GEOTECHNICAL ASPECT OF WASTE DISPOSAL AT SUNCOR OIL SANDS MINE

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ABSTRACT

At the Suncor Oil Sands Mine located north of Fort McMurray, about 80,000 m^3 per day of tailings waste and 30,000 m^3 per day of overburden must be disposed of in an economically and environmentally acceptable manner. To date the high water content tailings has been impounded behind large dykes, many of which approach 100 m in height. These dykes were constructed using the coarse sandy fraction of the tailings and/or suitable overburden stripped prior to the mining of oil sands feed. The overburden material are also disposed of in out-pit and in-pit dumps. Figure 1 shows the layout of the Suncor Mine. Although this is common practice at many mining operations, the large volume handled and the resultant cost require the design to be fine tuned to achieve the lowest possible cost consistent with safety. This and the lack of previous experience has led to the successful application of the "observational approach" which, when coupled with the long harsh winters and a variety of troublesome site (and construction) conditions, has resulted in a range of design and construction approaches.

This paper overviews the geotechnical design process and discusses some of the innovative designs and construction at Suncor. Case history of the design changes during construction of the dyke as well as the performance of these dykes and waste dumps are presented.

INTRODUCTION

The profitable operation of an oil sands mine, particularly during the low oil prices of the last decade, is enhanced by a sound and carefully executed waste handling plan. At Suncor waste handling begins with initial stripping of organic topsoil and muskegs (stored for ultimate lease reclamation) followed by glacial overburden deposits and reject or lean oil sands. The bitumen recovery process produces a tailings stream of fine sands and a high water content sludge that must be safety stored and ultimately reclaimed. In the early years of Suncor operation before a mature tailings pond allowed full reclaim water potential, the ratio of toal wastes (including process contaminated water) to bitumen produced was in the order of 22 to 25:1. This ratio is currently in the order of 14 to 15:1. Tremendous quantities of wastes are therefore created and for a continuous operation must be handled on a continuous year round basis through a wide range of climate extremes.

Keywords: mining, waste disposal, oilsands, dyke, winter construction

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The Suncor mine has been in operation for over 20 years. During that time there has been many advances in the state of geotechnical knowledge and in open pit mining technologies. This, coupled with the economic pressure of variable oil prices, has lead to a continuing modifications to the waste handling plan to obtain the lowest cost product consistent with safety and the risk taking associated with any mining operation. The objections of this paper is to illustrate by way of several case histories the manner in which geotechnical designs for several major dykes have evolved. It should be noted that as these structures are major water retentions dams, they fall under the review of the Dam Safety Branch of Alberta Environment.

GEOTECHNICAL DESIGN PROCESS

DESIGN CRITERIA

Dykes are designed to ensure an adequate factor of safety against movement and to minimize seepage related problems. A perimeter dyke is designed to a factor of safety of 1.5 because the design life is similar to that of a conventional earth dam. An in-pit dyke, on the other hand, is designed to a factor of safety of 1.35 because it is required only until an adjoining downstream dyke or pond is constructed to a sufficient height (usually 5 to 10 years). At Suncor some of the tailings dykes are constructed using the upstream construction method stepping out on the beaches formed by the overboarding. Therefore liquefaction of these tailings beaches on the stability of the dyke is also a design concern. Because of the mobility of liquefaction failure, both the perimeter and in-pit dykes are designed to a factor of safety of 1.10 based on steady state concepts to define liquefied strength. The out-pit waste dumps are designed to a factor of safety of 1.35 because the consequence of a failure is usually not very severe. If there are critical structures located near the waste area, a higher design factor of safety of 1.50 is used.

As discharge of seepage water from the tailings pond into the environment is not permitted, perimeter dykes are designed to either minimize seepage or collect and return the seepage water to the tailings ponds. All perimeter dykes must be also designed to allow for subsequent reclamation. This requires intermediate slopes no steeper than 2H:1V with access berm about every 18 metres in height.

CONSTRUCTION MATERIALS AND PROCEDURES

The disposal of both overburden and tailings in the cheapest way possible is one of the goals of a mining operation. The dykes should ideally be designed to be constructed of material as they become available.

At Suncor, the overburden material consists of glacial till, sand and gravels, Clearwater silts and shale as well as the top reject i.e. oil sands with less than 8% by weight bitumen. The overburden is excavated by a dozer assisted shovel operation feeding to trucks. The overburden material is placed and compacted at in-situ moisture content in lifts of variable thickness in the dykes and the shells of waste areas. The specifications are designed to reduce construction costs whenever possible. For example, a less stringent construction specifications may result in cost savings depending on material availability and relative distances even though such a specification results in a shallower dyke slopes and increased dyke construction volume. In the critical portion of the dyke, the overburden is placed in 450 mm lifts and compacted by construction traffic and packers. This construction produces reasonably densities but these densities are generally less than those specified in dam and highway construction. In the less critical portion of the dyke, and shells of the waste dumps, the overburden is placed in 1.5 metre lifts and compacted with construction traffic only.

