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COMPARISON OF ESTIMATES FROM A GROWTH MODEL 5 YEARS AFTER THE PREVIOUS INSPECTION

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ABSTRACT

A corrosion growth modelling procedure using repeated in-line inspection data has been employed as part of the maintenance program planning for a pipeline in the Alberta portion of the TransCanada system. The methodology of matching corrosion features between the different in-line inspections, and estimating their severity at a future date, is shown to be an excellent proactive cost saving methodology.

Throughout this paper estimated 80% confidence intervals for tool measurement error, total prediction error and growth methodology error are given. In this abstract the values have been rounded. For maximum penetration, for the features reported on three inspections, the confidence interval for total prediction error varies from ±12% to ±17%, and for the growth methodology from ±8% to ±10% of the wall thickness (for the 1998 and 1999 dig programs respectively). For features reported on two inspections the confidence interval varies from ±19% to ±22% for total prediction error (1998 and 1999 digs respectively), and is about ±17% for the growth methodology (for both dig programs).

The estimated confidence interval for prediction error in failure pressure is about ±560 kPa for the 1998 dig program. For the 1999 dig program a good estimate of the confidence interval for total prediction error could not be obtained. Assuming the failure pressure data obtained from field measurements were perfect, the estimate of the maximum confidence interval was ±850 kPa.

For the laser profile measurement field tool, compared to an ultrasonic pencil probe, the confidence interval for penetration is less than ±2% of the wall thickness.

The true confidence interval values in some cases are expected to be smaller than reported above for several reasons discussed in this paper.

NOMENCLATURE

A *triplet* is a feature reported on three inspections, a *doublet* on two inspections.

A *virtual inspection* is a snap shot of the estimate of severity at some future time after an in-line inspection.

Probability statements for measurement and prediction errors are given as 80% confidence intervals. 80% refers to the probability that four-fifths of the time, the measurement or prediction errors are expected to be within the given range of the confidence interval. The range of the interval can be penetration, such as ±10% of the wall thickness, or failure pressure, such as ±400 kPa.

INTRODUCTION

On a 500 km NPS 20 pipeline in Alberta, in-line inspections (ILI) were conducted in 1986, 1990 and 1994 using a high resolution magnetic flux leakage ILI tool.

It has been shown by Worthingham et al. (1999) that detailed analysis of in-line inspection data can be used to determine penetration rates and growth of corrosion features. Using this information, a pipeline operator can determine a rational and proactive plan to remove those features expected to be severe in the near future, thereby optimizing the timing of the next inspection, and avoiding unnecessary repairs where the corrosion is not active.

As part of the maintenance program and growth model

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validation for this pipeline, two dig programs were planned using the growth model output. The first dig program was conducted in February 1998 and the second was conducted in February 1999. The corrosion on the pipe was compared with the growth model predictions based upon the 1986, 1990 and 1994 inspections. The 1998 field measurements were obtained using an ultrasonic pencil probe, and the 1999 field measurements were obtained using a laser profile measurement device.

Some account has to be taken of the uncertainty in the measurement error of the ILI and field tools, and the error introduced by the prediction methodology. Systematic effects and matching error can also contribute to the total uncertainty. The statistical procedures used in this paper are discussed in Bhatia et al. (1998).

OBJECTIVES

The first objective was to assess the quality of the growth modelling by comparing predicted penetrations and failure pressures to those measured in the field.

The second objective was to test the corrosion sizing accuracy of the laser profile measurement device, since this device was used in the 1999 dig program. The device uses a laser imaging system to measure corrosion penetration on a 1 mm by 1 mm spacing. For details of the tool see Kania and Carroll (1998), and Kania (2000).

THE GROWTH METHODOLOGY

Before this procedure was implemented, it was noticed by engineers and field crews that in some areas they were excavating either on the same joint of pipe as previously, or they were close to a joint that was previously repaired. The operational program was as follows: after an inspection, those features of the greatest severity were removed from the pipeline. A single time averaged corrosion rate was then applied to all features in the pipeline to assess future corrosion severity and set the reinspection frequency. After the next inspection, the severe features at that time were removed. This method is sometimes candidly referred to as "pig and dig." While this procedure can have great utility when the number of features on a pipeline is small, for pipelines with tens of thousands or more features it can become prohibitive because of the number of short excavations.

