The August, 1995 failure of the Omai tailings dam in Guyana continues to reverberate through the mining industry. Just as the Summitville experience alerted the environmental community to the potential risks of heap leach gold extraction, so now has the Omai failure directed attention to tailings dam safety.

The geotechnical profession is being called upon for information and for answers, and the following article is excerpted from the final report of the independent body commissioned by the Government of Guyana to establish the failure cause.

The Omai gold mine is in the humid tropics of Guyana, a small former British colony tucked between Venezuela and Surinam on the northeast coast of South America. Omai Gold Mining Ltd. (OGML) started the open-pit mining operation in 1993, processing some 13,000 t/day of gold-bearing ore using cyanide extraction in a conventional carbon-in-pulp process. Finely-ground tailings slimes, predominantly minus 200 mesh, and residual cyanide solutions remain. Both the tailings dam to contain these wastes and the mine itself lie on the banks of the Omai River. Only several meters wide, the Omai carries a flow of 4.5 m³/s for a short distance where it joins the Essequibo, one of the principal rivers of South America with a mean annual flow of 2100 m³/s.

By mid-1995, the dam was only one meter short of its final planned height, and its operation was proceeding seemingly uneventfully. As late as 4:00 PM on the afternoon of the failure, inspection of the dam crest showed nothing unusual.

Failure Events

In the midnight darkness of August 19, 1995 an alert mine haul truck driver noticed a stream of water issuing from one end of the tailings dam, and dawn revealed another discharge at the opposite end along with extensive cracking on the dam crest. During these first hours the combined discharges to the Omai River reached some 50 m³/s. Through prompt emergency response, OGML was able to quickly divert one of the discharge streams into the mine pit, and over the next several days a cofferdam was built with mine equipment to divert the other. Ultimately 1.3 million m³ of mill effluent containing 25 ppm total cyanide was captured in the pit through these efforts, but the remaining 2.9 million m³ reached the Omai River and from there the Essequibo.

Within 48 hours reports of the failure were broadcast on satellite uplinks worldwide, with video footage aired as far away as China. The immediate response of the government was to declare the entire region an environmental disaster area and to call for international assistance, an understandable reaction in light of the macabre 1978 tragedy in Jonestown, Guyana where 900 died after drinking cyanide-laced fluids.

More considered assessments during the weeks and months that followed documented that a total of 346 fish were killed in the Omai River. Thorough surveys also found no measurable effects on the downstream environment or human health due to the tremendous dilution capacity of the Essequibo and the natural degradation characteristics of cyanide, which does not bioaccumulate. Even so, the failure has been widely viewed as a catastrophe for Guyana. The mine represents the largest single investment in the country, supplying almost 25% of government revenue and several percent of the country's entire
GDp, and its 6-month shutdown following the failure caused financial hardship on a national scale. On an individual level, many suffered from mine layoffs, an embargo on seafood imports by surrounding Caribbean countries, and ripple effects through the economy. Cash remained has provided a rare opportunity to understand the failure process.

**Dam Design and Construction**

The configuration of the dam at the time of failure is shown on Fig. 1. It had been raised ahead of the rising impoundment.

**Crest and exposed core of the Omai tailings dam after failure in August, 1995.**

Flow interruption to OGML itself amounted to an estimated US$15 million, with direct losses approaching this amount.

Within days the government convened a Commission of Inquiry and established three technical committees to report on various aspects of the failure. One of these, the Dam Review Team (DRT) was charged with determining technical causation, with an important additional purpose of promoting an understanding of these causes within the professional community, the mining industry, and the public of Guyana.

From a geotechnical standpoint, the failure was unusual in that nowhere did the dam physically breach. Rather, the integrity of its sloping core was completely lost, resulting in release of all of the contaminated water but comparatively little of the tailings solids contained in the impoundment at the time. The virtually intact body of the dam that level in customary tailings dam fashion from an initial starter dike to a height of 45 m. The dam contained an upstream-sloping core and a downstream rockfill section, with foundation materials having the classic weathering profile of residual saprolite soils derived from parent andesite/diabase rocks. These clayey, low-permeability soils provided fill material for the dam core, and they also comprised a major component of the mine waste materials excavated as pit overburden. This saprolite mine waste was deposited in a wide zone adjacent to and contiguous with the downstream rockfill section of the dam, extending outward 400 m to the Omai River and confining the rockfill zone in all except the two limited areas near the abutments where the failure discharges emerged.

