Highly Loaded Structures In MSE Applications In The Alberta Oil Sands – Retrospective

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ABSTRACT
In the last two decades MSE walls have become standard cost effective and reliable structures for meeting the high load support requirements of oil sands applications in Fort McMurray, Alberta, Canada. Here we discuss three types of structures including i) Bridge Abutments for heavily loaded bridges carrying mine site haul roads over conveyor systems as well as over the Steepbank River; ii) Very tall and heavily-surcharged crusher/dump walls to support the higher capacity and heavier mine haul trucks with longer design life demands; and iii) a unique circular precast structure application to support above grade settling tanks. Design and construction of such applications are reviewed in this paper. We will follow the changes in requirements and engineering approaches to show a series of innovations made over the years with respect to accommodating the evolving technical challenges.

RÉSUMÉ
Dans les deux dernières décennies, les murs TSM sont devenus les structures standards, fiables et rentables qui satisfont aux exigences des grandes charges de support rencontrées dans les sables bitumineux à Fort McMurray, Alberta, Canada. Dans cet article nous examinons trois types de structures y compris i) culées pour des ponts lourdement chargés supportant les routes de transport des mines aux dessus des courroies transporteuses ainsi qu'au dessus de la rivière Steepbank ii) des murs pour concasseurs très hauts et lourdement chargés avec une longue durée de vie pour supporter les camions lourds de transport de haute capacité et iii) une structure circulaire unique préfabriquée pour supporter les bassins de décantation surélevés. Cet article examine la conception et la construction de ces structures. Nous suivront les changements des conditions et de l'ingénierie pour montrer une série d'innovations faites au cours des années quant à l'adaptation aux défis techniques en évolution.

1 INTRODUCTION

The projects and techniques described in this paper are the experiences of the authors in their work with Reinforced Earth Company Ltd.

The first MSE structures in the Alberta Oil Sands were constructed in 1984. Since that time there have been many changes in the application of MSE structures to the challenges provided by the oil sands operations. Some of these have come from opportunities to apply MSE solutions to new types of structures (Truck Dump Walls, Bridges, Arch Structures, Foundations), some have come from the increases in the size of the operations and equipment (producing increases in loading), extending design life and some have come from balancing the economics and quality of the structures to meet the requirements of the Oil Sands projects.

This paper will consist of an introduction to the challenges provided by the oil sands in the design and construction of MSE Structures, followed by a discussion of the three major categories of structures built in the oil sands; Crusher Facilities, Bridge Structures (both actual bridges and arch structures) and Foundation Structures.

2 WORKING IN THE OIL SANDS MINES

There are two elements that make working in the Alberta Oil Sands markedly different than a normal MSE project. The first is the geology of the area and the second is the scale of the equipment and operations.

2.1 Oil Sands Geology & the Use of MSE Structures

There are two general types of oil production used in the Alberta Oil Sands; In-Situ and Mining. Which approach is better for a particular project depends on the geology of the site.

In general the oil sands deposits consist of a narrow band of saturated muskeg materials (normally up to three meters in depth) over a variable thickness of clay and/or barren sand overburden, followed by an oil sand layer of varying thickness (typically 40 to 60 meters) and bedded on a relatively flat surface of limestone rock.

It is the thickness of the overburden layer that determines whether in place-methods or surface mining is applicable to a given area. The thicker the overburden, the less attractive the site is for surface mining. Generally about 20% of the oil sands reserves are considered to be surface mineable (the total reserve is estimated at $27.9x10^9$ m^3)

MSE structures are primarily used in the surface mineable projects. The most common use of MSE structures are in the construction of haul roads and crusher facilities.

2.2 Scale of Equipment and Operations

Operations in the Oil Sands are carried out on a scale rarely seen on other projects. This has been true right from the earliest projects in the Oil Sands and is even more true today.

Consider for a moment that an MSE wall on a highway project supports a design vehicle with a capacity of perhaps 60 tons. The earliest MSE crusher facility structures circa 1984 supported, as design vehicle, a 240 ton (payload capacity) haul truck with a possible 15%

overload allowance and the most recent truck dumps are designed to support the CAT 797B trucks with a payload capacity of 400 tons (plus overhead allowance). The full design loading including the weight of the vehicle is 700 tons – with additional allowance for impact loading as the vehicle backs up to the crusher. In the case of some structures allowance is also made for multiple vehicles on the structure.

