is desired.

(c) WEIGHT OF COMPACTOR : The effectiveness and/or appropriateness of compaction equipment depends on several factors, one of which is weight of equipment. Total weight is significant in that a roller or crawler tractor will not deliver the compactive effort unless the total weight is adequate. Tailings with more than 20 percent minus 200 mesh material being used for embankment construction may be compacted by either a sheepfoot or a modified sheepfoot which has some of the feet removed and flat plates 20 to 25 cm diameter welded on the remaining feet. This modified version is best for silty soils of low cohesion.

(d) PLACEMENT MOISTURE : The moisture content of a material is most probably the factor that has the greatest influence on the properties of a soil. Clean, cohesionless material such as tailings sand will normally drain rapidly enough to permit satisfactory compaction within a short time after spigotting or cycloning. However, most tailings sand seldom contain less than 8 percent minus 200 mesh material and these materials often retain moisture in quantities greater than optimum making compaction difficult or unacceptable. Proper moisture content in a material is necessary to obtain desired densities.

(e) THICKNESS OF LOOSE LIFTS : In addition to inadequate compaction and improper moisture, another cause of low densities is the failure to spread the loose material into sufficiently thin lifts to enable the compactive effort to be distributed through the full thickness of the lift.

Placing thin loose lifts of material is specially cared when compacting in a confined area with hand held tampers.

If proper densities are not being obtained the following items should be checked :

i) Measure the thickness of the spread layers or loose material. Loose lifts of cohesive material in excess of 25 to 30 cm. generally are too thick for proper compaction. Pervious, free draining material may be placed in lifts ranging from 30 to 90 cm.

ii) Determine the placement moisture of the material and compare the value with the optimum moisture content determined by laboratory moisture density tests on samples of the same material.

iii) If the embankment construction material is being spread in loose lifts of the proper thickness and the moisture content is satisfactory, then the weight of the roller or crawler tractor should be checked. This is to determine whether the compactive efforts being applied are adequate.

iv) If the loose lifts thickness, moisture content and weight or the compacting equipment are all satisfactory, the number of passes or the compacting equipment per layer should be increased and the densities rechecked.

Once proper compaction conditions and adequate compaction are established and followed the quality of the embankment construction is reasonably assured.

C. CONSTRUCTION OF STRUCTURES

1. General

Every structure built up must have some kind of foundation, no matter how simple it may be. The hydraulic structures used with tailings are usually relatively small and consequently foundation pressures are quite low. However, if the structure is under a large embankment, foundation consolidation may cause undesirable structural settlement which could result in opening pipe joints or breaking the pipe, which might allow interval erosion.

2. DRAINAGE PIPE

Drainage pipe is often placed within portion of the tailings embankment to convey seepage to an acceptable discharge point. Drain pipe can be plastic, concrete or asbestos bonded corrugated metal pipe. The plastic and concrete pipes can be either plain or perforated. The asbestos bounded should be perforated and laid with closed joints. The pipes should be designed to withstand the maximum anticipated load of the overlying tailings.

Perforated pipe should normally be placed down (Fig. 7). This causes the water to flow up into the pipe, thus minimizing the chance of carrying fines into the pipe and blocking flow. For installation in very fine materials, a double layer filter and granular drain may be required to prevent material from entering the perforations. The diameter of the perforations should not be larger than one half of the 85 percent size of the drainage material surrounding the pipe.

The pipe trench should be kept free of water which might impair construction of the drainage system. The perforated pipe should be embedded in graded sand and graded gravel and care should be exercised to obtain true alignment and grade.

The drain pipes should be placed on a slope sufficient to keep them clean at least minus 0.5 percent preferably from one per cent to 2 percent and with no adverse slope.

Pipe drains can be very satisfactory with a good foundation and careful construction but blanket or strip drains may be more safe. A perforated pipe parallel to the upstream toe of the starter dam is the simplest with one or more solid pipes through the dam to the downstream toe.

If the foundation beneath a tailings embankment is compressible and differential settlement is possible, pipe drains should be avoided. The stresses may result in opening pipe joints or breaking the pipe which might allow internal erosion.

3. Decants and Culverts

Decant pipes and conduits are used to transport decanted water or flood water beneath the embankment, or as culvert spillways. Drop inlets to decant conduits require special bedding to develop the same foundation bearing values as developed under the conduits. Decant lines should not be built through the portion of the embankment constructed with tailings but should be placed on the firm foundation. Decant lines properly constructed on natural ground under starter dams have less risk of failure from seepage and piping. Seepage collars should be used on all pipes and conduits in an impounding embankment. All joints in the decant line should be watertight so that water cannot enter the embankment when pressure flow develops. When pipe is to be installed in rock, the foundation should be over excavated and replaced with the compacted gravel to provide more uniform bearing pressure for the pipe.

The backfilling and compaction of material around the pipe should be carried out in layers of 15 to 30 cm on each side of the pipe simultaneously. The backfill should be compacted to 30 cm minimum over the top of the pipe and the collars to prevent damage from equipment travel.

4. Concrete Structures

Structures which may be totally or partially constructed of concrete includes decants spillways, culverts and various drainage structures. The problems of deterioration from chemical attack and appropriate preventive measures are crucial in the consideration of concrete for any structure which may be in contact with tailings or leachate from tailings. Chemical tailing is recommended to determine the potential acidic and sulphate contents of tailings. Ground water near tailing disposal site may contain corrosive materials and cause deterioration of the concrete even if the structure is not in direct contact with tailings.

Minimum protective measures for concrete mixtures should includs :

i) Use of good cement,
ii) Use of low water-cement ratio,
iii) Use of rich mixes,
iv) Use of air entrainment additives,
v) Provision of extra cover over reinforcement,
vi) Vibration of concrete during pouring operation to increase density, and
vii) Use of good curing procedure.

5. Construction During Operation

a) WATER STORAGE DAM : Unless the water storage dam is con structed to full height prior to deposition of tailings some embankment construction will occur during operations. If the originally constructed width of the base of the embankment is not wide enough to permit the dam to be completed by continuing the slope of full height, some of the fill may have to be placed against the downstream slope in buttress fashion to maintain stability of the slope. When construction is planned for continuous operation, the capacity created by the portion of embankment constructed prior to start of mill, tailings disposal must be large enough to contain all the tailings produced without encroaching on the embankment under construction.

i) *Mine development waste* : In cases where the scheduled continuing embankment construction material is mine development waste, the supply of construction material may be interrupted or be unavoidably delayed. For this reason, construction should be scheduled to provide reserve storage capacity sufficient to store a year or more of tailings production.

ii) *Borrow materials* : A borrow area can be a reliable source of embankment materials provided ample explorations have been made to prove out the quantity available. Water storage dam embankments may be constructed entirely of borrow materials or borrow materials in combination with mine development waste. The mate rial dumped in piles may be spread evenly by bulldozers prior to compaction.

b) UPSTREAM CONSTRUCTION WITH SPIGOTS :- This is most widely used method of constructing tailings embankments. The popularity has been due to the economy of the method and stability of the em bankments which have not been exceedingly high compared to the heights of the present day large disposal embankments. Construction procedures that produce embankments of greater strength and uniformity of quality construction must be adopted and diligently followed. Where deposition is by spigotting and separation of tailings particles is by gravity, close attention must be paid to the gradation of mill grind and the pulp density. Figure 8 shows gradations of tailings containing 38 to 40 percent minus 200 mesh material discharged at 30 percent pulp density which produces sand with 10 to 15 percent minus 200 mesh. Figure 9 shows grada tion of the tailings containing 55 to 60 percent minus 200 mesh material discharged at 48 to 50 percent pulp density which produces very little separation of the sand and slime on the beach resulting in a very poor dyke building material. Tailings with this gradation should be cycloned or spigotted at a much lower pulp density to achieve better separation of the sand from the slime.

The common method of spigotting is to lay a header pipe along the upstream edge of the completed starter dam with the spigot valves located so as not to discharge from the bottom of the header pipe. If the valve intakes are near the bottom of the header pipe, the first few spigots in a series would discharge a disproportionate amount of the larger particles resulting in a poor distribution of the sand on the beach. Spacing of the valves will vary with the total tonnage and the size of the spigot pipe ranging from 3 to 5 cm for 5 cm pipe and upto 15 m for 10 to 15 cm pipe. Proper spacing of the spigot valves aids in preventing pockets from forming between the cones of sand build up at the end of the spigots, such pockets allow slime carrying water to pond and permit silt and clay to settle out near the crest of the embankment. When the tailings area filled to the top of the starter dam, the pipes are removed. The sand is allowed to drain and is then used to build a dam 2.5 to 3 m high with a 2 or 3 to 1 slope (or flatter is specified by design) which extends on the downstream side approximately to the header pipe.The compaction of this construction should be at least 95 percent of 'standard Proctor maximum. The sand beach must be allowed time to drain before the sand can be moved. This may require 1 to 2 months depending on climate and the permeability of the material.For this reason another tailings area is needed to accommodate production when a dam is being raised. The spigot pipes are moved up the slope of the dam and over the top to fill again the area. There should be sufficient hydraulic head on the pipeline to permit the embankment to be raised 10 m or more before it is necessary to construct a new berm wide enough for a roadway and the header pipe at the higher elevation. The operation of relo cating the header pipe and spigots to a higher elevation is more costly and requires much more time than raising the embankment for 3 m lift between relocations of the header pipe. During relocation of the header, this tailing pond or at least this particular area of the pond is not available for tailings disposal. Consequently, during the planning phase, provisions must be established in the overall schedule

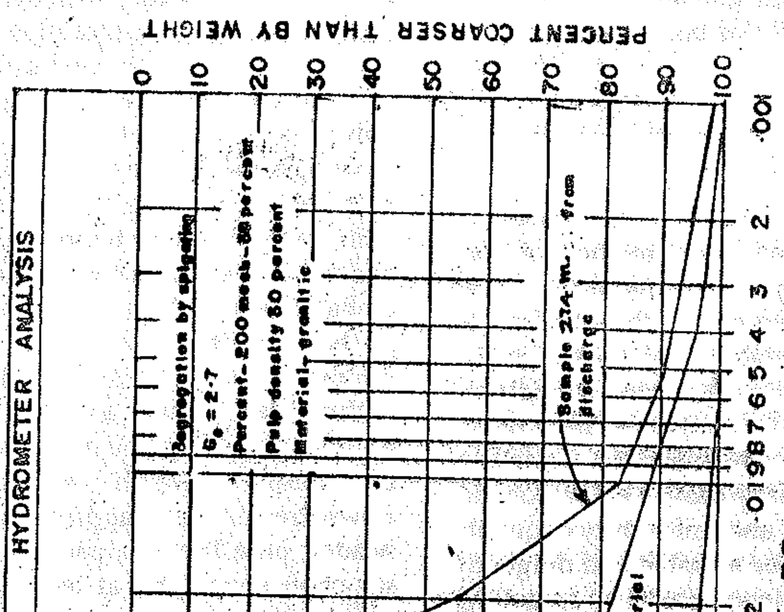

Figure - 8 Gradation of metal mine tailings - coarse grind, low pulp density

PREPARED BY G.R. BITDAVADE (?)

to shift disposal operations to a standby pond or an alternate area of the pond which is sufficiently distant and not to impede or endanger the work of raising the embankment and relocating the header pipe.

c) UPSTREAM CONSTRUCTION WITH CYCLONES : The procedure is the same as with spigotting except that the cyclones may be placed on towers 2.5 to 3 m high, be mounted on movable trucks, or be transported by dragline. The core should be taken to keep the overflow discharge at least 30 m or further upstream in order to keep the line of contact between the two cyclones products as far upstream as possible. The distance will be dependent on the total tonnage, percentage of minus 200 mesh and the yield of sand at the cyclones. The operation of cyclones must be properly controlled and monitored because their operation varies with the changes in pulp density, feed rates, pressure and wear or the cyclone orifice(refer fig. 10).