Two features on Fig. 1 are of special interest. The starter dike contained a 900 mm dia. corrugated steel pipe (CSP) diversion conduit to temporarily pass stream flows during starter dike construction. Problems were encountered during conduit backfilling on two occasions when the CSP was crushed by heavy equipment. Although the pipe was later repaired, portions of the underlying saprolite backfill were intentionally undercompacted to increase its structural capacity under these shallow-cover loading conditions. The conduit contained no conventional seepage collars. Instead, only dry powdered bentonite was sprinkled on the surface of the saprolite backfill lifts. Moreover, downstream portions of the conduit were backfilled with sand that was not adequately filtered at its contact with the adjacent rockfill. Thus, the diversion conduit had no effective seepage protection in any recognized engineering sense despite these conditions promoting concentrated seepage around it.

Fig. 1 also shows the thin filter sand zone intended to provide piping protection for the core. Underlying the sloping core and overhanging the rockfill, this filter sand was itself to be protected by transition rockfill immediately adjacent to it. Gradation specifications on Fig. 2 show that with allowable particle sizes from 25 to 600 mm, the transition rockfill was far too coarse to have been placed without segregation. This notwithstanding, the sole gradation test performed during construction showed the rockfill to be substantially coarser than even the specified range, with a rockfill/sand piping ratio (dS/dS) of as much as 100. This filter incompatibility is shown clearly on the photos of Fig. 3, illustrating how active piping of sand into rockfill on the dam crest was occurring merely from surface infiltration.

Despite its evident flaws related to diversion conduit seepage protection and filter incompatibility the dam was well instrumented, and piezometric data typical of that shown on Fig. 1 gave no indication of impending internal erosion. These data did reveal, however, an anomalous rise in water level within the rockfill that appears to have been pro-
duced by blockage of underdrains beneath the saprolite mine waste that were intended to evacuate water from the rockfill. This allowed surface water run-off to infiltrate, accumulate, and rise within the rockfill beginning almost two years before the failure and ending the following year when the water level stabilized at the pre-failure level shown on Fig. 1 with no evident effects on the dam.

Forensic Studies

The most striking and visible features of the failure were longitudinal cracks extending the full length of the dam core exposed on the crest. The widest of these shown on the cover photo was accompanied by rotation and tilting of the upstream portion of the crest inward toward the impoundment. While short transverse cracks were present locally, continuous or pervasive transverse cracking across the width of the core was notably absent, suggesting that the cracking process occurred simultaneously over the entire length of the dam without propagating longitudinally from some initial location.

Post-Failure trenching and detailed mapping showed that the longitudinal cracks were open principally within the upper 6 - 8 m (Fig. 4a), diminishing in frequency and aperture as they became discontinuous at greater depth. No continuous shearing surfaces were found, confirming extensional spreading and inward rotation of the crest as the mechanism of crack formation.

In addition to observed cracking, the post-failure drop in impoundment water level exposed higher portions of the upper stream slope, allowing about 20 subsidence features and sinkholes to be identified and mapped from low-altitude aerial photo reconnaissance flown especially for this purpose. Ranging from 1 to 20 meters across, many were subdued depressions obscured by the heavy overlying riprap, while some like that shown on Fig. 4b were open-throat sinkholes in the core fill that continued to form and collapse weeks after failure. Together these sinkholes and subsidence features clearly show internal erosion to have been responsible for loss of core integrity. Measurements of suspended solids in the failure discharge suggest that about 25,000 m<sup>3</sup> of core material may have been lost, amounting to about 2% of total core volume.