Figure 1 Mine Haul Trucks

Of course the loadings expected on the top of a truck dump structure are nothing compared with the loads experienced by a "true" bridge abutment – which supports not only the design vehicle, but, also the weight of the bridge structure and has been designed on some of the oil sands structures for pressures up to 500kPa (compared to 200kPa for a highway structure).

3 CRUSHER STRUCTURES

The most common use of MSE walls in the oil sands mines is at the Crusher Stations in the mines. Mineable oil sand is dug out of the bank of the mine placed in mining trucks and driven to the Crusher facility. The crusher facility consists of a large MSE wall with a huge crusher unit installed along its face. The trucks are routed up on to the top of the structure, where they back up to very near the edge of the MSE structure and dump their load into the crusher.

The material is crushed down to manageable size and then moved from the crusher by conveyors or other means to the Oil Sands Plant for processing

Figure 2 Typical Crusher Facility

The cycle time on these large mining trucks is critical to the productivity of the mining operation. For this reason these structures are designed for a limited life span after which the intention is to replace them with a new crusher station that is closer to the mine face.

During the time from the first use of MSE structures at crusher stations until now there have been a number of changes in the requirements for the MSE walls. These changes have involved the loadings the structures are designed for, the nature of the materials used in the walls and the backfill used behind the wall structure.

The driving factors in these changes are the increase in the size of the equipment and improving the economics of the structures.

3.1 Design and Innovations

An MSE wall built with a crusher along side it may seem like a very straightforward design, but, as is the case for many engineering structures, small improvements in the design can create large improvements in the utility of the structure and reap rewards in the cost efficiency of the structure.

This has proven to be true of the use of MSE walls in crusher facilities.

Figure 3 Syncrude APS-1 (1984)

The initial MSE structures were constructed with precast facing units. These structures were an improvement over previous designs using cast-in-place concrete or waste rubber tires. MSE structures proved both easier and faster to construct and to allow for larger structures – both in height and area.

With the technology proven efforts then moved into extending the capacity of the structures and reducing the costs of the structures.

3.1.1 Design Life

An important factor in the cost of crusher walls in the oil sands is design life.

One of the unique factors in designing MSE wall structures for use in the oil sands is the variability in the required design life of the structures. On one extreme we have structures that intersect with public infrastructure (eg. highways) which require a design life of 75 to 100 years. On the other extreme we encounter crusher facility structures with a design life as low as ten years, and nearly every possibility in between.

The difference stems from the reality that everything in an oil sand mine is temporary. The mines have a large fleet of haul trucks – now commonly Cat 797B trucks or equivalent. These vehicles cost in the range of six million dollars each and are likewise expensive to maintain and to operate.

Consider that oil production from the oil sands exceeds a million barrels per day and the majority of that is currently from mining operations. For each barrel of oil produced, four tons of raw oil sand must be mined and processed. That is a lot of material to be moved and crushed in preparation for processing.

As a result mine personnel are constantly balancing changes in routing and position of equipment to minimize the time it takes for the trucks to make a round trip. This includes moving/rebuilding crusher facilities periodically to bring them closer to the working face of the mine. Therefore these structures have a design life that reflects the anticipated rate at which the mine face moves away from them balanced against the cost of constructing a new crusher facility.

3.1.2 MSE Wall Facing

The first crusher facilities used MSE walls with precast facing panels over their full surface – resembling large highway bridge abutments. However, the crusher facilities did not need the design life provided by the concrete facing panels.

After building a couple of structures in this manner, it was decided to explore other options. These options included a wall with a steel panel facing and walls with wire mesh facing. These structures had the same type of soil reinforcing to provide the strength of the structure, but, replaced the solid concrete facing panels with lighter alternatives.

Figure 4 Syncrude APS-3 Wire Faced Wall (1991)

The wall facing that emerged from this was the wire “cage” facing that is in common use today. The facing units are constructed of a heavy wire grid and are lined with a geotextile fabric to retain the backfill. The geofabric consisting of two layers with the outer layer chosen for resistance to light and the inner layer selected for strength.

