

# Health Assessment of Old Tailing Dam- A Case Study

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## Abstract

The growth of the mining industry, mainly driven by increased resource demands, has accelerated the production and storage of mine waste. Tailings comprise the fine-grained fraction of this waste. Due to their intrinsically hazardous characteristics from a geochemical and geotechnical perspective, tailings are conventionally discharged in slurry form behind constructed dams for public and environmental safety purposes. However, tailings dams have been under significant scrutiny following a number of high-profile, catastrophic breach events in, for example, Jagersfontein, South Africa (2022), Corrego do Feijao, Brazil (2019), 2019 Hindalco Muri failure (Jharkhand) releasing red mud, and the 2022 Thelkolo breach (Odisha) from a JSW Bhushan Power slurry pond etc. Insufficient understanding of geotechnical properties of waste material (tailing), faulty construction method, heavy rainfall, seismic activity etc. are major cause of failure of tailing dam. This paper presents the results of Health assessment (geotechnical site investigation) in one of the old tailings storage facilities (copper tailing) located in the North Central part of India. The health assessment is required as the height of existing dam to be raised to accommodate more tailings. It is planned to raise the height tailing dam about 7.0 m which will serve the purpose of storage of tailing about 12 Years.

In the present health assessment, the author highlighted the following objective:

- I. Geotechnical investigations (borrow area) are carried at 06 location for characterisation of tailing.
- II. Foundation investigation of existing tailing dam in 03 Borehole locations.
- III. Determination of liquefaction capability of the tailing dam (factor of safety) based on SPT - N Value.(BH-1)

**Key Words:** Health Assessment, tailing dam, geotechnical properties, borrow area

## I. Introduction

### 1.1 Tailing and its Classification:

Tailings are the waste mineral remaining after the valued minerals have been removed from the ore. Typically, the ore is crushed to fine sand at a concentrator mill and “values” are removed by floatation or chemical processes in the form of “concentrates”. The valueless mineral remaining at the “tail” end of the process is referred to as tailings [11]. ICOLD (2020) has classified tailings into five categories depending on their geotechnical properties and these five categories are summarized in Table-1[6]:

Table 1: Summary of Tailings Types and Geotechnical Classification

| Tailings Type         | Symbol | Description (compare)  | Example of mineral/ore  |
|-----------------------|--------|--|---|
| Coarse tailings       | CT     | Silty SAND, non-plastic Salt   | Salt, mineral sands, coarse coal rejects, iron ore sands  |
| Hard Rock tailings    | HRT    | Sandy SILT, non to low plasticity  | Copper, massive sulphide, nickel, gold  |
| Altered Rock tailings | ART    | Sandy SILT, trace of clay, low plasticity, bentonite clay content        | Porphyry copper with hydrothermal alteration, oxidized rock, bauxite. leaching processes                            |
| Fine tailings         | FT     | SILT, with trace to some clay, low to moderate plasticity                | Iron ore fines, bauxite (red mud), fine coal rejects, leaching processes, metamorphosed/weathered polymetallic ores |
| Ultra Fine tailings   | UFT    | Silty CLAY, high plasticity, very low density and hydraulic conductivity | Oil sands (fluid fine tailings), phosphate fines; some kimberlite and coal fines                                    |

**1.2 Dam Failure Reasons:**

As per ICOLD 2020 [6], the potential failure modes for a tailings dam are as follows:

**1.2.1 Instability Due to Foundation Failure:**

Instability of the dam foundation can occur possibly due to undetected weak materials, incorrect strength assumptions, and or incorrect seismic hazard/response analysis. Other failure mechanisms could include, for example, pore pressure generation and artesian water pressures. Foundation failure is a common failure mode for tailings dams with the most recent examples of Cadia, Australia (2018), Mt. Polley, British Columbia, Canada (2016), Aznocolar (Los Frailes), Spain (1994).

**1.2.2 Instability Due to Failure of the Dam**

Slope Instability of the dam slope can occur due to inclusion of weak materials in the structural portion of the dam, lack of compaction and poor drainage, or incorrect seismic hazard/response analysis. Upstream tailings dams with thin structural shells are typically more vulnerable to slope failure as the tailings are normally placed in a heterogeneous manner and are contractive. This was observed with dam failure examples in Brazil in 2015 and 2019.

