FLOODING OF A MINE TAILINGS SITE
SOLBEC CUPRA

SUSPENSION OF SOLIDS:
IMPACT AND PREVENTION

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McGill

Geotechnical Research Centre

McGill University
Macdonald Engineering Building
817 Sherbrooke Street West
Montreal, Quebec, Canada H3A 2K6

Centre de recherche géotechnique

Université McGill
Pavillon Macdonald de génie
817, rue Sherbrooke ouest
Montréal (Québec) Canada H3A 2K6

Tel.:
Telex: Canada and USA: 05-268510
Other countries: 5268510
Fax: (514) 398-7361

FLOODING OF A MINE TAILING SITE
SUSPENSION OF SOLIDS - IMPACT AND PREVENTION

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Prepared by

A.M.O. Mohamed, R.N. Yong, F. Caporuscio, and R. Li

Geotechnical Research Centre
McGill University
817 Sherbrooke St. West
Montreal, Quebec Canada

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SOMMAIRE

Les résidus miniers produisant de l'acide sont un problème pour l'industrie minière. En limitant l'oxygène disponible pour le procédé d'oxydation, les "couvertures" d'eau sont une des méthodes pour contrôler la génération d'acide. Cette étude évalue la couverture d'eau optimale requise pour prévenir la remise en suspension des particules solides et ainsi réduire l'impact environnemental sur un site donné - Solbec Cupra. Suite à des expériences, on a trouvé que la hauteur d'eau minimale au dessus des résidus miniers devrait être 1,341 m. Toutefois, avec une couche de sable sur les résidus, la hauteur requise peut être réduite à 0,741 m. Aussi, on a calculé qu'une couche de sable peut réduire la charge totale en sédiments de 331.1 à 41.8 m^3/m/jour.

ABSTRACT

Acid generating tailings is a problem to be solved in the mining industry. By limiting the available oxygen for the oxidation process, water covers is one of the methods to control the acid generation. This study evaluates the optimum height of water required to prevent the resuspension of solid particles and thus reducing the environmental impact on a specific site - Solbec Cupra. Based on the experimental results, it has been found that the minimum height of water above the reactive tailing should be 1.341m. However, with a layer of sand on top of the tailings the required level may be reduced to 0.741m. Also, it has been calculated that a layer of sand can reduce the total sediment load from 331.1 to 41.8 m^3/m/day.

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1.0 INTRODUCTION

Environmental management of acid generating tailings and waste rock is a challenge facing the mining industry and government. The Canadian mining industry produces more than 500 million tonnes of tailings and waste rock a year, much of it resulting from wastes oxidize producing sulphuric acid. Acid generation, as well as acid consumption, is the resultant of a number of inter-related chemical reactions. The primary ingredients for acid generation are: (1) sulphide minerals; (2) water or humid atmosphere; and (3) an oxidant, particularly oxygen. Exclusion of absolutely all moisture or oxidant (O_2 or Fe^{3+}) will stop acid generation.

In contrast to the above ground disposal of reactive waste where oxygen and moisture are freely available, the storage of reactive waste underwater produces different reaction conditions. With atmospheric oxygen as the ultimate crucial oxidant in the acid producing reaction, underwater disposal can drastically curtail reaction rates. First, the concentration of dissolved oxygen in water can attain a maximum of 8.6×10^{-6} g/ml at normal conditions of pressure and temperature compared to 21% V/V (or 2.85×10^{-4} g/ml) concentration of oxygen in air. Secondly, the diffusion coefficient for oxygen in water ($\sim 2 \times 10^{-9}$ m^2/sec) is nearly five orders of magnitude less than in air (~ 1.78×10^{-5} m^2/sec).

Water cover on reactive wastes provide three important control measures:

(1) Limiting available oxygen for the oxidation process, and hence controlling acid generation.

(2) Eliminating surface erosion caused by wind and water action if placed in a depositional basin thus controlling dust problems.

(3) Creating a reducing environment, suitable for supporting sulphate and nitrate reducing micro-organisms in sediments, where soluble metals are precipitated as sulphides and ammonia generated by the reduction of nitrates.

The oxidation, reduction and diffusion kinetics in sediments, and the interaction with the overlying water and transport related to wave induced turbulent motion will play a key role in maintaining the physical and chemical stability of waste deposited underwater. In general, oxidation in natural sediments is inhibited where rapid accumulation is accompanied by a high organic matter content. Because the concentration of dissolved oxygen in water is relatively low, the available oxygen in the pore water will be rapidly depleted by oxygen consuming bacteria and a high linear sedimentation rate will settle newly dumped sediments reasonably fast therefore minimizing diffusive contact with overlying bottom water. Thus the combination of a high organic load and rapid sedimentation will ensure the establishment of anoxic conditions at shallow depths and prevent the oxidation of deposited sulphide minerals (Pedersen et la., 1991)

Water cover as an alternative includes: (1) subaqueous or underwater disposal in natural fresh water bodies such as lakes and marine disposal; (2) disposal into man-made impoundments or reservoirs; (3) disposal into flooded mine workings and open pits, and (4) building a water cover on existing waste management sites. This study is focused on alternative No. 4.

1.1 Water Cover on Tailings at Existing sites

The site specific requirements that need to be considered are the area hydrogeology, climatic conditions, topography, and seismicity. Water retention dams and spillways have to be carefully constructed for flood management and run-off flows to handle regional and probable maximum precipitation event. During periods of extreme summer drought combined with the driest observed winter conditions, water flow to the site have to be augmented to prevent beaching and exposure of the waste to the weathering and oxidation cycle.

The design impoundment should also provide a minimum water depth for prevention wave induced bottom erosion and sediment/water resuspension. Factors that determine the water depth at which resuspension occurs are: wind forces, wind force duration, wave-fetch (distance needed for a wave to develop) and particle size and density of bottom sediments. Depending on the impoundment size and waste characteristics, intermediate wave breaker dykes (break-waters), sand/soil cover in shallow waters and/or wetland type vegetation may be required to prevent resuspension and oxidation of the waste.

Although the water cover will prevent further direct oxidation of sulphide minerals, the presence of existing soluble oxidation reaction products and resident acidity will require that additional neutralizing agents be incorporated in the waste material prior to flooding. An effluent treatment plant will also be required during the transitional period until all the oxidized materials has been reduced, consumed or flushed away.

