

A CASE HISTORY OF ON-GOING CHANGES IN TAILINGS DAM DESIGN
AFTER INITIAL CONSTRUCTION

by

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ABSTRACT

This paper describes the evolution of the design of the tailings facilities at an operating mine in southwestern British Columbia. The changes in the design and construction techniques were prompted by changes in tailings disposal patterns and the expanding data base on the engineering performance of the available foundation and construction materials.

The starter dam was built in accordance with the original design based on the Downstream Method of Construction to allow for water storage against the dam. As a result of a change in pond management, the first extension was redesigned and built by the Centreline Method of Construction. Subsequent modifications to tailings disposal procedures and on-going testing programs resulted in further redesign of the embankment, and the second extension was built by the Upstream Method of Construction.

Included in the most recent design changes was a unique application of soil densification using wick drains to facilitate embankment construction on a tailings foundation, and an experiment with vibrocompaction to improve tailings density.

Keywords: construction techniques, design, embankment, evolution of design, tailings disposal, tailings facilities, soil densification, wick drains

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INTRODUCTION

The Blackdome Project is a gold-producing property located at Black Dome Mountain about 71 km (45 miles) northwest of Clinton in southwestern British Columbia. The property covers about 3,140 ha (7,800 acres), and is underlain by several vein systems. The mine is located about 2 km (1.25 miles) from the mountain peak, on a southwesterly extending ridge at an altitude of about 1,960 m (6,430 feet). The mill is located adjacent to the portal of a main haulage drive that is collared on the eastern flank of a steep-sided valley. The tailings impoundment facilities are contained in the valley immediately below the mill. The general layout of the structures is shown on Figure 1. The facilities were commissioned in 1986.

The tailings disposal facilities were originally designed to store the slimes fraction of the total mill tailings produced as well as to store water against the upstream face to act as a reservoir. Tailings were to be deposited at the head of the valley above the pond. As operations evolved, the parameters for tailings management changed. The first change involved the discharge of total tailings into the pond resulting in a foreshortened life of the starter dam. In addition, tailings were spiggoted from the dam face eventually resulting in a 'sand' beach. During operation of the first extension, tailings were separated at the mill, but both size fractions were discharged to the pond, with the sand placed in the beach adjacent to the dam. In the third year of operation and after construction of the second extension, tailings were split at the mill with the sand fraction being used for underground backfill. These changes in tailings makeup, in addition to experience gained with the tailings disposal system, led to evolution of the design of the tailings dam. The dam was originally designed to be built by the Downstream Method of Construction. Based on an expanded data base on the characteristics of the tailings and site, including availability of borrow materials and sand beaching, the first extension was redesigned to be less conservative and to be built by the Centreline Method of Construction. Additional investigations and testing produced a basis for further changes to embankment design involving improvement of beach tailings to provide an adequate foundation for extension construction by the Upstream Method.

BACKGROUND

The daily production from underground mining is about 225 tonnes per day (250 tpd). Mining is accomplished by stoping with draw points along drifts from the main haulage. Mill holes have been designed to serve as fill raises after stoping has been completed. Haulage of broken rock from underground dump points is by tracked Granby car. Mine drainage is collected and discharged from the haulage portals directly into the tailings impoundment.

The initial metallurgical test work indicated that the ore was amenable

to treatment by either flotation or cyanidation. It was decided to treat the ore by flotation and to market the concentrate at a smelter.

After crushing, the ore is transferred to a ball mill where the ore is ground to between 85 and 90 percent minus 200 mesh. The ball mill product is conditioned with reagents and discharged to rougher flotation. After two-stage cleaning of the rougher concentrate, a thickener and filtration are used to dewater the cleaned concentrate.

Tailings are limited to the rougher flotation tailings and represent 93 to 95 percent of the mill feed. Initially, total tailings were discharged by spigotting from the crest of the tailings dam to the impoundment. For impoundment management purposes, in 1987, the tailings were cycloned at the mill to achieve a split of coarse and fine fractions. The sand fraction was deposited adjacent to the tailings dam to increase the sand content of the beach, while the slimes fraction was discharged separately into the pond. In 1988, the coarse fraction of the tailings was diverted underground for use as backfill to stoped out areas, and only the slimes have subsequently been stored in the tailings impoundment. The size separation being achieved is about 40 percent sand and 60 percent slimes.