Further evidence for piping around the diversion conduit was obtained from the angled boreholes shown on Fig. 5 (drilled from a fill pad extending into the slimes not depicted) that indicated voids, cavities, and softened zones at various locations above, around, and beneath the CSP conduit. After serving its temporary function, the conduit had been plugged with concrete at its upstream end, with the rest remaining.

The hanging filter sand had been able to bridge the large voids in the rockfill beneath it only by arching due to capillarity at its original placement moisture content. With its apparent cohesion destroyed by submergence and saturation, sand trickled freely downward into and through the rockfill voids by gravity alone, reducing or eliminating support for overlying portions of the inclined core. This mechanism of filter sand "dropout" occurred more-or-less uniformly and simultaneously over the length of the dam as the internal rockfill water level rose accordingly.

The unsupported portion of the core then dropped and tilted as graben-like blocks on the upstream slope, principally beneath the water contained in the impoundment. Associated cracking and related damage rapidly produced sinkholes, subsidence features, and massive piping damage to the core. At the same time, these movements induced tension in higher portions of the core where underlying filter sand remained undisturbed, forming the longitudinal cracks on the crest.

Fig. 6 shows detailed mapping of the completed post-failure forensic trench of Fig. 4a. The pronounced thinning of the filter sand zone within the area inundated by the elevated internal rockfill water level is consistent with this explanation. Superimposed are stress and displacement patterns backanalyzed from a simple linear-elastic finite-element formulation that simulated filter sand dropout by assigning softened modulus. The predicted tension zone corresponds well to the upper region of open cracking, and displacement vectors conform to both marker bed offsets and the observed crest tilting. Although intended to provide only qualitative insight, sensitivity studies showed these stress and deformation patterns to pertain over a reasonable range of estimated soil properties and constitutive assumptions.

These operative failure mechanisms have been precluded in design of new replacement dams at Omai by adopting...
Figure 1. Dam configuration

Figure 2. Gradation data for dam fill and foundation soils
Figure 3. Filter sand and rock fill on dam crest

Fig. (3a)
Dam crest showing (left to right): remaining tailings, riprap coil, filter sand (piles), and rockfill

Fig. (3b)
Filter sand/rockfill contact

Fig. (3c)
Filter sand piping into rockfill from surface runoff
homogeneous saprolite section with internal chimney and blanket drains of filter sand. With ample precedent for dams of this type built of residual soils in neighboring Brazil, this concept contains neither rockfill in structural zones nor conduits of any kind. By eliminating the components responsible for the previous failure altogether, rather than simply attempting an improved design “fix,” the reliability of the new design is more apparent. This has helped to restore the confidence of the people and government of Guyana that renewed operations at Omai can be conducted safely.

Lessons Learned
The Omai case demonstrates yet again that no dam, tailings or otherwise, without adequate seepage protection around conduits or without adequate filters can be expected to survive for long. Even with the factors specific to the Omai situation, these failure mechanisms are by no means unique or new. Piping failures of earth-core rockfill structures as early as 1904 at Avalon Dam and again at Schofield Dam (1928) led eventually to the “Growdon”-type rockfill design in 1942 with its emphasis on graded filters, followed by many refinements in filter design, placement criteria, and construction techniques since then. Similarly, the historic preponderance of piping failures around outlet conduits has promoted wide acknowledgement of the internal erosion vulnerabilities these features produce, and USBR and others have responded by developing special procedures and design details to combat them.

Unlike some, the Omai failure was not caused by any concealed condition or hidden flaw. To the extent that it resulted from inadequate application of well-understood technology, it offers few lessons which are new except possibly that tailings dams possess no special immunity to the principles of soil mechanics or the teachings of past experience. Perhaps what is new may be the rapid and widespread reporting of such incidents that has given the Omai failure a visibility greatly disproportionate to any objective environmental or safety consequences it produced. If so, increasingly will future such failures reflect on the mining industry as a whole and the geotechnical community at large.

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Figure 5. Maximum extent of cavities and softened zones from forensic drilling

Figure 6. Forensic trench mapping with stress and displacement patterns