Reliability Assessment of Corroded Pipelines using Bayesian Updating Technique

by

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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WAN MUHAMMAD ISKANDAR SHARIFFADIN BIN WAN SU

ABSTRACT

In the oil and gas industry, metallic pipelines are widely used as the most efficient and safest way of hydrocarbon transportation. Pipelines are subjected to deterioration over time due to corrosion. Either internal or external corrosions, both can contribute to failure if left unmitigated. In-line Inspection (ILI) tools are used to inspect pipelines and are usually associated with a double-sided accuracy. The data from intelligent pigging however, does not give a 100% accurate result. Therefore, overestimation will lead to more frequent repairs and unnecessary inspection, which will be very costly. On the other hand, underestimation will cause critical damage which if left unmitigated can cause failure in the pipeline. Therefore, improvement of existing reliability functions based on Limit State Function (LSF) Design is needed to produce a reliable probabilistic model. A study of Bayesian updating theory incorporating both probability of failure and probability of survival is presented in this research in order to revise a calculated probability using additional data and prevent overestimation or underestimation of Maximum Allowable Operating Pressure (MAOP) in offshore pipelines. The case study involves a retired section of an offshore pipeline in Peninsular Malaysia. The updated probability of failure according to the different codes shows that the ASME B31G code predicted well with the burst test result, followed by the SHELL 92 code, and lastly the DNV RP-F101 code. The future prediction of the corrosion rate for the pipeline based on its historical corrosion data and also its respective updated probability of failure has also been projected and it is found out that the pipeline will run fine up until 2018.

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CHAPTER 1 INTRODUCTION

1.1 Background

In the oil and gas industry, pipelines are used to transport large quantities of hydrocarbons (e.g. crude oil and natural gas) from the production sites to the end users. Compared with other means of transporting hydrocarbons such as rail cars and tanker trucks, pipelines are safer, more efficient and cost-effective.

Metallic pipelines are widely used as the most efficient and safest way of oil and gas transportation. In offshore operation, these pipelines are exposed to hazards such as corrosion (internal and external), extreme weather conditions, trawl impact, free span, and collision with vessels, as shown in Fig. 1:

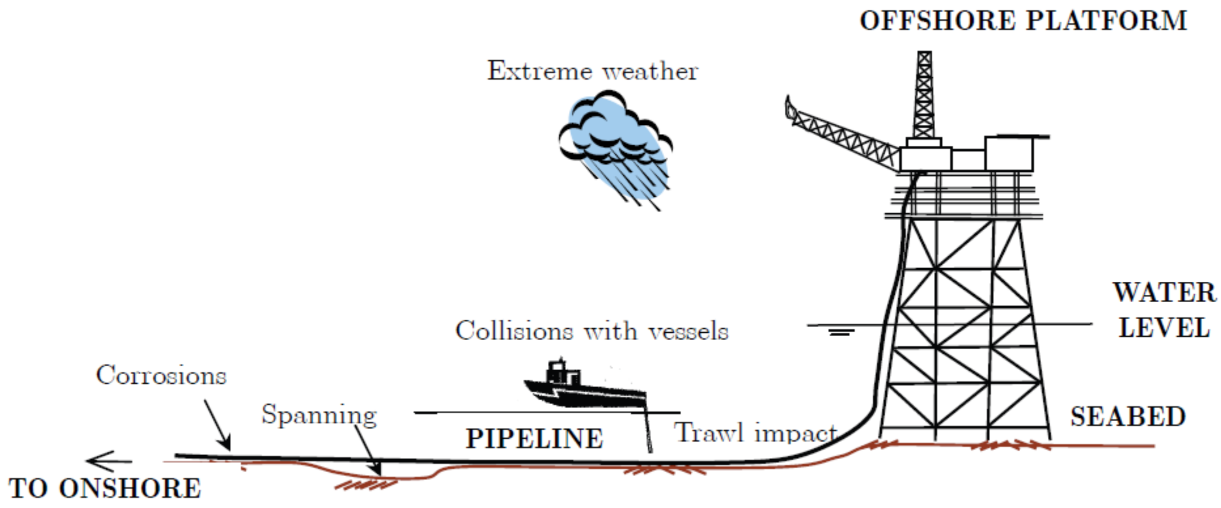


Figure 1: Different type of pipeline hazards (Mustaffa, 2011)

Nowadays, failure due to corrosion has been one of the greatest concerns in maintaining the pipelines integrity. Therefore, pipeline operators need an accurate defect assessment methodology to assure safe operation. There are several codes and methodologies available for pipeline defect assessment, and they are known to be conservative.

In-line inspection (ILI) tools, also known as “smart pigs”, are widely used to detect, locate and size corrosion anomalies in pipelines. There are mainly two types of ILI tools, namely the magnetic flux leakage (MFL) and ultrasonic (UT) tools (Al-Amin, 2012). The MFL tools are commonly used to inspect gas pipelines, whereas UT tools are used in liquid pipelines. A typical high resolution MFL tool is shown in Fig. 2:

Figure 2: A typical MFL tool

A research program has been underway for some years in UTP with the focus of corrosion mechanisms. Although early works focused on the study of corrosion rate calculation; recently the focus area is widened towards improving of corrosion assessment methods. Significant savings are possible by optimizing the inspection and corrosion prevention strategies. In order to achieve such optimization, a reliable corrosion rate model is paramount to determine a re-inspection time interval for pipelines.

Pipeline X (PL X) is a 10” diameter pipeline with 6.9 km length carrying wet and semi processed crude oil. It was constructed in 1982 and had a design life of 20 years. The original design life expired in 2002 and by that time it has been in operation for 25 years. The reported Maximum Allowable Operating Pressure (MAOP) was 40 bars and the de-rated pressure was 93 bars based on the Fitness for Service (FFS) assessment conducted by a pigging operator in 2005. The pipeline was set to operate at an average Operating Pressure (OP) of 28 bars (Shafiq et al., 2010).

