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Evolution of Design and Construction of Lornex L-L Tailings Dam

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SYNOPSIS The evolution of the Lornex tailings disposal facility, in particular the Lower L-L Dam, throughout the design and construction phases is presented with the emphasis on how economic considerations have dictated this process. Major episodes described here include: the early conversion to an energy efficient two-dam storage scheme, the reduction of the size of the L-L Starter Dam, the buttressing of the Starter Dam in an area involving soft foundations, and the development of hydraulic means to use cycloned tailings sand for annual raising of the L-L Dam. Extensive instrumentation was installed to monitor the performance of the L-L dam in critical construction periods. This helped the designers to adapt the design of the dam to its actual performance in order to ensure its safety.

INTRODUCTION

Tailings dams are usually raised slowly in stages, over a period of many years or even decades. Over the long period of their construction, mining companies have to maintain viable mining operations by coping with changes in economic, regulatory, and technical conditions. It is, therefore, essential for designers to adapt the design and construction of tailings dams to meet these changes in order to provide safe yet economical structures for retaining enormous quantities of mine tailings. This paper briefly reviews a case history outlining how the joint efforts of a mining company and its consultants have been coordinated to strive for an optimum design of the Lornex tailings disposal facility.

Lornex Mining Corporation's Highland Valley Mine is situated within the Interior Plateau of British Columbia, a low to moderate seismic zone of Canada. Operations were started in 1972, with a plant capacity of 43 600 tonnes (48,000 tons) per day, mining a low-grade porphyry copper deposit, and producing copper concentrate and molybdenum. This capacity was increased to 80 000 tonnes (88,000 tons) per day in July 1981 with a recent plant expansion. At present, the mining operation ranks as the second largest open pit copper mine in North America with the third largest milling capacity. The Lornex tailings storage facility involved construction of three tailings dams: the H-H Dam, the J-J Dam and the L-L Dam (Fig. 1). Prior to the completion of the L-L Starter Dam in 1977, all of the Lornex tailings were discharged into the tailings pond created by the H-H and J-J Dams. Presently, the tailings are discharged near the H-H Dam and flow past the J-J Dam through a gated concrete bypass conduit. Part of these tailings are pumped to the L-L Dam to be cycloned for the production of dam building sand, while the remainder flow into the pond, bounded

by the J-J and L-L Dams. Gradually, as the L-L and H-H Dams continue to be raised, the middle J-J Dam will be covered by tailings.



Fig. 1 Lornex Tailings Disposal Facility (1983)
(From Background: H-H, J-J and L-L Dams)

The Lornex Tailings Pond is approximately 9.6 km (6 miles) long, and ultimately it will contain in excess of 1.8 billion tonnes (2 billion tons) of tailings. This storage capacity is expected to be shared in the future with other neighboring mining operations.

The L-L Dam is located on the Pukaist Creek which drains the western portion of the Highland Valley. The valley is roughly U-shaped, with a relatively flat floor at elevation 1103.7 m (3620 ft) approximately. The valley floor is covered by recent swamp deposits, which in turn are underlain by lacustrine deposits containing soft and sensitive varved clays. The maximum thickness of these compressible soils is about 15.2 m (50 ft). Dense, hard, relatively incompressible, glacial till underlies and flanks the soft, compressible, recent deposits.

EVOLUTION OF ENGINEERING DESIGNS

The Lornex tailings disposal facility was designed by Canadian Bechtel in 1970 as a three-dam scheme. The Upper (H-H) Dam and Middle (J-J) Dam were constructed first, with the Starter Dam for J-J being built in 1971, and the Starter Dam for H-H being built in 1972-73. In 1976-77 the Starter Dam for the Lower (L-L) Dam was constructed. In late 1977 Kohn Leonoff were engaged by Lornex as their ongoing tailings dam consultants. The evolution of engineering designs for the tailings facility to date is discussed following.

Lornex Tailings Disposal Schemes

The original three-dam scheme (Fig. 2) envisaged the storage of 680 million tonnes (750 million tons) of tailings initially in the Upper Pond bounded by the H-H and J-J Dams at a crest elevation of 1303.4 m (4275 ft). Thereafter, the remaining storage will be provided by the Lower Pond between the J-J and L-L Dams. The reason for adopting this scheme involving an ultimately redundant Middle (J-J) Dam (approximately 46.7 million m³ of fill) was the lower capital cost (\$6.5 million) of the scheme compared with \$20 million of the two-dam scheme. Because of the shape of the tailings basin and the topography at the dam sites, it requires substantially less dam fill volumes to provide the same initial storage capacity for the three-dam scheme (1.9 million m³ of fill) versus the two-dam scheme (7.7 million m³ of fill). In 1970, the capital cost advantage of the three-dam scheme outweighed the drawback of its relatively higher operating cost when the energy cost was still low prior to the escalation of petroleum prices by O.P.E.C..