On the NPS 20 pipeline there were over 150,000 pits reported by the ILI tool in the 1994 inspection. Each feature on the pipeline is analyzed in the growth modelling procedure. Each pit is matched to its position on the other inspection data sets and the future penetration is estimated. Pit interaction is taken into account using rules specified by the pipeline owner. Snap shots of the expected state of the pipeline are prepared for future time intervals (sometimes referred to as "virtual inspections"). The corrosion rates and expected failure dates for each feature, and the probability of failure of each feature as a function of time are determined. The maintenance plans determined using the growth modelling are based, therefore, on the actual site specific pipe deterioration rates, and reflect the expected future integrity state of features adjacent to those identified for repair. The scope of the work performed in one location is then modified to prevent returning to the site at a later time for additional repairs.

The growth methodology is a statistical model. Repeat inspections of exterior and interior corrosion, cracks and dents may be analyzed using the procedure. The methods of matching and growing are proprietary.

MEASUREMENT ERRORS AND ILI TOOL REPORTING PHENOMENON

The total error in the prediction of corrosion penetration and failure pressure depends on many factors, amongst which are:

1. ILI tool reporting of feature sizes and ILI tool measurement errors.
2. Matching of features before growth modelling.
3. The growth modelling itself, the ultimate goal of the project.
4. Measurement error of the field tool, used for comparing ILI reporting, growth modelling results, and the complexity of the corrosion on the pipe.

The 1994 data for this pipeline contained some errors that were subsequently discovered by the pipeline operator and the ILI vendor. In the graphs in this paper these features are identified with a □ symbol.

The availability of three measurements of the penetration by the ILI tool reduces the sensitivity of the prediction to the ILI tool errors.

The predictions for doublets are, however, susceptible, as shown in Figures 2 and 4, where there is a systematic shifting of the □ symbols to overly conservative penetration estimates.

The growth methodology highlighted features that were misreported by the ILI tool, an additional benefit of the whole process.

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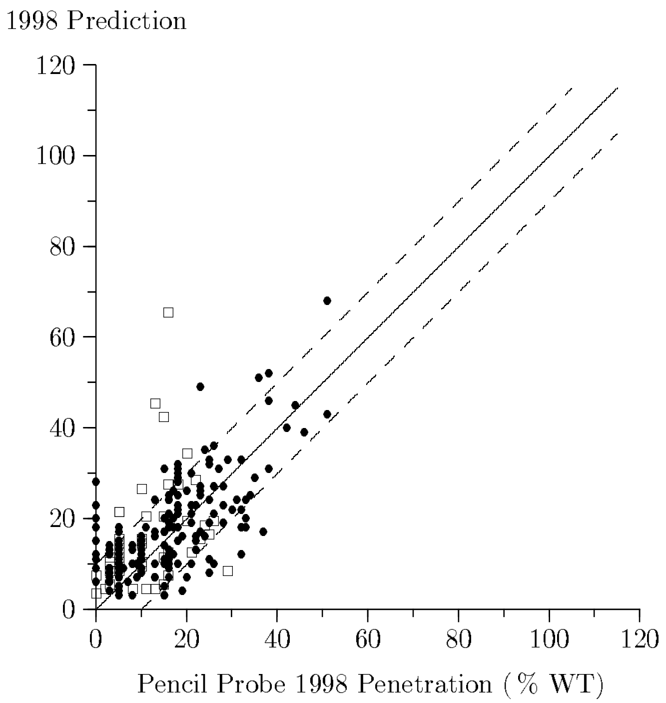