Because of the variable material encountered in the overburden, a procedural specification is used instead of a specified density requirement normally used in embankment construction.

In the winter months, the overburden is usually placed in waste dumps but is also used to construct dykes, see McRoberts et al 1983. Placement of fill in freezing weather is traditionally avoided in embankment construction. However major saving can also be realized by continuing overburden dyke construction through the winter months. Success operations have placed material in 450 mm lifts and have achieved compaction in weather as cold as -30°C.

The oil sands are mined by BWE feeding to conveyor belt which transport the feed to the plant for processing. In the tailings stream from the oil sands plants, the main constituents are predominantly sand and water, both of which contain a small fraction of fine grained silt and clay. The liquid phase of the stream includes a variety of contaminants in the water as well as free bitumen. The coarser fraction of the tailings is used to construct dykes using cell construction techniques. Compaction is provided by wide track dozers. A key element in the planning of the tailings dykes is to avoid placing sands below water in any structural elements of the tailings dykes. When the tailings is not used to construct dyke, it is overboarded into the pond. On deposition in a tailings pond, the sand fraction settles out to a relatively loose density and the silt and clay fraction is partially suspended in the water forming a sludge on top of the sand.

In addition to the overburden material and tailings, the waste also includes oversize reject material which are clay or siltstone stringers screened off during the first phase of extraction process. The oversize reject varies depending on the feed from relatively dry hard lumps of clay or siltstone coated with water to the very wet sloppy material.

Table 1 summarizes the properties of the various waste at Suncor.

DESIGN PROCESS

At Suncor, optimizing the dyke design is an ongoing, iterative process by both mine planning and geotechnical engineers as discussed in detail by Lahaie and Chan 1988. The role of the geotechnical engineer is in designing the dyke to have not only an adequate factor of safety against movement and seepage, but also to achieve minimum risk and maximum flexibility. Figure 2 shows the design procedure which is generally followed at Suncor.

The design process to ensure adequate factors of safety against movement and seepage is similar to that used in the design of conventional dams or dykes. The design process also examines possible worse case conditions that might be encountered during the life of the structure. If the factor of safety under these conditions is not acceptable the consequence of the resultant failure and the possible mitigative measures are evaluated. If the consequence or mode of failure has severe impacts on Suncor operation or if the required mitigative measures are either too expensive or impractical to implement, the dyke is re-designed to a higher factor of safety. The evaluation of the possible worst case condition is essential because of the large variations of overburden material encountered, the large quantities of waste, and the potential for mine plan and schedule changes.

The geotechnical designs should offer great flexibility. The overburden dykes at Suncor are designed to be constructed for a variety of overburden materials as encountered in the pit and varying climatic conditions (i.e. a wet versus a dry summer). Furthermore, the design of the dykes are evaluated for any possible impacts with any potential mine plan changes.

MONITORING

The observational and monitoring approach is an integral part of design process at Suncor. The performance data collected enables the stability of the dyke to be continually evaluated. If the computed factor of safety falls below the minimum accepted value, mitigative measures such as flattening the dyke slope, constructing stabilization berms can and have been implemented. Due to the size of the mining operation, most of the mitigative measures, if required, are easy to accommodate.

As shown in the following section, the dykes at Suncor have undergone several design changes which have been initiated by planning and economic consideration in order to minimize construction cost. Therefore many dykes have become complex structure and do not have a simple cross-section or an easily definable and straight forward seepage control system. Monitoring of critical elements of stability and seepage integrity is therefore imperative but is cost-effective in balancing risks and benefits to the overall economy of the mine.

CASE HISTORIES

TAR ISLAND DYKE

The Tar Island Dyke forms a tailings disposal created by damming off an oxbow in the Athabasca River Valley encompassing an area known as Tar Island. This facility was a vital part of the waste handling plan during start-up of the mine. Currently Tar Island Dyke is about 98 m high.

According to Hardy (1974) the original design for Tar Island Dyke was only 12 m high and was to be constructed out of overburden material. Tailings discharge was planned to be from the top of the valley wall which was some 60 m above the river level with hydraulically deposited sand forming a stable 8% slope, see Figure 3.

During the initial stages of the mining operations, it became clear that the 8% slope would not be realized and that clarification characteristics of the tailings pond effluent would be poor. These factors and a variety of mine planning logistics and economic considerations requires the design of Tar Island Dyke be modified and subsequently a series of changes including stepping out over beach placed below water occurred.