As these structures are being constructed for a limited design life in an industrial setting where appearance is not a large consideration, the thickness of the wire in the facing was reduced giving cost savings at the “expense” of an increase in the amount of local deformation in the wall face. The resulting structures were perhaps not as aesthetic, but, they were structurally as strong and less expensive. While a certain amount of bulging in the wire facing is acceptable in crusher structures, it is important that this bulging is kept within limits – particularly adjacent to the crusher unit assembly.

Further refinements in the wire facing reflected variations in the design life of the various structures, for structures with very short design life the wire facing supplied as black steel. While those with a design life somewhat longer have the facing galvanized to reduce the corrosion of the facing.

Structures with a lifespan exceeding that of a geofabric lining are designed with “gabion” sized rock lining the inside of the wire facing baskets so that exposure to light does not become concern for the fabric.

Figure 5 Wire Faced Wall with Gabion Rock

A further consideration with MSE wall structures with a wire facing can be the presence of equipment working along the base of the wall. It is often the case (particularly at crusher facilities) that equipment needs to work adjacent to the wall to cleanup material spillages or control water. Like all equipment in the mines this is large equipment and it can snag the wire facing units penetrating the facing and allowing backfill to escape. In order to control the risk of this happening it has become common to have either concrete barriers in front of the wall or to construct the bottom two to three meters of the wall with precast panels to protect the integrity of the structure.

3.1.3 MSE Wall Geometry

The first crusher facilities with an MSE wall had a linear face and the crusher unit set out in front of the wall and allowed a single truck to back up to the face of the wall and dump its load into the crusher.

An early improvement on this design was to place the crusher in a trapezoidal shaped pocket along the face of the wall. This allowed trucks to back up on either side of the pocket creating two dump locations at each crusher where the original structures had one. In order to make the best use of this capacity the wall structures were made longer to allow more room for the trucks to manoeuvre. With each increase in the size of the haul trucks the required space for manoeuvring increased further.

Figure 6 Crusher Facility Wall with Pocket before Crusher Installation

Figure 7 Crusher Facility Wall after Crusher Installation

The most recent crusher walls have been designed with two or more dump pockets to allow the same structure to handle more equipment and increase capacity.

The heights of the MSE wall structures have been increased since the first structures were constructed – reflecting the increase in the size of the crusher units they are built to service. The first crusher facilities had wall structures only 15m in height while some structures are as high as 25m in height.

3.1.4 MSE Backfill

The backfill in the reinforced zone of an MSE wall is critical to the strength of the structure. The walls count on the friction in the backfill to provide strength for the soil reinforcement. In order to attain the required strength requires a granular material properly placed and compacted.

At the same time the structures are designed on the basis of limited pore pressure forces at the wall face – requiring that the backfill allow water in the soil to drain relatively freely. This is reflected in the specifications common to most MSE structures.

However, when designing structures of the size of the crusher facilities the volume of backfill is extremely large. The volume of backfill for a large crusher structure (for just the reinforced zone) can approach a 100,000 m2.

Figure 8 Lean Oil Sand Test Structure

Finding and hauling that much good granular material for backfill is expensive. Accordingly, in 1990 a test project was conducted into the feasibility of using lean oil sand as a back fill for crusher structures and a specification developed for that material.

We learned that lean oil sand with a clean sand “chimney” at the wall face to allow for drainage was a workable solution. Based on this testing a specification for lean oil sand backfill was developed which is still in use. This innovation has saved the mines a small fortune in the intervening years while insuring that the strength of the structures remained acceptable.

3.1.5 Soil Reinforcement

The selection of reinforcement for the Oil Sands structure reflects the owner’s philosophy of reducing risk while managing costs.

The Oil Sands projects specify inextensible (steel) soil reinforcement because of their high tensile load capacity and durability. The steel reinforcement also helps to control the amount of bulging in the wall facing.

Structures in the Oil Sands (particularly Crusher Facilities) have a design life that reflects their operational life as specified by the owner. This can be as short as ten years to as long as a hundred years – with many variations in between depending on the type of structure. This is balanced in the design and material selection for the structure as described above.