Figure 1. TRIPLET GROWTH ESTIMATES VS. PENCIL PROBE MEASUREMENTS: 1998 DIG PROGRAM

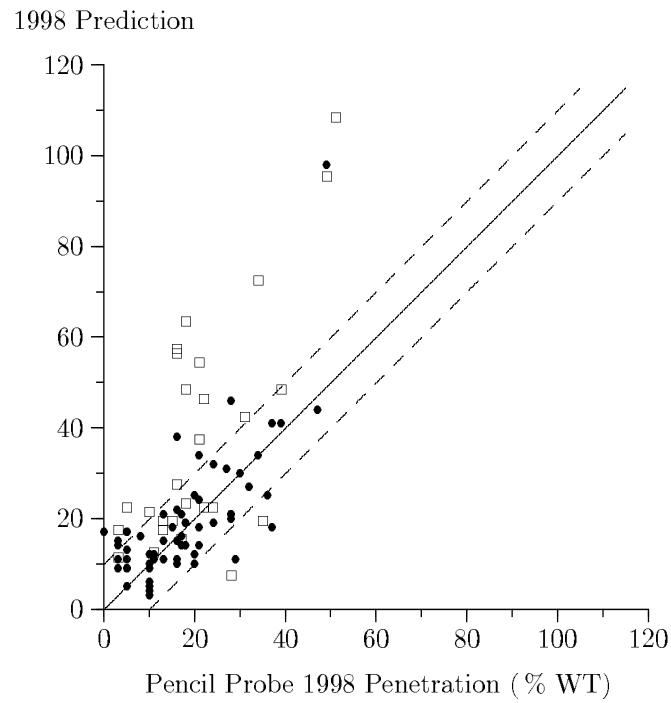

Figure 2. DOUBLET GROWTH ESTIMATES VS. PENCIL PROBE MEASUREMENTS: 1998 DIG PROGRAM

STATISTICAL RESULTS

1998 Dig Program

Comparisons of measured and predicted penetrations are given in Figures 1 and 2 for triplets and doublets respectively. The 1998 field measurements were made using an ultrasonic pencil probe. The data set consisted of every feature on five of the pipe joints removed in 1998.

In general, the more times a feature has been measured by an ILI tool, the better the estimation. The results for features observed three times are better than those for features observed twice, due to reduced scatter. With two inspections, it is possible for an underestimation on the first inspection to be compounded by an overestimation on the second inspection. Note the number of box symbols □ in the 1998 doublet (Figure 2) distribution, partly being responsible for the overestimation of penetration in the predictions.

A summary of penetration confidence intervals for the ILI tool measurement error, total prediction error and methodology error are given in Table 1.

The confidence intervals for the growth methodology errors cannot be directly obtained by subtracting the confidence interval values for the ILI tool from the total prediction confidence interval.

In Table 1, for triplets, the growth methodology error confidence interval is obtained using the following steps (recall that the standard deviation is equal to the square root of the variance, and an 80% confidence interval has a width equal to 1.28 times the standard deviation):

Penetration 80% Confidence Intervals for Error Components			
ILI	Growth Methodology	Total Prediction	No. Features
	Triplet		
± 8.7%	± 7.5%	± 11.5%	208
	Doublet		
± 8.7%	± 16.8%	± 18.9%	95

Table 1. 1998 DIG PROGRAM, ERROR DISTRIBUTION FOR COMBINATION OF ILI AND PREDICTION ERROR

1. The total prediction error is estimated using the variance of the difference between the predictions and field measurements, assuming the field measurements are the true values. The total prediction variance was determined to be 80.7. The confidence interval is

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Penetration 80% Confidence Intervals for Error Components			
ILI	Growth Methodology	Total Prediction	No. Features
	Triplet		
± 13.8%	± 10.3%	± 17.2%	113
	Doublet		
± 13.8%	± 17.6%	± 22.4%	265

Table 2. 1999 DIG PROGRAM, ERROR DISTRIBUTION FOR COMBINATION OF ILI AND PREDICTION ERROR

$1.28\sqrt{80.7} = \pm 11.5\%$.

2. Using different statistical approaches, the pooled variance of penetration measurement error of the ILI tool has been determined to be 46.2. The confidence interval is $1.28\sqrt{46.2} = \pm 8.7\%$.
3. The variance of the growth methodology error is obtained by subtracting the variance of the ILI tool error from the variance of total prediction error, and in this case is equal to 34.5. The confidence interval is $1.28\sqrt{34.5} = 7.5\%$.

For doublets, the total prediction error confidence interval is ±18.9%, and the growth methodology confidence interval is ±16.8%. The high growth methodology errors for doublets are due to the method used to grow them—any misreporting of feature penetrations by the ILI tool are compounded.

The failure pressure data set consisted of 102 features. The failure pressure prediction confidence interval of ±558 kPa was determined using the Case V estimator from Bhatia et al. (1998).

1999 Dig Program

Comparisons of measured and predicted penetrations are given in Figures 3 and 4 for triplets and doublets respectively. The 1999 field measurements were made using the laser profile measurement device. The data set consisted of every feature on five of the pipe joints removed in 1999.

The confidence intervals determined from the 1999 dig project are given in Table 2. For the ILI tool the pooled measurement error confidence interval is ±13.8%, which is wider than what was obtained for the 1998 dig data set. There are two major reasons for this:

1. The corrosion on the 1998 dig program joints was of less severity than that of the 1999 dig program joints. Earlier unpublished studies have shown that the confidence interval for a magnetic flux leakage ILI tool increases with increasing penetration.