The final decommissioning option may also incorporate the establishment of wetlands in shallow waters along the shorelines which will aid in maintenance of a wet cover and protect surface erosion by wave action, provide rich organic sediment cover layers as oxygen consumer and supplement carbon/nutrient source for nitrate and sulfate reducing bacteria. Bacterial reduction of nitride (denitrification), sulphate (sulphate reduction) and organic matter (methanogenises) produces salinity and hydrogen sulphide gas which precipitate soluble metals as sulphides (Kuyucak, et al. 1991).

1.2 OBJECTIVE

The objective of this project is to evaluate the optimum height of water required to prevent resuspension of solid particles and hence reduce the environmental impact.

1.3 TASKS

The research project consists of three fundamental stages: 1) determination of wind conditions; 2) water wave investigation, and 3) behaviour of suspended solids as a function of the input energy. The first stage consists of theoretical and field investigation of wind preferential direction, its force and the time of wind action. The second stage is theoretical approach to the water wave dynamics for the Solbec-Cupra specific conditions. The overview of various methods for calculating the required depth will be taken into consideration. The third stage consists of laboratory studies on dynamics of solid resuspension. A simulation of real field conditions will be studied in hydraulic laboratory on natural fine waste from Solbec-Cupra tailing. The suspended solid volume will be evaluated as a function of the different energy inputs and the solid particles behaviour.

2.0 EXPERIMENTATION

2.1 Test Procedure

A 20mm thickness of tailings was placed with light compaction at the bottom of a lucite box with dimensions of 1730mm (length) by 105mm (width) by 300mm (depth). Tap water was carefully introduced into the box so as not to disturb the placed tailings. The water level was initially adjusted to 214mm above the tailings. The wave was generated by immersing a horizontal placed cylinder (50.8 mm diameter) at a rate of 2 cycles per second to a depth of 25mm. Each cycle is defined as the motion of the cylinder from half submerged to fully submerged, and then back up to half submerged. Thus a 25mm high wave was achieved.

Waves were generated in the direction normal to the box. Visual observations were noted to the condition of the tailings. With no disturbance observed, the water level was dropped by 25mm. The procedure of inducing wave action and lowering the representative water level was continued until the fines in the tailings were suspended. Figure 2.1 illustrates the test setup. Fig. 2.2 shows the wave created by the equipment.

A second layer of sand (concrete grade-washed) of 13mm thick was then placed on top of the tailings. The above procedure was then repeated.