The tailings embankment can be built to a height of 10 to 12 m above the transporting pipeline as three successive cyclone towers are completely covered. The cyclones are then removed, the area is levelled to form a birm with room for an access road and the sand line is moved up to a new position and the process is repeated.

In this method, it is very important that the starter dam be protected by filters and drains along the upstream toe of the starter dam. The cycloned sand covers these drains and extends up the upstream face or the starter dam. The dam and relative perviousness of the sand cover protects the starter dam from saturation.

d) DOWNSTREAM CONSTRUCTION WITH CYCLONES : The main reason for using this method is the belief that embankments constructed are more stable and less susceptible to liquefaction by seismic shock. This type of method usually used when the mill grind is 60 percent or more minus 200 mesh. Cyclones are used when spigotting does not result in enough segregation on the beach to provide adequate sand for construction (refer Fig.11)

The design and construction vary from area to area because of different conditions of terrain, tonnage and grind. Generally, a relatively impervious starter dam is constructed of compacted borrow material and a second toe dam, which is pervious, is constructed 70 to 100 m downstream of the first dam. Between the two dams a drain system is constructed consisting of pipe, finger or blanket drains which drain downstream of the toe dam into a holding pond.

The overflow goes into the pond and the underflow is placed ahead of the truck or crane and downstream of the starter dam.

The starter wall initially acts as a storage dam for fines, thus allowing the coarse tailings to develop to a stage where they can form an adequate impoundment for confinement of the fines beach and pool.

The downstream method with cyclones provides flexibility for using borrow materials or pit waste as supplemental construction materials when the tailings sand yield is insufficient. Combining construction with tailings sand and borrow material can accelerate embankment construction sufficiently to provide storage space in excess of daily requirement and permit dumping of total tail ings for several months. This procedure not only reduces the cost, but is advantageous in winter when construction of the embankment should be avoided.

e) CENTRELINE CONSTRUCTION WITH CYCLONES : In centerline construction with cyclones, the underflows are deposited upstream and downstream of the starter dam. As embankment is raised, the location of the centerline of the dam remains constant. Embank ment construction equipment can be used to flatten both slopes or the slopes may be left at the angle of repose (Fig. 12).

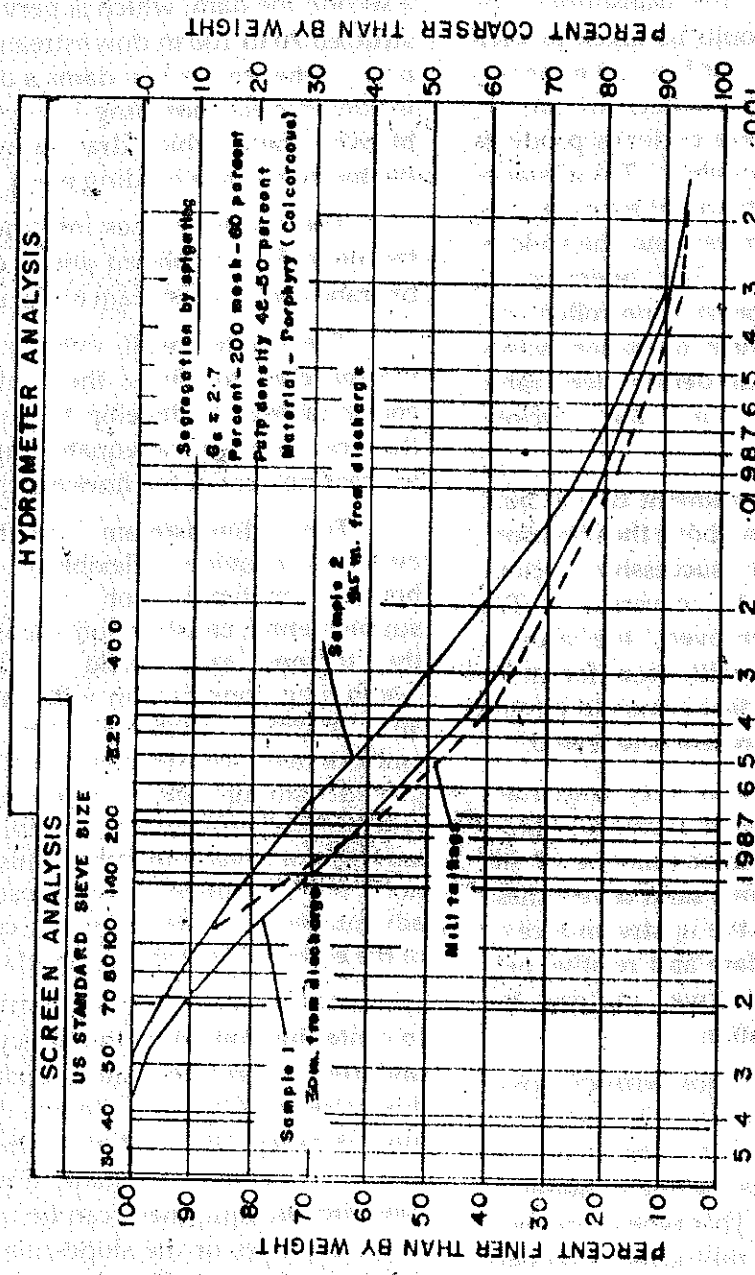

Figure - 9 Gradation of metal mine tailings - fine grind, high density

PREPARED BY G.R. EDTHAWARE STA (Dtg)