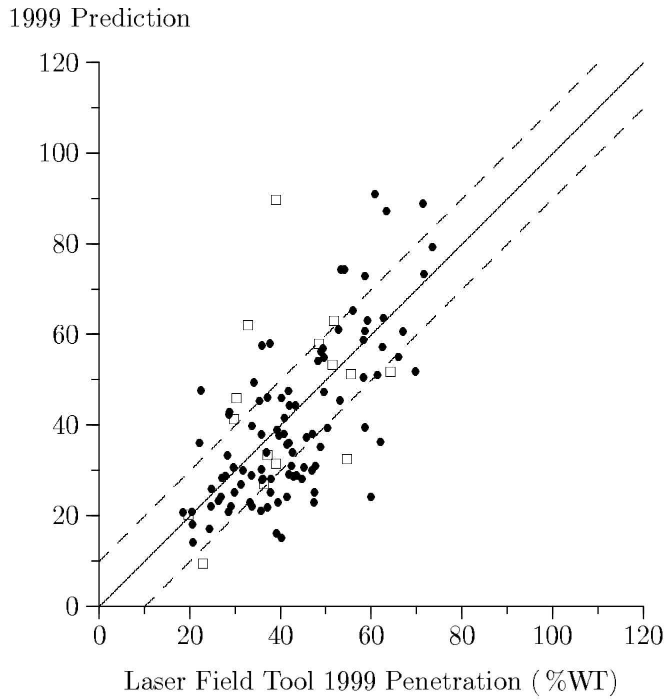

Figure 3. TRIPLET GROWTH ESTIMATES VS. LASER FIELD TOOL MEASUREMENTS: 1999 DIG PROGRAM

2. The time between the inspection and the dig program was a year longer. The longer the time between the last inspection and the dig program, the greater will be the error estimates of the ILI tool, field tool, and the predictions.

As was done for the 1998 dig data set, the growth methodology error for the 1999 dig program was obtained by subtracting the variance of the ILI tool error from the variance of the total prediction error.

The pattern of the confidence intervals for prediction and growth methodology error is similar to that of the previous dig program. For triplets the confidence interval for total prediction error is ±17.2% and for the growth methodology it is ±10.3%. For doublets the confidence interval is ±22.4% for the total prediction error and is ±17.6% for the growth methodology error.

The failure pressure data set consisted of 65 features. The predictions are plotted against those reported by the laser tool values in Figure 5. A good estimate of the confidence interval for the failure pressure prediction error could not be obtained. An estimate of the maximum confidence interval was determined assuming the field measurements

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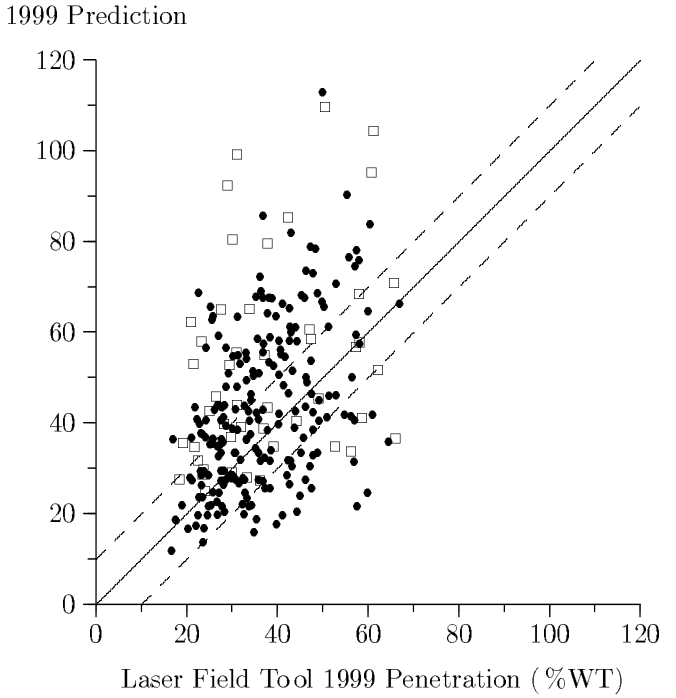