The grain size analysis of the tailings is shown in Figure 2.3

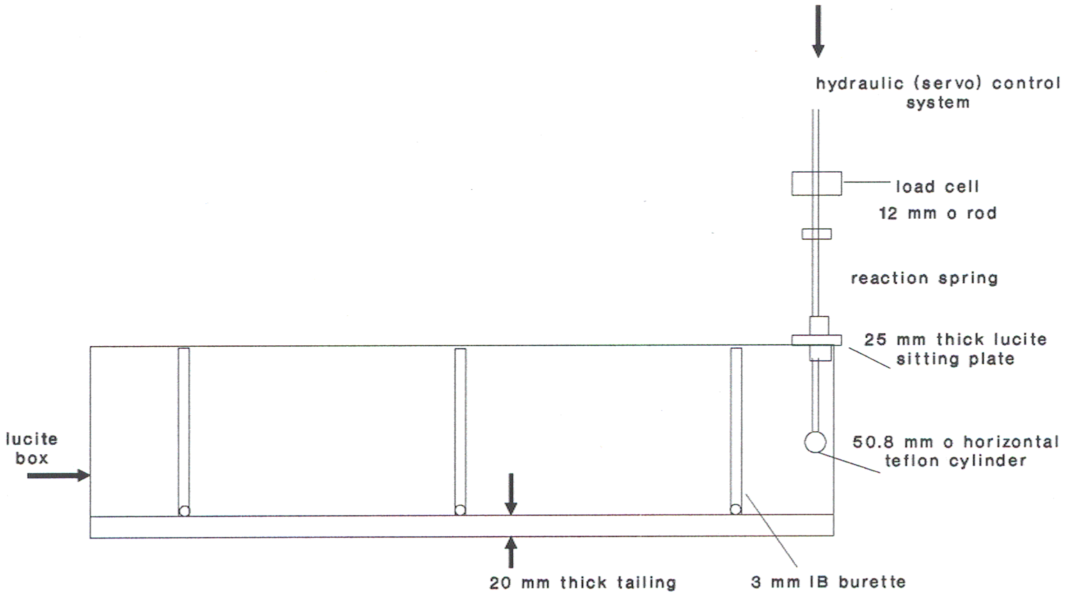

Fig. 2.1 Test setup

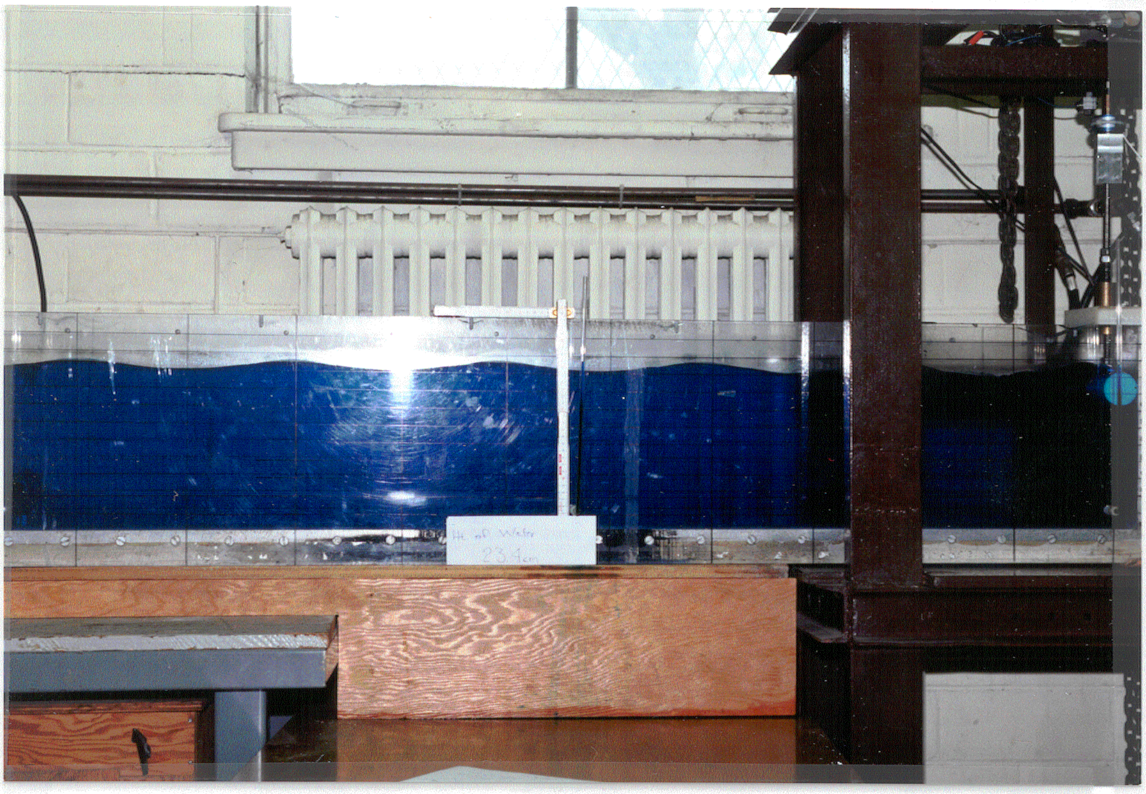

Fig. 2.2 Photo of equipment with wave action

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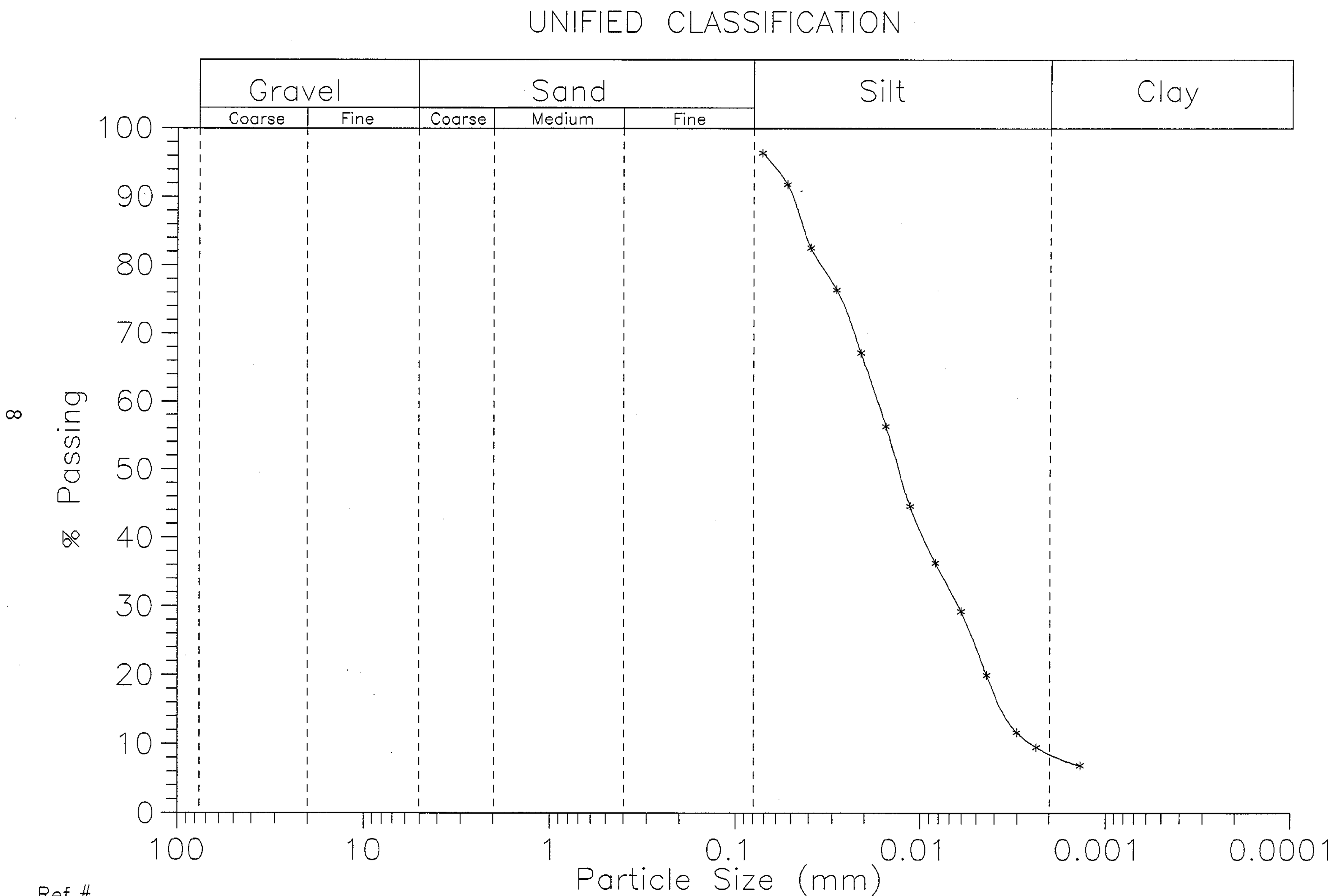
Figure 2.3 Particle Size Distribution for Sample for Solbec



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2.2 Laboratory tests

2.2.1 Case 1 - Testing with tailing and water only

Table 2.1 shows that particle resuspension occurred as the H/h ratio reaches 0.2129

Table 2.1 Data and observation of movement of tailing particle under wave action

Trial No.	h (cm)	H (cm)	H/h	input wave (cycle/sec)	Remark
1	21.3	2.3	0.1079	2	No particle movement observed
2	18.8	2.3	0.1223	2	Very small cloud of particles movement observed under the piston
3	16.2	2.3	0.419	2	ditto
4	13.5	2.3	0.1704	2	ditto
5	12.0	2.3	0.1916	2	ditto
6	10.8	2.3	0.2129	2	Horizontal and vertical movement of particles observed (6cm back and forth in horizontal direction)
7	9.7	2.3	0.237	2	Cloud of particles of 1 cm height moving at 1.5m form the source of input was observed

where h = height of water above sediment
H = height of wave

2.2.2 Case 2 - Testing with 13mm sand on the top of tailing

Table 2.2 shows that particle resuspension occurred as the H/h ratio reaches 0.3968