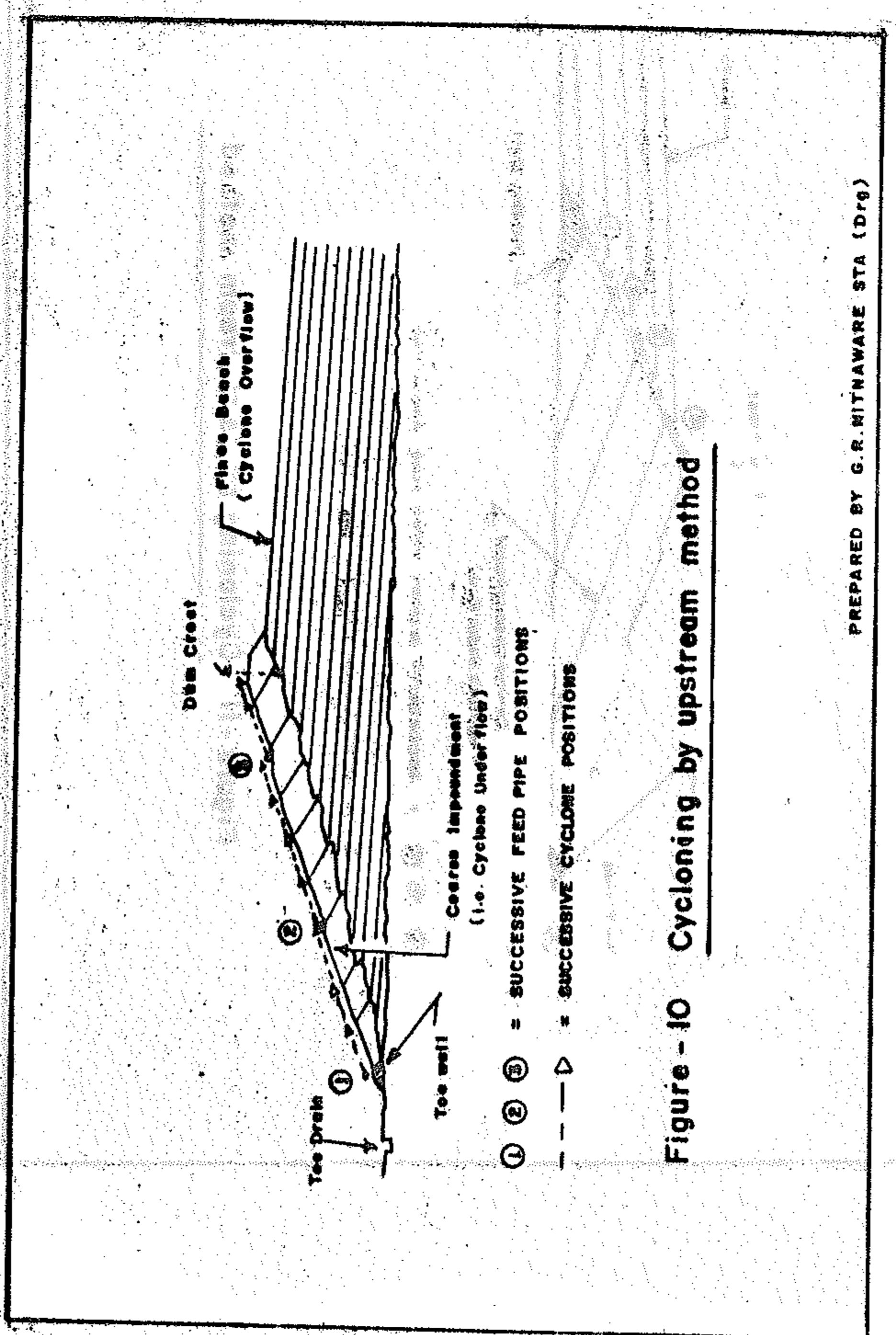

Figure - 10 Cycloning by upstream method

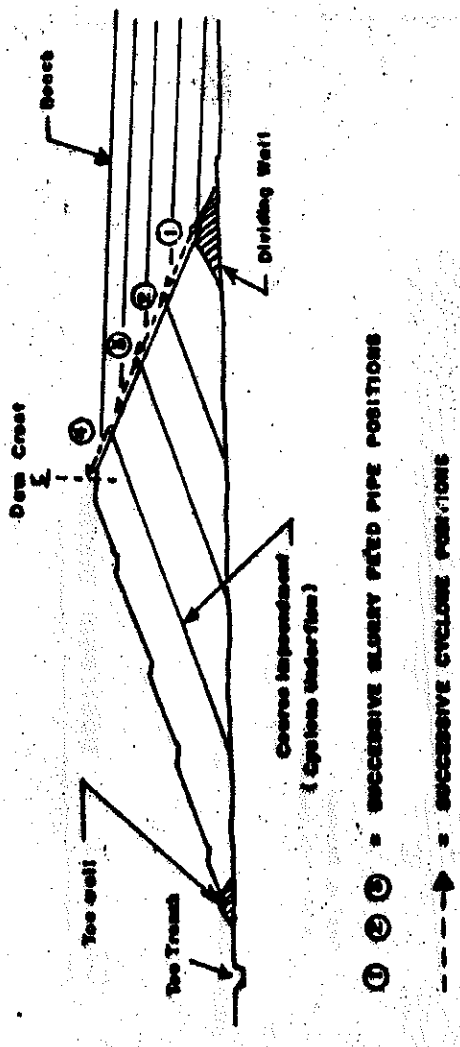

Figure-II Cycloning by downstream method

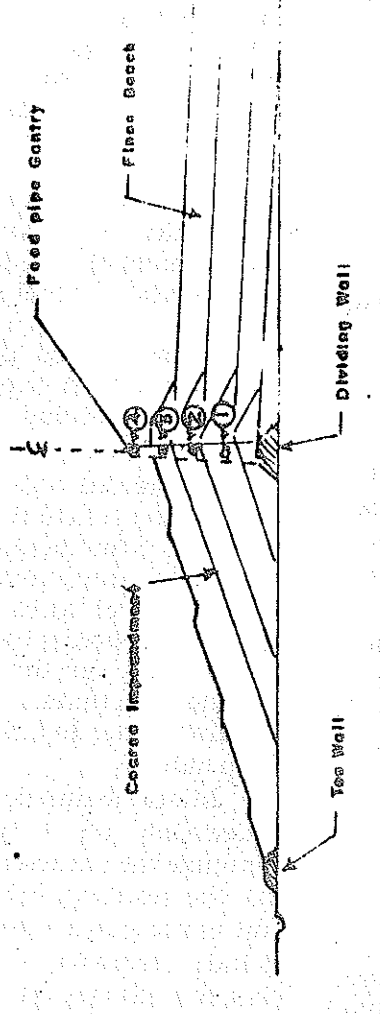

Figure - 12 Cycloning by centreline method

To increase the density of embankment, the cycloned sand may be compacted by rollers or equipment travel depending upon the design density.

f) THICKENED DISCHARGE METHOD : To utilize this method of con struction, a water storage dam or pervious peripheral retaining dike with a holding pond for treatment of runoff is required prior to deposition of tailings. Selecting the proper location for the discharge point is important to obtain the desired spread of the cone-shaped pile or tailings. Depending on the topography, the discharge point may be moved in line forming a ridge along the highest elevation of the tailings pile. As the tailings cone eventually builds up, the point of discharge must be elevated along with the ramp supporting the discharge line. To obtain the proper slope on the tailings deposit, the percentage of solids in the slurry must be closely controlled. The correct percentage of solids in the slurry will have been determined by laboratory deposition tests during planning and design. The volume of the flow of discharge also affects the slope attained by the tailings. When a large volume of slurry is being discharged, several points of discharge are established to maintain the velocity necessary to produce the desired slopes. Continuity in inspection is required to achieve the desired results.

D. MAINTENANCE

1. General

Since the life of a tailings dam may range from a few years to as long as 100 years, during the period of time many changes can occur that could affect the stability of the embankment. Since tailings disposal operations and embankment construction are nearly always a simultaneous operation, daily maintenance becomes an inseparable part of disposal and construction. Maintenance without prior inspection is not efficient or practical. Therefore operations, construction maintenance and inspection are all inter-related functions necessary to produce and perpetuate a successful tailings disposal operation. A continuous inspection and maintenance programme should be initiated at the beginning of construction and operations and carried out into the rehabilitation and abandonment stages.

2. Records

It is essential that accurate records be kept during the construction of a tailings dam such as embankment control tests density and moisture and maintenance record. They will be used for backup monitoring of the dam and will provide vital evidence of the performance of the dam. These records should include repair, replacement or substitution of cyclones and embankment construction equipment. Embankment repair, decant or outlet repair, spillway and channel repair, erosion repair, flushing of drains, should be recorded giving location of the maintenance and repair made and explaining in detail the procedures adopted and conditions initiating the action taken.

The record will help to identify the liner, other pollution control measures or whatever, other factors leading probably to the correct assessment of the failure. A complete set of "as built" working drawings and the predeposition and tailings placement design drawings should be kept on hand at all times.

3. Maintenance In Conjunction With Operations

Minor maintenance work should be undertaken on a continuous basis to minimize the occurrence of major difficulty and the resulting higher costs for repairs. This maintenance during operations should include removal of obstructions from diversion ditches and other flow channels, repairs of eroded areas and re-seeding of disturbed vegetated areas. Major repair should be distinguished from routine maintenance connected with disposal and embankment con struction operations. The conditions causing the problem of the continued maintenance and repair should be investigated and corrective measures implemented.

4. Inspections

Regular inspections are means by which satisfactory construction and operations are verified and assured and should be a part of an active tailings disposal operation. The daily inspection should include the spigots or cyclones, decant lines, the position of the water pool in relation to the decant or the tailings area boundary; elevation of the pool in relation to the crest of the retaining embankment, presence of any new wet spots on the embankment slopes, abutment contacts or at the toe of the embankment and any changes in the quantity and/or clarity of flow from drains.

High embankment should be thoroughly inspected by a competent engineer at least twice a year during the active life of the disposal facility. This inspection should include a review of the maintenance records and an analysis of the embankment performance as indicated by the periodically recorded readings of the instruments installed in the embankment and foundation.

During these visual inspections, particular attention should be paid to the following:

a) The presence of cracks parallel to or transverse to the crest of the slopes or the presence of cracks on the slopes themselves;

b) The presence of cracks in the soil at the toe of the slope and any visible displacement (either horizontally or vertically) of solution or drainage trenches at the toes of the slopes;

c) Any visible sagging of the crest of the slope or bulging at the toe of the slope;

d) The visible emergence of seepage at the toe of the slope. This would be indicated by wetness of the surface, local concentrations of plant growth or excessive erosion of the slope surface.

The appearance of any of these warning signs is a strong indica tion that the slope may be unstable and that remedial measures may be necessary.

If a tailings dam has been designed for a total height of 150 m and every thing has progressed satisfactorily to a height of about 60 m, a thorough investigation of inplace conditions should be made by drilling, sampling and testing of the embankment materials. Undisturbed samples can be tested for density, shear strength and cohesion. With this data, a factor of safety can be calculated and by projecting the slopes of the embankment and the phreatic surface, a factor of safety can be obtained for the ultimate height. If the unsatisfactory stability condition is forecast, design modification can be made to improve stability. If necessary, the ultimate height of the embankment may be re duced.

5. Conditions that Could Require Remedial Measures

Some minor deficiencies can be provided for routine maintenance, but occasionally conditions developed require significantly more efforts to stabalize or counteract the adverse effect created by such conditions.

(a) SURFACE DRAINAGE : From the standpoint of stability and economics, it may be desirable to control the amount of inflow water and to regulate the manner in which water leaves a tailing structure.

There is not much that can be done to control the inflow of water due to precipitation. Precipitation falling on the slope of the embankment, if not collected and controlled can cause severe erosion problems due to highly erosive nature of many tailings embankment materials.

A tailings embankment built on a flat ground will have no inflow from surface run off. A side tailings structure will have no inflow from surface run off.

The embankment slope runoff may be controlled by constructing berms on the face of the embankments and sloping the berms up stream to collect the flow in drainage ditches on the inside of the berm surface.

The drop pipes prevent excessive slope runoff from accumulating in the collector ditches and overflowing the outer edge of the berm creating erosion channels on the face of the slope. The berm grade must be maintained and drop pipes and berm collector ditches must be inspected (especially after a heavy rain) and kept clean and free of weeds and other debris. If erosion on the surface of embankment can be controlled and the soil pH or heavy metal content does not create a toxic situation, grass or other natural vegetation can be grown on the slope.

Unnecessary surface runoff into a tailings area should be prevented by use of diversion ditches and culverts. The control of the maximum potential runoff volume should be included in the design.

(b) SEEPAGE : The height and position of seepage surfaces must be observed by means of piezometers. It is usually convenient to install stand pipe piezometer once the dam has reached to a certain height. The stand-pipes can then be extended if necessary by adding sections of tubing at the surface to increase their height. Stand-pipes are usually installed along a section normal to the slope of the dam at critical points for stability. A sufficient number of stand-pipes must be installed to enable the seepage surface to be determined accurately and to pick up certain critical points on the surface, such as the height of the seepage surface adjacent to underdrains etc. The stand-pipes should be installed in positions where they will be readily accessible at all times.Suitable locations would be on dividing walls or similar prominences.

As an alternative to stand pipe piezometers, several other types are available. For example, twin-tube hydraulic piezometers, pneumatic piezometers, vibrating wire and strain-grouped dia phragm piezometers may be more suitable for specific applications. They use horizontal connections and avoid difficulties of maintaining vertical tubes during construction.

There may be cases when unanticipated seepage develops for which design and construction has not provided for the safe handling of the excess flow, or the velocity of the flow is high enough to create a piping condition, or the volume is excessive and of such poor quality that it degrades the drainage or ground water. In such cases, remedial procedures must be implemented to correct or stabilize the condition.