TAILINGS DISPOSAL FACILITIES

GENERAL ARRANGEMENT AND OPERATION

The tailings disposal facilities consist of the tailings impoundment contained by a staged earthfill dam, a seepage collection pond with overflow spillway, a reclaim water system and diversion ditches to limit inflow from the upper watershed. All of the facilities are located in the headwater area of a narrow-valley, steep-gradient, northward-flowing mountain stream. Tailings slurry from the mill and reclaimed water recycled back to the mill are transported through 100 mm (4-inch) ABS pipe.

The tailings dam has been constructed across the stream, about 300 m north of the mill. At the end of 1988, the tailings dam consisted of a starter dam plus two extensions. At maximum section, the crest of the dam is about 37 m (120 feet) above the base of the valley measured from the downstream toe of the dam. The valley slopes forming the abutments of the dam are inclined at 20 to 35 degrees and have been cleared for several tens of metres above the anticipated ultimate tailings level. The materials exposed in the slopes consist of bedrock with a thin veneer of glacial till and colluvium. An emergency spillway has been excavated into the west abutment around the end of the dam. A diversion ditch has also been constructed into the west slope to bypass the drainage of the upper watershed around the tailings pond. The diversion ditch discharges into the lower outflow channel of the emergency spillway.

A pump suspended from a trestle catwalk is used to recycle clarified tailings decant water back to the mill. Not all the reclaimed water is used for mill process, and the excess water is discharged through a 100 mm pipe to the settling pond.

Seepage through and under the tailings dam is collected in ditches along the downstream toe of the dam and discharged through a measuring weir into a settling pond. The settling pond is contained by an earth- and rockfill dam built across the stream about 130 m (400 feet) downstream from the tailings dam. The water level in the settling pond is controlled by a free overflow spillway consisting of a half-section of 900 mm corrugated steel pipe embedded in concrete around the west end of the dam. The retention capacity of the pond is about 3,000 cubic metres (190,000 US gal.).

TAILINGS CHARACTERISTICS

Much of the tailings embankment design was dependent on the nature of the tailings. Two aspects of the dam design affected by tailings properties included the height of different stages of the retention structure and the method of extension construction. During the initial design phase, the information on tailings properties was limited to the results of the metallurgical test work, anticipated milling procedures and experience with similar projects. After the project had become operational, a number of adjustments to the design were incorporated to account for differences between full-scale production and bench scale tests as well as for changes in operation such as deposition of tailings from the dam face and use of tailings sand for underground backfill. These modifications altered the tailings impoundment requirements and design conditions for dam extensions.

The post-commissioning changes at the Blackdome project are indicated by the following table, which lists the tailings characteristics used in the initial design and those found to prevail after three years of operation. The changes affected both the quantity of tailings to be stored and the engineering performance of the tailings as a construction material.

TABLE 1 - TAILINGS CHARACTERISTICS

	DESIGN ASSUMPTIONS	
	<u>INITIAL</u>	<u>EXTENSION*</u>
Total Tailings (tpd)	200	250
Tailings to Impoundment (tpd)	200	150
Slurry Solids Content (%)	25	17 to 40
Tailings Moisture Entrainment (%)	20	37
Tailings Specific Gravity	2.63	2.78
Tailings Dry Unit Weight (gm/cc)	1.28	1.29
Minus 200 Mesh (%)	85	90
Average Relative Density (%)	15	33

* - Data from operations and field/laboratory testing three years after commissioning

LIQUEFACTION POTENTIAL

The Blackdome mine is located along the eastern edge of the Coast Mountain earthquake zone. The site is in a relatively inactive area. The design-base earthquake - 10 percent probability of exceedence in 50 years - was determined to result in an horizontal bedrock acceleration of 0.063g at the site. Because of the remote location of the impoundment and the limited threat to life and property in the event of a dam failure, the analyses of extreme events were based on a 0.1g acceleration, equivalent to the ground motion due to 75 percent of the Maximum Credible Earthquake.