With the rapid rise of the energy cost since 1973, the relative advantage of the three-dam scheme was eroded quickly. In 1975, Lornex decided to convert the tailings facility to the two-dam scheme by constructing the Starter Dam for L-L in two stages, in 1976 and 1977, and allowing the flow of tailings through a bypass conduit at the J-J Dam into the Lower Pond created by the L-L Dam in 1977, thus delaying the need to raise the tailings lines and avoiding the associated pumping costs. In addition, the two-dam scheme doubled the catchment area of the tailings pond to 80 sq km and correspondingly reduced the required amount of make-up water, which would otherwise have to be pumped over a distance of 18 km against a total dynamic head of 1400 m from the Thompson River.

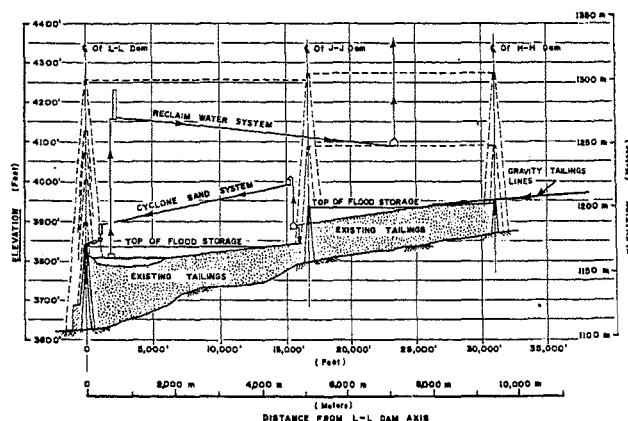


Fig. 2 Schematic Section of the Original Three-Dam Scheme (1970)

L-L Starter Dam

To make the two-dam scheme viable, it was necessary to pare down the construction cost of the L-L Starter Dam. Cost saving measures, included: minimizing the storage volume, hence the required dam fill, founding the Starter Dam over the soft deposits rather than replacing them with borrowed backfill, and using pit-run rather than processed sand and gravel as filter materials. These measures all contributed to the reduction of the actual construction cost of the Starter Dam to about \$10 million in 1977 from \$20 million estimated in 1970.

The storage capacity of the Starter Dam was minimized in two ways. Firstly, the tailings storage provided by the Starter Dam was trimmed by 41.6 million m³ from that required for the mining operation over two years to that over a single year. Secondly, the flood storage required by the L-L Dam was reduced by utilizing the existing capacity available at the Middle (J-J) Dam through the installation of a gated concrete flood control structure at the J-J Dam. The flood storage requirement at Lornex is rather stringent, it includes an average annual runoff, plus a 100-year return period flood, plus a probable maximum flood, and a five-foot freeboard. The flood storage shared by the J-J Dam amounts to 17.9 million m³, which reduced that required for the L-L Dam from 47.2 million m³ to 29.3 million m³. Thus, the total reduction in the storage capacity is 59.5 million m³, which reduced the required volume of the Starter Dam from the earlier estimate of 7.7 million m³ to 3.5 million m³.

In order to cope with the soft deposits left in the valley, Bechtel employed geo-drains and stage-construction to assist the soft foundations to develop higher shear strengths as quickly as possible so that they could safely support subsequent construction stages. In addition, extensive instrumentation was used to monitor the performance of the Starter Dam.

The effect of leaving the soft deposits in place had significant influences on lowering the construction cost of the Starter Dam beyond the savings in eliminating the cost of excavation and backfill. It reduced the required construction time as well as eliminated the need to mobilize specialized soft-soil excavators. This was instrumental in putting the project within the financial and physical capabilities of many medium-sized earth moving contractors with lower overhead. The additional competition resulting from these contractors greatly reduced the bid prices received. The three lowest bids were \$10 million, \$12 million and \$18 million, with the latter two bids from firms familiar to the international, heavy civil construction scene.

A typical section through the L-L Dam with the ultimate height of 163.1 m (535 ft) is shown on Fig. 3. The stippled portion with the maximum height of 42.7 m (140 ft) is the Starter Dam, details of its design and construction were reported by Burke and Smucha (1979).