The most immediate procedure to be implemented is to reduce the supply of water to the seepage area. This can be effectively implemented if spigotting or cycloning can be shifted to a stand by pond or a distant area within the same pond.

Seepage that occurs on the down stream slope of the embankment is usually a sign of high phreatic surface which may have developed because of low permeability of the starter dam, inadequate drainage, stratified construction in the embankment or spigotting too long in one area. This condition can usually be stabilized by constructing a buttress against the down stream slope extending high enough to cover the seepage area.

To be successful, remedial measures must lower the phreatic surface and increase stability. Seepage along pipes through starter dam embankment is difficult to control. Consequently, seepage rings or cutoff collars should be properly installed and backfill around pipes must be adequately compacted during construction.

(c) SLOPE STABILITY : During inspection and maintenance a slope stability problem may be encountered. The stability problem may involve either a major portion of the main

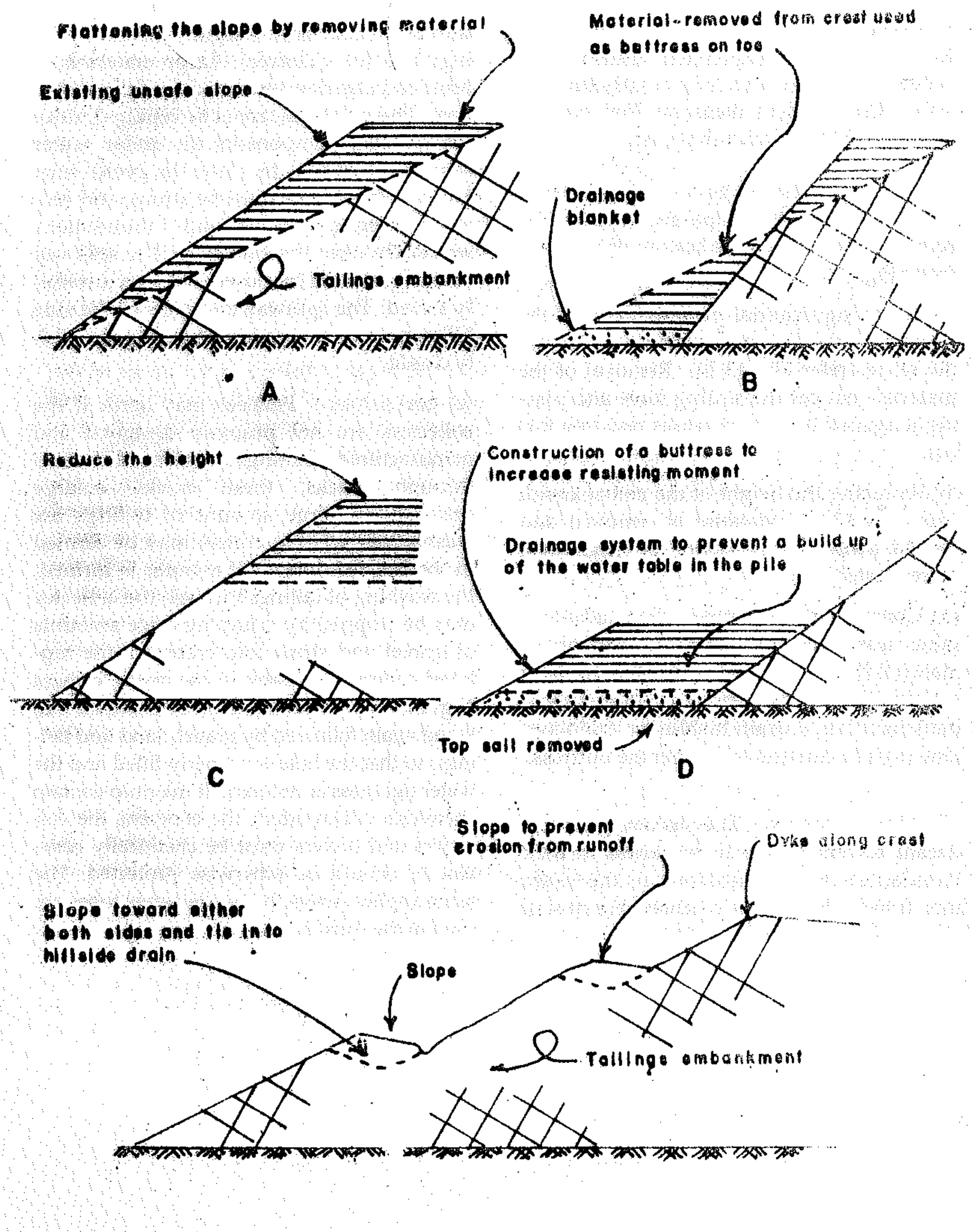

Figure - 13 Basic modification methods

embankment or a minor localized area. The first step is to implement measures to reduce the water that may be affecting the area. Construction measures that may be employed to stabilize a slope are :.

i) Flattening the slope by removing material from the top of the slope and keeping the removal cut towards the bottom of the slope (refer Fig. 13 A)

ii) Removing material from the crest of the embankment using the material to buttress the slope (refer Fig. 13 B). Removal of the material reduces the sliding force and placing it against the toe increases resisting forces.

iii) Reducing the height of the embankment (refer Fig.13 C). Material is removed and hauled away and reduction of height will increase stability.

iv) Constructing a buttress from available mine waste, cycloned tailings or borrow material (Fig.13D). If the buttress material is not significantly more pervious than the embankment toe, a drain blanket or drain system must be constructed under the buttress.

(d) DECANT TOWERS : The instability of the decant towers is due to weakness in their foundations and connections to the collectors. It may also be due to unreliable closing of the spillway openings. Tailings may flow through cracks and untightly closed openings into the collector. Large craters may form endangering the security of the whole dam. These defects cannot be repaired, since the affected components lie under water saturated tailings. In order to avoid such failures, the towers must be strong and reliable, erected on sound foundations separately from the collector. The spillway openings should be closed and very carefully sealed. The spillway openings of the side hill riser decants should also be very carefully closed.

(e) COLLECTORS : Failures may occur if the collectors are not properly designed and manufactured. Tailings pulp begins to seep through cracks, these cracks enlarge gradually, a large amount of tailings are washed out and big craters may be formed in the impoundment. If a crater is formed, the washing of tailings through the collector may be stopped by dumping large amounts of gravel and straw into crater. If the ruptured collector is visible in the crater, cement bags mixed with sand should be dumped into it and again followed by gravel, sand and tailings, so that the hole is properly filled and the water tightness is restored. If the pulp contain chemicals which attack the concrete, the collectors and towers must be chemically resistant or should be otherwise protected. The same applies where thin walled steel tubes are used in the construction.

Chapter-6

TAILINGS DAMS IN INDIAN MINES - CASE STUDIES

1. MINE 'A'

The tailings dam of the mine is located about 9 km away from the mine and 6 km from the plant. The mine is worked by opencast method and is in a hilly area whereas the plant is located in plain area. The nearest river is 3 km away from mine and plant, and 7 km away from the tailings dam.

The tailings is transported in the form of slurry from plant to tailings dam through a pipeline. The specific gravity of slurry is 2.86 and normal particle size is 48 mesh at the rate of 2.5 m/sec and occasionally particles of size 28 mesh is transported at the rate of 3.0 m/sec. The physical and chemical composition of tailings is given in Annexure I.

The rate of generation of tailings is about 1.58 million tonnes per month i.e. about 19 million tonnes per annum. The tailings is generated after froth flotation of copper from the slurry fed into Rougher and Scavenger cells after grinding and is not treated further and directly pumped to tailings dam. The storage capacity of the tailings dam is 88 million tonnes. There is an R and D laboratory to cater to the requirement of meteorological services. The tailings dam uses both upstream and down stream methods and the slope of embankment is 1:3. The necessary tests for stability and firm ground for construction have been carried out. The embankment material is tailings which has already been tested for the purpose. There is a seepage problem in the area and to prohibit it, filter drains are constructed in the area. The starter dam is constructed on the tested ground and in the event of rise of the height of the dam, the provision is kept at the planning stage.

The slurry tailings is treated by cyclones and thickened tailings is used for embankment and water is reused for plant. There is a problem for using the tailings for embankment for which consultants have been approached to suggest remedial measures in order to overcome backlog in dam build up with cyclone slurry. The life of the dam is 30 years.

No plantation has been carried out so far. However, after closing the mine/plant, it is planned that soil will be spread over the entire area and plantation will be carried out. In so far as vegetation or for use of land for agriculture, no testing of soils has been carried out.

2. MINE 'B'

The mine is worked by opencast method and is almost in plane ground. The plant and tailings dam are located about 0.5 km away from the mine on a plane area. The nearest tank is 500 m away from the mine , 800 m from plant and 1 km away from the tailings dam. Nearest river is 1 km away from the mine and 1.5 km away from the plant and tailings dam. No forest area is nearby the mine or tailings dam in about 10 km radius. The total population is 7,000 residing within the radius of 5 km from mine, plant and tailings dam. The life of the mine and plant is about 40 years.

The tailings is in the form of slurry which contains 30 to 40 percent solids and 70 to 60 percent water. The particle size is 100 microns. The specific gravity is 2.8. The tailings contains iron sulphides which is susceptible to oxidation, creating considerable acidity in soils and water which is hazardous for land disposal. From plant disposal tailings and at the tailings pond's tailings, there is no such change in physical properties but in chemical properties there is some change at about 10 percent. The tailings is generated at the rate of 180,000 cu.m. per month, say about 730,900 tonnes solids (1,980,000 cu.m.) in a year. After thickening the slurry, tailings is pumped to neutralisation tank. In neutralisation tank, lime solution is mixed with agitator and pumped to tailings dam. R and D work is under progress to recover the metal from the tailings. The water from tailings dam is not used for domestic purposes. However, reclaimed water is recycled back to beneficiation plant for reuse. The Project is designed on zero discharge condition. About 50 percent water requirement of the plant is met from the water received from tailings dam.

The storage capacity of the tailings dam is 4,370,000 cu.m. and annual requirement is 900,000 cu.m. To carry out the climatic/hydrologic studies, monthly monitoring of piezometer water analysis is done. Five peizometers are installed in down stream side of the tailings dam. There is a seepage problem at the sides of the embankments but ground water table is not affected as the water is reused/pumped for plant.

The area of the tailings dam is explored by drilling to find out devoid mineralised area. The tailings dam is constructed on the non-mineralised area. For the embankment waste rock of the mine, top soil of preproduction is used along with sand as these materials are economical. The upstream and downstream methods are used for embankment. The slope of the embankment for upstream method is 1.5:1 whereas for downstream method the slope is 2:1.