If a soil is saturated, and conditions do not permit rapid dissipation of pore pressure, the soil can liquefy under seismic motion. For damaging liquefaction to occur, the loss in strength of the soil must propagate over a significant area and depth. In addition to saturation, relative density is a critical characteristic of cohesionless soils in the determination of susceptibility to liquefaction. The tendency of a soil to compact or to dilate during seismic vibration depends on relative density.

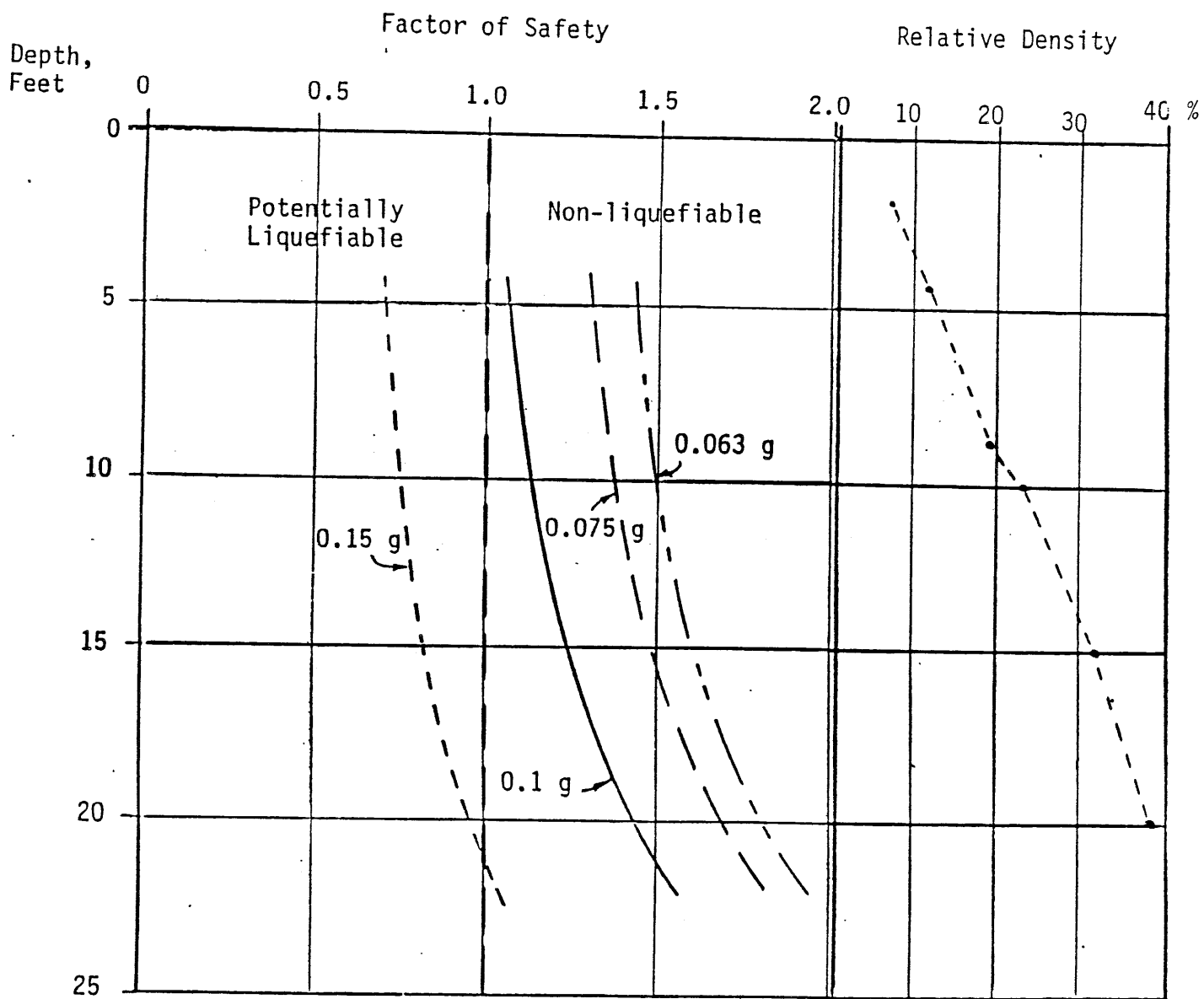
During the initial design stage, the analyses for liquefaction potential were based on the empirical methods developed by Seed and Idriss¹, which predicted dynamic stress ratios with depth from assumed relative densities.