Table 2.2 Data and observation of movement of sand particle under wave action

Trial No	h (cm)	H (cm)	H/h	Input Wave (cycle/sec)	Remark
1	19.9	2.5	0.1256	2	No sand particle movement observed
2	17.4	2.5	0.1436	2	ditto
3	14.4	2.5	0.1736	2	ditto
4	12.4	2.5	0.2016	2	ditto
5	9.8	2.5	0.2551	2	ditto
6	7.2	2.5	0.3472	2	Small particles movement observed under piston
7	6.3	2.5	0.3968	2	Only 1 particle moving back and forth was observed

where h = height of water above sand and tailing
H = height of wave

3.0 WIND AND WAVE EFFECTS

3.1 Introduction

The design of water cover impoundments containing reactive tailings requires that the physical erosion of the waste surface be prevented. The transport of particulate material to beaches and/or resuspension could expose them to the weathering and oxidation process, not only within the impoundment, but also downstream causing severe water quality problems.

Resuspension and erosion of sediment is restricted to shallow impoundments and lakes or the shores of deeper lakes. Factors that control the rate and extent of resuspension are shear forces near the bottom induced by flow and/or waves; the density, shape and size of sediment particles; and the cohesive properties of the sediment. The latter is a very complex factor related to the grain size distribution, the water and organic content, bioturbation and to the charge and charge distribution of the particles causing electrostatic interactions. The pH and ionic strength of the interstitial water affect these charges (Yong, Mohamed and Warkentin, 1992).

Two approaches are generally used for calculating resuspension : (1) empirical (Hakanson, 1977), and (2) to ensure the rate of resuspension as a function of shear force in the laboratory and use this empirical relationship in combination with hydro-dynamic models for wave and flow that generate data on bottom shear forces (Sheng and Lick, 1979). A laboratory annular flume has been used to assess the rate of resuspension under steady state conditions. Experiments have indicated that particle size variation is a significant factor, that the amount of material available for entrainment at a particular bottom stress is finite and that only particles below a critical size and not overlain by other coarser particles can be entrained (Lijklema et al., 1986).

The general procedure used in calculating sediment transport by either of the above approaches involves an hourly time series hindcast of wave condition and sediment transport rates along several directional axes across the waste impoundment for available wind recorded data, usually obtained from local weather stations or airports. From the wind data, a statistical data file for the open water season (unfrozen) is produced. The frequency of the occurrence of various wind and wave conditions are obtained using numerical methods. The integration of these results provides the sedimentation transport along the various selected axes.

The synthesis of an actual wave climate involves wave hindcasting procedures with a numerical model (Nairn, 1992). Wave prediction techniques are applied under the assumption of either shallow water or deep water conditions. Shallow water or long wave conditions exist if the local depth is less than one half to one third of the wave length of an individual wave. For most of the underwater impoundment, shallow water conditions exist. Deep water or short wave conditions are present where the wave length is much less than the water depth.

In shallow water the wave action extends to the bottom. Sedimentation is prevented in sufficiently shallow water, and the movement of the sediment-water column may be too severe for most aquatic plants to grow. In such conditions, recently sedimented material is constantly suspended and moved to deeper areas. As a result, in suitable shallow water of approximately 1 m depth, marl beaches on the steep sides of these water bodies do not

Expressions for the prediction of shallow water waves based on variables of wind speed and fetch length are provided in the U.S. Army Corps. of Engineer's Shore Protection Manual (1984). A semi-empirical method based on Sverdrup-Munk-Bretschneider (SMB) method for shallow water is used to calculate the significant wave height H_s, and significant wave period T_s, at a given location where wind speed and duration, fetch length and average depth over the fetch are known.

3.2 Water Depth Calculations

The graphical relationship relating significant wave height, H_s, peak energy period, T_p, and wind duration to fetch length, F, and wind speed, u is shown in Figure 3.1 This is based on the original relationships due to Darbyshire and Draper (1963) which were derived from observations around Britain and provides a means of estimating wave parameter from wind data for coastal waters. The significant wave height and associated peak energy period may be determined by the fetch or the duration of the wind depending on which limiting criterion is first encountered by the ordinate representing wind speed.

For Solbec-Cupra site, the following data are obtained:

(1) maximum wind speed, u = 10 m/sec

(2) fetch length, F = 1.5 km

From Figure 3.1, the following information can be obtained

(1) peak energy period, T_p = 2 sec

(2) wave height, H_s = 0.15 m

(3) wind duration = 0.2 h

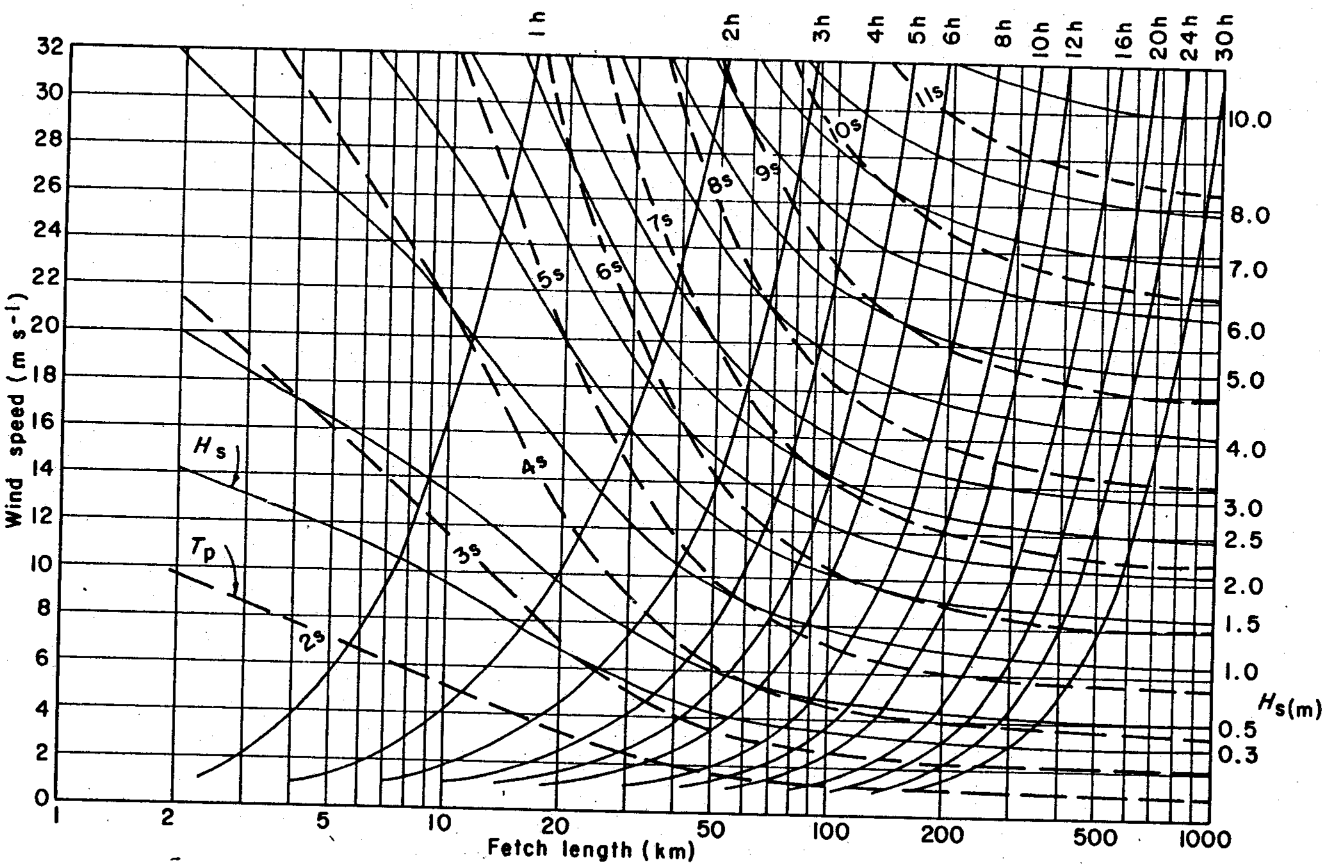

Fig. 3.1 Wind speed against fetch length

(3) wind duration = 0.2 h

For a storm lasting 0.2 h, the average number of incident waves (NIW) would be

$$NIW = \frac{0.2\ x\ 60\ x\ 60}{2} = 360$$

Therefore,the maximum wave height, H_s, can be calculated from

$$H_{max} = (0.5 \ln NIW)^{\frac{1}{2}}\ H_s$$
$$= (0.5\ \ln\ 360)^{\frac{1}{2}}\ x\ 0.15 = 0.257m$$

In order to check for shallow water condition, it is necessary to calculate the wave length, L_o. The wave length can be calculated form the following equation:

$$L_o = \frac{gT^2}{2\pi}$$

where: g is the gravity (m/sec^2); T is the wave period (sec).

For Solbec-Cupra site, T = 2 sec; hence;

$$L_o = \frac{9.81\ x\ (2)^2}{2\pi} = 6.245m$$

For shallow water condition, the height of water over the wave length should be less than one half. Hence, the height of water, h will be;

$$H \leq 6.246\ x\ 0.5$$
$$\leq 3.122m$$

At this stage, the actual water height is unknown.

However, the calculated maximum wave height, H_s, will be used in association with the experimental data to calculate the height of the water. Since one can not build a model with the same dimension as the field condition, a scale of 1:10 was used. Hence the wave height was set to be equal 0.025 m in all the experiments.

The experimentally obtained ratio between wave height, H, and water height, h, beyond which resuspension occurs is 0.1916. In order to transform this data to the field condition, the height of water in the field is calculated as follows:

$$\textit{height of water,h,} = \frac{\textit{actual wave height in the field}}{0.1916}$$

$$= \frac{0.257}{0.1916} = 1.341m$$

Therefore, the minimum height of water above the reactive tailings should be 1.341 m. The adopted solution for the Solbec-Cupra site is to flood the area with water. According to the topography of the site it is estimated that the height of the water will be 1 m in the north-west of the site and a height of about 5 m in the north-east of the site. The above experimentally calculated water height seems to be adopted in the north-west portion of the site. However, in the north-east, the solution will create major construction cost to build higher tailing dams. In order to overcome this problem, it is suggested to use a layer of construction sand placed over the tailing layer to prevent the resuspension and lower the required water height.

The experimental program conducted for the sand/tailing case has demonstrated that the required water height can be reduced to 0.741 m above the sand layer.

4.0 SEDIMENT TRANSPORT

4.1 Introduction

Nairn (1992) examined various wave condition for their potential to initiate sediment motion and to cause net sediment transport. The estimates were made for three different grain sizes, from very fine sand (0.1 mm) to fine sand (0.2 mm), and medium sand (0.4 mm). The results of the initiation of motion and sediment transport were obtained for possible wave conditions in ponds with depths 0.91 m and 1.82 m, respectively.

The results indicated that for many wave conditions, especially for 0.91 m basin with a 0.2 mm grain size, the sediment transport rates were appreciable in a shoreward direction and could mount to a considerable net sediment transport over a long period of time. For two different ponds the maximum annual sediment transport rates were calculated as 3.3 - 4.6 x 10^{-4} m^3/m.year, which leads to a stable beach development in 50,500 to 71,400 years for a 0.91 m deep pond.

4.2 Sediment Transport Modelling

The simplest one-dimensional time dependent suspended load distribution is given by the diffusion equation

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial z}\left(\epsilon_s \frac{\partial c}{\partial z} - c w'\right) \tag{1}$$

where: t is time; ϵ_s is a sediment diffusion coefficient, and w' is the vertical velocity of the sediment.