The dam section is designed by consultants. The construction will be taken into three phases. In first phase its area will cover 151,725 cu.m. (6.0 m high), in second phase 33,000 cu.m. (16 m high) and in third phase area will cover 446,775 cu.m. (24 m high). Before using the material for the embankment viz. mine waste rock has been tested for its strength. There is a seepage problem at embankment sides. For construction of starter dam the area is scrapped for 300 mm and for drainage system, toe drain is provided. The provision of decantation well with submersible pumps is also made. There are three decantation wells in the down stream side of the tailings dam.

The water is not used for domestic purpose but reused for plant only. The water has been tested and found fit for plant use. The tailings is disposed by spigotting. The life of the tailings embankment is 25 years. The embankment area is inspected regularly. The monitoring of water level is being done daily.

The tailings dam is likely to be closed after 40 years. The reclamation of the tailings dam will be done by spreading top soil over it and then afforestation. Afforestation will be carried out after closing the dam.

3. MINE 'C'

Tailings dam of the mine is 2.5 km away from mine and plant. The mine, plant and tailings dam are all on the plane terrain. Irrigation ponds are at a distance of one km to 3 km from the tailings dam, one km from the plant and 0.5 km from the mine itself. The population in the vicinity within 5 km radius from mine, plant and tailings dam is about 10,000,; 7000,; and 5,000 respectively. The mines, plants and tailings dam are almost in the forest. The life of mine and its plant is about 20 years. Nature of tailings is in the slurry form. The slurry mainly consists of 90 to 95 percent of minus 400 mesh particles of lead, zinc, copper, copper-pyrite which varies with rock matrix of calc silicate and graphite mica schist minerals. The chemical composition of slurry is as follows :

Lead(Pb) 0.4 to 0.5 percent, Zinc(Zn) 1 to 1.2 percent, Copper(Cu) 0.04 to 0.6 percent, Iron(Fe) 7 to 9.5 percent, Insoluble Suspended Matter(ISM) 65 to 67 percent, Silica(SiO_2) 44 to 48 percent.

In the mill tailings the components which are potentially hazardous for land disposal are of two types namely (1) Heavy metals like lead, cadmium, copper and (2) residual chemicals viz Xanathate, Cynide and Dichromate.

The physical properties of slurry tailings are as follows:

pH - 7.5 to 8.0

Proctor Density (PD) 1.3 to 1.5 kg per litre

Bulk density - 1600 kg/cu.m., on drying 3 to 5 contipose at 40 to 50 percent solids specific gravity 3.1.

Volume of tailings generated is about 3000 tonnes per day.

Volume of tailings at plant and tailings dam is as follows :

At plant	To tailing dam
175,000 cu.m.per month	50,000 cu.m. per month
2,100,000 cu.m. per year	600,000 cu.m. per year

Tailings are originated at concentrator. These are classified in mine fill plant where fines are separated out for ultimate disposal to tailings dam. Coarser material is sent to underground mine for back filling.

Out of the slurry tailing which is pumped into tailings dam, only water is recycled for use in the plant. No process is adopted to recover any material from tailings. Neither any air pollution control device is required to clean up the effluent nor there is any necessity to clean the tailings before its discharge to embankment. Water which is recycled is not used for drinking purposes by human/domestic animals/wild animals. Recycled water is used only for plantation and its daily requirement is about 600 to 1000 cu.m..

Tailings Dam embankment/impoundment is having its storage capacity about 3,000,000 cu.m. Annual tailings generation is about 300,000 cu.m.. The area is free from stormy zone and heavy rainfall. Before the construction of tailings dam, soil from dam site is subjected to various standard tests by consultants. Environmental Management Plan was also prepared by consultants. The resulting data from above studies is used to design the said Tailings Dam. Seepage from the tailings dam is negligible and studies are underway for monitoring its effect on water table. The area is free from seismic zone. Soil/sub surface of the tailings dam site is tested. No material other than local soil is used for the construction of embankment, being economical.

Ring Dam/embankment with the slope 2:1 is constructed on stabilized soil section for which bearing capacity test was already carried out and results were satisfactory. The total area covered by the embankment is about 60,000 square metre. Proposed height of the dam is 10 m. No drilling is carried out to test the firm ground before construction. Factor of safety of 1.5 is considered for dam height. Dam is free from seepage problem and free from any possibility of flood effect. The dam is provided with storm water drains and 100 m long gravel sand filter. Water is allowed to seep through filter bed.

Initial construction of dam was impervious benching upto 30 cm. and was carried out on surface of the ground. Sand filter bed and necessary drain outside filter section is provided for decant water. Decant water is used by plants. At plant cyclone, over flow is collected into tailing thickners and thickened pulp is then disposed of to tailings dam through pumps. The life of tailings dam/embankment after raising to full height is expected to be about 20 years. Routine checkups are carried out.

Deficiency observed : There is uneven filling of tailings inside the dam.

Remedial measures taken : Tailings from the discharge points are being rearranged to maintain water free flow tov ards filter bed.

Area restoration : 90 percent of area can be restored by vegetation afer closing mine or plant. Plantation is possible by laying 0.6 m good quality soil layer on top surface.

Stability : (1) Physically, dam is stable and till now no adverse chemical effect has been observed any where.

(2) Plantation is also possible on embankment/tailings dam area.

4. MINE 'D'

The mine is located on hummock terrain whereas plant and tailings dams are constructed on plane ground. The distance of tailings dam from mine is 0.5 km and 1.5 km away from the plant. The nearest water reservoir is 0.5 km away from the tailings dam. About 1,000 people are living in the vicinity of 5 km from mine/plant and tailings dam. Forest which is moderated with vegetation is 5 km away from the mine/plant /tailings dam. The life of the mine and plant is about 20 years based on the rate of production.

The nature of tailings generated is in the form of slurry having solid contents about 10 percent. The size of the particle is minus 325 mesh. The tailings contains 45 to 50 percent Fe. The tailings is in the form of micro-fine inorganic particles and is potentially hazardous for land disposal, as it forms thick layer, thus reducing water holding capacity and nutrients status of soil. The pulp density is 1.08 and having specific gravity of 3.8 (solid particles in tailings).

There are maximum one, percent change in physical properties and maximum 0.5 percent change in chemical properties of the tailings at the plant and at the tailings dam. About 60,000 cu.m. tailings is generated per month i.e. 675,000 cu.m. per annum. The tailings is generated by hydrocyclones and recuperator of washing plant and intercepted for treatment near tailings pond. The water recovered is used for plant and the tailings is used for restoration of land in mined out area on which the plantation is carried out. The daily requirement of water for beneficiation plant is 22,000 cu.m..

The storage capacity of the embankment is 3,400,000 cu.m. Whereas annual disposal of tailings is 700,000 cu.m. The tailings is discharged in abandoned/exhaused pits which are synclinal basins with magniferous clays as footwall which is totally impervious. However due to tailings, no ground water is affect ed.

For embankment, clay material with laterite pitching is used, which is obtained from mine. The centre line method is used for embankment. The slope of the embankment is 30 to 35° and the area falls under the heavy rainfall zone. As such no starter dam is constructed. The abandoned/exhausted pit is used as tailing pond.

The tailings is disposed via vertex finder of cyclones. Fifteen primary cyclones of capacity of 80 cu.m per hour and sixteen secondary cyclones of 80 cu.m per hour capacity are deployed. At the embankment, all safety measures are considered and water level is monitored every day. At the time of closing of the tailings dam most of the area will be restored. The life of the mine/plant is 20 years.

Once the operating pit is exhausted, extensive plantation programme will be undertaken by backfilling with laterite and top soil. The restored area can be utilised for agricultural pur pose.

After filling the tailings dam, one metre laterite capping will be provided. After proper pitting for using top soil plantation of suitable species will be taken up and grass cover will be provided. Plantation will be carried out to prevent erosion of laterite and top soil will be spread for physical stabilisation. On the embankment area(slope) Accacia, Ariculiformis, Accacia of mangium, and cashew are grown.

5. MINE 'E'

The working of mine is carried out by underground method. Tailings dam is located 2.0 km away from the mine and plant. The mine, plant and tailings dam are located in hilly area. The nearest river is 1.5 km away from the mine/plant/tailings dam. The population within the vicinity of 5 km. of mine/plant and tailings dam is about 20,000. The life of the mine and plant is more than 40 years.

Tailings is generated in the form of slurry. Alkaline around silicon ore slurry of around 15 percent solids is generated. About 80 percent of tailings is of minus 325 mesh (44 microns) size. The tailings contains manganese and radio-nuclides which are harmful for human beings. The specific gravity of the settled solids of tailings is 1.4.

There is narrow change in chemical properties of tailings discharged for this plant and the tailings on the tailing pond. The tailings is generated @ 30,000 cu.m. per month i.e. 3,60,000 cu.m. per annum of settled solids.

The tailings is generated after digestion of the mineral and secondary filtration. Liquid after ion exchange i.e. after separation of mineral (barren liquor) is tailings. The water is not used for drinking purposes, however, the recovered water about 1,200 cu.m. per day is used for plant.

Before discharging to the embankment, tailings is treated. The storage capacity of the embankment is 7,500,000 cu.m. The annual requirement of holding capacity is 300,000 cu.m.. The seepage problem is negligible. The area falls under the seismic zone II as per IS 1893.

For the embankment, sand, earth and slimes are used. Earlier, upstream method was used for embankment whereas at present centerline method is used. The slope of the embankment of up stream is 1:3 and 1:2 at downstream. The total area covered for the embankment is 47,000 cu.m. and height is 22 m. While using the material for embankment's construction, necessary tests have been carried out. There is a provision for drainage system and hydraulic structure like spill way and decantation wells are also provided.

The starter dam is constructed which is impervious in nature. The area of starter dam is stripped upto 0.5 m. Reinforced Cement Concrete lime pipes are used for decant water. The decant water is again treated in effluent treatment plant and the effluent is used partly in the plant. Tailings is classified by hydrocyclones and the coarser fractions are used for back filling in the mines. Fines are sent for impoundment. The capacity of the hydrocyclone is 130 cu.m. per hour at 35 percent solid.

The embankment area is regularly inspected. If necessary, remedial measures are taken for the safety of the embankment. It is found that safety factor is less at the upstream method and hence down stream side has been strengthened. Further, embankment is made by centerline method.