For the design of the extensions, field data were available from drilling programs completed on the tailings beach. With measured relative densities and other properties of the tailings, it was possible to carry out more sophisticated methods of determining the probability of the tailings to liquefy. During subsequent design stages, to assess the susceptibility of the Blackdome tailings to liquefaction, the Cumulative Damage Assessment, as presented by Donovan², was completed. The Cumulative Damage procedure is a probabilistic approach based on the concept that the effect of cyclic loading on a soil is analogous to fatigue effects in structural materials. The iterative procedure results in a factor of safety defined by the ratio of the stress required to initiate failure after several cycles of loading and the peak available shear strength. The results of the assessment are presented on Figure 2, which also shows the relative density profile used in the analysis. This analysis predicted a low probability of liquefaction within the range of seismic ground motions that could be reasonably expected at the Blackdome site.

STARTER DAM

The tailings dam is located in a narrow valley with a steep longitudinal gradient. The selection of this site was based on the proximity to the mill and the most favourable ratio of storage capacity to fill volume of several sites considered. As the initial design was based on the assumption that the coarse fraction of the tailings would be deposited underground and the pond was to be used for water storage, the starter dam was built using the Downstream Method of Construction.

At the time of the initial design, the ore reserves indicated a project



LIQUEFACTION
POTENTIAL

FIGURE 2

life of slightly in excess of 4 years. The tailings dam was therefore designed to be built in two stages, with the starter dam sized to accommodate 2 years of tailings production. On the basis of the storage capacity calculations, the starter dam was built to a height of 20.7 m (68 feet) to Elev. 1815.4 m. The crest width was about 11 m and the upstream slope was built to 2.5:1 (horizontal : vertical). While designed to be 2:1, the downstream slope was built to 1.8:1 to within 5 m of the crest and 2.2:1 for the upper 5 m. The as-built cross-section of the starter dam is shown on Figure 3.

The body of the starter dam was built with glacial till borrowed from within the impoundment area. In some areas, this inadvertently resulted in removal of more till cover than prudent. During filling of the impoundment, more seepage through the bedrock under the dam was observed than had been estimated.

For seepage control, a cutoff trench and a downstream drainage blanket were provided. The trench was excavated under the centre of the dam to a depth of 3 m and a width of 5 m. The cutoff was backfilled in lifts with compacted glacial till. The drainage blanket extended under the entire downstream slope of the starter dam and was constructed with talus.