In order to arrive to equation (1) it must be assumed that sediment diffusion in the horizontal direction is negligible compared to the vertical and that conditions are changing slowly enough to neglect lateral differences in advective transport of sediment and hence horizontal concentration gradients. In a quasi-steady state for which it can be assumed that

$\frac{\partial c}{\partial t} = 0$, $w_s = -w'$ so that $\frac{\partial w'}{\partial z} = 0$ where w_s is the particle fall velocity, equation (1) can then be reduced to

$$\epsilon_s \frac{\partial c}{\partial z} + c w_s = 0 \tag{2}$$

where c is sediment concentration, and z is vertical distance measured upwards from the water surface. If one substitutes z by z' where $z' = z + h$, equation (2) takes the following form

$$\epsilon_s \frac{\partial c}{\partial z'} + c w_s = 0 \tag{3}$$

To solve equation (3) it is necessary to specify the vertical distribution of eddy viscosity or dispersion coefficient ϵ_s. As sediment suspension occurs at levels for which the shear stresses due to the oscillating motion are extremely difficult to measure, it is more convenient to find a sediment exchange coefficient which is not based on shear stress distribution. Due to the relatively low intensity of turbulence outside the breaker zone, velocity fluctuations are comparable to the settling velocity of the sediment (MacDonald, 1973). Under these conditions it has been shown by Einstein and Chein (1955) that the momentum exchange coefficient no longer gives a good estimate to the sediment exchange coefficient.

Various forms of eddy viscosity distribution have been investigated including the case of zero viscosity or which the sediment is assumed to be supported entirely by wave orbital motion. Either laboratory measurements for distribution of turbulent velocity fluctuation or concentration distributions measured in the field must be used to determine the sediment diffusion coefficient.

It may be assumed (Kennedy and Locher, 1972) that

$$\frac{\epsilon_s}{\epsilon_o} = \left(\frac{z'}{z_o}\right)^{\lambda} \tag{4}$$

where the sediment diffusion coefficient is a function of depth related to a value ϵ_o at reference level z_o and λ is a positive constant. Equation (4) cannot satisfy the boundary conditions at the free surface, but as sediment concentration under waves attenuates rapidly away from the bed this inconsistency may be considered admissible.

The solution to Equations (3)and (4) is

$$\ln\left(\frac{c}{c_o}\right) = \frac{w_s z_o}{\epsilon(1-\lambda)}\left[1-\left(\frac{z'}{z_o}\right)^{1-\lambda}\right] \tag{5}$$

when $\lambda \neq 1$ and

$$\frac{c}{c_o} = \left(\frac{z'}{z_o}\right)\exp\left(-\frac{w_s z_o}{\epsilon_o}\right) \tag{6}$$

when $\lambda=1$ and c_o is a reference concentration at the same reference level z_o.

The simplest distribution results from constant diffusivity over depth (λ =0) when

$$c = c_o \frac{-w_s}{\epsilon_o}(z' - z_o) \tag{7}$$

One of the expression for the diffusion coefficient based on Equation (7) is

$$\epsilon_o = K\frac{HL}{T} \tag{8}$$

where K, a dimensionless coefficient, can be shown to be of the order 2.8 x 10^{-5}.

A slightly different approach has been proposed by Bijker (1971) who based a sediment transport model of unidirectional flow methods for which only the shear stress was modified to allow for the combination of waves and currents.

Using the Einstein-Rouse formulation for uniform flow

$$\epsilon_s = kv_{*wc} \frac{z'}{h}(h - z') \tag{9}$$

From equation (3)

$$\frac{c}{c_o} = \left(\frac{h-z'}{z'} \; \frac{z_o}{h-z_o}\right)^{\frac{w}{kv_{*wc}}} \tag{10}$$

where v_{*wc} is the shear velocity due to waves and currents defined as

$$\frac{v_{*wc}}{v_{*c}} = \left[1 + \frac{1}{2}\left(\xi \; \frac{u_o}{v}\right)^2\right]^{\frac{1}{2}} \tag{11}$$

where

$$\xi = \frac{pkch}{\sqrt{g}} \tag{12}$$

$$ch = 18 \log\left(\frac{12h}{k_N}\right) \tag{13}$$

Ch is chezy roughness coefficient and P is a constant with an experimental value of 0.45.

Based on a similar ideas and a concentration distribution of the form given by Equation (6), an empirical expression of the exponent has been proposed (Delft Hydraulic Laboratory, 1976) as

$$\frac{w_s z_o}{60} = 1.05\left(\frac{w_s}{dv_{*wc}}\right)^{0.96}\left(\frac{k_N}{h}\right)^{0.013\left(\frac{w_s}{kv_{*wc}}\right)} \tag{14}$$

Equations (13) and (14) require the definition of a roughness length. Bijker chose a value of k_N as one-half of the ripple height and assumed that the reference level is the same.

4.3 Roughness Length

The problem of determining how much applied shear stress is available to the transport sediment and how much is used to overcome bed form resistance is linked to the roughness length of the bed, a parameter that frequently appears in both bed load and suspended load calculations.

Roughness length is essentially an empirical parameter associated with the physical dimensions of a boundary expressed either as the grain size or as ripple size. It is basically used to overcome the lack of detailed knowledge of events in the boundary layer and may be used as an empirical parameter to be determined by best fit of formulate to experimental data.

The Delft Hydraulics Laboratory (1976) suggests an empirical framework for estimating both ripple dimensions and roughness length when data on ripple geometry and corresponding roughness are plotted as the ratio of the roughness length to ripple height against bed form steepness. The relationship can be expressed as

$$\frac{k_N}{\Delta_r} = 25\left(\frac{\Delta_r}{\lambda_r}\right) \tag{15}$$

where Δ_r is the ripple height and λ_r the ripple wavelength so that the bed geometry must be know in order to estimate k_N.