**1.2.3 Overtopping**

Tailings dams can overtop during flood events possibly in concert with blocked spillways or improper water management. Baie Mare (2000) is an example of overtopping due to rain on snow event, common in cold temperate climates.

**1.2.4 Other Natural Hazards and Erosion**

In addition to flood events within the TSF, natural hazards could include rock, soil or snow avalanches into the TSF impoundment leading to overtopping or instability of the dam or natural landslides that may form part of the dam abutment or foundations. Other natural hazards include extreme floods in adjacent streams that could erode the toe of the dam or erosion of the dam due to high intensity rainfall on the downstream slope of the dam.

**1.2.5 Piping**

Piping (internal erosion) occurs when the hydraulic gradients are high enough to move fine particles within the dam fill and there are not adequate filters to control movement of particles that can lead to failure of the dam. The Omai (1992) piping failure occurred when the water pond was against the face of the downstream constructed dam and the filter between the clay core and the rockfill shell was not adequate to prevent piping of fines out of the core.

**1.2.6 Failure Along Decant Towers, Pipes or Pipelines**

Where used, decant towers or pipes through the dam or foundation can fail due to lack of structural integrity under static and dynamic loading, blockage with debris, piping of fines along/around the pipe extension through the dam. An uncontrolled rupture of a tailings slurry delivery or water reclaim pipeline could erode the dam crest potentially leading to release of tailings and water.

**1.2.7 Environmental Effects**

Tailings dams are typically constructed to limit surface and groundwater contamination. Potential failure modes include release of acidic waters or neutral metal leaching. Failure of seepage barriers to perform as per the design may be due to unidentified seepage paths, poor construction and other factors. Other environmental failure modes may include, for example, dust generation or fauna impacts with contaminated water.

The Figure 1 represents no of incidents and cause of failures for failure of mine tailing dam (1915 to 2016) all over the world, taken from website of GRID-Arendal (11) is a non-profit environmental communications centre based in Norway.

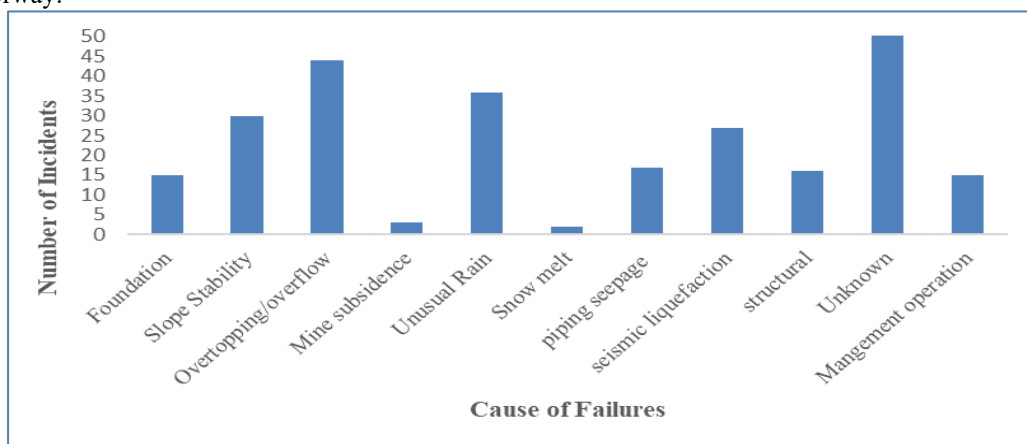


Figure 1: Various causes of mine tailings dam failures in the world

If failure of tailings dam occurs, the risks are high costs, hindered public perception, environmental cleanup and worst of all, the loss of life; as shown in Table 2, which illustrates some of the greatest fatalities due to tailings dam failures [9].