The design and construction of Tar Island Dyke have been discussed in detail by Mittal and Hardy (1977) and Chan et al (1983). The present design as shown on Figure 3, consists of an overburden starter dyke 24 metres high and a tailings dyke to a height of 98 metres constructed using an upstream construction technique. Construction of Tar Island Dyke commenced in 1965 and the dyke was constructed to the present crest elevation in 1984. The design issues at Tar Island Dyke are foundation stability, liquefaction of the loose beach tailings and seepage.

Tar Island Dyke is founded on originally lightly overconsolidated soft silt or/and clay up to 12 metres thick underlain by sand and gravel over limestone and on waste dump deposits and muskeg at the north end of the dyke. Settlements up to 3.5 to 4 metres have been inferred based on changes in total clay layer thickness, elevation changes and changes in moisture content. Horizontal movements have also been monitored (Chan et al 1983). Even 4 years after the dyke was completed, there are still continued movements although the rates of movement are low. Excess pore pressures due to dyke construction have been dissipated upwards into tailings sand and downwards into the underlying sand which is hydraulically connected to the Athabasca River. Because of the thinner clay layer and the more silty nature of the clay at the toe, all the excess pore pressure under the lower portion of the dyke have been completely dissipated while significant pressure still exist in the remainder of the foundation clays.

Liquefaction of the loose tailings sand is also a geotechnical concern. Early studies indicated that sluicing procedures alone gave a relative density of about 50% while 70 - 75% relative density could be attained by dozer compaction. Tailings overboarded on the beach above pond level produce a relative density of around 40% while material deposited below pond level procduce relative density of 30% or less. Liquefaction, especially of the tailings placed below water is a geotechnical concern. Liquefaction failure of the beach tailings placed underwater, reported by Mittal and Hardy (1977) have occurred when compacted cells and/or overboarded beach were constructed at too rapid a rate. Procedures which empirically limits the rate of construction and overboarding duration, were adopted to provide protection against future occurrence. There has been no instance of liquefaction failure of the compacted cell compacted to minimum relative density of 75% by dozers and beach placed about water.

More recent studies indicate that the key to achieving suitable density is hydraulic fill placement in what is referred to as "beach above water". Earlier studies suggesting higher density for dozer compacted sands may in part be due to higher horizontal stresses induced by compaction. However because of the variability inherent in hydraulic fill operations dozer compaction is still followed to ensure a consistent product.

Although the risk of liquefaction triggered by seismic activities is low in Fort McMurray area, the potential for liquefaction triggered by foundation movement remains a concern. At Tar Island Dyke, assessment of the liquefaction potential of a hydraulic fill sand at depths of 50 to 100 metres offers considerable geotechnical challenge. At these depths, the use of existing SPT or CPT correlations would have required significant extrapolations of known correlations and therefore these correlations are considered unreliable. As discussed by Plewes et al (1988), it was judged that a downhole nuclear density technique likely offered the best solution and a good agreement between corrected nuclear bulk density logs and core samples was reported.

The tailings sand are highly erodible and seepage in the downstream shell should be controlled. By coincidence it was founded that coke produced as a by-product of the upgrading process had an ideal gradation to act as a filter in contact with the tailings sand. Three coke filters 1.2 m deep by 30 m wide were used at Tar Island Dyke. Piezometer data, geophysical logs, and field observation indicates that the presence of sludge in the pond and a low permeable layer at the beach formed by the suspended clay size material in the pond water have impeded the flow into the dyke resulting in a significant lower phreatic surface upstream of the uppermost coke filter.

EAST WEST DYKE

The East-West Dyke, the largest overburden dyke constructed to date in the Suncor mine, is 73 m high, 3 km long and contains 90 million m^3 of fill. Figure 4 shows the initial design of East-West Dyke which is similar to a conventional dam design. The construction of the dyke commenced in 1971 and was completed in 1983. During the initial stages of the construction, the overburden material consisted of large quantities of wet Clearwater silt which resulted in very high construction pore pressures. After a series of instabilities discussed by Morgenstern et al (1988) including a slope movement 30 metres in height in 1979, the dyke was redesigned to meet the planned construction and schedule.

The revised design sections, shown on Figure 4 was arrived at by flattening the downstream slope to 3.5H:1V overall and incorporating a series of horizontal sand drains. The geotechnical requirements was satisfied by shifting the centreline downstream of the clay core in the western half of the dyke. In the eastern half, the presence of the feed conveyor necessitated shifting the centreline upstream of the clay core. This design change required the construction of the overburden dyke stepping over compacted tailings upstream.