In order to manage the often difficult geotechnical conditions on these projects it is common for the structures to have longer reinforcement in the lower third of the structure as required by a global stability analysis. The reinforcement in the remainder of the structure is defined by the requirements of the internal stability of the structure and the support of the high loading. In this way the required strength of the structure is maintained while remaining cost effective.

3.1.6 Crusher Apron

Even with a well designed and compacted backfill in the MSE structure the large mine trucks travelling along the top of the structure can cause a severe rutting problem at the top of the structure, particularly with frequent and repeated turning – ruts that may be half a meter deep.

For this reason the MSE backfill adjacent to the crusher pocket is capped by a concrete apron slab that extends out to the crusher unit. This apron has a barrier along the outside edge to stop the trucks from backing up too far (see figure 2).

So now we have our 700 ton haul vehicle backing into a barrier at the top of the MSE wall inducing an impact force to the concrete which must be taken up by the MSE wall structure. Then the truck proceeds to dump its load – slowly elevating its bed and concentrating the weight of its load over the back tires of the vehicle – only a couple of meters from the face of the wall structure.

The concentrated forces produced in this area are enormous and result in a requirement for extremely high soil reinforcement densities immediately below the concrete crusher slab.

4 MSE BRIDGE STRUCTURES

Over the past twenty years there have been a number of bridge structures built in the oil sands. These structures have ranged from concrete or steel arch structures under highways and haul roads to bridge abutments supporting the bridge structure directly on the MSE structure (without piles).

In some ways these structures are very similar to the structures built on conventional highways, but, then there are the loadings……

A bridge structure capable of supporting a pair of loaded 797B trucks is a bit more challenging than one designed for a pickup or even a B-Train.

4.1 Arch Structures

Over the past two decades MSE wall structures have been used with two types of precast arch systems and with corrugated steel pipes and arches in the oil sands. These structures have carried both highways and mine haul roads over top of pipelines, conveyors and roadways. Also, with arch structures the MSE walls are used as headwalls at the ends of the arches in order to limit the length of the arch.

The type of MSE facing used on arch structures largely depended on the location of the structure. Those structures which are visible to the public having precast concrete facings and those in the mines having wire mesh facings – with the type of wire mesh facing reflecting the design life of the structure.

The first bridge structures involving MSE walls built in the oil sands were arch structures that carried Hwy. 63 over top of conveyors carrying materials to the Syncrude plant. In this case the arches used consisted of paired precast sections that were mated at the crest of the arch. This allowed the arch to be assembled while the conveyors continued operating. The length of the arch structures was minimized by using vertical MSE headwalls at each end.

Several structures were constructed using arches that consisted of a single precast unit per arch segment. In this case the arches needed to be positioned before work could proceed under them, but, this did not affect the construction of the MSE walls.

Figure 9 Foreground Arches over Conveyors, Background MSE Bridge over Haul Road

Recently MSE walls have been used in conjunction with steel arch structures. This can create a challenge with respect to matching the shape of the arch with the MSE wall facing – particularly precast facing. During the placement of backfill the steel arch structure tends to flex and change shape. The facing panels must be designed with considerable tolerance to allow for this flexing.

4.2 Bridge Abutments

MSE walls have been used in bridge abutments in many locations around the world, however, construction of bridge abutments in the oil sands provided significant challenges.

The first bridge structure in 1994 was built to carry Hwy 63 over a mine haul road. As such the loadings on it were similar to other structures and the main challenges were related to impacts on the wall from haul road traffic.

Figure 10 Bridge to Carry Haul Road over Conveyors

However, ten years later bridges were being built with the mine haul roads running over the top of the bridge structure. This was a whole new challenge. These structures were constructed using the MSE wall structure to support the bridge (no piles). While the bridges had fairly short spans they were designed to carry the weight of two 797B haul trucks simultaneously. The pressure under the bridge abutments was calculated to be 545kPa. (As a comparison a normal highway bridge yields pressures of about 200kPa.) The structures were designed with a more robust precast facing due to the loading and because equipment would be working under the bridges in close proximity to the abutment walls.