Table 2: Incident of live lost due to mine tailings dam liquefaction [9]

| Year  | Location                               | Impact           |
|-------|--|------------------|
| 1965  | El Cobre New Dam Chile                 | > 200 fatalities |
| 1966  | Aberfan, Wales                         | 144 fatalities   |
| 1966  | Sgorigrad,Bulgaria                     | 488 fatalities   |
| 1970  | Mufulira,Zambia                        | 89 fatalities    |
| 1972  | Buffalo Creek, West Virginia,USA       | 125 fatalities   |
| 1985  | Stava,Italy                            | 268 fatalities   |
| 1988  | Jinduicheng,Shaanxi province,China     | 20 fatalities    |
| 1994  | Merriespruit,South Africa              | 17 fatalities    |
| 1995  | Placer, Surigao del Norte,Philippines  | 12 fatalities    |
| 2000  | Nandan county, Guangxi province, China | 15 fatalities    |
| 2006  | Milang, Shaanxi Province, China        | 17 fatalities    |
| 2019* | Brumadinho, Minas Gerais, Brazil       | 270 fatalities   |

Therefore, a better understanding of characteristics of mine tailing dam is essential for a mining or geotechnical engineer. Therein lies the scope of this paper, which is to present geotechnical investigation (borrow area) for characterisation of mine and foundation investigation of existing tailing dam.

## II. Scope of work

A comprehensive scope of work for material investigation shall include the following major components:

### 2.1 Borrow Area Investigations

All the tailing samples collected from borrow areas for Health assessment was subjected to the following laboratory tests for ascertaining their suitability as the borrow area material:

- Mechanical Analysis - IS:2720 - 4
- Atterberg Limits - IS:2720 – 5
- Standard Proctor Compaction - IS:2720 - 7
- Specific Gravity - IS:2720 - 3

### 2.2 Field Investigations:

A total of 3 boreholes were drilled of 100 mm diameter and varying depths from 13.7 m to 20.5 m at existing tailing dam for carrying out foundation investigation and collection of soil samples for further laboratory testing for ascertaining index and engineering properties of sub soil.

The following field tests were carried during drilling process as described above as per the mentioned Bureau of Indian Standards:

- Standard Penetration Tests - IS: 2131
- Field Permeability Tests - IS: 5529 Part-1
- Collection of Undisturbed Soil Sampling - IS: 2132

The following laboratory investigations were carried out on all the collected soil samples from bore hole as described above as per the mentioned Bureau of Indian Standards:

- Mechanical Analysis - IS:2720 - 4
- Atterberg Limits - IS:2720 – 5
- In-situ Density and natural Moisture Content - IS:2720 - 7
- Specific Gravity - IS: 2720 – 3

## III.Geotechnical Investigations (Borrow Area)

### 3.1 Borrow area Investigations

The Figure 2 represents location of pits in copper mine as well as borrow area investigations:



Figure 2: Location of pits in copper mine as well as borrow area investigations

The results of borrow area (laboratory) investigations are tabulated in Table 3

Table 3: Geotechnical Properties of Borrow area Samples

| Description of Test                     | BA-1      | BA-2        | BA-3  | BA-4  | BA-5       | BA-6  |
|---|-----------|-------------|-------|-------|------------|-------|
| Clay Size Particle                      | 2.7       | 2.6         | 4.0   | 2.2   | 1.8        | 2.1   |
| Silt Size Content (less than 75 Micron) | 40.4      | 34.3        | 40.6  | 39.8  | 30.4       | 37.0  |
| Sand Size Particle                      | 56.9      | 63.1        | 55.4  | 58.0  | 67.8       | 61.0  |
| Liquid Limit                            | 21.2      | 21.3        | 21.1  | 21.8  | 21.9       | 22.0  |
| Plastic Limit/<br>Plasticity Index      | <b>NP</b> |             |       |       |            |       |
| D <sub>10</sub>                         | 0.004     | 0.004       | 0.003 | 0.004 | 0.005      | 0.004 |
| D <sub>30</sub>                         | 0.023     | 0.036       | 0.020 | 0.025 | 0.058      | 0.031 |
| D <sub>60</sub>                         | 0.131     | 0.152       | 0.124 | 0.135 | 0.164      | 0.148 |
| C <sub>c</sub>                          | 1.07      | 1.96        | 1.07  | 1.15  | 4.10       | 1.68  |
| C <sub>u</sub>                          | 33.9      | 34.9        | 41.3  | 33.8  | 32.8       | 37.0  |
| IS Classification                       | SM        | SM          | SM    | SM    | SM         | SM    |
| Specific Gravity                        |           | 2.99        |       |       | 2.96       |       |
| MDD (g/cc) & OMC (%)                    |           | 1.97 & 11.2 |       |       | 2.00 & 9.0 |       |