To meet dyke construction schedule and to gain optimum use of the overburden fleet, it is desireable to construct overburden dyke in winter months. Performance monitoring studies on winter fill placement of waste dumps, and a small test section at East-West Dyke indicated that it is feasible to spread and to compact overburden fill in the winter months before it freezes and to obtain densities more or less equal to summer fill, see McRoberts et al 1983. However, if large zones of frozen fill are incorporated in the dyke, subsequent thaw and settlement of the frozen fill could result in internal cracking. Finite element stress analyses were used to ensure that incorporation of winter fill would not cause cracking in the critical area of the dyke leading to a piping failure, see Lahaie & Chan 1988.

Presently Suncor is planning to raise the Eastern portion of East-West Dyke to 99 metres high, refer to Figure 4. The design concerns are liquefaction of the beach tailing when the proposed dyke construction steps over on the beach and the potential of hydraulic fracture caused by the higher pond level in areas where the overburden dyke has stepped over the upstream compacted tailings. This configuration is undesireable and was not contemplated in the original design. However, mitigative measures can be taken and inclined relief wells and densification of the beachtailings are incorporated in the re-design to minimize liquefaction and hydraulic fracture potentials.

DYKE 5

The original design for Dyke 5 contemplated a tailings sand structure almost entirely of tailings sand using the centreline construction technique. Three coke filters in the tailings sand dyke portion to control the seepage and a large overburden stabilization berm along the northern portion because of poor foundation condition were specified.

Because of the high cost of the coke filter (estimated at over $1,000 per linear foot of dyke) and the overburden stabilization berm (because of 1.6 km longer haul than the next closest dump), potential cost reductions can be realized if these details can be eliminated. It was recognized that the oversize reject, comprised mostly of clay and rock lumps could be used to construct the stabilization berm. Furthermore the oversize reject material was relatively impermeable and if placed against the dyke could largely eliminate seepage through it and could permit coke filters to be designed for a shorter life. The redesign had four coke filters daylighting on the downstream slope and an oversize reject berm along the entire length of the dyke (Figure 5). A cost savings of 20% of the initial design was achieved. Furthermore additional cost saving was realized by using the upstream construction technique in the tailings dyke portion which also accommodates a change in the mine plan which created more demand for sand storage.

In 1986 as the result of changes in mine plan, more tailings sand was available for hydraulic cell construction at Dyke 5. Consideration was given to flatten the downstream slope to reduce the seepage gradient and therefore permit to reduce the requirement of coke filters. Through additional study it was found that by flattening the downstream slope to 5:1 and incorporating a narrow (15 metre wide) oversize reject core in the dyke, the need for both coke filters and the stabilization berm were eliminated. The stage 2 redesign resulted in a savings equal to 65% of the coke filter for stage 1 redesign.

WASTE DUMPS

Since the start of mining operations Suncor has been constructing waste dumps to store wet, frozen or muskeg material outside the pit limit. The design concept requires the construction of a shell of overburden fill which is built up first leaving an interior space in which waste can be dumped. These dumps are typically in the order of 30 to 55 metres high. Initially , the dumps were built with an overall slope of about 3.3H:1V. For a variety of reasons including the performance of intermediate berm slopes and the closer proximity of the toe of later dumps to the crest of pit wall, the overall slopes were flattened to slopes from 3.75:1 to 4.4:1. The shells of the dumps were constructed mainly in the winter months by placing approximately 450 mm thick lifts and by routing the truck traffic over the freshly spread area to gain additional compactive effort. Most of the waste dumps were constructed over variable thickness of muskeg. The normal construction procedures are placing a 3 m thick lift and then allowing the muskeg to consolidate. After the muskeg has been consolidated, the construction of the waste dump can proceed in a normal manner. McRoberts et al (1983) reported that the average compacted dry density is about 1690 kN/m^3 lower than those obtained from dyke construction, but the pore pressure ratio was lower than that of the dyke fill (0.17 versus 0.25) because of the lower degree of saturation.

Winter fill operations have resulted in the formation of permafrost. During drilling programs between 1975 and 1980 frozen fill was encountered within the shell and in the cores of waste dumps. All the frozen soil had thawed out in the south facing shell where as significant frozen soil still existed in the core and in the northern shell.

CONCLUSION

The success of geotechnical engineering in practice relies greatly on the application of the observation method. At Suncor, the designers and operator overall part of the same team, working towards a common goal such that the ability to utilize observational data and effect appropriate operating or design changes is enhanced. Geotechnical engineers have participated in many aspects of planning and production and have continually re-assessed designs to achieve efficient and cost effective waste handling.