An in-line inspection using Magnetic Flux Leakage (MFL) tool was conducted in November 2006. The ILI tool result reported 10,804 metal loss defects with 10,803 internal defects concentrated at 700 m from the platform. There was only 1 external defect reported at the riser.

This pipeline was later classified as not fit to continue its operation and a portion of the pipeline was cut and replaced. However, when the retired portion was further inspected onshore, it has been found that the corrosion was not as severe as reported by the ILI tool. For projected integrity, this pipeline had already exceeded the corroded pipeline pressure against MAOP at the year of inspection, 2006. Universiti Teknologi PETRONAS (UTP) was engaged in failure analysis of this retired section of the pipeline. About 100 meter of the retired pipe section was delivered to UTP.

1.2 Problem Statement

In assessing the anomalies in pipelines, the data from ILI tool does not give a 100% accurate result. The accuracy of an ILI tool is commonly specified as a two-sided confidence interval, e.g. the measured defect depth is accurate within ±10% wall thickness (*w.t.*) with a confidence level of 80%. Since reliability assessment rely on the data from ILI tool, on one hand, overly conservative estimates of the corrosion growth rates lead to too frequent inspections and unnecessary excavations and repairs, making integrity management program costly. On the other hand, under-estimation of the corrosion growth may leave critical defects unmitigated and result in failure of the pipeline. In worst case scenario, a failed pipeline needs to be replaced, but question about how accurate the reliability of the present assessment is raised when the pipeline seems to be fine after the retired section is inspected.

As discussed, for the case study of this project, PL X had already exceeded the design life and operated under integrity status. From the latest inspection by pigging operator in

2006, the inspection reported 10,896 defects with 10,804 defects due to metal loss. Out of this number, 10,803 defects are internal defects which concentrated at 700 m from the platform and only 1 external defect reported.

Because it was already operating under pressure, it is important for us to know not only the probability of time to failure, but we also need to know the probability of survival so that the information can assist engineers in deciding whether the pipeline is still safe for operation. Therefore, study of Bayesian updating theory incorporating both probability of failure and probability of survival is needed to produce a reliable probabilistic model.

1.2.1 Significance of Project

Since it is almost impossible to prevent corrosion, it is becoming more apparent that controlling the corrosion rate may be the most economical solution. Engineers are therefore increasingly involved in estimating the cost of their solutions to estimating the survival probabilistic of pipeline.

1.3 Objective & Scope of Study

The objectives of this project:

- To develop the reliability functions based on Limit State Function (LSF) Design and Bayesian Updating technique.
- To compare the updated probability of failure according to DNV RP-F101 with other design codes (ASME B31G, SHELL 92).
- To predict reliability of the pipeline based on its historical corrosion data.

Scope of study:

- Corrosion
- Offshore pipelines
- Bayesian updating

1.4 Relevancy of the Project

This project is relevant to the case study as statistics have shown that most of the age of the pipelines has already exceeded the design life. Many more in other operations are operating under integrity status as well; therefore an improved probabilistic model can incorporate the probability of survival and help make better decisions.

1.5 Feasibility of the Project

The project is believed to be feasible given that the theory on Probability of Survival can be derived and integrated into the calculation of Probability of Failure.

CHAPTER 2 LITERATURE REVIEW

2.1 Corrosion

Corrosion is defined as the deterioration of a metal or its properties, attacking every component at every stage in the life of every oil and gas field. From casing strings to production platforms, from drilling through to abandonment, corrosion is an adversary worthy of all the high technology and research we can afford.

Corrosion encountered in petroleum production operations involves several mechanisms. The common types of corrosion can be summarized into Fig. 3.

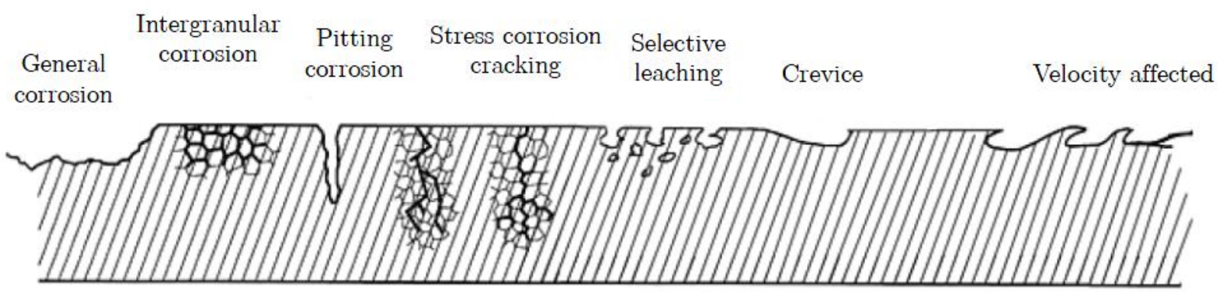


Figure 3: Corrosion types (Freeman, 2002)

Ageing underground oil and gas pipelines can suffer from several localized forms of corrosion, primarily pitting. Often termed "under deposit corrosion", pitting is a form of extremely localized corrosion that leads to the creation of small holes in the metal. The driving power for pitting corrosion is the lack of oxygen around a small area. This area becomes anodic while the area with excess of oxygen becomes cathodic, leading to a much localized galvanic corrosion (Yap, 2010). The corrosion penetrates the mass of metal, with limited diffusion of ions further pronouncing the localized lack of oxygen. The mechanism of pitting corrosion is probably the same as crevice corrosion.

2.2 Flaws in pipeline

Conventional reliability method is known for not being efficient because of the following reasons:

- Not all flaws actually present contribute to probability of failure.
- In-tube inspection result does not yield true number of actual flaws.
- Issue with the accuracy of intelligent pig for the inspection of corrosions in pipeline.