The Figure 3 represents average Grain size distribution curve of copper tailing

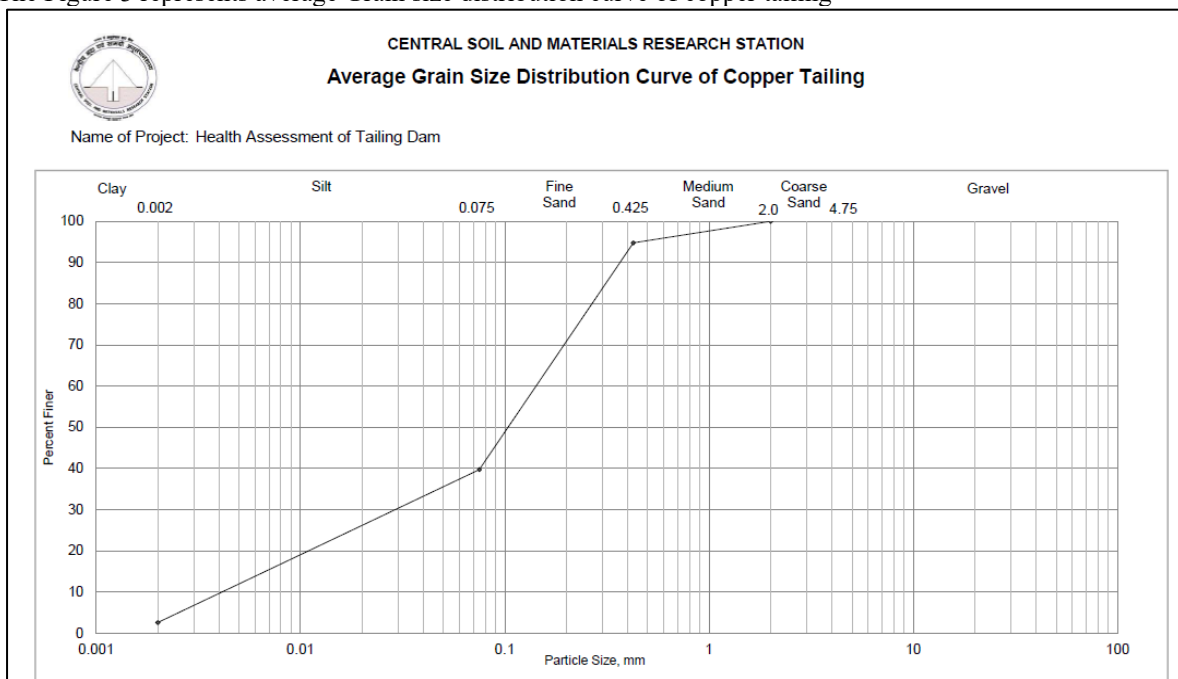


Figure 3: Average Grain size distribution curve of copper tailing

Based on the findings of the borrow area investigations carried out on the mine samples collected from the borrow area for raising the height of existing Tailing Dam, the following points have been observed:

The grain size analysis of the borrow area materials indicate that the tested soil samples in general possess predominantly fine sand sizes followed by silt sizes and clay sizes. The Liquid Limit values of the tested soil samples indicate that the soil samples in general possess low compressibility characteristics. The plasticity index values of the tested soil samples indicate that all the 6 tested soil samples are non-plastic in nature. The values of Maximum Dry Density and Optimum Moisture Content of the tested soil samples vary from 1.97 g/cc to 2.00 g/cc and 9.2 % to 11.2 % respectively. Based on the Standard Proctor Compaction tests, it is inferred that the tested soil samples can achieve good compaction densities.

**3.2 Filed Investigations:**

In the present study, three bore holes of 100 mm diameter have been conducted in copper tailing mines with varying depths from 13.5 m to 20.5 m. In the bore hole SPT tests have been carried out as per IS 2131 (1981). The Figure 3 presents map for locations of 3 boreholes. The BH-1 is at 0.5 Km from BH-2 in upstream side whereas BH-3 is 1.5 km from BH-2 in downstream side.