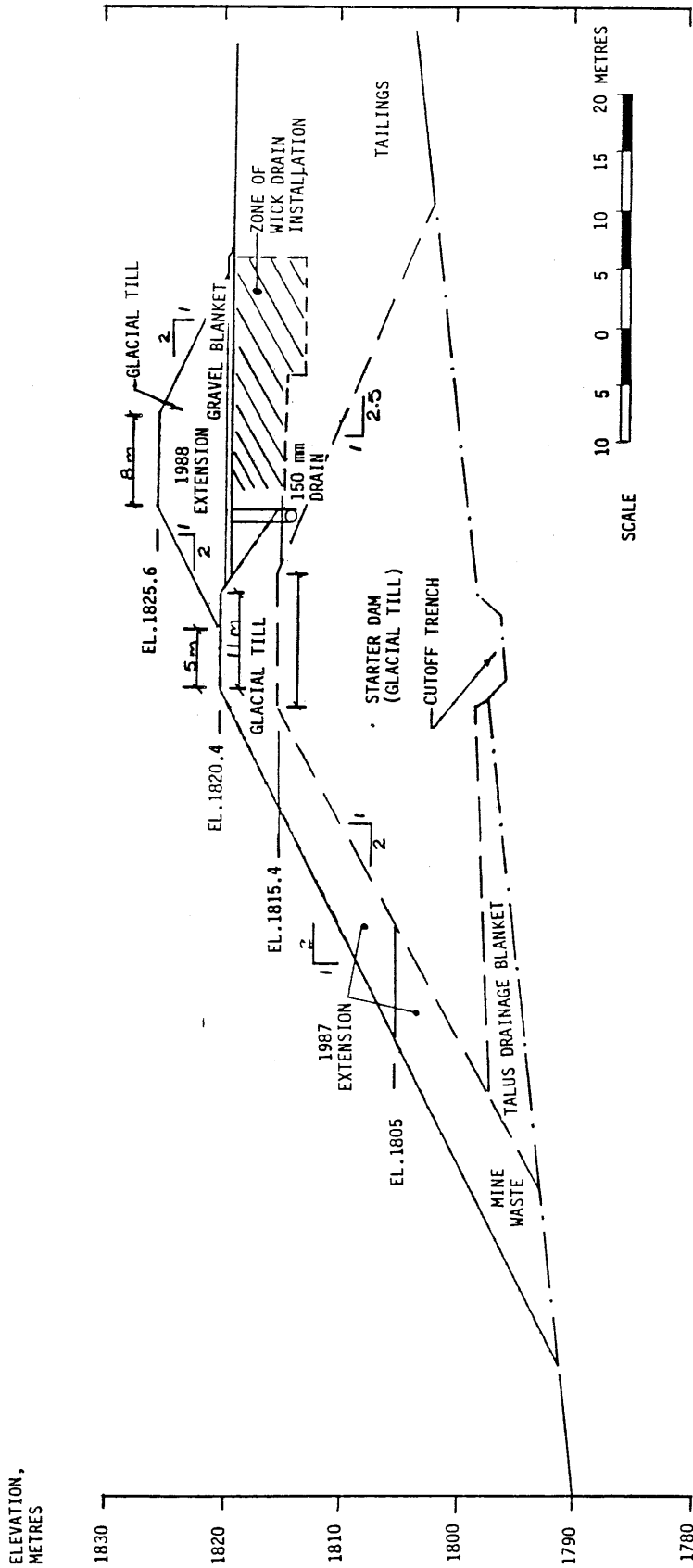
Because of the change to discharge of total tailings into the pond, the starter dam capacity was reduced to one year of storage. It was therefore necessary to design and build the first extension in 1987.

FIRST EXTENSION

By the end of construction of the starter dam, it was apparent that the availability of borrow materials was not as extensive as previously estimated. In addition, increased ore reserves and the practice of storing total tailings in the impoundment resulted in the need to increase the ultimate height of the dam. With the deposition of total tailings from the embankment, it was possible that a stable foundation of sand tailings could be used to support Centreline or Upstream sections of an extension. In 1987, a detailed field and laboratory investigation was undertaken to support a change in extension construction technique to facilitate raising the dam while using the minimum amount of fill. The alternative methods of Centreline and Upstream Construction had been assessed in an earlier study and discussed with the regulatory authorities. The major impediment to approving construction by a method other than the Downstream method was the stability - particularly the stability under seismic loading - of an embankment built on a foundation of tailings.

In order to further improve tailings foundation conditions prior to extension construction, cycloning of tailings at the mill was initiated early in 1987. The coarse fraction was spiggoted adjacent to the dam to form a sandier beach, and the fines (slimes) were discharged further into the pond.

From the field and laboratory results, the data for the design analyses were obtained, including the in situ densities of the tailings for the seismic liquefaction assessment described previously. On the basis of the



TYPICAL AS-BUILT CROSS-SECTION

FIGURE 3

evaluations, a design incorporating Centreline Construction was developed, which was satisfactory to the review agencies.

In the summer of 1987, the first extension to the tailings dam was built to Elev. 1820.4 m (a 5 m extension). The extension had a crest width of 8 m and the upstream and downstream slopes were constructed to 2:1. Mine waste was used to extend the drainage blanket and to build a free-draining buttress against the downstream slope of the starter dam. The mine waste was placed to a height of 15 m. Glacial till was used above the mine waste to complete the downstream section of the extension and to build the lift above the crest of the starter dam. Irregularities in the downstream slope created at the time of starter dam construction were straightened during extension construction. The as-built cross-section of the extension is shown on Figure 3.