There are four types of anomalies that can be detected using in-tube inspection. These anomalies can be categorized as below:

- True (correctly detected)
- Falsely detected (phantom)
- Falsely undetected (missed)
- Correctly undetected (regions without flaws)

2.2.1 Granular nature of probability

It is known that when evaluating the reliability of an operated pipeline with flaws as a system of elements connected in series, a classical approach that is taken from the structural reliability theory leads to unrealistically low reliability of a pipeline segment or a pipeline as a whole (Kuznetsov et al., 2012). When considering flaws as a complete group of events, one can conclude that the probability has a granular nature because it can change only by values of indivisible probabilistic masses (granules), each of which has a mass of 1/N. Here, N is the total number of flaws that are present in the pipeline that can really contribute to the Probability of Failure of the pipeline; therefore, consideration of falsely detected (phantom) flaws causes errors in evaluating the Probability of Failure, because these reduce the probabilistic mass of each real probabilistic granule. The omission of some true flaws in the probabilistic consideration may introduce a large error in the estimate of the Probability of Failure for a pipeline as a system.

2.3 Burst test

Burst test is generally conducted to obtain the burst pressure. The burst test method involves the filling of a container with liquid and pressurizing it until it bursts, thus establishing its tolerances. This is usually a destructive test. A full-scale pipe burst test is considered as the most appropriate and commonly used experimental procedure type in determining the strengthening technique and the estimation of the percentage capacity lost (Shafiq et al., 2010).

This project utilizes the highest burst pressure value of 326.5 bar obtained during the burst test conducted on 5 samples of pipeline (PL X) mentioned in the problem statement. The table showing the burst test results is given below.

Table 1: Burst test samples

Test No	**Average wall thickness (mm)**	**Defect Dimensions (mm)**			**Burst Pressure (bar)**		
		Depth, d	**Length, L**	**Width, w**	**Burst Test**	**FE Simulation**	**Error (%)**
T001	10.87	4	200	100	326.5	316.8	3.0
T002	10.58	N.A.	N.A.	N.A.	385	368	4.4
T003	12.11	6	200	100	294.9	285.6	3.2
T004	11.94	9	200	100	Leak at 158.2	196.6	N.A.
T005	11.79	10	200	100	N.A.*	143.9	N.A.

The burst tests were successfully conducted for test sample T001 to T004, but test sample T005 failed during machining of simulated defect due to imbedded pinhole defect on the corroded pipeline internal wall. The corresponding numerical simulation results were also calculated. Finite Element (FE) simulations were used for simulated defects and analytical calculation was made for test sample T002. This test sample (T002) was with general corrosion defect evenly distributed over the internal surface of the pipeline (Shafiq et al., 2010). We may use the maximum hoop stress theory to predict the burst pressure of this pipeline section. However, it is not within the scope of this project. The basic hoop stress theory will be elaborated further in Chapter 4.

2.4 Bayesian Methodology

2.4.1 Introduction

The two broad types of uncertainties are the aleatory uncertainty that is associated with the inherent variability of information, and the epistemic uncertainty that is associated with the imperfections in our knowledge or ability to make predictions (Alfredo and Wilson, 2007). The aleatory uncertainty gives rise to a calculated probability, whereas the epistemic uncertainty leads to a lack of confidence in the calculated probability. In this regard, the Bayesian approach can be relevant in two ways:

- To systematically update the existing aleatory and epistemic uncertainties as additional information or data for each type of uncertainty becomes available.
- To provide an alternative basis for combining the two types of uncertainties for the purpose of decision making or formulating bases for design.

2.4.2 Formulation

The Bayesian approach is an advanced tool to fit a probability model to a set of observations by evaluating the unknown parameters of the model in a probabilistic way. The Bayesian method treats the unknown parameters of a physical process as random variables rather than as deterministic values (Al-Amin, 2012). It incorporates the prior knowledge about the parameters, which may arise from the results of previous studies or experience. The prior knowledge is then updated based on the observed data to obtain the revised opinion about the parameters. The updated belief can be further considered as the prior distribution for future updating when new data are available. Therefore through this iterative process the uncertainty in the parameters is minimized.

Accurate estimates of the parameters require large amounts of data. When the observed data are limited, as is often the case in engineering, the statistical estimates have to be supplemented (or may even be superseded) by judgmental information. With the classical statistical approach there is no provision for combining judgmental information with observational data in the estimation of the parameters.

The Bayesian method approaches an estimation problem from another point of view. In this case, the unknown parameters of a distribution are assumed (or modeled) also as random variables. In this way, all sources of uncertainty associated with the estimation of the parameters can be combined formally (through the total probability theorem). With this approach, subjective judgments based on intuition, experience, or indirect information are incorporated systematically with observed data (through the Bayes Theorem) to obtain a balanced estimation. The Bayesian method is particularly helpful in cases where there is a strong basis for such judgments (Alfredo and Wilson, 2007).

P(E1|E2) is read as the probability of E1 assuming the occurrence of E2, or simply the probability of E1 given E2. It can be read as below:

$$P(E_1|E_2) = P(E_1 E_2) / P(E_2) \quad (1)$$

In the Venn diagram of Fig. 4, it can be observed that the conditional probability P(E1|E2) may be interpreted as the likelihood of realizing a sample point E1 that is in E2. In other words, the interest is focused in the event E1 within the “reconstituted sample space” E2. Therefore, the conditional probability pertains to the sample points of E1 relative to those of E2 and thus must be normalized with respect to E2; hence, with the appropriate normalization, the conditional probability is obtained as in Eq. (1).