**Figure 3.** Location of 3 boreholes, SPT and field permeability test

The result of SPT (N-Values) conducted at different depths in 3 boreholes and percentage fine contents are shown in Table No. 4, 5 and 6:

**Table 4: Result of Standard Penetration Test, Percentage Fine Content (BH -1)**

| Test No | Depth (m)   | N <sub>60</sub> | Soil Classification | Percentage Fine |
|---------|-------------|-----------------|---------------------|-----------------|
| SPT-1   | 1.50-1.95   | 39              | SM (Silty Sand)     | 25.7            |
| SPT-2   | 3.00-3.45   | 10              | SM (Silty Sand)     | 18.3            |
| SPT-3   | 4.50-4.95   | 19              | SM (Silty Sand)     | 16.4            |
| SPT-4   | 7.50-7.95   | 28              | SM (Silty Sand)     | 21.4            |
| SPT-5   | 9.00-9.45   | 34              | SM (Silty Sand)     | 23.8            |
| SPT-6   | 10.50-10.95 | 40              | SM (Silty Sand)     | 24.2            |
| SPT-7   | 12.00-12.45 | 43              | SM (Silty Sand)     | 30.4            |
| SPT-8   | 13.50-13.95 | 52              | SM (Silty Sand)     | 40.6            |
| SPT-9   | 15.00-15.45 | 28              | SM (Silty Sand)     | 36.5            |
| SPT-10  | 16.50-16.95 | 33              | SM (Silty Sand)     | 22.3            |
| SPT-11  | 18.00-18.45 | 36              | SM (Silty Sand)     | 22.5            |
| SPT-12  | 19.50-19.45 | 24              | SM (Silty Sand)     | 26.2            |

**Table 5: Result of Standard Penetration Test, Percentage Fine Content (BH-2)**

| Test No | Depth (m) | N <sub>60</sub> | Soil Classification | Percentage Fine |
|---------|-----------|-----------------|---------------------|-----------------|
| SPT-1   | 1.5       | 12              | SM (Silty Sand)     | 51.2            |
| SPT-2   | 3.0       | 18              | SM (Silty Sand)     | 33.4            |
| SPT-3   | 4.5       | 17              | SM (Silty Sand)     | 18.2            |
| SPT-4   | 6.0       | 19              | SM (Silty Sand)     | 49.0            |
| SPT-5   | 7.5       | 25              | SM (Silty Sand)     | 47.3            |
| SPT-6   | 9.0       | 25              | SM (Silty Sand)     | 15.0            |
| SPT-7   | 10.5      | 47              | SM (Silty Sand)     | 31.0            |

|        |      |    |                 |      |
|--------|------|----|-----------------|------|
| SPT-8  | 12.0 | 35 | SM (Silty Sand) | 48.1 |
| SPT-9  | 13.5 | 60 | SM (Silty Sand) | 60.8 |
| SPT-10 | 15.0 | 47 | SM (Silty Sand) | 40.0 |
| SPT-11 | 16.5 | 54 | SM (Silty Sand) | 44.8 |
| SPT-12 | 18.0 | 38 | SM (Silty Sand) | 30.0 |
| SPT-13 | 19.5 | 44 | SM (Silty Sand) | 35.5 |

Table No. 6: Result of Standard Penetration Test, Percentage Fine Content (BH-3)

| Test No | Depth (m) | N <sub>60</sub> | Soil Classification | Percentage Fine |
|---------|-----------|-----------------|---------------------|-----------------|
| SPT-1   | 1.5       | 13              | SM (Silty Sand)     | 62.4            |
| SPT-2   | 3.0       | 7               | SM (Silty Sand)     | 69.1            |
| SPT-3   | 4.5       | 39              | SM (Silty Sand)     | 77.0            |
| SPT-4   | 6.0       | 8               | SM (Silty Sand)     | 73.1            |
| SPT-5   | 7.5       | 7               | SM (Silty Sand)     | 73.9            |
| SPT-6   | 9.0       | 37              | SM (Silty Sand)     | 66.9            |
| SPT-7   | 10.5      | 20              | SM (Silty Sand)     | 46.7            |

From the Table No. 4, 5 & 6, it has been observed that at all 3 bore holes lithology presents Silty Sand (SM) and N values varies from 7 to 60.