The top of area of the tailings pond will be covered by top soil as a final close up measure. The area of the tailings dam cannot be used for plantation or for vegetation of agriculture use. Plantation of trees and bushes is on the tailings. At the end of the life of the tailings dam, the area will be topped by soil and stabilisation will be made. The plantation/vegetation of the embankment area of the tailings dam has already been done.

6. MINE 'F'

The mined out ore from various pits is treated in a single beneficiation plant and also there is only one tailings dam which is located between one to three kilometres from various pits. The terrain of the area is hilly. The beneficiation plant is constructed at plane ground and the tailings dam is on hilly terrain. The nearest river is not perennial and is about 1 km away from the beneficiation plant and 2 km from the tailings dam. The population within the vicinity of 5 km radius of the plant/mine and tailings dam is 25,000.

The tailings is generated in the form of slurry having pH 7.2 value. Bulk density is 1.65 to 1.80 cu.m per tonne. The tailings contains 90 percent of minus 45 microns particles. All the constituents of the tailings are insoluble in water, only slurry needs settling. Specific gravity of the tailings is 1.3 of solids in tailings slurry. In the physical properties and chemical properties, there is no change at the tailings of beneficiation plant and tailings dam. The rate of generation of tailings is 3,300 tonnes per day. At this rate, monthly 80,000 tonnes or say 1,000,000 tonnes per annum, tailings is generated.

Tailings is generated after the beneficiation of base metal minerals at the plant. After recovery of base metal concentrate, the unwanted remaining non-sulphide particles having mainly gangue is considered as tailings. In the tailings dam, the tailings slurry is being allowed to settle and entire water is reused by the beneficiation plant and watering the plant saplings at the old tailings dam. About 3,000 cu.m. per day water is reused by the beneficiation plant. From the bio-assay and Bio chemical Oxygen Demand of effluent shows that it is not harmful.

The storage capacity of the embankment is 10.35 million tonnes as against 1 million tonnes of the annual capacity requirement. As the tailings dam was constructed about 20 years back, the climatic and hydrological studies have not been carried out for the ground where tailings is stored.

Clear water is being allowed from side wears/filter bed/ hume pipes. The entire filtrate is being reused in mill for benefici-ation by maintaining zero discharge and thus impact of dam on ground water is very little.

The area has been explored for the mineralisation zone in the area of the tailings dam and found that there is no mineral under the area. For the construction of the dam embankment, sand and gravel from near by river, waste rock from mines, hard soil, top soil, cement concrete stone, steel and tailings underside soil and down side waste rock are used.

For the embankment, downstream method is adopted. The slope of the embankment is 1:2.5 upto 30 m height and 1:2 above that. The proposed height of the dam is 45 m. Before constructing the dam, drilling has been carried out for confirmation of firm ground. There is possibility to increase the height of the dam by 7 m or so.

In respect of safety, consultants were engaged and it is constructed as per their design.

There is a provision of drainage system. Decantation wells and siphone systems are provided to recover water effluent. The starter dam is of impervious type. Nominal stripping is made for the construction.

Daily inspection of the embankment area is made and recorded. Any deficiency found, is rectified on the priority basis.

The tailings dam will be reclaimed with top soil and plant saplings after about 10 years as the tailings dam is likely to be closed. As the tailings has no nutritive values, there is no possibility of using the ground of tailings dam for agriculture at present. However, top soil, cow dung and heavy foliage plants will be put on the tailings and hope that it will be useful for agriculture purpose in future.

There is no chemical stabilisation. The chemical composition shows that there is very little amount of base metal sulphides. They are insoluble in water. At a later stage, if oxidation takes place, base metal may oxidize to metal sulphates which are insoluble in water. Some base metals which are essential for plant are also present in the tailings.

On the old tailings dam which is abandoned at present, about 135,000 plants are planted and also 15 hectares of grass. The erosion of the soil due to air will be minimised by grass and plant saplings. The heavy foliage of the plants changes the top tailing chemistry after few years. The top layered tails changed and stabilisation has taken place.

7. MINE 'G'

The mining is carried out by underground method. The mine, plant and the tailings dam are located on the plane ground. The distance of tailings dam from the mine is 200 to 500 m and about 100 m from the plant. The nearest river is about 20 km from the mine/plant or tailings dam. The population within the vicinity of 5 km radius of the mine/plant and tailings dam is 50,000 approximately. The distance of forest from the mine/plant or tailings dam is about 20 km. The forest is protected hillock with thin afforestation. The life of the mine and plant is 40 years. The area is covered with black cotton soil.

The tailings is generated in the powder form. The size of the grain particle is 75 microns on an average. The tailings contains chloride biotite schist with quartz. The area covered under the tailings dam is 24 hectares and the proposed height of the dam is 20 m. For embankment of the tailings dam, tailings is used which is quite stable. However, no stability tests have been carried for this purpose.

There is a seepage problem with the tailings dam area, for which a trench is dug to collect the seepage water.

Before construeting the starter dam, no exploration has been carried out for confirmation of firm ground. Also there is no provision to increase the height of the tailings dam.

The total suspended solids in the tailings is 90. The tailings is generated after the extraction of precious metal from the ore, a large quantity of water is required at the rate of about one tonne per tonne of ore treated. This water is mainly obtained from the underground workings. The process also requires the addition of toxic reagent like sodium cyanide (NaCN) to the ground ore. The consumption of sodium cynide per tonne of processed ore is about 0.5 kg. After recovering precious metal from the ore, the tailings in the form of siliceous pulp along with cyanide bearing waste water containing 30 to 40 percent solids is pumped through a 100 mm diametre pipeline to a series of tailing dump pits and is allowed to settle by spreading over the dump by forming bands of settled tailings.

The starter dam is of pervious in nature. The tailings is allowed to settle on the natural slopping ground. The decanted water is used for beneficiation purpose only. The tailings is disposed of by direct pumping from the plant to tailings dam area. The life of the embankment is 45 years. The embankment area is being inspected daily and record is maintained regularly. If there is any deficiency, necessary action is being taken promptly.

No area of tailings dam has been reclaimed or afforested so far. However, plantation and vegetation can be possible in future with low growth rate.

8. MINE 'H'

In this mine the mineral is mined by underground method. There are two beneficiation plants for the treatment of metallic ore. One is High Intensity Magnetic Separation(HIMS) plant and other is Electrolytic Manganese Dioxide(EMD) Plant. HIMS is for beneficiation of the lower grade metallic ore to very high grades. The process involves drying, crushing, conveying screening, magnetic separation and stacking of different products. The process further includes (i) material preparation by crushing and grinding, (ii) reduction roasting, (iii) Leaching purification and filtration, (iv) electroplating and (v) product finishing washing, drying and grinding. The water after cake washing and anode washing is discharged into effluent collection pit. As such no tailings dam is constructured at the mine. There is a lime solution tank from which lime solution is discharged to neutralisation tank and to settling tanks. The size of the effluent collection pit is 6m x 4m x 1.5m. The settling tanks (2 Nos) are of 6m x 2.5m x 1.5m. The holding pit is of 2.5 m x 2m x 1.5 m size. The tailings/effluent are generated at different places i.e. washing of filler cakes, washing of anodes, neutralisation of EMD flakes and floor washing. About 45 cu.m. per day effluent is generated.

The treated water is sent back for floor washing and also using for green belt development. The remaining part of the water is discharged to nearby nallah. The alternate arrangement has been made for setting tank to facilitate removal of sludge.

9. MINE 'I'

It is a very old mine worked by underground methods. The tailings dam is about 2 km away from the mine and the mine, plant and tailings dam are located on plane ground. The nearest reservoir is 10 km away from the mine/plant and tailings dam. The population in the vicinity of 5 km radius of mine, plant and tailings dam is 150,000. The forest is about 5 km away from the mine, plant and tailings dam area.

The run of mine ore is crushed and ground. Precious metal assays 3 to 4 grams per tonne. After recovering precious metal, the tailings is disposed of in the tailings dam. The tailings is formed in the form of slurry. The particle size of slurry is minus 200 mesh 70 percent and plus 200 mesh 30 percent. Tailings contains SiO_2 50 to 70 percent, CaO 10 percent, MgO 10 percent and minor quantities of Fe, Al_2O_3, S, Na and K. The bulk density of solid particles of slurry is 1.5. The rate of tailing generation is 2,000 tonnes per month and 228,000 tonnes per year. There is no physical or chemical change in the tailings at the generation point and tailings dam. In the tailings 0.5 to 0.8 gramme per tonne of precious metal remain is contained and processing such as heap leaching and carbon in pulp is being carried out for the precious metal recovery. In addition to this, carbon in pulp technique is under examination.

The tailings is neutralised to kill the free cyanide, which was used in the plant for precious metal recovery from ore, by nascent chlorine. In all thirteen tailing dumps are spread over 400 acres of land. The height of the dump ranges 15 to 30 m and about 35 million tonnes of tailings sand are present. The tailings are cycloned and water is sent to tailings dam and pulp is used for embankment. The capacity of cyclone is 30 tonnes per hour. The active tailings dumps can further accommodate 10 million tonnes. The water is reclaimed and reused in the plant. There is no proposal for increasing the height of the tailings dumps.

The mine management has their own meteorological services. There is no seepage problem. To monitor rock burst activity in the underground, mine has its seis-mic laboratory. No exploration work has been carried out before constructing the dam as the dam is more than a century old. For the embankment, tailings is used and alongwith sand consolidation benches have been formed. Bunds are raised with waste rock to arrest flow of rain water. The slope of the embankment is 60°.

As the ground is very stable, no stripping has been made for construction of the starter dam. The water is being decanted by gravity and is tested before use. It is found that less than one pantide per million free cyanide is contained in the water. Daily inspection of embankment is being carried out by maintaining record thereof and immediate steps are taken to rectify the difficulties.

No plantation or afforestation is carried out on the embankment or tailings as there is a proposal to retreat the tailings on large scale. The possibility of the usefulness of the area for agriculture use, can be examined after the retreatment of tailings carried out. However, 80 percent area of the tailings dam can be restored and used for plantation. Afforestation work has been carried out on many other old dumps.

10. MINE 'J'

Low grade ore, on a very large scale is being mined and the beneficiated concentrate is sent hydraulically over a 67 km pipeline distance to port. The beneficiation process requires large quantities of water and the slurry transportation of ore and waste requires large quantities of water some of which is lost into the sea at port.