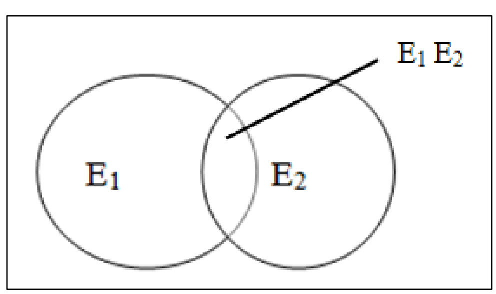


Figure 4: Venn diagram for E_1 given E_2

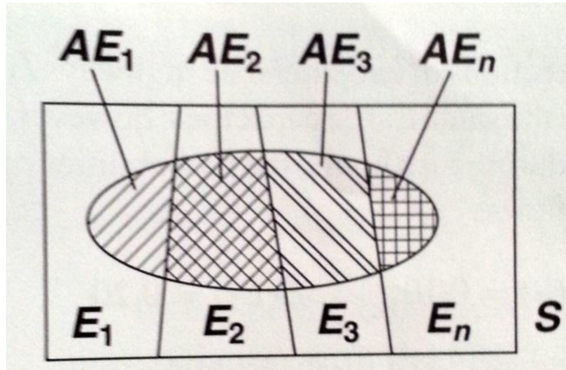


Figure 5: Intersection of A and E_1, E_2,…, E_n in sample space S

Theorem of total probability:

$$P(A) = P(A|E_1)P(E_1) + P(A|E_2)P(E_2) + \dots + P(A|E_n)P(E_n) \quad (2)$$

2.4.3 The Bayes' Theorem

In deriving the theorem of total probability, Eq. (2), the total probability of event A depends on which of the conditioning events Ei, i = 1, 2, …, n, has occurred. On the other hand, one could be interested in the probability of a particular Ei given the occurrence of A. In a sense, this is the "inverse" probability, which is given by the Bayes' theorem, which may be derived as follows:

$$P(A|E_i)P(E_i) = P(E_i|A)P(A) \quad (3)$$

From which the "inverse" probability is obtained:

$$P(E_i|A) = P(A|E_i)P(E_i) / P(A) \quad (4)$$

This is known as the Bayes' Theorem. In Eq. (4), if P(A) is expanded using the total probability theorem, Eq. (4) becomes:

$$P(E_i|A) = \frac{P(A|Ei)P(Ei)}{\sum_{j=1}^{n} P(A|Ej)P(Ej)} \quad (5)$$

The Bayes' Theorem provides a valuable and useful tool for revising or updating a calculated probability as additional data or information becomes available. Prior information (which may be based on subjective judgments) can be combined with test results to update a calculated probability.

2.4.4 Limit State Function Models

Probabilistic techniques have been integrated into design codes and standards by several attempts made by past literatures. A general limit state function, Z model can be formulated as,

$$Z = R - S \qquad (6)$$

where R is the strength or more generally the resistance to failure and S is the load conducive to failure. Z=0 is known as the limit state. Z>0 is known as survival region while failure occurs when the failure surface falls in the region of Z<0. The probability of failure, PF can be written as,

$$PF = P_r\ (Z \leq 0) = P_r\ (S \geq R) \qquad (7)$$

The reliability is the probability Pr (Z≥0), and hence, when described in terms of probability of failure it becomes,

$$P_r\ (Z > 0) = 1 - PF \qquad (8)$$

CHAPTER 3 METHODOLOGY

3.1 Introduction

An experimental study was made for a sample taken from 6.9 km pipeline carrying wet and semi processed crude oil between two jacket platforms in offshore Malaysia. The sample was taken at the recommendation of evaluator since the strength of the pipeline has deteriorated due to corrosion and should be replaced. About 750 m of the pipeline was replaced in 2008. The pipeline nominal diameter was 274 mm and nominal wall thickness was 14 mm. The material was carbon steel and the grade was API 5L-X52. Design code used for pipeline was ASME B31G. According to this code metal loss of 80% of characteristic wall thickness shall not be considered and metal loss of maximum of 10% of characteristic wall thickness is not limited to allowable length. The operating temperature at inlet was 55 ºC and at outlet was 30 ºC. The minimum water depth was in range of 65 to 67 m. Pipeline was fabricated and installed in 1982 for a design life of 20 years which expired in 2002. The original maximum allowable operating pressure was 93 bars, which has been de-rated two times i.e. 40 and 28 bars. Two types of results based on experimental study were available i.e. Magnetic Flux Leakage (MFL) and Ultra Sonic test (UT).

Once this corroded pipe was removed, 2 m sections of the pipe were selected for burst testing. Burst test was carried out for longitudinally real and artificial corrosion defects in pipe subjected to internal pressure. The artificial defects were made by using machine pits and flat bottom defects. The real corrosion always has defects with irregular profile. Corrosion in pipeline is difficult to characterize as it will have irregular depth profile and it extends in irregular profile in longitudinal and circumferential directions. These defects may be single or group of contiguous defects separated by non-corroded material. In this research three codes will be used for evaluating the remaining strength of pipeline and to compare the probability of failure.

In probability of failure, two types of equations are important i.e. the actual capacity and Maximum Allowable Operating Pressure (MAOP) equation. Capacity equation is used to predict the capacity of corroded pipeline for given area, material properties, defect shape and size. This equation will give us the actual resistance of pipe. The other is called acceptance equation which gives safe allowable operational pressure. This will provide the pipeline the maximum allowable operating pressure with corrosion defects.