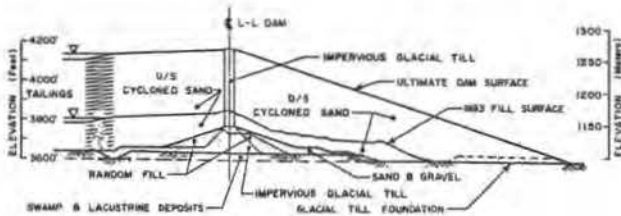


Fig. 3 Section Through The Lower L-L Dam

L-L Tailings Dam

The schedule for raising the L-L Dam (Fig. 3) envisaged staged, centerline construction with compacted cycloned sand downstream and sluiced cycloned sand and tailings upstream. A vertical, impervious, glacial till core, 15.2 m (50 ft) in width, would be raised each year as part of the staged construction.

A critical point in the L-L Dam construction is considered to have been in 1977, when the second stage fill was placed for the Starter Dam. At this time large pore pressures and shear movements developed in the soft foundation clay. This concerned the designers to the extent that, a portion of the dam underlain by the soft clay was not raised to grade until the following year, in order to allow the pore pressures to dissipate.

To date, with one major modification, the L-L Dam has been constructed essentially in accordance with the original design. The modification has involved excavating the soft swamp and lacustrine deposits from beneath future, downstream construction stages of the dam and replacing them with compacted fill. In addition,

a large buttress berm has been constructed downstream of that portion of the Starter Dam founded on the soft deposits in the valley, and enlarged annually. These revisions were made to improve the foundation stability of the L-L Dam and to allow the construction rate of the dam to accelerate in the event that other mines started to share the usage of the tailings pond. The excavation and backfill operation required special attention to construction sequence. Extensive instrumentation and careful field control were established to ensure the safety of the Starter Dam as described by Klohn, Lo and Olsen (1982).

EVOLUTION OF CONSTRUCTION METHODS

Raising of the L-L Dam by the centerline method minimizes the quantity of dam fill required for tailings storage. Upon the completion of the Starter Dam in 1977, a large portion of the tailings pumped to the L-L Dam was used to fill the void at the bottom of the valley immediately upstream of the dam. The filling initially involved end discharging from large pipes and on-dam cycloning. In 1983, uniform spigotting from 6-inch spigot pipes were successfully implemented. As this void gradually filled up (Fig. 4), the tailings delivered to the L-L Dam became in excess of that required for building the upstream section of the dam. The surplus was cycloned to produce clean, free draining sand for the downstream shell. In 1978 and 1979, no cycloned sand was available for the downstream zone. In 1980 and 1981, nominal amounts of cycloned sand in the order of 82,000 m³ and 130,000 m³, respectively, were used in the downstream zone. The sand in this zone was first stockpiled and then mechanically borrowed, placed and compacted in the dam using scrapers.



Fig. 4 Upstream Shell Construction - L-L Dam (1983)

In 1982 and 1983 the entire downstream zone, involving about 625,000 m³ a year, was almost exclusively constructed of cycloned sand. In addition, by 1982 the consistent quality of the cycloned sand product was assured through the experiences gained over several years. Direct

hydraulic placement of the sand into the dam was initiated by the middle of that construction season. In 1983, all of the downstream zone was constructed by hydraulically placed cycloned sand. Of prime importance to the cost-effective hydraulic placement scheme is the hydraulic cycloned sand delivery system.

Hydraulic Cycloned Sand Delivery System

The cycloned sand system developed by Lornex consists of two-stage cycloning. Tailings is delivered to a primary cyclone house at the left abutment of the L-L Dam. It is equipped with fifteen 20-inch cyclones with adjustable apexes, and two 12-inch x 10-inch slurry pumps working in parallel to feed the underflow (coarse fraction sand) to two 14-inch polyethylene main delivery pipelines on the dam. The overflow (fine fraction sand) from the cyclone house is discharged upstream into the tailings pond. Three secondary-cyclone units, each equipped with four 20-inch cyclones, are located 120 m apart on the crest of the dam and supplied by the two main delivery lines. Extensive valves are installed to enable any two units of secondary cyclones to operate simultaneously, while allowing the third to be maintained or relocated. The underflow from each secondary-cyclone unit is collected in a launder (discharge box) and is conducted by one of two 14-inch delivery lines by gravity down the downstream slope for hydraulic placement (Fig. 5). The overflow from the secondary cyclones with more fines is discharged upstream for beach construction. The launders are equipped with emergency discharge valves to allow the diversion of lower-quality sand flow to the tailings pond upstream.



