

SCREW ANCHOR BUOYANCY CONTROL SAVES AN ESTIMATED \$12 MILLION FOR ENBRIDGE PIPELINE

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ABSTRACT

In today's competitive environment, oil and gas pipeline companies must search for materials and construction methods that reduce project capital costs while maintaining the quality and integrity of the pipeline. Pipeline buoyancy control can be a major cost of large diameter pipelines, particularly for routes that cross wet terrain.

In 1999, Enbridge Pipelines (Athabasca) Inc. constructed the 541 km NPS 30 Athabasca Pipeline from Fort McMurray to Hardisty, Alberta. Because of the substantial areas of muskeg that the pipeline route traversed, Enbridge selected a pipeline anchor system as the primary means of buoyancy control for the project. This new technology saved greater than an estimated \$12 million CDN when compared with the cost of concrete set-on weights, which is the traditional method of controlling buoyancy of pipelines in North America.

This paper describes the design of the anchor system selected for this project, details the calculations performed to determine anchor spacing, documents the challenges which were overcome during installation, and analyses the cost savings which were achieved by the use of this technology.

INTRODUCTION

The Athabasca Oil Sands are located in North East Alberta, near the city of Fort McMurray. Oil production from these oil sands averaged 320,000 barrels of heavy crude oil each day throughout 1999. The Oil Sands, which contain established reserves of over 43 billion barrels, currently account for over 15% of Canada's oil production. To compliment the ongoing expansion and production increases by the companies active in the oil sands, a need for additional export capacity was identified by Enbridge Pipelines.

Enbridge Pipelines, with over 14,000 km (8,750 miles) of mainline liquid pipelines, serves as the main transportation

system for deliveries of Western Canadian Oil production to markets in Eastern Canada and the USA. The Enbridge Hardisty Terminal serves as a major crude oil transportation hub at Hardisty, Alberta. Enbridge constructed a new 541 km (338 mile) pipeline from Ft. McMurray to the Hardisty Terminal to transport increased production from the Fort McMurray and Cold Lake areas. The pipeline route is shown in Figure 1

Common to this area of Alberta are low lying areas inundated by water. These peat bogs, or muskegs, are areas of high water table, and mostly organic soil. Access for construction activities through these muskeg areas is confined to the winter months when these areas freeze over.

Because of the high water table in these areas, pipeline buoyancy control is a significant design consideration. Traditionally, concrete set on weights, bolt on weights, or continuous concrete coatings were used. In recent years, the popularity of screw anchor buoyancy control has increased. Screw anchors can provide adequate buoyancy control at much less expense. As well, transportation, relocation, and installation are simplified and costs are significantly reduced. On the NPS 30 Athabasca Pipeline project, Cyntech Corporation supplied approximately 1,250 screw anchor sets for installation. These anchor sets replaced approximately 10,000 concrete set on weights, and resulted in a cost saving to Enbridge Pipelines of over (\$CDN) \$12,000,000.