3.2 Research Methodology

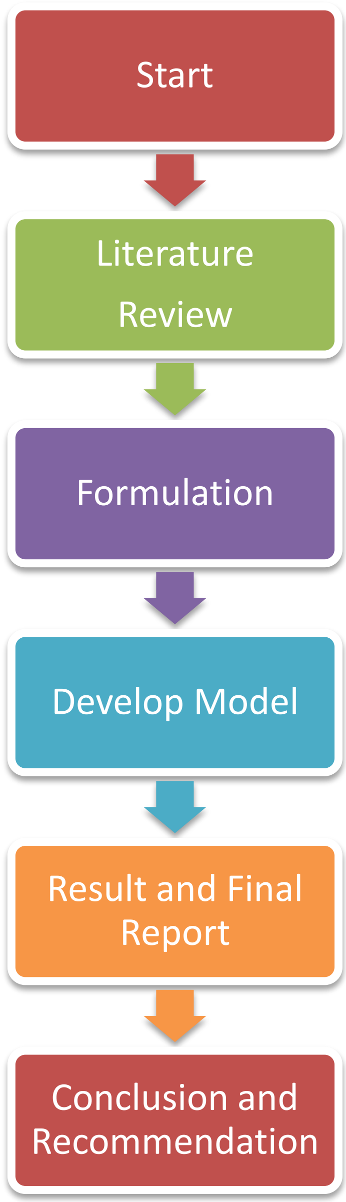
The research can be divided into two parts. First is using the Bayesian Updating Theory to develop the reliability functions based on Limit State Function. The aim is to obtain Probability of Survival from the Probability of Failure calculation. The second part involves the burst test information to update the probability of failure calculation according to ASME B31G code and compare it with other famous codes such as DNV-RP-F101 and SHELL 92. The next step is to simulate the random values by using MATLAB software to obtain the probability of failure from the capacity equation and Maximum Allowable Operating Pressure ratio until it reaches the maximum value obtained during the Burst Test. During the first semester, the research aims to find out how to incorporate the Survival Probability into the calculation based on the Limit State Function (LSF) Design and Bayesian Updating technique. In the second semester, the progress involved simulation of MATLAB for the stated codes to find the updated probability of failure and prediction of the reliability of the pipeline based on its historical corrosion data.

3.3 Tools

Tools needed for this project:

- MATLAB software
- Microsoft Excel spreadsheet

3.4 Project Activities/Key milestone/Gantt Chart



- Topic Selection.
- Review past thesis and references.
  Choose and finalize relevant information.
- Collect/Arrange data
  Analyze/Interpret data
  Formulate survival probability and LSF design calculation
- Develop updated probability of failure
  Project the reliability of the pipeline based on its historical corrosion data
- Report findings
  Compare effectiveness of the existing probabilistic model with the updated one.

Figure 6: Project Activities for FYP1 & FYP2

DETAIL / WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection Of Project Topic														
Preliminary Research Work					●									
Submission Of Extended Proposal						●								
Proposal defense														
Project Work Continues														
Completion Of Interim Report													●	
Submission of Iinterim Report														●

Figure 7: Gantt chart showing research activities for FYP1

DETAIL / WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Work Continues														
Submission of Progress Report										●				
Project Work Continues														
Pre-SEDEX											●			
Submission of Draft Report												●		
Submission of Dissertation (Soft Bound)													●	
Submission of Technical Paper													●	
Oral Presentation														●
Submission of Project Dissertation (Hard Bound)														●

Figure 8: Gantt chart showing research activities for FYP2

CHAPTER 4 CRITICAL COMPONENTS

For assessment of pipelines subjected to failure caused by corrosion attack, there are numbers of assessment code available to be used by the operators. In this section, three different codes of assessment will be discussed from the view of deterministic implementation, which are fully based on equation with safety factor inclusion in the code. All these assessment codes, which are the ASME B31G criterion, SHELL 92 and DNV RP-F101, can be used to evaluate the pipeline condition by calculating the remaining allowable operating pressure that can be carried out safely by the corroded pipeline. The ASME B31G Criterion, the most established from the other codes was a method developed more than 30 years ago in order to determine the serviceability of pipelines impaired by corrosion. The SHELL Company developed SHELL 92 in 1992 for the same purposes. In 1999, Det Norske Veritas (DNV) in co-operation with BG Technology produced Recommended Practice (RP) series for corroded pipelines assessment called the RP-F101, tailored with the semi probabilistic approach within the assessment equation.

4.1 Comparison of Codes

4.1.1 ASME B31G

In the late 1960s and early 1970s, the original criterion was developed through research sponsored by Texas Eastern Transmission Corporation and the Pipeline Research Committee of the American Gas Association (A.G.A) to evaluate the integrity and safety for determining the remaining strength of corroded pipelines (Kiefner and Vieth, 1989). The development work forms the basis of ANSI/ASME B31G-1984 Manual. This criterion usually referred as the B31G Criterion has been reissued as the ASME B31G 1991 Criterion (ASME, 1991) in order to suit the most recent findings and up-to-date technology, and to deal with sources of conservatism embodied in the original criterion. The excessive conservatism inherent in this criterion is well acknowledged by researchers as well as industry practitioners. The corrosion defect assessment procedure using the B31G criterion was based on a semi-empirical fracture mechanism calibrated by extensive testing of pipe vessels with narrow machined slots and a series of corroded pipe burst tests. The semi-empirical fracture mechanics relationship referred as the "NG-18 surface-flaw equation", named after the NG-18 Line Pipe Committee of the American Gas Association who sponsored the original work.

Original ASME B31G

The original B31G Criterion is based upon hoop stress level shown in Eq. (9) as follows:

$$S_p = S_f \left[\frac{1 - \frac{A}{A_0}}{1 - \frac{A}{A_0 M}} \right] = \left[\frac{1 - \frac{\frac{2}{3} Ld}{Lt}}{1 - \frac{\frac{2}{3} Ld}{Lt \times M}} \right] \tag{9}$$

Where;

S_p = hoop stress level at failure (MPa)

S_f = flow stress of the material (MPa)

A_0 = original cross-sectional area of the pipe at the defect (mm^2)

A = projected area of the defect in the longitudinal plane through the wall thickness represented by a parabola, 2/3 Ld (mm^2)

M = Folias or bulging factor, accounting for effect of stress concentration at notch

L = defect length of metal defect along the axis of the pipe

t = nominal pipeline thickness

d = depth of corrosion defects

The above equation is used to calculate the failure stress level of a pressurized pipe containing a longitudinally oriented crack or defect. It is also used to predict the residual strength of corroded pipelines. Two assumptions have been made, the Folias Factor, M and flow stress, S_f, is a result of built-in conservatism. Folias factor or bulging factor is a function of the defect length and the diameter and thickness of the pipe.