Table 7: Result of In-situ dry Density and Moisture Content, Specific Gravity (BH-1)

| Test No | Depth (m)    | Bulk Density (g/cc) | Natural Moisture Content (%) | Insitu Dry Density $\gamma_{dry}$ (g/cc) | Specific Gravity |
|---------|--------------|---------------------|------------------------------|--|------------------|
| UDS-1   | 2.25-2.55    | 1.659               | 4.9                          | 1.582                                    | 2.95             |
| UDS-2   | 5.25-5.55    | 1.646               | 5.2                          | 1.565                                    | 2.95             |
| UDS-4   | 11.25- 11.55 | 1.643               | 5.8                          | 1.553                                    | 2.94             |
| UDS-5   | 14.25-14.55  | 1.653               | 5.4                          | 1.568                                    | 2.94             |
| UDS-6   | 17.25-17.55  | 1.668               | 5.0                          | 1.589                                    | 2.94             |

Table 8: Result of In-situ dry Density and Moisture Content, Specific Gravity (BH-2)

| Test No | Depth (m)   | Bulk Density (g/cc) | Natural Moisture Content (%) | Insitu Dry Density $\gamma_{dry}$ (g/cc) | Specific Gravity |
|---------|-------------|---------------------|------------------------------|--|------------------|
| UDS-1   | 2.25-2.55   | 1.889               | 11.5                         | 1.694                                    | 2.94             |
| UDS-2   | 5.25-5.55   | 1.732               | 7.5                          | 1.611                                    | 2.92             |
| UDS-4   | 11.25-11.55 | 1.678               | 7.7                          | 1.558                                    | 2.92             |
| UDS-5   | 14.25-14.55 | 1.662               | 7.0                          | 1.553                                    | 2.91             |
| UDS-6   | 17.25-17.55 | 1.721               | 11.2                         | 1.548                                    | 2.92             |

Table 9: Result of In-situ dry Density and Moisture Content, Specific Gravity (BH-3)

| Test No | Depth (m)   | Bulk Density (g/cc) | Natural Moisture Content (%) | Insitu Dry Density $\gamma_{dry}$ (g/cc) | Specific Gravity |
|---------|-------------|---------------------|------------------------------|--|------------------|
| UDS-1   | 2.25-2.55   | 1.85                | 10.3                         | 1.677                                    | 2.92             |
| UDS-2   | 5.25-5.55   | 1.74                | 9.8                          | 1.585                                    | 2.92             |
| UDS-3   | 8.25-8.55   | 1.98                | 11.5                         | 1.776                                    | 2.93             |
| UDS-4   | 11.25-11.55 | 1.93                | 12.5                         | 1.716                                    | 2.90             |

Based on the findings of the field investigations carried out on the mine samples collected from the Bore Hole 1, 2 & 3 for health assessment of Tailing Dam, the following points have been observed:

The grain size analysis of the borrow area materials indicate that the tested soil samples in general possess predominantly fine sand sizes followed by silt sizes and clay sizes. The Liquid Limit values of the tested soil

samples indicate that the soil samples in general possess low compressibility characteristics. The plasticity index values of the tested soil samples indicate that all the tested soil samples are non-plastic in nature. The values of In-situ Dry Density and Natural Moisture Content of the tested soil samples vary from **1.55 g/cc to 1.77 g/cc and 4.9 % to 12.5 %** respectively.

#### IV. Liquefaction Analysis

##### 4.1 Theory behind Evaluation of Liquefaction Hazard

The main parameter required for liquefaction susceptibility includes location of water table, SPT blow count and fine content of soil encountered at particular depth. Starting in the 1970's, Seed and his colleagues worked to develop a reliable method for assessing liquefaction potential based on SPT data. In 1996, T. L. Youd and I. M. Idriss convened a workshop with 20 experts from all over the world to consolidate and incorporate the research findings on liquefaction. Following procedure for evaluation of liquefaction is based on this paper [10]:

**Step 1:** Factor of Safety against liquefaction = Cyclic Resistance Ratio/ Cyclic Stress Ratio

**Step 2:** Evaluation of Cyclic Stress Ratio (CSR)

$$CSR = \text{Average cyclic shear stress} / \text{Effective overburden stress} = \left( \frac{\tau_{avg}}{\sigma'_{vo}} \right)$$

$$= 0.65 \left[ \left( \frac{a_{max}}{g} \right) \left( \frac{\sigma_{vo}}{\sigma'_{vo}} \right) \right] \gamma_d$$

Where  $r_d = 1.0 - 0.00765 z$  for  $z \leq 9.15$  m

$$r_d = 1.174 - 0.0267 z \text{ for } 9.15 \text{ m} < z \leq 23 \text{ m}$$

**Step 3:** Evaluation of Cyclic Resistance Ratio (CRR) using SPT-N values Let  $N_m$  be measured standard penetration blow count.

