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Failure of Micaceous Waste Tailings Dam

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SYNOPSIS

The paper describes the failure and reconstruction of an 80 ft. high, 8 acre tailings impoundment in Western North Carolina. The dam was constructed using the upstream method of construction. The coarse fraction of the tailings was used as embankment construction materials; these consisted of coarse to fine sands. The fine fraction tailings consisted of low density, relatively low plasticity, layered fine sands and fine sandy silts with frequent interbedding of micaceous silty clays. Although a 200 ft. section of the dam failed, the fine saturated tailings did not liquefy but rather slumped into the breach. Reconstruction was complicated because there was no convenient access to the toe of the dam. Since this dam had been previously studied and found to be marginally stable, the failure reinforces the need for the engineer to keep accurate records of telephone conversations and other correspondence to help protect himself from having any liability in the failure.

BACKGROUND

The Deneen Mica Company owns and operates a mica mine in Western North Carolina near the town of Burnsville. In 1963 the company began the development of a new tailings facility on the site of a previous pasture adjacent to the South Toe River. By 1974 the tailings dam was almost 80 ft. high in places and the tailings pond covered an area of about 8 acres. This dam was overtopped during a storm in the spring of 1974 and, although the eroded areas created when the dam was overtopped were refilled, the dam failed on June 24, 1974. This paper describes the nature and properties of the embankment materials and the impounded slimes and the steps that were taken to rebuild the structure.

The tailings dam was constructed by the mine personnel using the upstream method of dam construction. With this procedure the dam is raised by adding embankment materials on previously deposited tailings. A small rock starter dike was provided at the downstream toe of the dam although this rock starter dike may not have been continuous around the periphery of the impoundment. In order to provide the maximum tailings storage capacity the starter dike was constructed as close as possible to the South Toe River. The materials used for embankment construction after placement of the starter dike consisted of the coarse fraction of the classified tailings; these classified tailings were essentially coarse to fine sands. The embankment was raised periodically to provide the required tailings or slimes storage capacity. The dam was raised by hauling the coarse tailings sands to the area in trucks and spreading them with a Cat. D-6 Bulldozer; the only compaction effort that was obtained by spreading with the bulldozer.

The tailings facility was operated using a single point tailings input system at one end of the impoundment. Water was decanted from the impoundment at the other end of the facility and discharged directly to the South Toe River. This resulted in considerable fluvial segregation of the deposited tailings. The coarser tailings settled near the input location while the finer gravined silts and clays settled at the lower end of the impoundment near the decant point. Extensive layering of wastes in the impoundment occurred with frequent thin layers of silts, clays, and mica rich seams of silt and clay occurring in the deposited sandy tailings. The failure which occurred in June, 1974 occurred in an area at the lower end of the pond where the slimes consisted primarily of interbedded fine sandy silts, and mica rich silty clay seams. The facility was always operated such that the amount of ponded water was kept to a minimum. It is estimated that the maximum impoundment area covered by standing water was 20%. A photograph of the tailings facility is shown in Figure 1.

SUBSURFACE CONDITIONS

In June, 1973, the State of North Carolina authorized Golder Associates to undertake a study of the Deneen tailings facility. As part of this study, fourteen borings were drilled in the embankment and several test pits were excavated in the tailings pond and in the embankment. Four of these borings were drilled near the portion of the dam which ultimately failed. A section through the dam near the failure area is shown in Figure 2. Also shown in Figure 2 are the standard penetration resistances ("N" values) and the stabilized water levels measured in the borings.
The impounded tailings consisted of very loose to loose micaceous fine sands and sandy silts. Because of the method of deposition, the tailings were interbedded with thin layers of mica rich seams of silty clay. The tailings varied considerably in composition both areally and with depth.