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TABLE 1
SUMMARY OF MATERIAL PROPERTIES

Material	Effective Strength Paramters c' kPa	ϕ Degree	Placementor Insitu Moisture Content %	Placementor Insitu Dry Density kN/m^3	Standard Proctor γ max kN/m^3	Optimum Moisture Content
1. Tailings Sand						
a) Compacted	0	36	--	Dr = 80%	$\gamma_{max} = 1670$	
b) Beach Above Water	0	32	--	Dr = 50 - 58%		
c) Beach Below Water	0	30		Dr = 0 - 33%	$\gamma_{min} = 1300$	
2. Overburden Fill						
a) Compacted	0	33	10 - 28	1520 - 2160	1670 - 2035	6 - 14
b) Waste Area	0	30	10 - 28	1330 - 2110		
c) Winter Fill	0	30	10 - 28	1370 - 2190		
3. Sand Filter	0	35	7 - 12		1920 - 2030	7-10
4. Coke Filter	0	38		50 - 65		
5. Oversize Reject						
a) Shell	0	27-30	6-28	1590 - 1910	1620 - 1880	14-17.5
b) Core	3	26.5	11-25	1430 - 1790		

*Range of permeability measured in field or laboratory tests

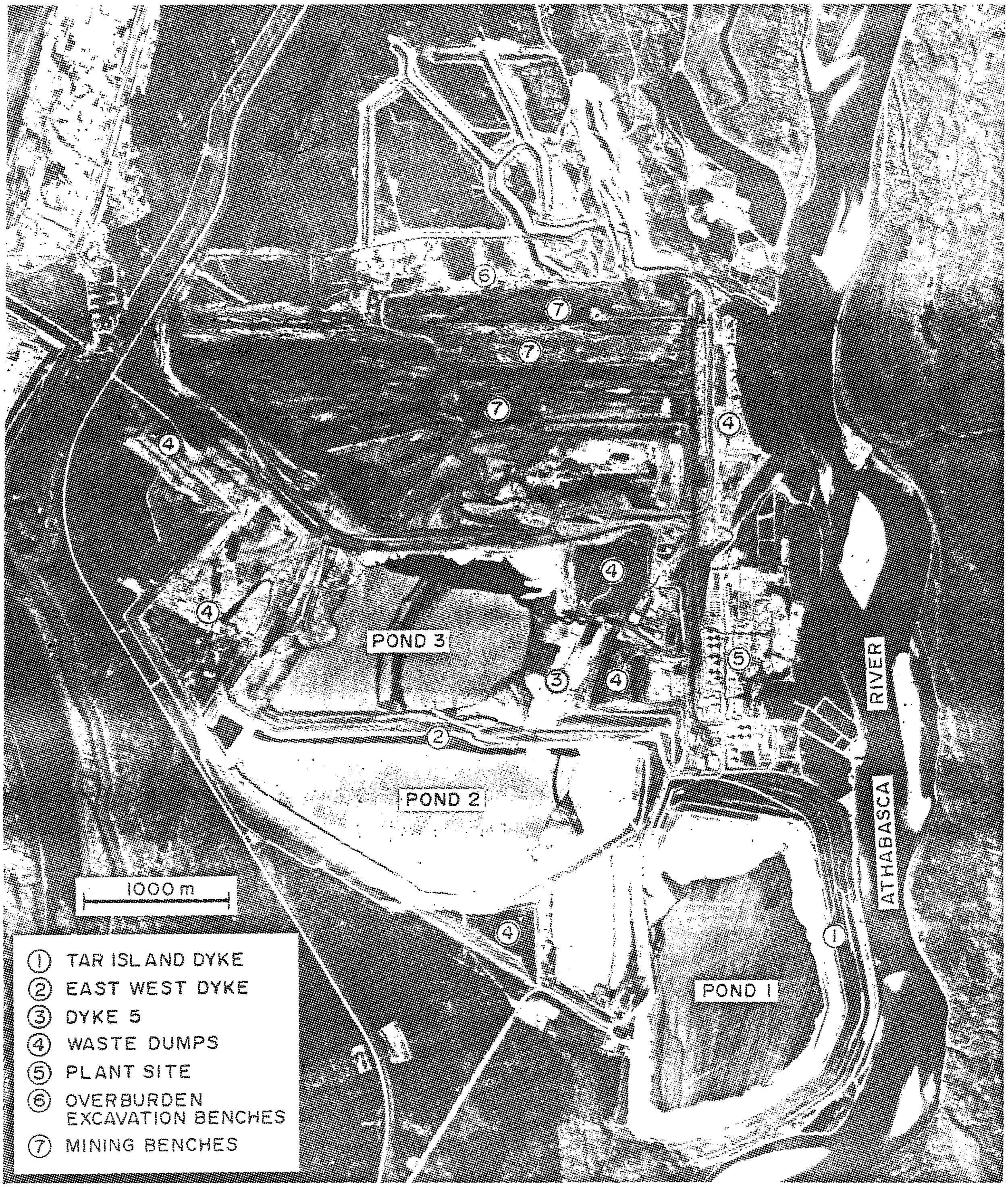


FIGURE 1: SUNCOR OIL SANDS MINE LAYOUT

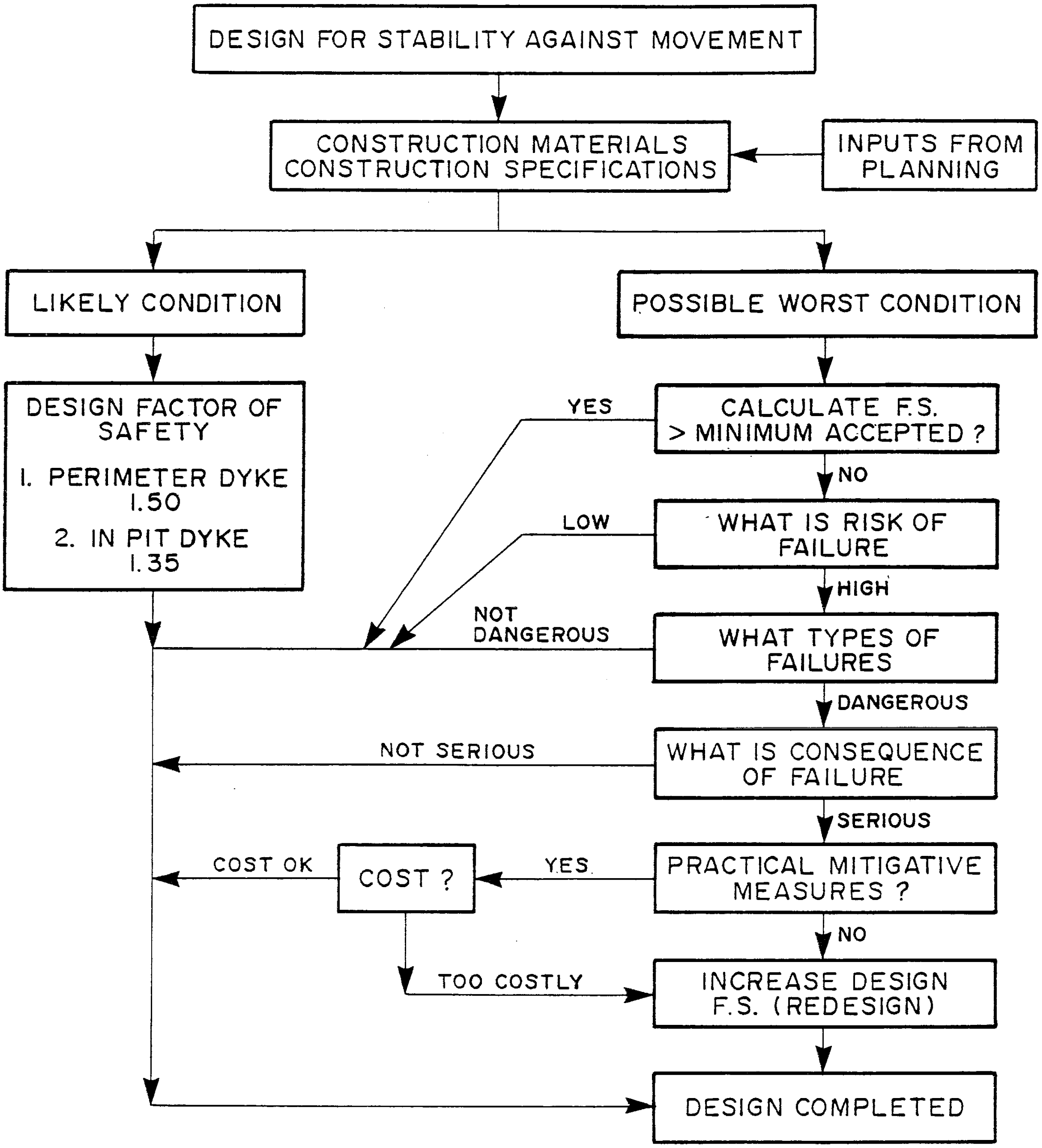
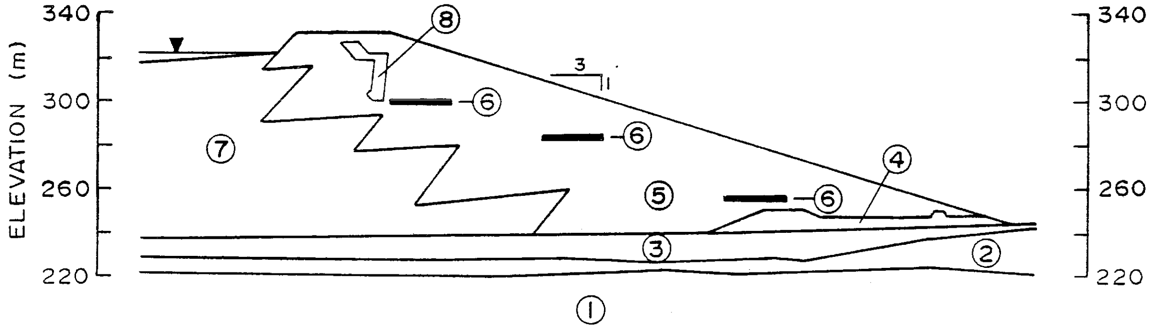