4.4 Prediction of Total Sediment Load

In this elaboration of the prediction, the total load sediment will be considered as a total with no distinction to bed load and suspended load. The formula for one total load sediment transport model may be summarized as follows (Swart, 1972):

$$F_{wc} = \frac{\bar{v} I_{wc} n}{(C_D)^{1-n}\,(ch)^n\,(\Delta_s\, D_{35})^{\frac{1}{2}}} \tag{16}$$

where

$$I_{wc} = \left[1 + \frac{1}{2}\left(\frac{\xi_j\, u_o}{v}\right)^2\right]^{\frac{1}{2}} \tag{17}$$

$$\xi_j = ch\left(\frac{fw}{2g}\right)^{\frac{1}{2}} \tag{18}$$

$$C_D = 8 \log\left(\frac{10h}{D_{35}}\right) \tag{19}$$

$$n = 1 - 0.2432 \ln(D_{gr})$$

f_w is a wave friction factor; D_{gr} is a dimensional grain size factor defined by

$$D_{gr} = \left(\frac{g\Delta_s}{\nu^2}\right)^{\frac{1}{3}} D_{35} \tag{20}$$

where Δ_s is the relative density ratio, and ν is the current velocity . The total sediment transport is then given by

$$Q = \left(\frac{1}{1-P}\right) D_{35}\nu\left(\frac{ch}{\sqrt{g}}\right)^n (I_{WC})^{1-n}\frac{C}{A^m}(F_{wc} - A)^m \tag{21}$$

where:

$$m = \frac{9.66}{D_{gr}} + 1.34 \tag{22}$$

$$A = \frac{0.23}{\sqrt{D_{gr}}} + 0.14 \tag{23}$$

$$C = \exp\ [2.86 \ln(D_{gr}) - 0.4343\ [\ln(D_{gr})]^2 - 8.128] \tag{24}$$

All of the constants shown above are similar to those of uniform flow, but they may be defined to allow for the dependence of beginning of movement on wave orbital velocity.

Equation (23) applies when current velocities predominate $(u_o/v_{*c} \leq 3)$. If wave particle velocities predominate $(u_o/v_{*x} \geq 10)$ A becomes

$$A = 2.29\left(\frac{f_w}{\Delta_s g}\right)^{\frac{1}{2}} \frac{T^{0.043}}{D_{50}^{\ 0.12}} \tag{25}$$

A linear transition between the limiting values may be assumed.

Finally, an extremely straight forward expression to apply for approximate calculations of total sediment load may be derived from the oscillatory flow equivalent of Engelund and Hansens uniform flow total sediment load predictor.

$$Q=0.05v\frac{chv^{4}_{*wc}}{g^{\frac{5}{2}}\ \Delta_s^2\ D_{50}} \tag{26}$$

This express intends to overestimate sediment transport rates especially at low transport rates because of lack of a threshold of movement criterion.

4.5 Application to Solbec-Cupra Site

To proceed with the calculation for Solbec-Cupra site, the following data are used which based on the available information related to the site:

(1) maximum wind speed = 10 m/sec

(2) current velocity = 0.5 m/sec

(3) length of the lake = 1.5 km

(4) wave height as calculated in the previous sections = 0.257 m

(5) sediment characteristics

(a) average diameter from hydrometer analysis = 10 μ_m = 0.01 mm.

(b) specific gravity, G_s = 2.85

(c) unit weight of water = 1.03 Mg/m^3

(d) D_{35} = 0.02 mm

(e) D_{50} = 0.015 mm

In order to calculate the height at which c = 0 above the bed due to both the effect of wave and currents, the following assumptions were used.

(1) ripple dimensions are as follows:

(a) length = 100 times the average diameter = 1 mm

(b) height = 10 times the length = 10 mm

(2) the concentration of solids due to resuspension would be less than 10% of the solid concentration at the bed surface, i.e., $c/c_o < 10\%$.

The following steps were used:

(1) calculate the length of the wave

$$L_o = \frac{gT^2}{2\pi} = \frac{9.81\ (2)^2}{2\pi} = 6.245m$$

(2) Calculate the maximum particle displacement, a_o

$$a_o = \frac{H}{2\ \sinh \frac{2\pi h}{L}} = \frac{0.257}{2\ \sinh\left[\frac{2\pi(1.34)}{6.245}\right]}$$

$$= \frac{0.257}{2\ \sinh\ (1.348)} = 0.0625m$$

(3) Calculate the maximum water particle velocity, u_o

$$u_o = \frac{2\pi a_o}{T} = \frac{2\pi(0.0625)}{2} = 0.1963 \ m/sec$$

(4) Calculate the roughness length, k_N

$$k_N = \frac{25(\Delta r)^2}{\lambda_r} = \frac{25(1)^2}{10} = 2.5 \ mm$$

(5) Calculate chezy roughness (ch)

$$ch = 18 \log \left(\frac{12h}{k_N}\right)$$

$$= 18 \log \frac{12(1.34)}{2.5} = 14.55 m^{\frac{1}{2}}/sec$$

(6) Calculate the shear velocity due to current alone, ν_{*c}

$$\nu_{*c} = \frac{\nu g^{\frac{1}{2}}}{ch} = \frac{0.5(9.81)^{\frac{1}{2}}}{14.55} = 0.1076 \ m/sec$$

(7) Calculate the exponent constant, ξ

$$\xi = \frac{pkch}{g^{\frac{1}{2}}} = \frac{0.45 \times 0.4 \times 14.55}{(9.81)^{\frac{1}{2}}}$$

$$= 0.83618$$

(8) Calculate the shear velocity due to wave and currents, ν_{*wc}

$$v_{*wc} = v_{*c}\left[1 + \frac{1}{2}\left(\xi\frac{u_o}{v}\right)^2\right]^{\frac{1}{2}}$$

$$= 0.1076\left[1 + \frac{1}{2}\left(0.83618\ \frac{0.1963}{0.5}\right)^2\right]^{\frac{1}{2}}$$

$$= 0.11046\ m/\mathrm{sec}$$

(9) from hydrometer analysis of the sediment, calculate the sedimentation velocity of a 0.01 mm diameter, w_s

$$w_s = 0.014\ \frac{cm}{\mathrm{sec}} = 0.00014\ m/\mathrm{sec}$$

(10) Calculate the concentration distribution

$$\frac{w_s\ z_o}{t_o} = 1.05\left[\frac{w_s}{kv_{*wc}}\right]^{0.96}\left[\frac{k_N}{h}\right]^{0.013\left(\frac{w_s}{kv_{*wc}}\right)}$$

$$= 1.05\left[\frac{0.00014}{0.4\times0.11046}\right]^{0.96}\left[\frac{2.5}{1.34\times10^3}\right]^{0.013\left(\frac{0.00014}{0.4\times0.11046}\right)}$$