It was difficult to obtain good quality undisturbed samples of the tailings (slimes) at the lower end of the pond. It was possible, however, to sample these saturated, low density, relatively low plasticity tailings with a fixed piston thin walled sampler; reasonably good recoveries were obtained using the fixed piston sampler. Density tests were run on these relatively undisturbed samples. The following was the range in soil parameters measured in the tailings:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
<th>Average Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical &quot;N&quot; Values</td>
<td>2 to 10</td>
<td></td>
</tr>
<tr>
<td>Water Content (%)</td>
<td>51 to 64</td>
<td>58.0</td>
</tr>
<tr>
<td>Liquid Limit (%)</td>
<td>57 to 70</td>
<td></td>
</tr>
<tr>
<td>Plasticity Index (%)</td>
<td>9 to 15</td>
<td></td>
</tr>
<tr>
<td>Dry Unit Weight (pcf)</td>
<td>63 to 70</td>
<td>67.9</td>
</tr>
</tbody>
</table>

Ripley (1) (1972) measured dry unit weights in micaceous clay waste ranging from 67 to 93 pcf. The density data obtained in the Deneen waste facility was slightly lower than that reported by Ripley.

It was estimated that the relative density of the low plasticity tailings ranged from as low as 40 or 50% to as high as 90%. The higher relative densities were encountered near the edge or beneath the embankment sands.

The embankment sands consisted of loose to compa coarse to fine micaceous sand with between 8% and 20% passing the No. 200 sieve. The "N" values in these embankment sands typically ranged between 3 and 14. The dry unit weight of the embankment sand ranged between 62.3 and 91.3 pcf and averaged 79.8 pcf.

The natural ground beneath the tailings facility consisted of a decomposed mica schist that had weathered into a micaceous fine sand and silt by the remnant rock fabric was clearly visible. The "N" values in the natural ground ranged between 8 and 25.

Seven observation wells were set during the initial investigation to monitor the groundwater levels. The measured water levels suggested that the potentiometric surface had a steep gradient.
approximately where the tailings came in contact with the embankment sands. The existence of this steep gradient is most probably explained by the depositional nature of the tailings. Because the tailings were layered and there were frequent mica and clay rich seams, the water in the pond tended to seep laterally and "cascade" or produce a "waterfall effect" where the layered tailings met the more homogeneous cleaner embankment sands. The groundwater level measured in one section is shown in Figure 2.

STABILITY ANALYSES

Stability Analyses were run on several cross sections of this dam including the section shown in Figure 2. Both circular and non-circular analyses were run, using a range of effective stress strength parameters and groundwater conditions. For the embankment sands effective angles of internal friction, \( \phi' \), of 34\(^\circ\) and 37\(^\circ\) with a cohesion intercept of zero were used. These values were consistent with the downstream slopes on the dam.

Because of the extreme variability of the tailings, an elaborate strength testing program was not undertaken to define the appropriate strength parameters. Instead, analyses were run using a range of strength parameters which were considered to bracket the actual conditions. Effective angles of internal friction of 17\(^\circ\), 20\(^\circ\) and 24\(^\circ\) with a zero cohesion intercept were used in the analyses. These values are slightly less than those reported by Ripley(1) (1972) but the dry unit weights obtained in this study were also lower than those measured by Ripley.

Stability analyses run using what was judged to be the most realistic piezometric level for the section shown in Figure 2 and using strength parameters of \( \phi' = 34^\circ \) for the sands and \( \phi' = 20^\circ \) for the tailings yielded a factor of safety of 1.08. Using these parameters and analyzing a dam that was 10 ft. higher produced a factor of safety of 0.92. The strength parameters used in this analysis were deemed to be the most representative for the section shown in Figure 2.

Because it was possible to obtain reasonable quality samples of the saturated, low plasticity tailings with a fixed piston sampler and because the relative density data suggested the tailings, although loose, were not metastable, it was concluded that the tailings would not liquefy in the event of a dam breach.

The above analyses were done in July, 1973 almost one year before the dam actually failed. The report submitted to the State of North Carolina stated that the dam was at best only marginally stable and should not be raised any further. It was further concluded that raising the dam only a few feet could result in changing from a marginally stable to an unstable condition. At that time the mining company was considering abandoning the facility and building a new tailings dam.