Initially, the original Folias factor was represented by Battelle (Bjornoy, 2001) as:

$$M = \sqrt{1 + \frac{2.51\left(\frac{L}{2}\right)^2}{Dt} - \frac{0.54\left(\frac{L}{2}\right)^4}{(Dt)^2}} \tag{10}$$

Folias factor adopted in the original B31G criterion is complex and was intended for short defect length (Kiefner and Vieth, 1993). The principle of Folias factor is when the defect length becomes longer; the Folias factor should be increased. However, the original Folias factor shows the opposite result. Therefore, Kiefner has proposed a simplified Folias factor.

$$M = \left[1 + \frac{0.8L^2}{Dt}\right]^{\frac{1}{2}} \tag{11}$$

Flow stress of the material was defined as:

$$S_f = 1.1 \, x \, SMYS \tag{12}$$

Where;

L = defect length of metal defect along the axis of the pipe

t = nominal pipeline thickness

D = outer diameter

$SMYS$ = Specified Minimum Yield Strength

The B31G criterion also permits a corroded region to be evaluated on the basis of its maximum length, L and maximum depth, d. The corroded area is supposed to be acceptable if:

$$L_{max} = 1.12B(Dt)^{\frac{1}{2}} \tag{13}$$

Where;

$$B = \left\{ \left[\frac{\left(\frac{d}{t}\right)}{1.1\left(\frac{d}{t}\right) - 0.15} \right]^2 - 1 \right\}^{\frac{1}{2}} \tag{14}$$

The remaining pressure-carrying capacity or safe maximum pressure capacity of corroded pipelines using the B31G method are determined based on metal loss area and strength yield of the material. If the calculated safe maximum pressure capacity exceeds the maximum allowable operating pressure (MAOP) of the pipeline by a sufficient margin of safety, the corroded segment is still applicable. Otherwise, it must be repaired or replaced. To put in simple terms, the maximum allowable design pressure is defined as follows:

$$P_p = \frac{2 \times S_f \times t \times F}{D} \left[\frac{1 - \frac{A}{A_0}}{1 - \frac{A}{A_0 M}} \right] \tag{15}$$

Where;

P_p = Design Pressure

F = Factor of safety

The original formulations of the B31G Criterion are found to be over-conservative. Sources of excess conservatism include assumption of Folias factor, expression of flow stress and parabolic representation of the metal loss area (Kiefner and Vieth, 1989). Several modifications to the original B31G Criterion was proposed by Kiefner which covers:

i. expression for flow stress
ii. approximation used for the Folias factor
iii. parabolic approximation for metal loss used in the B31G document

This new approach was called as RSTRENG, an extension of Original B31G. In the RSTRENG approach, there are two types of definition for Folias factor, *M*, depending on the extent of defect. These definitions were later incorporated in the newly adopted ASME B31G-1991;

For L^2/Dt <50

$$M = \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\frac{L^4}{D^2t^2}} \tag{16}$$

For L^2/Dt > 50

$$M = 0.032\left(\frac{L^2}{Dt}\right) + 3.3 \tag{17}$$

As in the original B31G criterion, two types of area, parabolic and rectangular are put into consideration. In the parabolic representation, metal loss area $A = 2/3dL$ and in rectangular representation, area $A=dL$. Kiefner and Vieth (1989) commented that predictions using the rectangular method was too conservative, but those made using the parabolic method consistently underestimated the actual failure stress levels.

The new area representation proposed by Kiefner and Vieth (1989), is called Effective Area Method. A detailed measurement of the corrosion area is required by divided the area into small rectangular section. RSTRENG software was developed for these purposes, to facilitate the analysis of corroded areas using the Effective Area Method. Even though this method is reported as the most accurate in calculating the total metal loss area, it is tedious to apply manually. Therefore, a second method called 0.85A method is proposed as the alternative. 0.85A is taken as the averaged between rectangle area, $A=dL$ and parabolic area, $A = 2/3dL$. For flow stress, the original $1.1\times SMYS$ substantially underestimates the flow stress of a pipeline material. Suggestion on the modification of flow stress values has been proposed in many ways. The new flow stress has been demonstrated as;

$$S_f = 1.15\ \text{SMYS} \tag{18}$$

$$S_f = 0{,}5\ (SMYS+SMTS) \tag{19}$$

$$S_f = SMYS + 68.9MPa \tag{20}$$

$$S_f = x.SMTS \tag{21}$$

Where;

$SMTS$ = Specified Minimum Tensile Strength

x = 0.9, 1.0 or 1.1

4.1.2 SHELL 92

Shell has adopted a code to determine a maximum safe pressure for pressure pipelines (Asmaliyana, 2007). The equation to calculate the maximum safe pressure is almost similar to the B31G Criterion. However, the flow stress is represented as:

$$S_f = 0.9 \text{ x } SUTS \tag{22}$$

Where;

$SUTS$ = Specified Ultimate Tensile Strength

The maximum safe working pressure is expressed as:

$$P_p = \frac{F \times 0.9 \times SUTS \times 2 \times t}{D}\left[\frac{1 - d/t}{1-(d/t)M^{-1}}\right] \tag{23}$$

Where;

F = Factor of safety (always taken as 0.72)

$SUTS$ = Specified Ultimate Tensile Strength (573 N/mm^2)

D = Outer diameter

d = depth of corrosion defect

t = nominal pipeline thickness

M = Folias or bulging factor, accounting for effect of stress concentration at notch

4.1.3 DNV RP-F101

Development of the Recommended Practice (RP-F101) was initiated as ASME B31G was found to unable to synchronize with the design principles adopted in the DNV pipelines rules. The goal for this research and development project with BG Technology is to develop a recommended practice for determination of allowable operating pressure of corroded pipes, with a consistent reliability level. The equations in RP-F101 were derived by a probabilistic calibration (DNV, 1999; Bjornoy et al, 2001), taking into account for uncertainties in defect measurements and burst capacity. The equations account directly for the accuracy in sizing the corrosion defect. Hence, the increased allowable pressure obtained by improving the accuracy of the inspections can be seen immediately.