The largest bridge structure built in the oil sands to date was built for Suncor in 2007. This bridge carries a mine haul road over the Steepbank River and in keeping with the name the abutment walls were 20 and 23 meters in height. The bridge is supported directly on the MSE fill. The design load for this structure was not the paired 797B trucks, but, rather a single P&H 4100C Boss Shovel Crawler that weighs 1600 tons. The bridge footings were 4.5m wide and 1.5m thick and the pressure under the footing was over 350 kPa.

Figure 11 P&H 4100C Shovel Loading a 797B Hauler

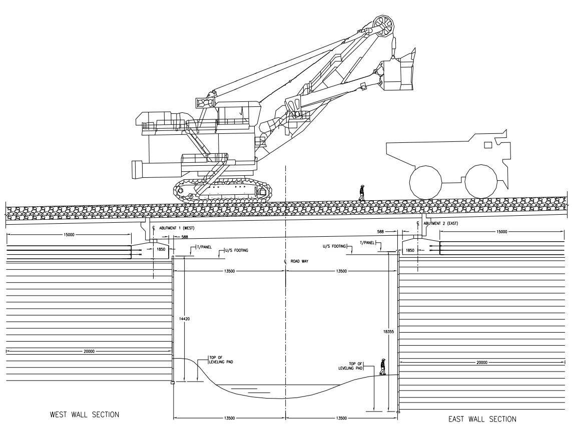

Figure 12 Steepbank Bridge Cross Section

Figure 13 Steepbank Bridge Aerial View

5 FOUNDATION STRUCTURES

A new application was introduced into the oil sands in the year 2000. MSE walls have been called upon to serve as foundations for large tank structures used to extract oil by a Froth Settling method. A series of six settler tanks at the Muskeg oil sands project were built using an MSE wall foundation to support the tanks.

Each tank was a circular structure either 54m or 43m in diameter. The tanks had a conical bottom profile and were raised off the ground about 4m at the center of the tank increasing to 7.5 or 8.2m at the outer edge (depending on the tank diameter).

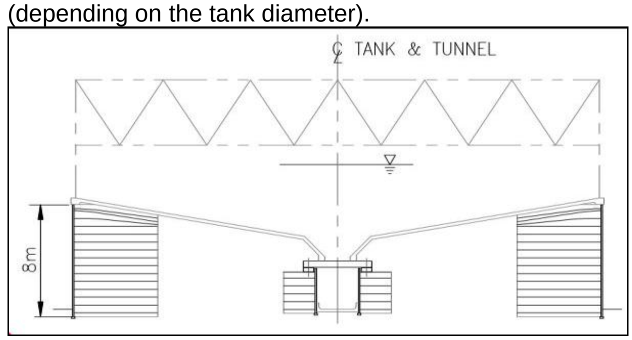

Figure 14 Section Through Settler Tanks

The settler tanks were elevated to allow for the presence of pumps and piping at the bottom of the tanks that were used to drain off the waste materials that settled in the bottom of the tanks. Access was therefore needed under the tanks in order to operate and maintain this equipment.

The use of an MSE structure allowed the construction of a foundation virtually the same size of the settler tanks they supported – minimizing the project footprint.

Each foundation structure consisted of an MSE wall face around the exterior periphery of the structure to support the steel tank at its roof. In addition – to provide access to the piping under the structure, an MSE bridge structure was constructed through the middle of the fill to form a tunnel passage from outside the structure to the center of the structure. This bridge structure also carried its share of the weight of the tank, its equipment and the fluids surcharge that rested on the tunnel.

Figure 15 Settler Tank During Construction


Figure 16 Completed Froth Settler Tank

6 SUMMARY

As presented in this paper, many types of applications are feasible and have been successfully deployed in using MSE technology in the oil sands industry. Each project brings new demands and different conditions. The scope and scale of the applications continue to challenge the engineering and material designers due to the size of industry's equipment, critical nature of its un-interrupted operations, safety concerns, geotechnical issues, economy and of course competitiveness.

All of these challenges require continuous application of prudent engineering, innovative designs and applications, optimizing approach in balancing material utilisation, and awareness, understanding and experience of the unique nature and operations of the oil sands industry.

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