Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

PIPELINE INVESTIGATION REPORT

P01H0004

CRUDE OIL PIPELINE RUPTURE

ENBRIDGE PIPELINES INC.
864-MILLIMETRE LINE 3/4, MILE POST 109.42
NEAR HARDISTY, ALBERTA
17 JANUARY 2001

Canada

Pipeline Investigation Report

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Summary

At 0045 mountain standard time on 17 January 2001, a rupture occurred on the Enbridge Pipelines Inc. 864-millimetre outside diameter Line 3/4 at Mile Post 109.42, 0.8 kilometres downstream of the Hardisty pump station near Hardisty, Alberta. The rupture occurred in a permanent slough that was fed by an underground spring. Although the line was shut down at the control centre in Edmonton, Alberta, within minutes of the rupture, the exact location of the rupture was not found until 1415 mountain standard time. Approximately 3800 cubic metres of crude oil was released and contained within a 2.7-hectare section. As of 01 May 2001, 3760 cubic metres of crude oil had been recovered.

Ce rapport est également disponible en français.

Other Factual Information

At 0045 mountain standard time (MST),[1] the control centre operator in Edmonton, Alberta, controlling Line 3/4 noticed a pressure drop at the Hardisty pump station and immediately began to shut down the mainline units at that pump station. As the line was being shut down, the emergency notification procedure was begun.

During the morning of 17 January 2001, the pipeline route downstream of the Hardisty pump station was both walked and flown along numerous times in an effort to identify the possible leak location. At approximately 1415, company personnel walking the line noticed that crude oil had surfaced through a crack in the ice near the edge of a slough about 300 metres (m) downstream of the Hardisty pump station. At that time, company personnel secured the site and began to implement oil containment, oil recovery and pipeline repair operations.

On 21 January 2001, Enbridge Pipelines Inc. (Enbridge)[2] voluntarily implemented a 10 per cent reduction in maximum operating pressure (MOP) on those sections of the 864-millimetre (mm) line containing pipe similar to that which failed. On 23 January 2001, approximately 35 m of pipe, which included the failed joint of pipe, was replaced. The failed joint of pipe was sent to the Canspec Group Inc. (Canspec) laboratory in Edmonton for analysis.

Canspec determined that multiple cracks had initiated on the outer pipe surface along the corner formed between the pipe body and the edge of the electric resistance weld (ERW) longitudinal seam. Minor pitting corrosion was present at the crack-initiation point of the area that exhibited the maximum crack depth. The cracks had coalesced after approximately 1 mm growth to form one single crack front. Canspec determined that the crack had continued to grow by fatigue until the pipe could no longer support the normal internal operating pressure of the pipeline. The Supervisory Control and Data Acquisition (SCADA) records indicate that the pressure at the time of failure was 3916 kilopascals (kPa). Canspec also determined that the failure site was located in a mildly corrosive slow groundwater discharge area.

The section of the 864 mm line in which the rupture occurred had been manufactured in 1967 by Canadian Phoenix of Calgary, Alberta, using the ERW process according to pipe standard API5LX52 of March 1967. This section of line had been installed and hydrostatically tested in 1968 to a minimum pressure of 5040 kPa. The pipe had been coated with spiral-wrapped polyethylene tape. The tape had bulged along the ERW seam of the failed joint of pipe and exhibited minor wrinkling at other locations along the joint. The bulge reached a maximum height of 13.7 mm about 4 m from the rupture and tapered away at the upstream and downstream girth welds. Minor pitting corrosion was detected on the pipe surface under the tape coating immediately adjacent to the ERW seam. Once the tape was removed, it could be seen that the external flash resulting from the forging of the ERW seam had not been trimmed flush with the outer surface of the pipe. However, the height of the flash was still within allowable tolerances of the pipe standard.

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1 All times are MST (Coordinated Universal Time [UTC] minus seven hours) unless otherwise stated.

2 Formerly Interprovincial Pipe Line Inc.

The failed joint of pipe was located in a field sag bend with the ERW seam located at the three o'clock position. The failure initiation point occurred near one end of the bend. Following the rupture, the bend was manually measured at 3.5 degrees. Data from an in-line inspection completed in 1994 indicated that the bend was a three-degree bend; construction markings under the tape coating also indicate a three-degree bend.

Line 3/4 consists of 1242 kilometres (km) of 864 mm diameter pipe and transports batches of crude oil of varying viscosities. The pipeline experiences cyclic pressure fluctuations due to batch operations. The pressure cycles may occur once per day and may fluctuate within a range of between 690 kPa and 3790 kPa.