The low grade ore generates large quantities of waste. To safely impound these fine minus 100 mesh tailings and to provide the huge water requirement to the tune of 28 million metre cu.m. a large earthern dam was designed and constructed across the river valley. The design was given by consultants. The dam was the first in the country to accommodate such a huge quantity of tailings. The dam can be technically classified as a large dam with an ultimate height of 100 m and is comparable with many irrigation and hydrolitive dam projects in the country. It is also the biggest homogenous earthern dam (without any rockfill core) in the country and second only, in the world.

The task of designing such a dam was in the country and it was hoped that the design would provide for the fine tailings to spread evenly and occupy the full reservoir area. It was required that the tailings should settle down quickly and not remain suspended for extended periods and flow out over the spillway to pollute the river 'K' which joins the river 'L' slightly downstream. However, in actual practice, after systematic sounding of the dam over the years, it became clear that the tailings was not spreading towards the upstream side of the dam and after accumulating towards the dam axis, the suspended solids started flowing out of the dam across the spillway located on the dam axis due to the force of the water in the monsoon months. It was therefore obvious that the vertical capacity of the dam could not be utilised fully before undertaking next stage extension of the dam height. This situation became critical after monsoons, when only half the dam capacity had been utilised.

A decision was taken to raise the dam height from the existing level in two phases viz. in the first phase by 8 m before monsoon and in the second phase by 27 m. After the first stage of 8 m was completed before 1992 monsoon, a temporary spillway was constructed over the new embankment to discharge the monsoon flow. This spillway failed midway through the monsoon and created a potentially dangerous situation of dam erosion due to the large discharge over exposed fill. Various protective measures however saved the situation and it was decided after this mishap to relocate the spillway through a discharge tunnel located at a point upstream of the reservoir by the time the dam was further raised to its 100 m height.

The tunnel spillway was to remain functioning even as the tailings level in the dam started rising. The tunnel spillway was therefore designed to have water inlet at different levels and through an inclined shaft ultimately. The water discharge is led out through an exist portal and extended cement concrete lined channel into the river 'L'.

To cater to the reclaimation of water for beneficiation and slurry pumping purposes, a vertical shaft was constructed with opening at different elevations at the intake of a gravity pipe line tunnel to ensure the supply of plant process water free of silt from different elevations of the reservoir.

Salient features of the Dam

1.	Type of the dam	:		Homogeneous Earth Dam
2.	Length of the dam	:		1048 m
3.	Height of the dam	:		100 m
4.	Dam top width	:		7 m
5.	Maximum base width in valley portion at toe.	:		500 m
6.	Catchment area	:		18.70 square kilometre
7.	Reservoir capacity at different outlet levels			
			(i) 113 million cu. mtr.	
			(ii) 133 million cu. mtr.	
			(iii) 245 million cu. Mtr.	
8.	Type of spillway	:		Tunnel spillway with an inclined shaft
9.	Total earthwork in embankment	:		11 million cu. m.
10.	Life of the dam	:		Dam is designed to hold 300 million tonnes of tailings

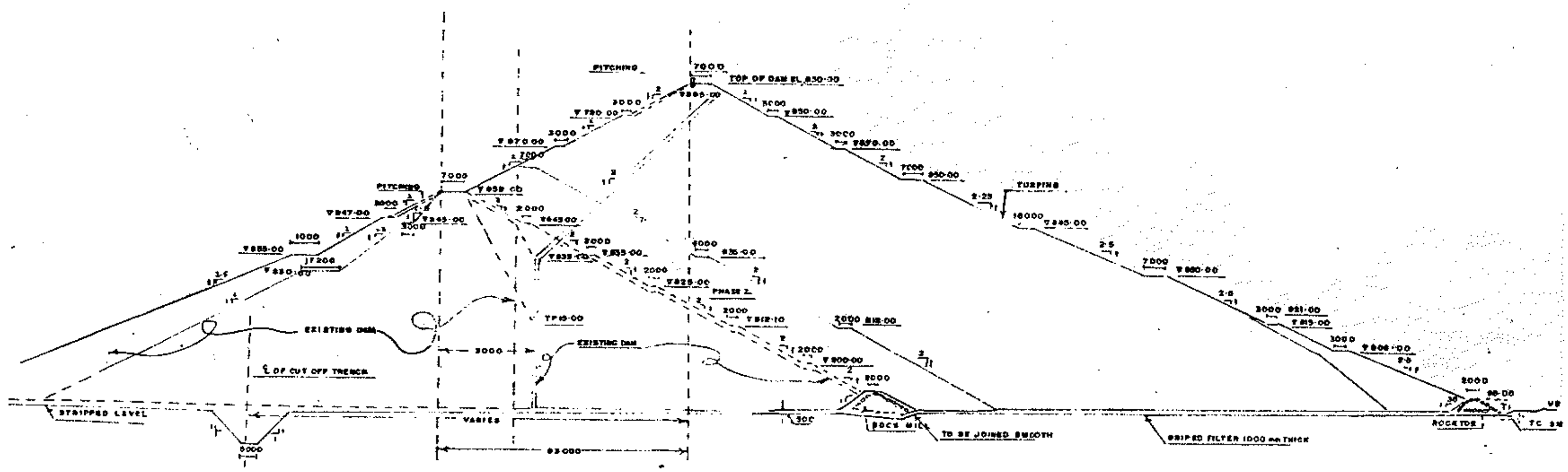

Figure.-14 TYPICAL CROSS SECTION OF EARTH DAM OF MINE-'J'

PREPARED BY G.N. NITNAWARE DY. (Drg.)

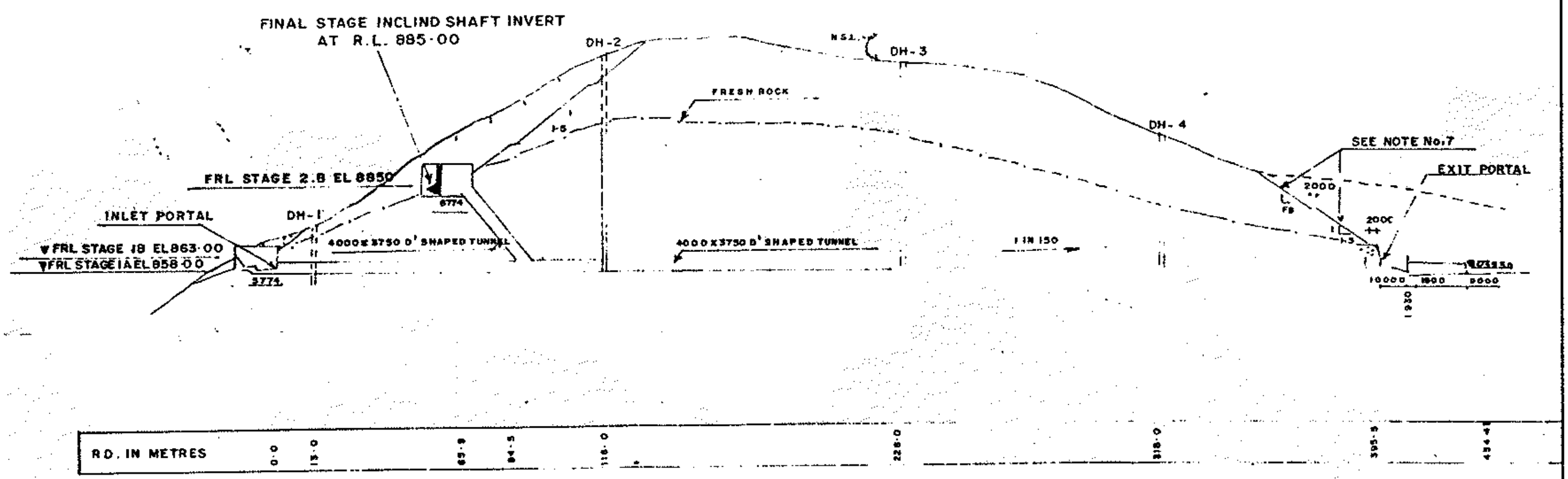

Figure.-15 L- SECTION TUNNEL SPILLWAY OF MINE - 'J'

Salient features of tunnel spillway of dam

1.	Length of the main tunnel.	:	425 m
2.	Length of the inclined shaft.	:	31 m
3.	Shape of the tunnel	:	'D' shaped.
4.	Size of the tunnel	:	4.00 m. X 3.75 m
5.	Design discharge	:	30 cu.m. per second

Design parameters adopted for embankment design

a.	Effective cohesion	:	2 tonnes per square metre
b	Angle of internal friction	:	26°
c.	Permeability	:	10^{-5} to 10^{-6}cm per second
d	Moisture content	:	± within 2 percent of optimum moisture content.
e	Bulk density (moist)	:	1.80 tonne per cu.m.
f.	Field density of the compacted fill in the embankment should not be less than 98 percent of proctor density.		

MONITORING FACILITIES INSTALLED

1. Twin tube hydraulic type piezometers are embedded in the foundation and embankment of Tailings Dam. In all there are 102 piezometer tips, 39 numbers of which are installed in the section during construction of first stage and remaining 63 numbers are installed during enlargement of the dam to an increased height of 100 m. The installation of piezometers have been done at two cross-sections.

The polypropelene tubings from all the piezometers are conveyed to two terminal buildings constructed on downstream slope.

The piezometers installed in the foundation and embankment, during construction help studying the development of pore water pressure during construction and its dissipation with time and also development of pore pressure during the operation period of the reservoir Pore pressure and height ratio of any individual piezometer should not exceed 2, where water is being used as circulation fluid in the tubes, where P is pore pressure and H is the height of overburden above the tip.

A digital read out system is installed in place of the earlier conventional system connected with the brass manifold operating pannel. The digital read out unit indicates pressure in metre head of water with a least count of 0.01 m. The pressure can be read accurately in digital units. Readings are being taken at interval of 15 days and results are closely monitored.

2. Settlement points

96 number embankment settlement points and 14 number of parapet settlement points have been provided in the dam. Initial co-ordinates and reduced levels of all the points have been recorded. Periodically the co-ordinates and reduced levels of all the points are taken and compared with the original one to check any excessive settlement/movement in any plane. One percent settlement initially is allowed.

Chapter -7

ENVIRONMENTAL ASPECTS OF TAILINGS DISPOSAL

A. GENERAL

The public is more conscious of environmental issues associated with resource developments. This has led to closer scrutiny of mining by the public, government and the resource industry itself.