$N_m$  is corrected for (a) equipment used (b) overburden stress (c) procedure followed, and (d) fines content (if fines > 5%).

Corrected N value for equipment, overburden stress and procedure:

$$(N_1)_{60} = N_m C_N C_E C_B C_R C_S$$

where  $C_N$  is overburden correction =  $\left\{ \frac{P_{atm}}{\sigma'_{vo}} \right\}^{0.5}$

$P_{atm}$  is atmospheric pressure (100 kPa) &  $\sigma'_{vo}$  = effective overburden stress.

$C_E$  is correction for hammer energy ratio =  $\left\{ \frac{EE}{60\%} \right\}$

EE (Energy Efficiency) depends on hammer type; US equipment, EE is 60%.

$C_B$  is correction for borehole diameter (65-115 mm,  $C_B = 1$ ). Varies 1 to 1.15

$C_R$  is correction for SPT rod length (For Rod length 10-30 m,  $C_R=1$ ; For 6-10 m,  $C_R=0.95$ ; For 4-6 m,  $C_R=0.85$ ; For 3-4 m,  $C_R=0.8$ ; For < 3m,  $C_R=0.75$ ).

$C_S$  is correction for sampler with or without liner. (Standard sampler = 1)

**Step 4:** Evaluation of Cyclic Resistance Ratio (CRR): CRR available for clean sand only. Therefore convert  $(N_1)_{60}$  to  $(N_1)_{60CS}$  by considering effect of fines content (FC)

$$(N_1)_{60CS} = \alpha + \beta(N_1)_{60}$$

where  $(N_1)_{60CS}$  is corrected  $(N_1)_{60}$  for equivalent clean sand value.

$\alpha = 0$  for  $FC \leq 5\%$ ,

$\alpha = \exp \left\{ 1.76 - \left( \frac{190}{FC^2} \right) \right\}$  for  $5\% < FC < 35\%$ ,

$\alpha = 5.0$  for  $FC \geq 35\%$ .

$\beta = 1.0$  for  $FC \leq 5\%$ ,

$\beta = [0.99 + (FC^{1.5}/1000)]$  for  $5\% < FC < 35\%$ ,

$\beta = 1.2$  for  $FC \geq 35\%$ .

**Step 5:** Evaluation of CRR for EQ magnitude of 7.5 =  $CRR_{7.5}$

When  $(N_1)_{60CS} < 30$ ,

$$CRR_{7.5} = \left\{ \frac{1}{(34 - (N_1)_{60CS})} \right\} + \left\{ \frac{(N_1)_{60CS}}{135} \right\} + \left\{ \frac{50}{((10(N_1)_{60CS}) + 45)^2} \right\} - \frac{1}{200}$$

Where,  $(N_1)_{60CS} > 30$ , clean granular sands are too dense to liquefy. As a conservative estimate,  $CRR_{7.5}$  is considered as 0.6.

##### 4.2 Evaluation of Liquefaction potential

For the computation of FOS with respect to liquefaction potential, the value of earthquake magnitude considered as  $MW=7.5$  and copper tailing dam lies in seismic zone IV. The water table considered in Ground level. The dry density value calculated as  $20 \text{ kN/m}^2$  in borehole. In the present study, using data available at Table No. 2, 3 & 4, liquefaction potential evaluated and presented in Table No. 10:

Table No. 10: Evaluation of Liquefaction Potential for Bore Hole No. 1

| Depth | % fine | $\sigma'_{vo}$<br>kPa | $r_d$    | CSR     | $N_m$ | $C_N$ | $\alpha$ | $\beta$ | $(N_1)_{60sec}$ | FoS  |
|-------|--------|-----------------------|----------|---------|-------|-------|----------|---------|-----------------|------|
| 1.5   | 25.7   | 15                    | 0.988525 | 0.30842 | 39    | 2.58  | 4.36     | 1.12    | 88.97           | 1.95 |
| 3.0   | 18.3   | 30                    | 0.977050 | 0.30484 | 10    | 1.83  | 3.30     | 1.07    | 17.92           | 0.59 |
| 4.5   | 16.4   | 45                    | 0.965575 | 0.30125 | 19    | 1.49  | 2.87     | 1.06    | 28.30           | 1.26 |
| 7.5   | 21.4   | 75                    | 0.942625 | 0.29409 | 28    | 1.15  | 3.84     | 1.09    | 37.29           | 2.04 |
| 9.0   | 23.8   | 90                    | 0.931150 | 0.29051 | 34    | 1.05  | 4.16     | 1.11    | 41.82           | 2.07 |
| 10.5  | 24.2   | 105                   | 0.893650 | 0.27881 | 40    | 0.98  | 4.20     | 1.11    | 47.49           | 2.15 |
| 12.0  | 30.4   | 120                   | 0.853600 | 0.26632 | 43    | 0.91  | 4.73     | 1.16    | 50.17           | 2.25 |
| 13.5  | 40.6   | 135                   | 0.813550 | 0.25382 | 52    | 0.86  | 5.0      | 1.20    | 58.71           | 2.36 |
| 15.0  | 36.5   | 150                   | 0.773500 | 0.24133 | 28    | 0.82  | 5.0      | 1.20    | 32.43           | 2.49 |
| 16.5  | 22.3   | 165                   | 0.733450 | 0.22883 | 33    | 0.78  | 3.97     | 1.10    | 32.11           | 2.62 |
| 18.0  | 22.5   | 180                   | 0.693400 | 0.21634 | 36    | 0.75  | 3.99     | 1.10    | 33.42           | 2.77 |
| 19.5  | 26.2   | 195                   | 0.653350 | 0.20384 | 24    | 0.72  | 4.41     | 1.12    | 23.73           | 1.32 |

### V. Conclusions:

In the present study author has highlighted:

- (i) All the parameters required for the design of tailing dam or raising the height of tailing dam have been presented here, namely grain size distribution, in-situ density and moisture content, moisture-density relationship, shear strength parameters and permeability.
- (ii) Copper mines tailings are of non-plastic in nature and Silty Sand (SM) as per soil classification.
- (iii) % fine content as well as SPT nos are critical in evaluating Liquefaction potential.
- (iv) As the deposition of copper mine tailing are being carried out in the form of slurry through pipe and no field compaction carried out along with deposition, therefore strata is very much heterogeneous and density/N value does not have any consistency with depth.
- (v) Liquid limit values of tailing samples indicate that the tailing sample in general possess low compressibility characteristics.
- (vi) The grain size analysis of the borrow area materials indicate that the tested soil samples in general possess predominantly fine sand sizes followed by silt sizes and clay sizes.

### References

- [1]. Bureau of Indian Standards (1985, Reaffirmed 2015) "Method of Test for Soils (Grain Size Distribution)" Code of Practice. IS: 2720 –Part IV.
- [2]. Bureau of Indian Standards (1980, Reaffirmed 2002) "Method of Test for Soils (Determination of Specific Gravity)" Code of Practice. IS: 2720 –Part III/Sec II.
- [3]. Bureau of Indian Standards (1980, Reaffirmed 2013) "Method of Test for Soils (Determination of Water Content-Dry Density Relation Using Light Compaction)" Code of Practice. IS: 2720 –Part VII.
- [4]. Bureau of Indian Standards (1983, Reaffirmed 2002) "Method of Test for Soils (Determination of Density Index (Relative density) of Cohesion less soils.)" Code of Practice. IS: 2720 –Part XIV.
- [5]. Bureau of Indian Standards (1985, Reaffirmed 2006) "Method of Test for determination of Liquid Limit and Plastic Limit.)" Code of Practice. IS: 2720 –Part V.
- [6]. ICOLD 2020 "Sustainable Development of Dams and River Basins,"
- [7]. Bureau of Indian Standards (1981, Reaffirmed 2002) "Determination of Shear strength parameters of soil from Consolidated Undrained Triaxial Compression test with measurement of Pore Water Pressure" Code of Practice. IS: 2720 –Part 12
- [8]. Bureau of Indian Standards (1981, Reaffirmed 2002) "Method for Standard Penetration test for soils" Code of Practice IS 2131
- [9]. Puri Vijay K and Kostecki Todd R. (2013) "Liquefaction of Mine Tailings" International Conference on Case Histories in Geotechnical Engineering.
- [10]. Youd T. L, Idriss I M (2001) "Liquefaction resistance of soils: summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils".
- [11]. Controller General, Indian Bureau of Mines (1995) "Tailing Dam Design, Technical Bulletin No. 30"