The line was cathodically protected by an impressed current system. Cathodic protection surveys that were done annually indicate that pipe-to-soil readings were within industry standards.

The 864 mm line had been internally inspected in October 2000 between Edmonton and Regina, Saskatchewan, using a crack detection tool. Because of the complexity of the data analysis phase of the in-line inspection, Enbridge had requested a staged approach to data assessment and reporting. Stage 1 was to be completed within six weeks of the in-line inspection company receiving the raw data. Stage 1 reporting was to include all crack indications greater than or equal to 100 mm in length and 1 mm in depth for the first 15 km downstream of the 10 pumping stations on the pipeline. In mid-December, Enbridge was notified that Stage 1 reporting would be delayed into January 2001. Enbridge was waiting for the Stage 1 report when the failure occurred on 17 January 2001. Following the failure, Enbridge requested and received immediate data analysis for the pipe segment extending 2 km downstream of the Hardisty pump station. The data analysis found indications at the failure location and similar indications in the adjoining section of pipe. The analysis by Canspec found that the indications in the adjoining section of pipe resulted from the corner formed between the exterior flash of the ERW seam and the pipe body.

Stage 1 data analysis was reprioritized using 100 mm in length by 2 mm in depth for the pipe segments downstream of the pump stations. By mid-February 2001, Enbridge had received the Stage 1 report that identified 30 sites as requiring excavation. By mid-March, Enbridge had completed excavation at all 30 sites and had removed its self-imposed pressure reduction. No further evidence of cracking in the toe of the ERW seam similar to that which occurred at Mile Post (MP) 109.42 was found. Stress corrosion cracking (SCC) was identified at six of the sites; the SCC at two of the sites was considered significant according to Canadian Energy Pipeline Association (CEPA) criteria, and was repaired.

The following long seam-related failures have occurred on the 864 mm line during its operating history:

- 1974-1979—5 ruptures between Edmonton and the Strome pump station due to manufacturing defects;
- 01 September 1989—rupture at MP 549.5 due to corrosion fatigue;
- 17 October 1990—leak at MP 722.8 due to sulphide stress cracking;
- 16 June 1995—rupture at MP 518.87 due to narrow, axial, external corrosion (NAEC) under disbonded coating (TSB report No. P95H0023);

- 13 November 1995—rupture at MP 548.86 due to fatigue cracking under disbonded coating (TSB report No. P95H0047);
- 27 February 1996—rupture at MP 506.68 due to NAEC under disbonded coating (TSB report No. P96H0008); and
- 20 May 1999—rupture at MP 444.18 due to corrosion fatigue under disbonded coating (TSB report No. P99H0021).

Since the five failures that occurred in the 1970s occurred in pipe from the same pipe order, Enbridge replaced all that pipe order between 1979 and 1980 with IPSCO Inc. double-submerged arc-welded (DSAW) pipe.

In response to the rupture at MP 549.5 in September 1989, Enbridge committed financial support to the development of an elastic wave tool—an internal inspection device designed to locate and size longitudinal planar defects, such as fatigue cracking, in the longitudinal seam. The first field trial of the elastic wave crack detection tool on the 864 mm line took place in 1993 on 36 km of pipe between Cromer and Gretna, Manitoba. Based on the positive results of this trial, Enbridge conducted additional field trials in 1994 and 1995 on a total of 152 km of pipe between Regina and Cromer and had inspected most of that section by 1996.

Between 1989 and 1990, a high-resolution magnetic flux leakage (MFL) tool was used to internally inspect the 864 mm line for metal loss. Enbridge set the in-line inspection interval for metal loss at four years. MFL technology was again used in 1993-1994 to inspect the line. Following the failure at MP 518.87 in June 1995, the TSB determined that the MFL tools used during the 1989-1990 and 1993-1994 in-line inspections had limitations in sizing long, narrow bands of corrosion in the axial direction (TSB report No. P95H0023). The term coined by Enbridge for this type of corrosion was NAEC, or narrow, axial, external corrosion.

In response to the June 1995 failure, Enbridge developed an action plan, the Susceptibility Investigation Action Plan (SIAP), to reduce the rupture potential associated with NAEC. The SIAP was designed to characterize NAEC using the particular MFL signals generated by the anomaly shapes specific to that type of corrosion. In addition, the in-line inspection company made a commitment to analyze the in-line inspection data on a manual joint-by-joint basis rather than using computers to sort through the data.