Fig. 5 Downstream Shell Construction - L-L Dam (1983)

Hydraulic Construction - 1982 to 1983

Hydraulic construction of uncompacted sandfill in relatively large construction cells (150 to 1000 m long by 30 to 60 m wide) was described by Klohn and Maartman (1972). Hydraulic con-

struction of compacted sandfill in cells of similar size (300 to 450 m long by 30 to 90 m wide) was reported by Mittal and Hardy (1977). The hydraulic construction at Lornex initiated in July 1982 involved placement of compacted fill in similar cells (120 m long by 60 m wide) on the downstream buttress berm. About 153,000 m³ of cycloned sand was placed hydraulically and spread and compacted in six cells by D-7 and D-8 dozers. Containment dikes were constructed to control the excess water within each cell under construction (Fig. 6). As the excess water separated from the sand, it was conducted by ditches, and pipelines from the dam to the Seepage Recovery Pond downstream without the need of any expensive underdrains.



Fig. 6 Downstream Berm Construction - L-L Dam (1982)

With the completion of this phase of construction in September 1982, an experimental construction program involving about 69,000 m³ of sand fill was carried out in narrow cells (300 m long by 8 to 10 m wide) along and up the downstream face of the dam. This experiment proved the feasibility of constructing, by hydraulic means, the narrow sand fill against the existing downstream slope.

In 1983, the entire downstream zone of about 612,000 m³ of sand fill was constructed hydraulically as a 24-hour a day, 5-day a week operation involving D-7 and D-8 dozers under a firm priced contract. This resulted in a considerable reduction in cost for Lornex. The downstream slope was raised in two panels approximately 460 m long by 10 to 12 m wide with a dike on the outside edge approximately 1 m high and 1.5 m wide (Fig. 7). The dike fill is relatively loose, and is to be recomacted with the new dam fill in the following year. At the lower end of each panel, two 14-inch drain pipes carried the excess surface construction water down to the area beyond the toe of the dam. After the completion to grade of the two panels on the top of the dam, the secondary-cyclone units were relocated on the surface of the completed sand section. This allowed the glacial till core to be constructed on the top of the dam using conventional scraper operation, while the downstream berm was raised

simultaneously by hydraulic means in several steps, each step involving a narrow cell about 370 m long by 15 to 25 m wide. Through judicious use of modular pipelines and valving arrangements, relocations of secondary-cyclone units were kept to a minimum.



Fig. 7 Dozer Compaction in Narrow Construction Cell - L-L Dam (1983)

The compaction of the hydraulically placed sand, using bulldozers, was optimized by limiting the width of the cells to 10 to 25 m and limiting the maximum dozer push to about 60 m. Tight construction control on the quality and density of the sandfill, provided by a resident geotechnical engineer and his assistant, ensured the proper execution of the fill placement by the contractor, but still allowed him the flexibility to maximize the efficiency of his operation.

Relative Cost Comparison

The basic philosophy used to develop the L-L Dam was to minimize the costs of the Starter Dam by taking advantage of the existing tailings facilities and the geometry of the tailings basin, and to delay the construction of additional facilities until they became necessary. In addition, every effort was made to maximize the use of the tailings as dam building materials, and to develop new construction methods more cost effective than conventional means. The resulting benefits derived from these efforts can be illustrated in Table I, which compares the relative storage characteristics and costs of raising the L-L Dam from 1976 to 1989.

Items indicated in Table I are, in general, self explanatory. In 1982, the placement of cycloned sand involved a stockpile operation (costing

TABLE I
COMPARISON OF RELATIVE COSTS AND STORAGE CHARACTERISTICS
OF RAISING THE L-L DAM (1976 to 1989)