$$= 1.05\ [0.003168]^{0.96}\ [0.00187]^{0.00004}$$

$$1.05\times0.00398\times0.99975$$

$$=0.00417$$

(11) Assume $z_o = \frac{1}{2}$ roughness length $= \frac{2.5}{2} = 1.25$ mm

(12) Calculate z/z_o

(13) Calculate the total sediment transport rate, Q

$$\frac{c}{c_o} = \left(\frac{z}{z_o}\right) \exp\left(-\frac{w_s z_o}{\epsilon_o}\right)$$

$$= \left(\frac{z}{z_o}\right) \exp\,(-0.00417) = 0.9958\frac{z}{z_o}$$

$$\therefore \frac{z}{z_o} = 1.0049\left(\frac{c}{c_o}\right)$$

$$= 1.00419(0.1) = 0.100419$$

$$z = 0.100419 \times 1.25 = 0.1255\ mm$$

$$D_{gr} = \left(\frac{g\Delta_s}{\nu^2}\right)^{\frac{1}{3}} D_{35}$$

$$= \left[\frac{9.81 \times (2850 - 1030)}{(10^{-6})^2 \times 1030}\right]^{\frac{1}{3}} \left(\frac{0.02}{1000}\right)$$

$$= 0.517$$

$$n = 1 - 0.2432 \ln\,(D_{gr})$$

$$= 1 - 0.2432 \ln\,(0.2070)$$

$$= 1.160$$

Since $0 \le n \le 1$, n is taken to be equal 1

$\therefore$ the corresponding $D_{gr} = 1.0$.

$$m = \frac{9.66}{D_{gr}} + 1.34 = \frac{9.66}{1} + 1.34 = 11$$

$$C_D = 18 \log\left(\frac{10h}{D_{35}}\right)$$

$$= 18 \log\left(\frac{10 \times 1.34}{0.02}\right) = 50.869$$

$$C = \exp\left[2.86 \ln(D_{gr}) - 0.4343 \left[\ln (D_{gr})^2\right] - 8.128\right]$$
$$= \exp\left[-8.128\right] = 0.000295$$

Check for the ratio of $\frac{u_o}{v_{*c}} = \frac{0.1963}{0.1076} = 1.824 < 3$; therefore A can be calculated

using Equation (25)

$$A = 2.29\left(\frac{f_w}{\Delta_s g}\right)^{\frac{1}{2}} \frac{T^{0.043}}{D_{50}^{0.12}}$$

$$= 2.29\left(\frac{0.028 \times 1030}{(2850 - 1030) \times 9.81}\right)^{\frac{1}{2}} \frac{(2)^{0.043}}{(0.015 \times 10^{-3})^{0.12}}$$

$$= 2.29 \times 0.04019 \times 3.9067 = 0.359$$

$$I_{wc} = \left[1 + \frac{1}{2}\left(\frac{\xi_i u_o}{v}\right)^2\right]^{\frac{1}{2}}$$

$$= \left[1 + \frac{1}{2}\left(\frac{0.83618 \times 0.1963}{0.5}\right)^2\right]^{\frac{1}{2}}$$

$$= 1.0265$$

$$F_{wc} = \frac{v I_{wc}^n}{(C_D)^{1-n}(Ch)^n(\Delta_s\ D_{35})^{\frac{1}{2}}}$$

$$= \frac{0.5 \times 1.0265}{(50.869)^{o}\ (14.55)\left[\frac{2850-1030}{1030} \times \frac{0.02}{1000}\right]^{\frac{1}{2}}}$$

$$= 5.9338$$

$$Q = \left(\frac{1}{1-P}\right) D_{35}\ \nu \left(\frac{ch}{\sqrt{g}}\right)^{n} I_{wc}^{1-n}\ C \left(\frac{F_{wc} - A}{A}\right)^{m}$$

$$= \left(\frac{1}{1-0.35}\right)\frac{0.02}{1000} \times 0.5 \left(\frac{14.55}{\sqrt{9.81}}\right)^{1} (1.0265)^{o} \times 0.000295 \left(\frac{5.9338-0.359}{0.359}\right)^{5}$$

$$= 0.0000153 \times 4.645 \times 1 \times 0.000295 \times 902971.85$$

$$=0.01893\ m^{3}/m/\text{sec}$$
$$=1.635.552\ m^{3}/m/day$$

Using Equation (26), the total sediment load, Q

$$Q = 0.05\nu \frac{ch\ \nu_{*wc}^{4}}{g^{5/2}\ \Delta_{5}^{2}\ D_{50}}$$

$$Q = \frac{0.05 \times 0.5 \times 14.55 \times (0.11046)^{4}}{(9.81)^{5/2}\left(\frac{2850-1030}{1030}\right)^{2} \times \left(\frac{0.015}{1000}\right)}$$

$$= \frac{0.0000541}{301.42 \times 3.122 \times 0.000015}$$

$$= 0.0038326\ m^{3}/m/\text{sec}$$

$$= 331.14\ m^{3}/m/day$$

It seems that the quantity of sediment transport is big. However, in order to mitigate the situation a layer of sand could be placed on the top of the tailings after neutralization. For weight 2650 kg/m^3, the total sediment load is

$$Q=\frac{0.05\times0.5\times14.55(0.11046)^4}{(9.51)^{2.5}\left(\frac{2650-1030}{1030}\right)^2\times\left(\frac{0.15}{1000}\right)}$$

$$=\frac{0.0000541}{301.42\times2.473\times0.00015}$$

$$= 0.000483 m^3/m/\mathrm{sec}$$

$$= 41.80 m^3/m/day$$

5.0 CONCLUSION

By reducing the available oxygen, it is possible to control the acid generation from mining wastes. Water cover is a on-site method to reduce available oxygen for oxidation and reduction in the sediments. By simulating the site conditions in the laboratory, it has been found that the minimum required height of water to prevent wave induced erosion and resuspension of particles is 1.341m. Because of the topography, the height of the water in the northeast area of the site may be as high as 5m. However, laboratory test results show that a layer of sand placed on top of the tailing can reduce the height of required water from 1.341m down to 0.741m, thereby reducing the construction cost of the dam. Mathematical analysis also demonstrates that such a layer of sand can reduce the total sediment from 331.1 to 41.8 m^3/m/day.

6.0 REFERENCES

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