In November 1995, a rupture occurred on the 864 mm line downstream of the Langbank pump station near Langbank, Saskatchewan (TSB report No. P95H0047). The pipeline failed as a result of a fatigue crack that had initiated in a zone of shallow external corrosion adjacent to the longitudinal seam. The rupture occurred in a section of line that had been inspected by the elastic wave tool in 1994. However, during that inspection, one of the wheel probes had been firing intermittently, and the defect was rejected during the final stage of data assessment due to a misinterpretation of the data.

Following this occurrence, an action plan was developed to ensure that similar defects had not been overlooked in the original analysis. Enbridge also developed an action plan to address fatigue cracks by conducting a detailed landscape characterization of the known locations of corrosion fatigue, by overlaying those characteristics with pressure cycle profiles, and by prioritizing inspections based on the susceptibility model.

In February 1996, the 864 mm line experienced another rupture, this time at MP 506.68 (TSB report No. P96H0008). The TSB determined that this failure was caused by NAEC and was assisted by low-pH SCC. The TSB also determined that the SIAP had not identified this location as one requiring excavation. Following this failure, Enbridge recognized that there were shortcomings with the SIAP in the identification of NAEC and decided to replace the SIAP with tools using ultrasonic and circumferential MFL (versus traditional longitudinal MFL) technologies to more accurately size NAEC.

In response to a directive issued by the National Energy Board (NEB) to Enbridge in March 1996, Enbridge prepared an operational reliability assessment of the entire 864 mm line between Edmonton and Gretna and implemented an action plan to address the integrity of the line. The action plan included a hydrostatic test of a section of the line, operating pressure reductions, and in-line inspections for NAEC and cracking.

In March 1996, Enbridge indicated to the NEB that it had reduced the operating pressure on the 864 mm line between Odessa, Saskatchewan, and Cromer to 80 per cent specified minimum yield stress (SMYS) and would maintain this pressure reduction until that section of line had been successfully hydrostatically tested.

In September 1996, a 198 km section of Line 3 between Odessa and Cromer was tested for four hours at pressures corresponding to 83 per cent SMYS at the high points and 93 to 94 per cent SMYS elsewhere. Before the hydrostatic test, Enbridge had excavated 73 sites between Regina and Cromer based on the results of an elastic wave in-line inspection and had sleeved 18 of those sites due to crack indications. There were no leaks or ruptures during the hydrostatic test.

In 1996-1997, the entire line from Edmonton to Gretna was inspected with an ultrasonic metal loss tool, and excavations were carried out in 1997-1998. In September 1997, an ultrasonic crack detection tool was run through those sections of the 864 mm line between Cromer and Gretna that had not yet been inspected for cracking. Eighteen excavations were conducted in 1998 based on the analysis of the in-line inspection data.

On 20 May 1999, a rupture occurred at MP 444.18 near Regina (TSB report No. P99H0021). The metallurgical examination indicated that the pipe had failed due to corrosion fatigue. Cracking had initiated in a narrow, shallow corrosion groove that extended along the entire pipe joint adjacent to the longitudinal seam. The TSB determined that, although this section of line had been inspected for cracking with the elastic wave crack detection tool in 1994, the failure site had not been identified as one requiring excavation.

In July 1999, Enbridge inspected the Regina-to-Cromer section of the line with an ultrasonic crack detection tool, a more advanced tool than the elastic wave tool that had been used during the 1994-1996 in-line inspections. Based on this inspection, Enbridge conducted investigative excavations to determine whether defects similar to that which failed in May 1999 could be detected using ultrasonic crack detection technology. Enbridge concluded that such defects (cracking initiating in a narrow, shallow corrosion groove) could be detected using current in-line inspection technology.

Analysis

Since the exterior flash of the ERW seam had not been ground-flush with the pipe, the tape coating tented over the seam providing a narrow channel into which groundwater could seep. The longitudinal seam was located at the three o'clock position where soil stresses are at a maximum. Repeated freeze/thaw cycles, possibly combined with minor pipe settlement, exacerbated the coating disbondment. Although the pipe was cathodically protected, the disbonded tape coating shielded the pipe from the cathodic protection current. Groundwater provided a corrosive environment that contacted the pipe steel and allowed a corrosion cell to be set up.

The corner formed between the exterior flash of the ERW seam and the pipe body provided a stress concentrator. Pitting corrosion that occurred intermittently along this corner increased the stress concentration factor. A corrosive environment would have lowered the threshold stress intensity factor for crack initiation and propagation. The cyclic pressures due to batch operations provided the necessary stress levels for cracking to initiate and propagate.