As a further provision to ensure embankment stability, a drain was installed below the upstream section of the extension to control the phreatic surface. The drain consisted of 150 mm perforated plastic pipe wrapped in filter fabric and placed in a gravel-filled trench in the tailings foundation. The outfall of the drain pipe was located to discharge into the seepage pond rather than into the spillway channel, which bypassed potential treatment facilities should the collected drainage exceed discharge permit quality limits.

The extension was designed for a life of one year. During that time, the effects of further operational changes, including underground sand backfill, and alternative methods of disposal, such as thickened tailings and subaerial deposition, were evaluated. These evaluations were undertaken to recalculate storage capacity requirements and to determine if other methods of tailings disposal could more effectively use the capacity of the tailings pond. The studies concluded that, because of climatic and topographic conditions at the Blackdome site, conventional perimeter tailings discharge was the most economic procedure. Accordingly, a design was prepared for the second extension to the tailings dam.

SECOND EXTENSION

In the continuing effort to reduce fill quantities while ensuring a capacity for future tailings storage should ore reserves be increased, investigations were undertaken in the Spring of 1988 to prepare a design for Upstream Construction of the next extension. Because of cycloning, the sand beach had the appropriate gradation for support of the next lift. However, the relative density over part of the area was below that required to ensure that liquefaction, under the maximum earthquake loading, would not occur. It was therefore necessary to improve the foundation density beneath the extension to ensure stability under the design earthquake loading.

Two methods of foundation improvement were selected for evaluation: the PhoenixTM method and wick drains. The PhoenixTM method involves localized liquefaction of the soil with a vibrating probe, vacuum suction of the mobilized pore water, and a resulting consolidation/densification of the material. A limited field trial of the method at the site showed promise

that the procedure would work and provide an economic approach that would more than offset the extra fill required for Centreline or Downstream Construction. However, the relatively low permeability of the tailings resulted in more time being required at each probe location. Further, the vibration caused severe damage to the drilling equipment provided at the site, resulting in excessive downtime. The Contractor concluded that his approach could be guaranteed to be completed before fill placement had to be initiated. He felt that the system would work effectively with free-standing equipment suspended from a crane rather than a drill rig, such as supplied for this trial.