a) RP-F101 Criteria

The RP-F101 recommends the assessment of corroded pipelines subject to internal pressure and internal pressure combined with longitudinal compressive stresses (DNV, 1999). Moreover, this new criterion provides an assessment procedure for single defect, interacting defects and complex shaped defects. These three different types of defects can be describes as follows;

i. Single defect

The defects do not interact with the neighboring defects. Therefore, it is assumed that the failure pressure for a single defect is independent of other defects in the pipelines.

ii. Interacting defect

Unlike single defects, interacting defects interacts with neighboring defects either by axial or circumferential. The interaction will reduce the failure pressure.

iii. Complex shaped defect

It is a defect that results from combining colonies of interacting defects, or a single defect for which a profile is available.

b) Capacity Equation

The design pressure in pipelines for a single defect is given as:

$$P_p = \frac{\gamma_m \times 2 \times t \times SMTS \times (1 - \gamma_d (d/t)^*)}{(D-t)(1 - \gamma_d (d/t)^* Q^{-1}} \leq P_{mao} \quad (24)$$

Where;

$$Q = \sqrt{1 + 0.31[L / Dt)^{1/2}]^2} \tag{25}$$

$$(d/t)^* = (d/t)_{meas} + \varepsilon_d StD[d/t] \tag{26}$$

and;

D	=	outer diameter
d	=	depth of corrosion defect
t	=	nominal pipe wall thickness
L	=	measured length of corrosion defect
$(d/t)_{meas}$	=	measured relative corrosion depth
γ_m	=	partial safety factor for prediction model and safety class
γ_d	=	partial safety factor for corrosion depth
ε_d	=	factor for defining a fractile value for the corrosion depth
P_{mao}	=	maximum allowable operating pressure
$StD[d/t]$	=	standard deviation for measurement (d/t) ratio
$SMTS$	=	specified minimum tensile strength

Fundamentally, Eq. (24) is similar to ASME B31G. However, the difference between these two criteria is that partial safety factors are included in RP-F101 equation to ensure a consistent reliability level for various combinations of material properties, pipe geometries and corrosion defects configurations.

c) Partial Safety Factors

The partial safety factors γ_m and γ_d, and the fractile value ε_d are determined from tables which depend on the safety class classification, the pipe quality, inspection method and sizing accuracy of the inspection tool (DNV, 1999). It was given as functions of the sizing accuracy of the measured defect depth for inspections based on relative depth measurements (Part A) and for inspections based on absolute depth (Part B).

Table 2: Standard deviation, StD [*d/t*], for MFL inspection tool

Relative sizing accuracy	Confidence level	
	80%	90%
Exact	StD[*d/t*] = 0.00	StD[*d/t*] = 0.00
± 5%	StD[*d/t*] = 0.04	StD[*d/t*] = 0.03
± 10%	StD[*d/t*] = 0.08	StD[*d/t*] = 0.06
± 15%	StD[*d/t*] = 0.16	StD[*d/t*] = 0.12

Table 3: Partial safety factor γ_m, for MFL inspection tool

Additional material requirements	Safety class		
	Low	Normal	High
Not fulfilled	$\gamma_m = 0.79$	$\gamma_m = 0.74$	$\gamma_m = 0.70$
Fulfilled	$\gamma_m = 0.82$	$\gamma_m = 0.77$	$\gamma_m = 0.73$

Table 4: Partial safety factor, γ_d and fractile value factor, ε_d

Inspection sizing accuracy StD [*d/t*]	ε_d	Safety class		
		Low	Normal	High
0.00	0.0	$\gamma_d = 1.00$	$\gamma_d = 1.00$	$\gamma_d = 1.00$
0.04	0.0	$\gamma_d = 1.16$	$\gamma_d = 1.16$	$\gamma_d = 1.16$
0.08	1.0	$\gamma_d = 1.20$	$\gamma_d = 1.28$	$\gamma_d = 1.32$
0.16	2.0	$\gamma_d = 1.20$	$\gamma_d = 1.38$	$\gamma_d = 1.58$

4.2 Definitions of Pressure

For academic purposes, assessment methods with different terms have been standardized to ease understanding of the fundamental theory of Failure Pressure, Capacity Pressure and Maximum Allowable Operating Pressure (MAOP).

4.2.1 Failure Pressure (P_f)

The theoretical failure pressure of a plain, non-corroded pipe is defined as follows:

$$P_f = \frac{2 \times FS \times t}{D - t}$$

FS is the failure strength of the pipe material. When P_0 is found, it can be used to find the burst or capacity pressure (P_{cap}) of the corroded pipes.

4.2.2 Capacity Pressure (P_{cap})

The expression of the burst capacity for a single longitudinally oriented, rectangular shaped, corrosion defect was developed based on a large number of Finite Element analyses, and a series of full scale burst tests. By using finite element analyses the effect of each important parameter was investigated, while the accuracy of the analyses was verified by a large number of full-scale burst tests. In general, the prediction of capacity pressure is identified as below:

$$P_{cap} = P_f \times RSF(D, t, d, L)$$

P_0 is the theoretical failure pressure and RSF is known as the multiplier and is used to account for the lower capacity of the corroded pipe.

The simplified capacity equation of a single rectangular shaped defect for each code considered in this study is given as:

ASME B31G

$$P_{cap} = \frac{2*SMYS*F*T*t}{D}$$

DNV RP-F101

$$P_{cap} = 1.05\ \frac{2*SMTS*t}{D-t}\frac{\left(1-\left(\frac{d}{t}\right)\right)}{\left(1-\frac{\left(\frac{d}{t}\right)}{Q}\right)}$$

SHELL 92

$$P_{cap} = \frac{2 * (0.9 * SMTS) * t}{D - t}$$

This capacity equation represents the mean (best) estimate of the capacity of a pipe with a rectangular shaped corrosion (metal loss) defect. This implies that on average the equation should represent the capacity of the pipe but that some of the defects will fail at a slightly lower pressure, and some at a slightly higher pressure, than predicted.