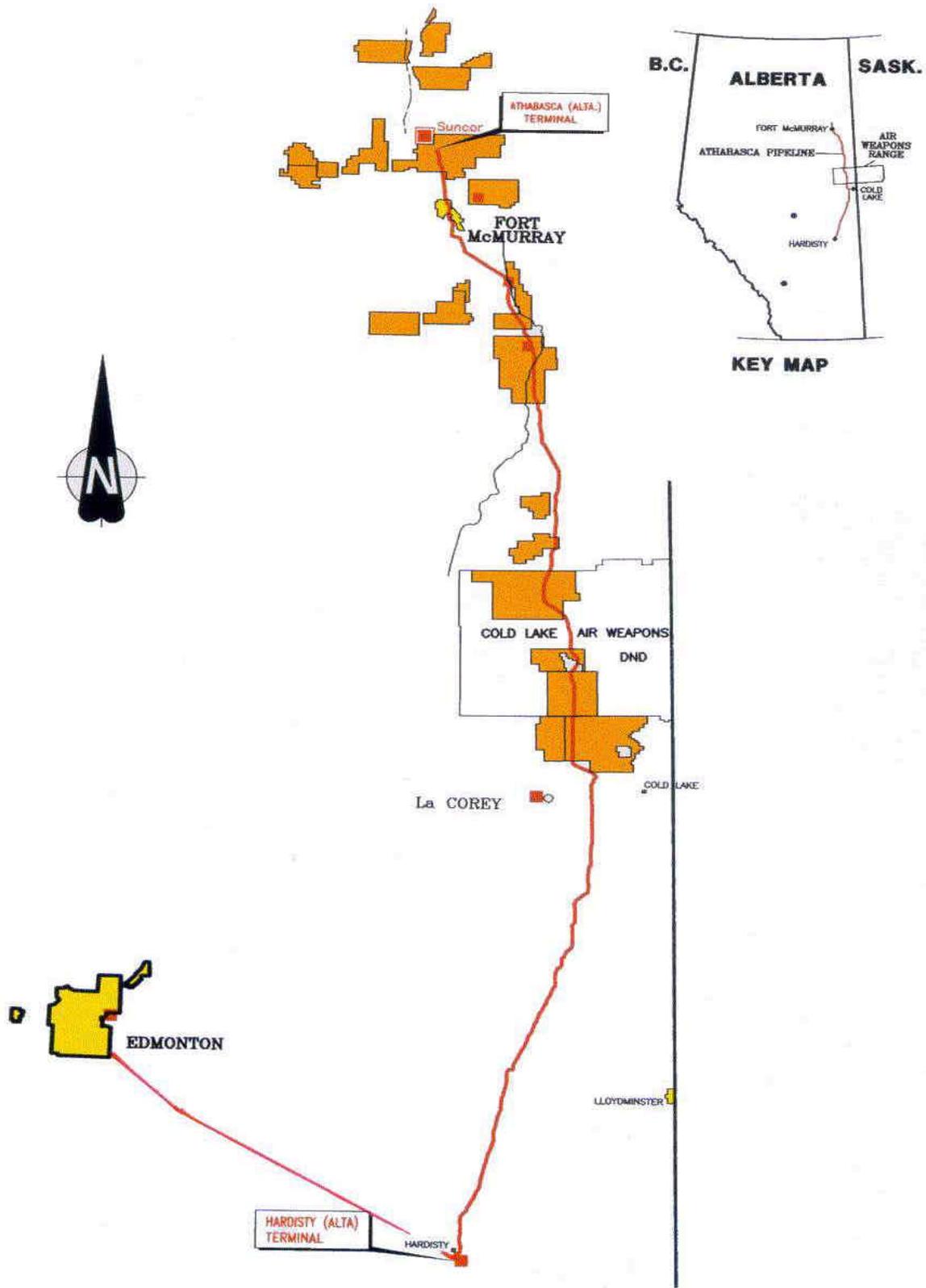


Figure 1 - Athabasca Pipeline Route through Northeast Alberta Oil Sands Leases

ENGINEERING

As part of the engineering process for the Athabasca Pipeline, numerous options and combinations of material and construction were investigated. Each component of the overall project was analyzed to ensure it was fit for purpose and that it was the optimal design for not only capital cost, but also construction and maintenance, to arrive at the lowest life cycle cost. One area investigated was pipeline buoyancy control.

Engineers at Enbridge learned about the use of screw anchor buoyancy control through discussions with colleagues at Trans-Canada PipeLines. Trans Canada has been using screw anchor buoyancy control since 1993 on all of their pipelines NPS 10 and larger. Their experience convinced Enbridge that screw anchor technology could be cost effectively used on the Athabasca Pipeline.

The design basis for the Athabasca Pipeline is as follows:

Diameter:	NPS 30
Wall Thickness:	9.8 mm
SMYS:	483 MPa
MOP:	9,930 kPa
Max. Operating Temp:	65 C
Negative Buoyancy:	10%

The first step in the engineering for a screw anchor buoyancy control system is to calculate the maximum allowable spacing between anchor sets. This dimension is critical, as pipeline bending between the anchor points will result in longitudinal stresses that must be accounted for during the design. These stresses must also be in compliance with applicable design codes.

The pipeline is modeled as a continuously loaded fixed end beam. The pipeline is subject to continuous loading by the buoyant force throughout its length. From a structural analysis, the maximum bending stress in the pipe will be:

$S = M \times Y / I$, where:

M	Maximum Bending Moment on the Beam
Y	Distance from neutral axis to extreme fibre
I	Moment of Inertia

We also know, from structural analyses, $M = W \times L^2 / 12$, where:

W	Uniformly Distributed Load
L	Span Length

The uniformly distributed load W, is the net buoyant force of the pipeline. Net buoyant force is the sum of the pipeline buoyancy, subtracting the self-weight of the pipeline. Typically for pipelines NPS 16 and larger, no contribution due to strength of the backfill material is assumed.