Year	Required Compacted Dam Fill Per Unit of Storage ($m^3/1000 m^3$)			Cost of Fill Placement in 1983 Dollars (\$/ m^3) Col. B	Year Since 1976	Present Worth Factor (Discounted at 10%) Col. C	Relative Cost of Storage in 1983 Dollars (\$/ $1000 m^3$) Col. AxBxC	Comments
	Tailings Storage	Flood Storage	Total Storage Col. A					
1976	142.54	-	142.54	3.46	0	1	448.3	Average cost of the Starter Dam in 3 years.
1977					1	0.909		
1978					2	0.826		
1979	39.98	-	39.98	3.13	3	0.751	93.98	D/S zone constructed of borrowed native soils.
1980	43.69	-	43.69	3.13	4	0.683	93.40	
1981	43.57	-	43.57	3.13	5	0.620	84.55	
1982	36.89	-	36.89	2.25	6	0.564	46.81	Cycloned sand from stockpile as well as from hydraulic placement.
1983	32.00	-	32.00	1.27	7	0.513	20.84	Cycloned sand hydraulically placed, mechanically compacted.
1984	33.91	-	33.91	1.27	8	0.466	20.07	
1985	33.55	3.10	36.65	1.27	9	0.424	19.73	
1986	30.57	8.73	39.30	1.27	10	0.385	19.21	
1987	28.84	13.18	42.02	1.27	11	0.350	18.68	
1988	28.97	15.97	44.94	1.27	12	0.318	18.14	
1989	18.78	-	18.78	1.27	13	0.289	6.89	

\$2.73/m³) as well as hydraulic operations (costing \$1.47/m³), and a weighted average value of \$2.25/m³ was used in the table. In 1983, the unit cost of hydraulic placement was further reduced to \$1.27/m³, and this figure was applied for future years. From 1985 to 1988 the flood storage capacity at the L-L Dam is incrementally increased to replace the corresponding amount currently provided by the J-J Dam, which will be lost as the J-J Dam becomes inundated sometime in 1989. The relative cost of providing this storage in 1985 to 1988 averages only \$18.94/1000 m³ as compared with a cost of about \$448.3/1000m³ in building a higher Starter Dam in 1976. By delaying the provision of this flood storage at the L-L Dam, not only was the capital cost of the Starter Dam reduced, but also the relative cost of providing this storage was reduced by waiting until the storage ratio had improved and less expensive materials were available.

TREND OF FUTURE DEVELOPMENTS

The raising of the L-L Dam will continue for many decades to come. As the J-J Dam becomes inundated, the present two tailings ponds will merge into one, and both the Upper (H-H) Dam and Lower (L-L) Dam will be raised concurrently at rates much slower than the current rate of about 13 ft a year.

In the future, the tailings pond is expected to meet the joint demand of tailings disposal from Lornex Mine as well as other mines in the area. The joint use of the tailings pond will require close coordination of activities to ensure orderly construction of additional storage facilities and a smooth transition to combined tailings operations. Special attention will be given to merging the make-up water and tailings storage requirements of all operations, as well as to ensuring the production and delivery of dam-building cycloned sand of adequate quantities and qualities.

As to the construction of the L-L Dam itself, efforts will be made to further reduce its construction cost. Options under active considerations include:

- incorporating a substantial zone of hydraulically placed, uncompacted sandfill in the downstream section above the saturation line without compromising the dam's resistance to seismic loadings;
- substituting eventually the upper part of the glacial till core with a wide tailings beach as the seepage barrier;
- developing more cost effective methods in placing dam fills.

Ongoing design studies and construction experimentation will continue to confirm the technical feasibility and economic viability of these options.

SUMMARY

This paper presents a case history illustrating how the economics of the mining operations influenced and shaped the evolution of the Lornex

tailings disposal facility. Throughout the design and construction phases, constant adjustments were made to economize the construction of the facility. Important episodes in its development have been:

- the early conversion of a three-dam scheme to an energy-efficient two-dam scheme in 1977 in the face of rising energy cost since 1973;
- the reduction of the size and cost of the L-L Starter Dam to make its construction in 1976-1977 economically viable;
- the incremental buttressing of the Starter Dam in the valley section since the winter of 1978 to increase its stability steadily without drastic impact on the operating cost of the mining operation;
- the use of cycloned sand as dam building materials initially for the upstream section since 1977, and gradually also for the downstream section since 1980;
- the development of cost effective hydraulic means to place cycloned sand on the dam in 1982 and 1983.

A basic tenet of the L-L Dam design is careful ongoing monitoring and review of the performance of the dam foundation. Particular care is taken to monitor slope indicators and foundation piezometers as each stage of fill is added. To date, the monitoring program has confirmed that the L-L Dam has performed in a satisfactory manner.

The relative cost of storage provision in 1983 dropped approximately to one-twentieth of that incurred in the earlier years, and will drop even further after additional flood storage is provided in 1988 and the J-J Dam is overtopped in 1989. Continuous efforts will be made in the future to actively explore other cost saving measures in raising the L-L Dam as more sand becomes available due to improving storage ratios, and to phase in the joint use of the tailings facility by other mines in the area.

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