Figure 4. DOUBLET GROWTH ESTIMATES VS. LASER FIELD TOOL MEASUREMENTS: 1999 DIG PROGRAM

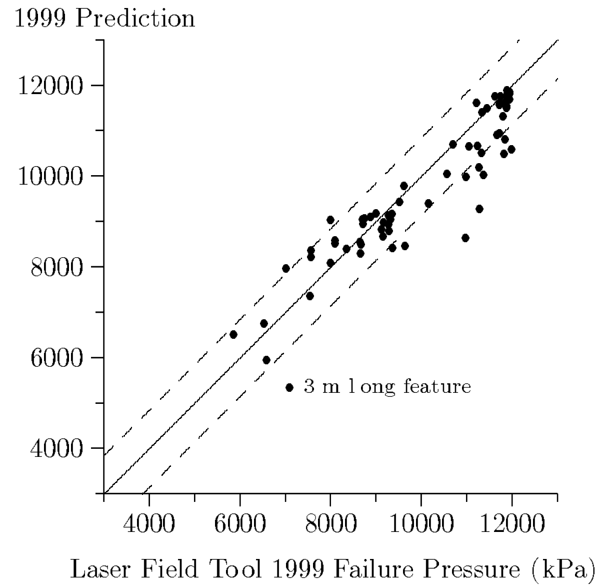

Figure 5. 1999 PREDICTED VS LASER FIELD TOOL 1999 FAILURE PRESSURES

were perfect. Thus, with all the error assigned to the prediction methodology, the confidence interval was ±850 kPa. This value would be smaller by accounting for error in the field instruments. The confidence interval is shown on the figure as the dashed lines.

THE ESTIMATION OF PENETRATION MEASUREMENT ERROR FOR THE LASER FIELD TOOL

In 1997, measurements of natural and artificial corrosion on NPS 36 pipe were undertaken as part of a study to determine measurement errors in a variety of instruments, including an ILI tool. The 1997 data included pencil probe (6 penetration measurements per feature), and an earlier version of the laser field tool (4 penetration and failure pressure measurements per feature). The new laser field tool was used to make 4 penetration and failure pressure measurements per feature in early 2000.

The maximum penetrations reported by an earlier version of the laser field tool, the new laser field tool and the ultrasonic pencil probe were all very close.

Note that some researchers quote repeatability as an estimate of measurement error, determined by the closeness of each penetration or failure pressure estimate reported by a single device. The reader should be aware that repeatability is only one component of the measurement error. The measurement error has to be determined by comparing two or more devices to account for both scatter and systematic error.

The confidence interval for measurement error of penetration by the laser field tool, compared to the pencil probe, has been determined to be ±1.7% of the wall thickness. One may get a larger confidence interval if the same laser tool is compared with a tool of less accuracy.

SUMMARY AND CONTINUING WORK

Work is proceeding on using the growth rates obtained for this pipeline to estimate potential severities of corrosion features on other pipelines that have only been inspected once using a high resolution ILI tool. These studies will be reviewed in a future paper.

The growth modelling methodology has been tested twice during the 1998 and 1999 dig programs for the NPS 20 pipeline, and the same methodology has been used on an NPS 36 pipeline.

After the 1986 inspection 7 locations were identified for pipe removal. The number of repairs grew to 25 after the 1990 inspection, and to 54 after the 1994 inspection. The 1998 dig program consisted of 4 digs, and the 1999 dig program consisted of 8 digs. Using the value added information given by the growth modelling, the number of digs as a func-

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tion of time is far lower than using the previous procedure. Twelve well planned digs in 1998 and 1999, validating the growth modelling, have been responsible for deferring the next in-line inspection of the NPS 20 pipeline for 6 years compared to the 4 year intervals used before as determined using a *single* time averaged corrosion rate.

The results presented in this paper, coupled with past work, have produced an estimated future cost savings of $10 million for the NPS 20 pipeline over the next 30 years. The planned lifetime of this pipeline has also been markedly increased compared to estimates made before the growth modelling was implemented.

Applying this approach to an NPS 36 pipeline in Northern Alberta, 2 repairs resulted in deferring the next inspection for 10 years as compared to the 5 year interval previously used by applying the single time averaged corrosion rate. Pipeline availability is increased due to a reduced level of maintenance activities to achieve the same level of reliability.

A detailed understanding of the reporting of the ILI tool, and the growth modelling, have enabled the pipeline operator to fully understand the risk of these pipelines to future corrosion induced incidents.

Summary of the Growth Modelling With Respect to ILI Tool Phenomenon.

The 1998 and 1999 dig programs, based on the growth modelling, have both been successful. The features removed were justifiably identified. The maximum penetration of one feature was 73% of the wall thickness. The growth modelling depends on the ILI tool reporting and measurement accuracy thereof. The corrosion matching and reporting process identified a number of suspect locations.

ACKNOWLEDGMENTS

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