The disposal of waste from mining operations and tailings from beneficiation plants affects the environment both directly and or indirectly. The direct effects are : large areas of land are required for disposal embankments which do not blend with local landscape; and the land cannot be returned to its original state after the termination of mining operations. The indirect or secondary effects are the air and water pollution and health hazards, that can result from these disposal facilities[2].

Improper disposal of mine tailings has the potential to cause serious or even catastrophic environmental damage[4].

Such damages may be damages of (1) Tailings disposal sites, (2) air quality, and (3) water quality.

1. Tailings Disposal sites

Tailings is disposed mainly on land, in river and sea.

(a) LAND DISPOSAL

For the majority of mining operations, land disposal represents the only feasible and acceptable means of tailings disposal.

The main issues associated with land disposal of tailings are :

(i) PUBLIC SAFETY : The risk of failure is the paramount consideration in the planning, design, construction, operation and abandonment of tailings impoundments.

(ii) LAND USE CONFLICT : Tailings impoundments may occupy large areas and involve the inundation or displacement of natural ecosystem, agricultural land and human settlement.

(iii) EFFECTS OF PLANNED OR UNPLANNED RELEASE ON DOWNSTREAM AREAS : Suspended sediments and/or dissolved salts in water overflowing or seeping from tailings impoundments may have adverse effect on the receiving waters.

(iv) REHABILITATION OF IMPOUNDMENTS : Restoration of tailings impoundments to a sustainable and productive land use is necessary to minimise the long term land degradation resulting from land disposal of tailings.

The solution of these problems can be very difficult and expensive, particularly in mountainous, high rainfall area.

Various approaches may be implemented to handle water entering the tailings impoundments from upstream catchment areas. These include :

(i) Provision of freeboard to provide significant storage capacity during the active life of tailings retention system with an overflow spillway to discharge excess water during operation. After tailings disposal ceases, the spillway remains to discharge inflow from the upstream catchment. The spill way may be designed to pass the 1 in 100 year flood event.

(ii) Construction of an upstream dam and diversion tunnels, channels or pipelines to intercept and divert runoff from the upstream catchment and discharge it downstream of the tailings embankment.

(iii) Construction of decant towers, decant culverts, or siphons to convey water from the tailings pond to the drainage below the tailings enbankment.

Careful management of tailings discharge is required to ensure that overflow or decant water does not contain suspended tailings. Consideration of dissolved constituents, including cyanide if used in the process is also required in selecting the system to handle excess water.

(b) RIVER-IN DISPOSAL

River-in disposal of tailings from mining operations was widespread in the past and still occurs in most of the mining operations where the rivers are located nearby. Discharge of tailings to rivers and streams, is an integral and unavoidable part of most of the mining operations in high rainfall areas.

The main issues associated with river-in disposal are :

(i) Degradation of aquatic habitates due to turbidity caused by tailings solids in suspension or burial caused by sedimentation of tailings solids.

(ii) Changes of hydraulic characteristics of river channels due to the accumulation of tailings solids within or adjacent to river flow channels. These changes can interfere with irrigation system and aggravate flooding problems.

(iii) Contamination of surface waters by dissolved salts which can adversely effect the reproduction or growth of aquatic organ isms or, in some cases, may accumulate in certain organisms to levels which can be harmful to man.

(iv) Contamination of irrigation waters by suspended solids or dissolved salts, which may lead to reduced agricultural production.

(v) Effects on the marine environment caused by tailings solids and dissolved salts discharged by rivers to sea.

The overall goal of any system of tailings discharge into rivers should be that the discharge should not exceed the assimilative capacity of the river. This means that :

(i) the tailings should not significantly lower the water quality downstream of the discharge location,

(ii) the solids should be transported rapidly to the sea with little accumulation in the river valley, and

(iii) the concentration of dissolved constituents in the tailings should be sufficiently low that they will not adversely effect aquatic or humans using these.

There are few such rivers which have sufficiently high flow rates throughout the year to absorb significant volumes of tailings without a substantial reduction in water quality. However, there are many situations where river can accommodate overflow of supernatant water from tailings impoundments, provided that the solid fractions have settled in the impoundments.

(c) MARINE DISPOSAL

In some cases where mines occur close to the coast, marine disposal may not only be the cost effective approach to tailings disposal, it may also represent the most environmentally acceptable approach.

Marine disposal provides major advantages over land disposal since no land needs to be acquired for storage, no on-going rehabilitation or maintenance is required and there are also no risks to life or property as a result of instability due to storms or earthquakes.

A possible disadvantage of marine disposal is that it is likely to preclude recovery and retreatment at some time in the future, should the tailings include significant recoverable minerals. It also may result in habitat modification, which could be significant to fisheries if disposal occurs in shallower waters.

2. Air Quality

Air quality can be affected by dust from dry inactive tailings ponds and mine waste piles only in the immediate surrounding area. However, an exception is the radon gas emitted from uranium and some phosphate tailings. Most tailings is of fine particle size and thus particularly susceptible to wind erosion.

Primarily, the degradation of air quality by waste disposal is due to dust generated by the loading and dumping of coarse waste, truck travel to and from the coarse waste dump, and wind drying of tailings embankment. Air quality is also affected by vehicle exhaust emissions; however, these are controlled primarily by exhaust emission control devices on the vehicles.

When the surface of the tailings embankment dries, the tailings can be blown from the pile. Drying of the tailings can occur at several stages during the life of the tailing disposal area.

There are many problems associated with dust that require attention.

It is generally considered that particles smaller than 5 microns are respirable. Particles smaller than 0.5 micron are of particular concern, since this size is likely to pass through the nasal tract into the lungs.

3. Water Quality

Mine waste and tailings impoundments can adversely affect the quality of ground water in nearby drainages. Water quality problems are dependent upon the composition of the tailings and most commonly are caused by acids, heavy metals, reagent chemicals and radioactive materials.

One pollution prevention procedure is to reduce the amount of surface water that can come into contact with the waste pile or tailings. Where possible, designers should make maximum use of diversion ditches, drainage structures and catch basins to divert rainfall and storm runoff away from, around, or off a tailings embankment to minimize pollution.

One alternative for protecting ground water quality from contamination due to tailings ponds is to perform some chemical or physical treatment of the tailings before discharge to the ponds.

Some of the potential toxic contaminants associated with mining and milling wastes are given in Table 2.1. in Chapter II.

Mill tailings, and to a lesser extent coarse waste, can be a source of many surface water contaminants : toxic heavy metals such as lead, mercury and arsenic; sediment and suspended solids and others.

The methods for protecting surface water quality during operation of the waste disposal areas are largely the same as that during reclamation, namely;

i) runoff diversion,

ii) collection of direct precipitation,

iii) chemical, physical or vegetative stabilization, and

iv) other soil erosion and sediment control methods.

Soil erosion and sediment control are important means of protecting surface water quality for areas and activities associated with the waste disposal areas, such as haul roads and construction and expansion activities.

Chapter-8
CONCLUSIONS

1. The disposal of tailings does not generate profit, therefore, the cost of the tailings control structures must be minimum consistent with safety and ecological requirements.
2. The most economic tailings dam construction programme generally involves the use of coarse fraction of the tailings for a major portion of the dam.
3. For dams that are high or are located in areas of earthquake potential, the downstream method or centreline method of construction is recommended. For these conditions, the downstream slopes must be compacted.
4. The planning and design programme must include a thorough evaluation of the physical and mechanical properties of the foundation soil and rock, ground water, borrow materials and tailings fractions proposed for use in the dam. This requires a site investigation and field and laboratory test programme.
5. Analysis of stability, settlement, seepage, erosion control, environmental impact and reclamation is a fundamental requirement in the planning of any tailings dam.
6. Construction control using field instrumentation is required to ensure the tailings dam constructed according to the design specifications, and functioning as intended.
7. All the parameters required for the design of a tailings dam have been prevented namely, grain size distribution, relative density and moisture density relationship, shear strength, consolidation and permeability.
8. Sand-type tailings has a wide application as an engineering construction material.
9. Silt type tailings will probably be too difficult to compact and are suspectible to severe erosion and frost action, thus these tailings should not be used for the construction of tailings dams. However, silt type tailings, if dense enough, are an excellent sealant of pervious sand.
10. Liquefaction can be averted by increasing the insitu relative density to 60 percent at a limiting degree of saturation.
11. Consolidation tests disclosed that the density of loose deposited tailings does not significantly increase with depth or time.
12. Drip irrigation is a new method with many advantages and used on mine waste areas. The drip system saves enormous quantities of water yet does much more effective job of leaching. The principle of drip irrigation has long been proven effective in green house culture where an inert growing media is used. New equipment and technology has made drip irrigation an expensive dependable method for establishing vegetation on mine waste areas.
13. Tailings which have a very high sulphide content can under favourable conditions of air and moisture heat spontaneously and burn. The fires can be extinguished with wet tailings pulp or water sprinkling.
14. Radioactive uranium tailings and sodium cyanide rich gold tailings and mercury tailings require positive control of seep age. All soils allow some seepage, although for compacted clay it will be small, so that special procedures are required if downstream contamination is a potential problem. For maximum seepage control, the upstream slope of the dam may be covered with a plastic or similar type membrane.

15. On potash project care must be taken to ensure the brine does not escape. If any of the dyke is constructed of the settled and hardened brine, care must be taken that solution channels do not develop. Usually the retaining dyke must be constructed of impervious borrow soils. The base of the settling pond should be selected where fine grain soils exist to minimize seepage under the dam. Frequently, two ponds are used. In this case much of the brine is decanted from the primary pond to the second pond for sedimentation of the clay fraction.
16. The surface erosion is a problem; in this regard special control or construction methods may be considered while planning of the design of tailings dam.
17. Competent engineering supervision should always be specified for construction of the starter dam and periodic inspections by a stability specialist are necessary.

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ANNEXURE - I

Physical & Chemical composition of Tailings at Mine A

Spcific Gravity of Tailings	-	2.86
Normal particle size	-	48 mesh
Occuasional particle size	-	28 mesh
pH	-	7 to 8
Dissolved 02 mg/litre	-	3 to 8
Flow velocities	-	Min. velocity
size		
- 48 mesh	-	2.5 m/sec.
- 28 mesh	-	3.0 m/sec.
Chemical composition		
Element		Wt%
Cu	-	0.03
Pb	-	Traces
Ni	-	0.007
Mo	-	0.006
Fe	-	3.08
S	-	0.43
SiO_2	-	84.24
Al_2O_3		5.68
CaO	-	1.11
MgO	-	1.43