For the NPS 30 Athabasca Pipeline, the net buoyancy of the pipeline was calculated to be 3.14 kN/m (215 lb/ft). This was assuming 10% negative buoyancy. We can therefore assume a spacing of 45m and calculate the bending moment accordingly.

$$M = W \times L^2 / 12 = 3.14 \times 45^2 / 12 = 529.9 \text{ kNm}$$

This results in a maximum bending stress of:

$$S = M \times Y / I = 529.9 \times .381 / 1.638 \times 10^{-3} = 123.3 \text{ MPa}$$

According to CSA Z662 "Oil and Gas Pipeline Systems" a check must be performed to ensure that the combined stresses are within allowable limits. Because it is arguable whether the pipeline is restrained or unrestrained while in a swamp or muskeg, both conditions are checked.

For the restrained pipeline, the sum of hoop stress, negative longitudinal stress, and bending stress, must be less than SMYS.

$$S(h) - S(l) + S(b) < SMYS$$

For the unrestrained condition, the sum of one half of the hoop stress plus bending stress must be less than SMYS multiplied by location factor, and design factor.

$$0.5 \times S(h) + S(b) < S \times L \times F$$

For this pipeline, there will never be an operational condition where hoop stress and bending stress due to buoyancy will act at the same time. As the line is a liquid line, once the pipeline is filled with product and pressurized, the weight of the pipeline and contents is greater than the buoyancy of the pipeline and no bending exists. The only time there will be bending stresses from buoyancy is when the pipeline is empty, and therefore de-pressured.

With these operational constraints in mind, the spacing can be much greater than on a natural gas pipeline, where it is possible to have both hoop stress and bending stress from buoyancy acting on the pipe at the same time.

Checking our 45m spacing for the above two conditions results in both conditions being met. It is important to note that if this were a natural gas pipeline with the same design basis, the allowable spacing would be less than 35m.

For the Athabasca Pipeline, a Cyntech Model S-175 screw anchor system was selected. This anchor has been used on many large diameter pipelines in the past, and is the most suited for this application. The anchor lead section is made up of a 44mm (1 3/4") square steel shaft with a 400mm (16") diameter, 16mm (5/8") thick helix plate welded to it. The square steel

shaft is designed to resist not only the working load (either tension or compression) imparted on it, but also the torsional load encountered during installation. The helix plate is designed to have enough area for the particular soil bearing capacity to ensure adequate load resistance is supplied, and also to resist loads that it may be subjected to during installation. This anchor has a rated torque capacity of 10,000 ft-lbs. Ultimate pull-out capacity of this anchor is over 18,000 kg (39,600 lbs.).

In addition, the Cyntech polyester saddle was specified. This patented polyester saddle has a lower cost and is more lightweight than comparable steel saddles. Its relative ease of installation, high strength and lower cost, made it the best choice for a saddle. The typical Athabasca Pipeline Screw Anchor assembly drawing is shown in Figure 2.

The calculated anchor load (per set) on this pipeline was 141.6 kN (31.8 kips). This resulted in an anchor working load of 70.8 kN (15.9 kips). Enbridge engineers selected a 3.0 safety factor, and thus the design load was 212.4 kN (47.7 kips).

INSTALLATION

With screw anchors, a widely accepted ratio exists between the anchor installation torque and ultimate holding capacity. This ratio has been determined through thousands of anchor installation and pull tests worldwide, and is an accepted basis for specifying installation torque values. Generally, a 10:1 ratio exists between the installation torque (measured in foot pounds) and the ultimate holding capacity of an anchor (in pounds). It is important to note that this ratio does not exist when using metric units.

For the Athabasca Pipeline project, the anchor design (factored) load was calculated above to be 212.4 kN (47.7 kips). Using the 47,700 lb. design load and the 10:1 ratio, the minimum installation torque is 4,770 ft-lbs., or 4,800 ft-lbs.