DAM FAILURE

The report on the geotechnical investigation of this dam was submitted in July, 1973. Although strong recommendations were made against raising the dam, essentially nothing was done to alter the disposal technique and the dam was raised several times during the fall of 1973 and early 1974. By the spring of 1974 the dam was 8 ft. higher than the July, 1973 level.

In about May, 1974, the dam was overtopped slightly by heavy rains. This overtopping created two erosion gullies in the dam very near the section shown in Figure 2. These gullies were quickly filled in by mine personnel by end dumping soil from the top into the gully.

On June 24, 1974 this end dumped sandy soil used to fill the erosion gullies slumped and slid into the South Toe River. This reduced the thickness of the embankment section and reduced the ability of the structure to retain the impounded slimes. On June 24, 1974, a 200 ft. section of the dam failed resulting in about 50,000 c.y. of embankment sands and slimes sliding and slumping into the South Toe River. A photograph of the failure zone immediately after the failure is shown in Figure 3.

![Figure 3. Failure Zone Prior To Reconstruction](image-url)

The repair of the failure zone was complicated by the fact that there was no access to the toe of the dam in the failure area. The dam itself was constructed immediately adjacent to the edge of the river and the embankment was too steep to permit construction of an access ramp in the downstream face. A road about 1,000 ft. long had to be constructed in the river bed itself to gain access to the failure zone. The slide debris was excavated with a dragline, loaded into trucks and hauled to a disposal area.

In reconstructing the failed section the downstream slope was flattened to 2.0 hor.:1.0 ver.; this required some placement of fill in the South Toe River. Quarried stone having a maximum size of 36 in. was keyed into the South Toe River; the thickness of this rockfill was about 20 ft. The height of this rockfill was such that it was above the maximum recorded high water level of the South Toe River and the slope of the rockfill...
was 1.25 hor. : 1.0 ver. Because of a lack of sufficient quantities of adequate construction material, well-graded river gravel between 1/2 in. and 6 in. was used as embankment material behind the quarried rockfill and in the lower portions of the reconstructed dike. The coarse to fine classified tailing sand was used to "top out" the dam when the supply of river gravel was depleted. All the reconstructed embankment materials were placed in lifts and systematically compacted. A section showing the reconstruction details is shown in Figure 4. The factor of safety of the reconstructed embankment was calculated to be in excess of 1.3. Considering that this factor of safety was greater than other portions of the dam and considering that the use of the waste impoundment was to be permanently discontinued, this factor of safety was deemed satisfactory.

Ten years have elapsed since this failure was reconstructed. There has been no evidence of slope movement or distress. The toe of the dam has been subjected to several periods of flooding of the South Toe River. There has been no evidence of slope distress, movement, or detrimental erosion in the rockfill toe of the dam.

LESSONS AND CONCLUSIONS

Several important observations were made and lessons learned as a result of the Deneen dam failure. During the original investigation it was concluded that tailings would not liquefy in the event of a dam breach. Actual observations made of the failure debris verified that no liquefaction took place. The upper 20 ft. to 30 ft. of tailings, however, were softer and weaker than the underlying tailings and tended to slump more into the dam breach. This superficial slumping effect in the upper portion of the tailings can be seen in Figure 3.

The reconstruction work on this dam was complicated by the fact that access to the toe of the dam was very difficult. It is recommended that a toe road be provided for all dams. These toe roads permit better dam inspections to be made and allow access for construction equipment if required.

The Deneen failure reinforced the principle that a consultant must keep thorough records, including records of telephone conversations. In the original geotechnical investigation it was recommended that the dam not be raised any higher. In the year following the geotechnical investigation repeated caveats were given to the mining company not to raise the dam further. The fact that records were kept of the telephone conversations with mine personnel advising them again raising the dam helped absolve the consultant of any liability in the dam failure.

REFERENCES