Through its in-line inspection programs on the 864 mm line, both for metal loss and cracking, Enbridge has made an effort to ensure that injurious defects such as corrosion or cracking are detected, evaluated and repaired. However, the effectiveness of an in-line inspection program depends on tool selection, timeliness, both in running the tool and in data reporting, data analysis, and defect selection. Enbridge has recognized that the same tool will not provide information on both types of defects and has used different technologies in its in-line inspection programs. When a problem has been identified with an inspection program, Enbridge has taken measures to modify that program in an effort to prevent the problem from recurring.

Although the performance of metal loss in-line inspection tools has been proven for over a decade, such is not the case for crack detection in-line inspection tools. The May 1999 failure revealed certain limitations with the elastic wave crack detection tool. The September 1997 and October 2000 in-line inspections during which a more advanced crack detection tool was used suggested that the tool is sensitive in locating indications but that there are difficulties during data analysis in differentiating among those indications.

The staged approach to data analysis and reporting would have helped to target those locations between Edmonton and Regina most susceptible to cracking. However, since the pipeline was not inspected until October 2000, it is not clear whether the fatigue crack at MP 109.42 could have been identified and repaired before failure considering the time required for the first stage of data analysis. The timing of the October 2000 in-line inspection appears to have been based on how best to allocate resources taking into consideration the inspection and repair history of the 864 mm pipeline and Enbridge's commitment to inspect all segments of that line.

It can be difficult for data analysts to distinguish between the corner geometry created by the untrimmed external flash of an ERW seam and certain defects immediately adjacent to that seam. Data analysis is an iterative process combining information from various sources including excavations to better evaluate raw data and to further refine the assessment and selection process. In addition, other sources of information, including as-constructed drawings, operating conditions, and environmental conditions, can be used to target possible problem areas.

Findings as to Causes and Contributing Factors

1. The tape coating tented over the untrimmed weld flash of the electric resistance weld (ERW) longitudinal seam and shielded the pipe from the cathodic protection current, allowing a corrosive environment to contact the pipe metal.

2. The combination of a corrosive environment, the geometry of the ERW longitudinal seam, the corrosion pitting coincident with that seam and the cyclic stresses due to normal pipeline operating pressures allowed cracking to initiate.

3. The cyclic stresses due to normal pipeline operating pressures allowed the fatigue crack to propagate until the pipe wall could no longer support those pressures and the pipe ruptured.

4. Although the subsequent analysis of the October 2000 in-line inspection data identified the failure site as a high-priority location, because of the time required for data analysis and reporting, this information had not been received by Enbridge at the time of the failure.

Findings as to Risk

1. A better understanding is needed of the sensitivities of the crack detection tool in identifying indications and of the difficulties in differentiating among indications during the subsequent data analysis.

Other Findings

1. The timing of the October 2000 in-line inspection was a result of resource allocation based on the inspection and repair history of the 864 mm line.

2. Following each failure on the 864 mm pipeline, Enbridge has modified its in-line inspection programs to rectify problems with the program in place at the time of the failure.

3. Problem areas on a pipeline can be better targeted when information from an in-line inspection program is combined with information from other sources relating to the design, construction and operations of the pipeline system.