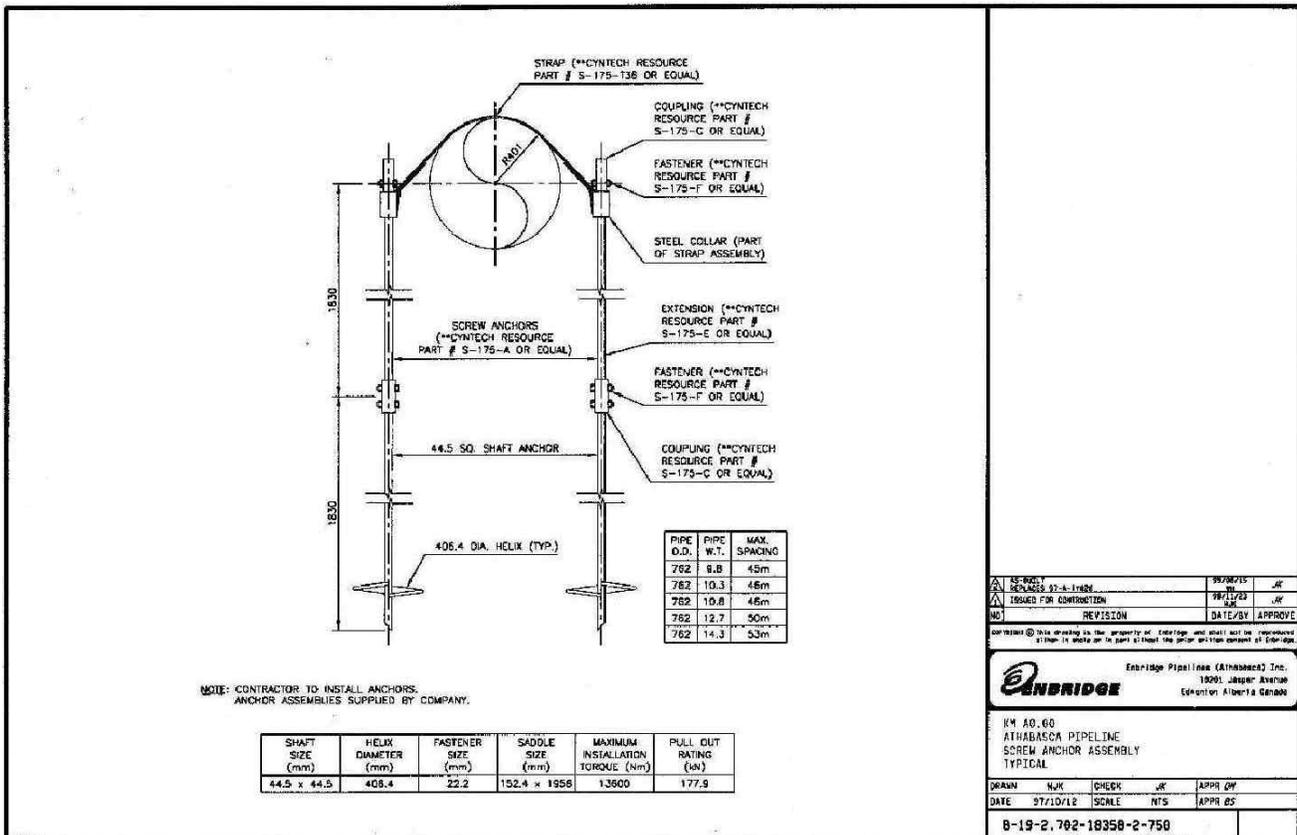


Figure 2 – Typical Screw Anchor Assembly Drawing

The design of the anchor incorporates several criteria required for installation. The shaft rated torque capacity is 10,000 ft-lbs. even though the minimum installation torque is 4,800 ft-lbs. An anchor shaft with a minimum rated capacity of 2 times the specified minimum installation torque is recommended for glacial tills and other irregular soil types. This shaft design will enable the installation to proceed even though the anchor may encounter soils slightly firmer than the design soil strength, and also will enable the installation to proceed when the anchor encounters gravel or cobbles. For these same reasons, a thicker helix plate is required. A standard helix thickness is 10 mm (3/8"). When the installation will be into the glacial till soils, additional strength is required in the helix plate. This will prevent any deformations or failures, during the installation process.

Due to the 300km length of the winter construction portion the project was constructed with two separate construction spreads. The two spreads each started from approximately the centre, with one working north, the other south.

The two spreads encountered markedly different muskeg quantities and depths. The south spread was characterized by numerous short muskegs, spaced out along the length of the right of way. The north spread encountered fewer, but longer, more widespread muskegs. This necessitated a different construction approach for each spread.

The north spread encountered several long muskegs in the first 50 km. The first 50km of right of way was 65% muskeg. This large length of muskeg, in a relatively short distance required this spread to use additional equipment to maintain construction progress. They chose to utilize 3 Caterpillar 340 back hoes each mounted with a twin drive unit for installation. This style of installation uses two hydraulic motors to install 2 anchors at the same time. Each screw anchor is manufactured with an opposite helix configuration, so that one anchor will install clockwise, the other counter-clockwise. This counter rotation is required to avoid excessive torque being applied to the installation unit itself, by compounding torque from two motors. With all three excavators and crews installing anchors, the contractor was able to install 70 screw anchor sets per day in muskeg.