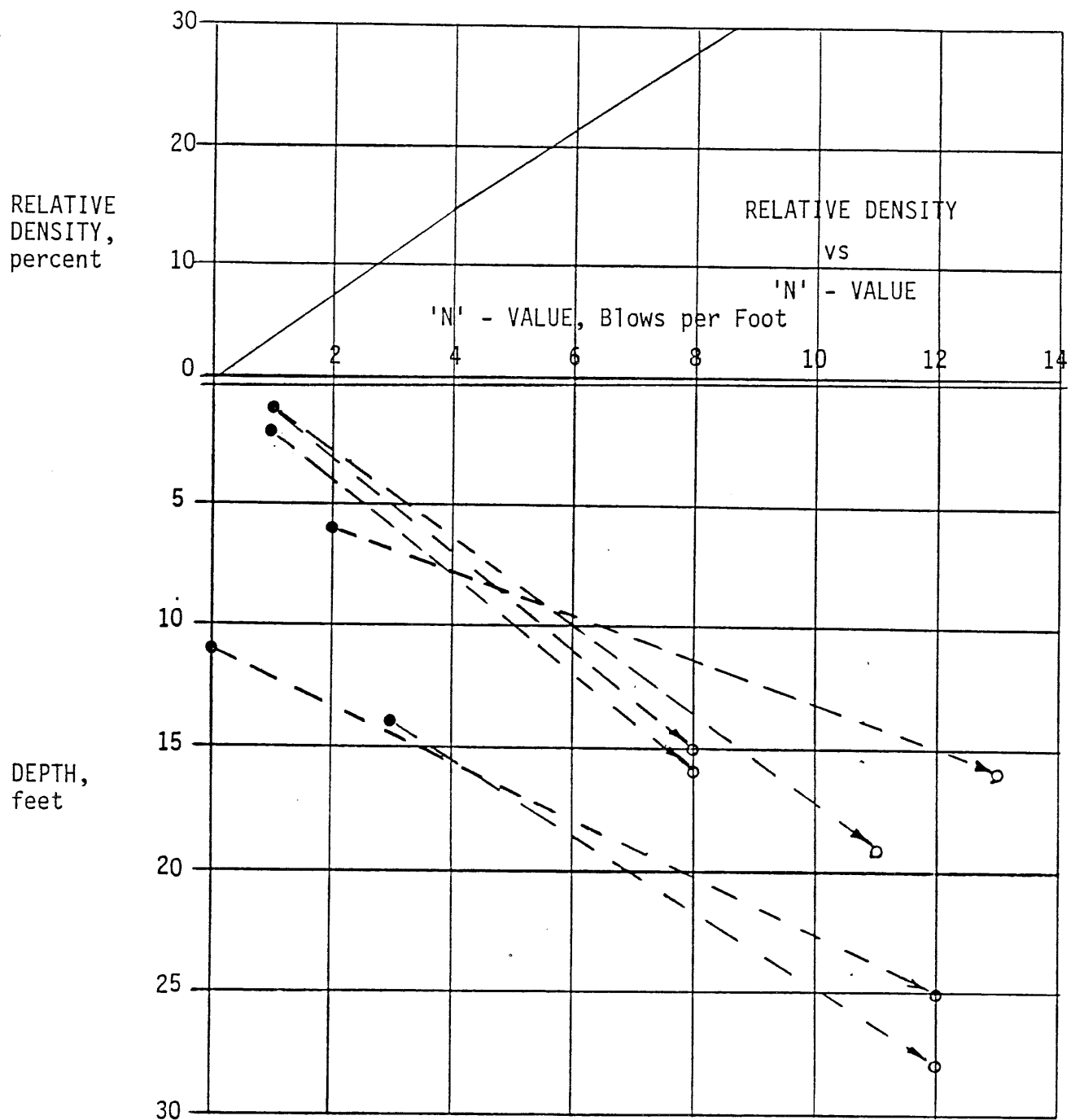
The alternative - wick drains - was determined to be workable based on installation experience in soils with similar fine gradation, and was implemented without preliminary field trial. Existing field data were sufficient to obtain conditional approval for the method at Blackdome. The drilling results from earlier field work were prepared on a drawing similar to Figure 4 to support the initial application to proceed with Upstream Construction. For legibility, the results on Figure 4 represent only a small fraction of the data, and have been screened to show the typical trends.

The basis for the conditional approval consisted of a requirement to complete detailed site drilling before and after installation of the wick drains. As illustrated by Figure 4, consolidation under self weight results in substantial increases in the relative density of the tailings as measured by the blow counts. The earlier data were deemed insufficient for full approval, and a formal program of drilling on a grid with both Standard Penetration and Cone Penetration tests before and after extension construction was required for certification and additional approvals. At the time of preparation of this paper, only the pre-construction drilling has been completed. The post-construction investigation is planned for the summer of 1989.

The wick installation was followed by construction of a sand and gravel drainage blanket over the entire area of the treated foundation. The blanket was hydraulically connected to the drain pipe under the upstream toe of the 1987 extension. In addition to providing a conduit for wick drain discharge, the blanket formed a working base over the tailings for subsequent fill placement and a control for future water levels within the embankment. Glacial till for construction of the extension was then placed and compacted in horizontal lifts on the treated tailings surface. As shown on Figures 1 and 3, the 1988 extension was built 5 m high with a crest length of about 180 m. The crest width is about 8 m and the upstream and downstream slopes are built to 2:1.

FURTHER WORK

In accordance with the conditional approval for the 1988 extension to be built by the Upstream Method of Construction, a drilling program is scheduled for the 1989 summer. On the basis of the field results, recommendations will be prepared for Blackdome to proceed with planning for additional extensions by the Upstream Method of Construction or a suitably revised alternative. It is also intended that, if the



LEGEND

- Initial 'N'-Value for indicated depth of tailings
- 'N'-Value at same location after additional tailings deposition

IN SITU TAILINGS DENSITY

FIGURE 4

anticipated foundation improvement is confirmed, variations of tailings foundation stabilization methods, including rock mats, will be assessed to reduce overall embankment construction costs.

REFERENCES

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