FIGURE 2: FLOW CHART FOR GEOTECHNICAL DESIGN PROCESS FOR DYKES

ORIGINAL CONCEPT

PRESENT CONFIGURATION



SECTION OF TAR ISLAND DYKE

LEGEND:

① LIMESTONE	⑤ COMPACTED TAILINGS SAND
② FOUNDATION SAND AND GRAVEL	⑥ COKE FILTER
③ FOUNDATION CLAY	⑦ BEACH TAILINGS SAND
④ OVERBURDEN DYKE	⑧ CLAY CORE

FIGURE 3: TAR ISLAND DYKE - DESIGN SECTIONS

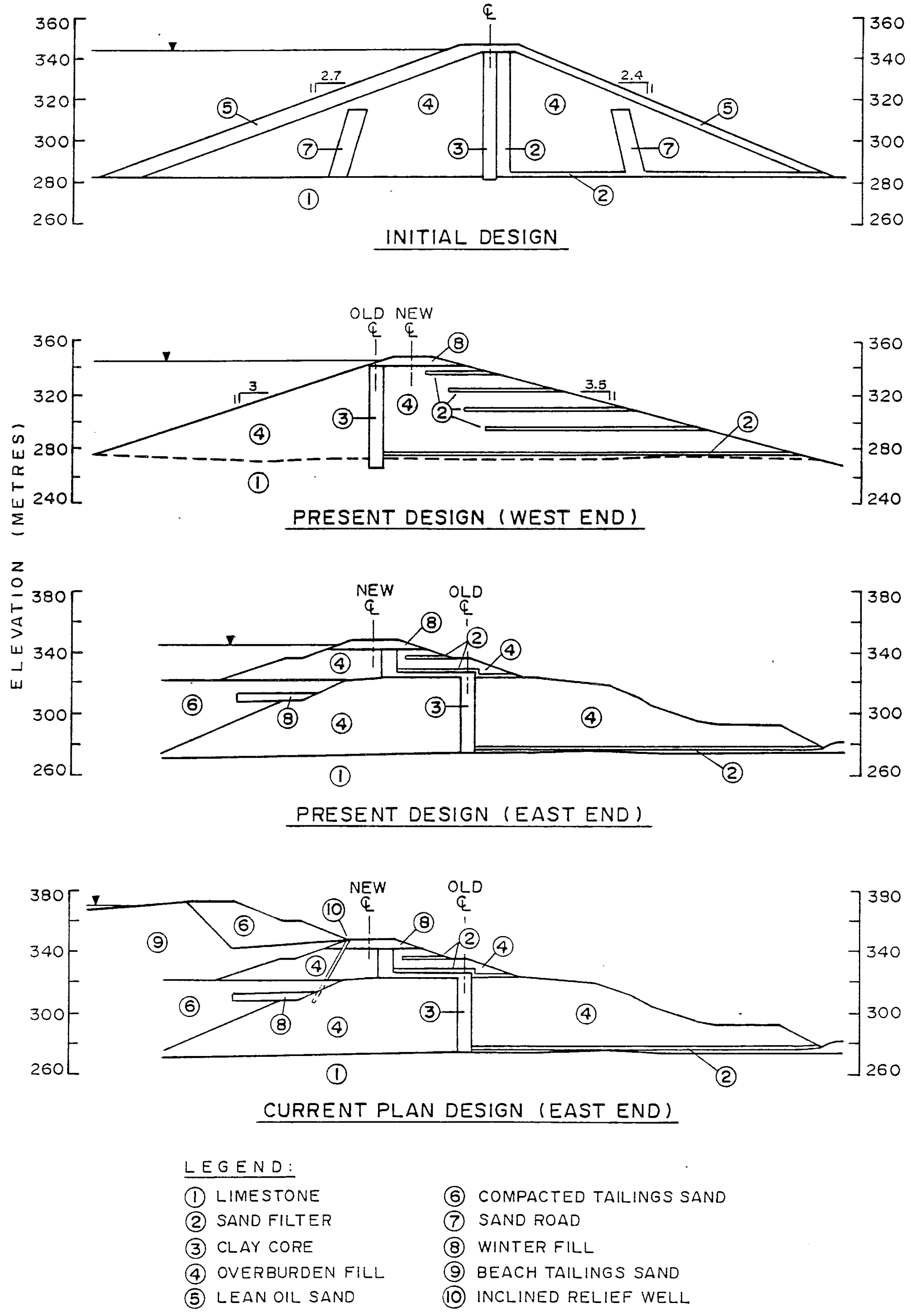


FIGURE 4: EAST WEST DYKE, DESIGN SECTIONS

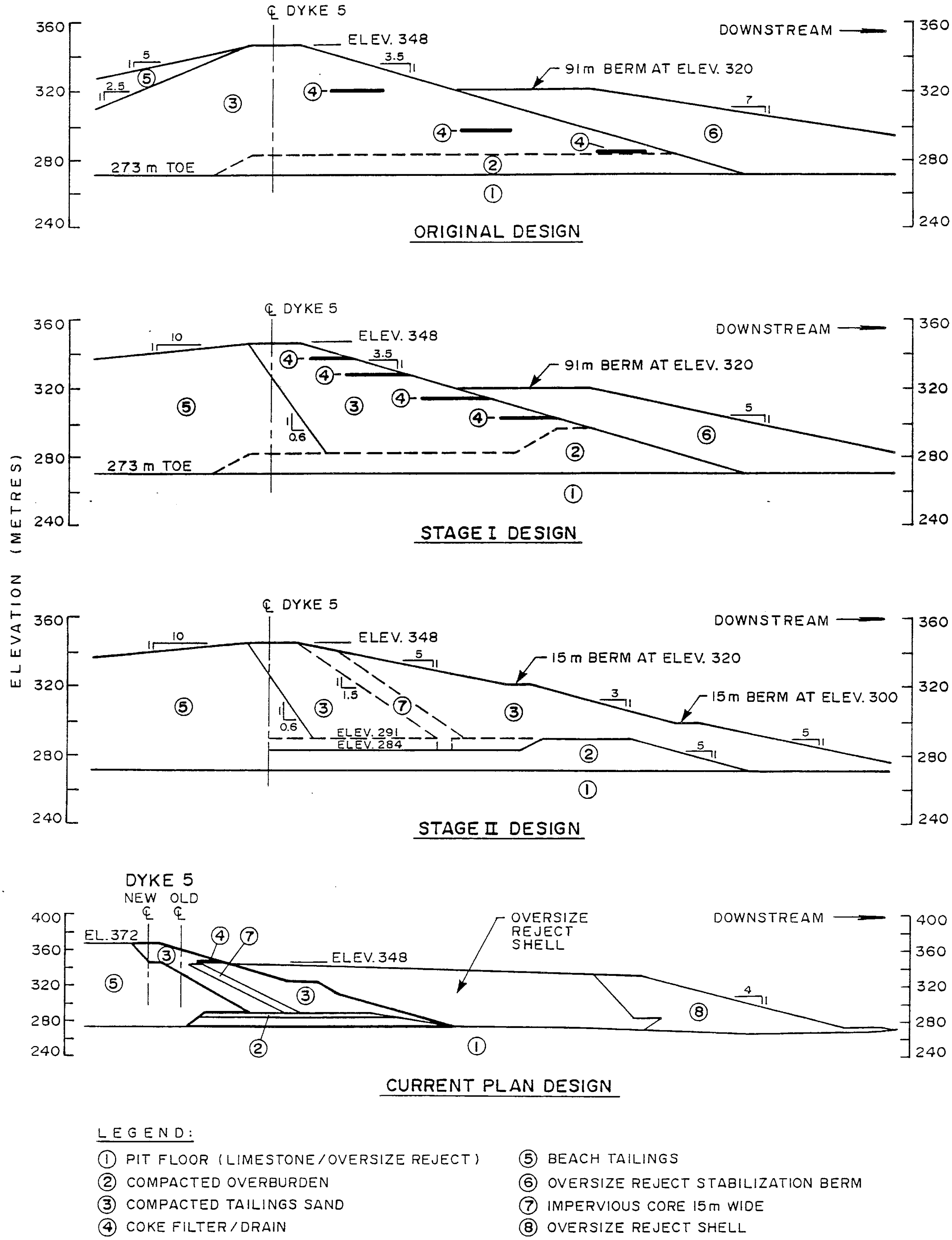


FIGURE 5: DYKE 5 DESIGN SECTIONS