When using a back hoe for installation, the bucket is first removed from the boom of the back hoe. The hydraulic hoses that are normally used to maneuver the hydraulic cylinder for the bucket are also removed. It is this hydraulic circuit that powers the hydraulic installation motors. In this fashion, the back hoe operator can control the installation of the anchors through the normal cab controls.

The contractor also chose to mount the installation equipment on the back hoes using Caterpillar 'quick connect' style attachment fittings. The hydraulic motors, installation torque gauges, and hoses, were all mounted on a single 'quick

connect' fitting. By using this type of connection, the contractor was able to greatly improve the efficiency of the screw anchor installations. When right of way conditions dictated, the three back hoes were used to install screw anchors, when there were fewer screw anchors to install, the hydraulic motors were removed, the buckets were put back on, and the back hoes were used as normal excavators. Typically, it took less than 30 minutes to change from hydraulic motor to bucket, or vice versa.

Because the south spread encountered numerous, but shorter muskeg sections they chose to use one Caterpillar backhoe with the twin hydraulic motor configuration. A second backhoe was fitted with the 'quick connect' fittings and was used when required to ensure anchor installation was able to proceed along with lower-in and backfill operations. With one anchor crew installing anchors, they were able to install up to 35 anchor sets per day. Typical installation conditions are shown in Figures 3, 4, and 5

ECONOMICS

The primary reason for using screw anchors for buoyancy control is economics. Significant cost savings can be realized when a screw anchor system is used in place of concrete set on or bolt on weights.

Enbridge Pipelines saved over \$12,000,000 by using the Cyntech screw anchor buoyancy control system on the NPS 30 Athabasca Pipeline. The cooperation between client, contractor and supplier throughout the engineering and construction phases ensured a smooth procurement cycle, and an effective installation program.

There are several other practical and economic advantages to using screw anchors as a primary method of buoyancy control.

Screw anchors can be spaced at far greater intervals than concrete weights. Due to the high load capacity of an anchor set, they are able to resist the buoyancy of a longer segment of pipeline. Where concrete weights are typically spaced at 4-5 m (13-16 feet), screw anchors can be spaced at 30-40 m (98-131 feet). This increased spacing greatly reduces the quantity of buoyancy control devices that are required.

Screw anchors are significantly lighter and easier to handle than concrete weights. A typical NPS 30 screw anchor assembly weighs 225 kg. (495 lb.), while a comparable concrete weight weighs 3,200 kg. (7,040 lb.). This substantial weight difference means that handling is easier and less costly than for concrete weights. Screw anchor placement along the pipeline R.O.W. can be altered much easier than concrete. After being strung out along the right of way in anticipation of placement on the pipeline, screw anchor locations can be changed, additional screw anchors added, or surplus screw anchors deleted, quickly and easily. Once a concrete weight is

strung out, its location becomes relatively fixed, and flexibility in location is lost. Adding more concrete weights, or deleting surpluses becomes difficult.

Screw anchors do not add weight to the pipeline. Screw anchor buoyancy control is a ‘passive’ system, rather than an ‘active’ system, like concrete weights. The screw anchor does not add any mass to the pipeline; it only prevents the vertical rising of the pipeline. For a liquid pipeline, where generally buoyancy is only a concern immediately after construction, and during times of outages, this is a significant advantage during operation. During operation the pipeline will be negatively buoyant through the weight of contents and the pipe itself. The addition of concrete weights may cause unacceptably high stress on the pipeline.

Screw anchors are easier to restock than concrete weights. At the end of a project, remaining screw anchors can be returned, or placed in inventory, and used on another project. With concrete weights, their mass and the difficulty and expense in trucking and loading generally prohibits their re-use.

A summary of the financial analysis for the Enbridge NPS 30 Athabasca Pipeline is shown:

Buoyancy Control Method	Spacing (m)	Supply Cost (C\$)	Install Cost (C\$)	Cost per metre (C\$)
Concrete Weights	5.5	\$800	\$800	\$290.91
Screw Anchors	45.0	\$800	\$550	\$30.00

As this paper presents, for the Enbridge NPS 30 Athabasca Pipeline, Cyntech’s model S-175 screw anchor system resulted in a safe, efficient, and very economic design. Virtually no problems were encountered through the supply and installation phases, and none have been reported during the operation phase.

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Figure 3 – Screw Anchor “Quick Connect” Fitting



Figure 4 – Screw Anchor Shaft Extensions Connected and Ready to Install



Figure 5 – Screw Anchors Guided in Place for a Typical Wet Muskeg Installation