Safety Action Taken

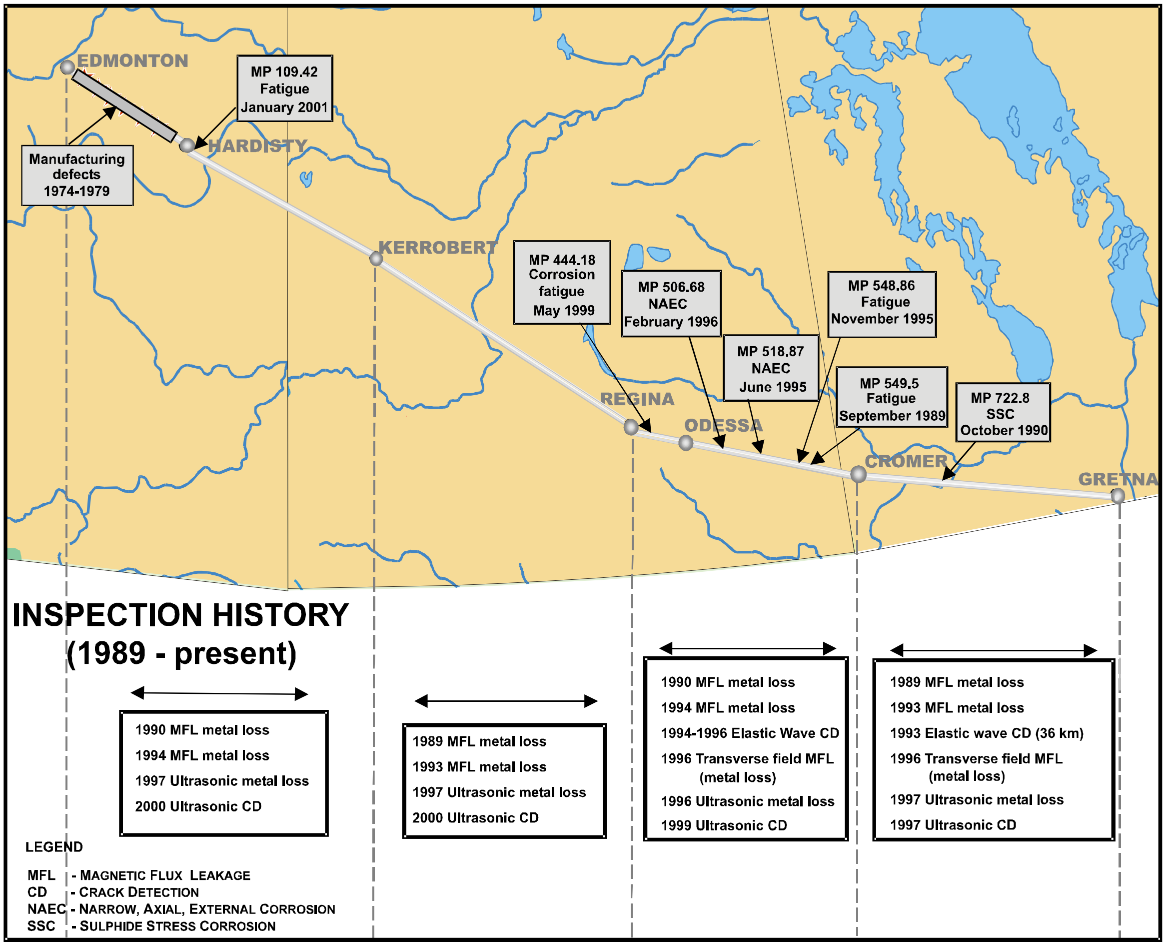
Following this rupture, Enbridge is

- continuing with the staged approach to data analysis of the Edmonton-to-Regina section of the 864 mm pipeline;
- continuing to use information from all excavations on the 864 mm pipeline to better understand the tool tolerance in detecting defects and in differentiating among them;
- conducting laboratory tests to better understand the behaviour and signal characteristics of the crack detection tool;
- conducting crack growth studies to better understand crack growth rates;
- evaluating information from a variety of sources including pressure cycle analysis and fatigue crack growth rates to determine future crack growth in-line inspections;
- collecting coupons during investigative digs to assist in calibrating non-destructive testing techniques and to better understand crack morphology and origin;
- assisting in the development of a program for the qualification of non-destructive testing technicians and ultrasonic testing techniques;
- participating in research projects regarding long seam cracking; and
- scheduling crack detection in-line inspections for 2001-2002 on other pipelines within the Enbridge system using the same tool that was used to inspect the Edmonton-to-Regina section of the 864 mm pipeline.

In addition, Enbridge has established that the frequency of inspections for cracking on the 864 mm pipeline will be 10 years minimum and has indicated that it intends to refine this schedule through some of the work mentioned above.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 19 December 2001.

Appendix A – Long Seam Failures on Line 3/4 (864 mm)



Appendix B – Glossary

Canspec	Canspec Group Inc.
CD	crack detection
CEPA	Canadian Energy Pipeline Association
DSAW	double-submerged arc-welded
Enbridge	Enbridge Pipelines Inc.
ERW	electric resistance weld
km	kilometre
kPa	kilopascal
m	metre
MFL	magnetic flux leakage
mm	millimetre
MOP	maximum operating pressure
MP	Mile Post
MST	mountain standard time
NAEC	narrow, axial, external corrosion
NEB	National Energy Board
SCADA	Supervisory Control and Data Acquisition
SCC	stress corrosion cracking
SIAP	Susceptibility Investigation Action Plan
SMYS	specified minimum yield stress
SSC	sulphide stress corrosion
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time