Since the equation is simplified, some effects, and combination of effects, are not represented in detail. This includes e.g. yield to tensile ratio, *d/t* ratio, and length and depth effect. For example it is known that the equation over-predicts the failure pressure (capacity) for medium long defect with high yield to tensile ratio (high grade steel), and under-predict the failure pressure for low yield to tensile ratio (low grade steel).

The accuracy of the capacity equation had to be known for establishing the appropriate safety factors, and the above mentioned effects were accounted for. If the equation is used for irregular or parabolic defect shapes, and the maximum depth and lengths are used, the equation will in general underestimate the failure pressure, as the defect is not as large as the rectangular shaped defect assumed in the capacity equation. This will result in a conservative estimate of the failure pressure capacity for defects shapes other than rectangular.

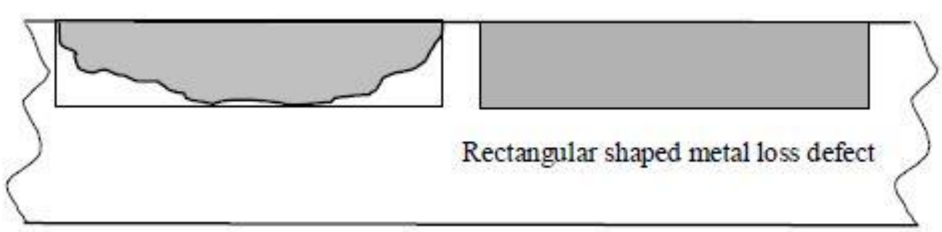


Figure 9: Irregular and rectangular defects

4.2.3 Maximum Allowable Operating Pressure (P_{corr})

Most of metal loss assessment methods calculate a safe working pressure, P_{corr} by applying a multiplier, *RSF* (Remaining strength factor using API RP-579's terminology), and a safety factor, F_s to the predicted failure pressure for the plain pipe, P_0. The multiplier, *RSF* is generally a function of the pipe diameter (*D*), thickness (*t*), defect depth (*d*), and defect length (*L*).

$$P_{corr} = \frac{P_f \times RSF(D, t, d, L)}{F_s}$$

4.2.4 Theory of Hoop Stress

Wall thickness of an internally pressurized cylindrical vessel is determined by computing the hoop stress. The hoop stress must be less than the maximum allowable stress. If the calculated hoop stress is greater than the allowable stress, the pipe wall thickness must be increased. For a pipe-in-pipe design in which the inner pipe is enclosed by an outer casing pipe with the annulus pressurized or a pipe in a marine environment exposed to external hydrostatic head, the external pressure should be considered in the pipe wall thickness determination. Hoop or circumferential stress is the stress which is set up in resisting the bursting effect of the applied pressure and can be most conveniently treated by considering the equilibrium of the cylinder.

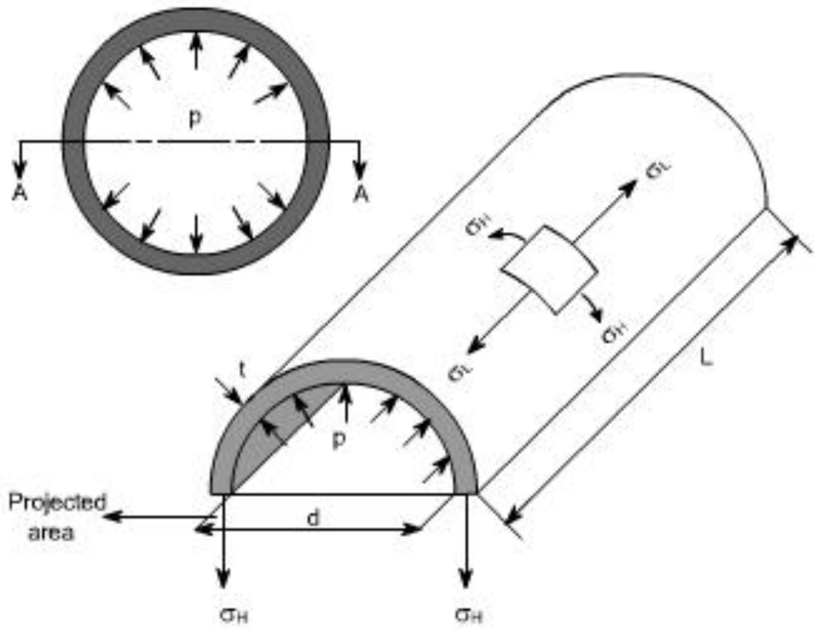


Figure 10: Cylinder subjected to internal pressure

The cylinder shown in Fig. 10 is one half of a cylinder, subjected to an internal pressure, p.

Where;

p = internal pressure

d = internal diameter

L = length of cylinder

t = wall thickness

The total force on one half of the cylinder due to the internal pressure 'p' is as follows:

$$p \times d \times L \tag{27}$$

The total resisting force due to hoop stresses σ_h set up in the cylinder walls is as follows:

$$2 \times \sigma_h \times L \times t \tag{28}$$

Equating both equation 27 and equation 28:

$$2 \times \sigma_h \times L \times t = p \times d \times L \tag{29}$$

Therefore, circumferential or hoop stress can be rewritten as:

$$\sigma_h = \frac{pd}{2t} \tag{30}$$

CHAPTER 5 DATA ANALYSIS

5.1 Description of the corrosion data

The defects data obtained from MFL inspection in 2006 is separated into two parts. The first part covers the first 1000 m log distance from the riser. This part is critical due to single and interacting defects having allowable corroded pipe pressure of 0 and containing highest density of defects, which account for 88%. It has been identified that 7 types of defects have inhibited this pipeline.

Table 5: Defects inhibiting the first part

Defect types	**Defect counts**
Axial Grooving (AXGR)	556
Axial Slotting (AXSL)	199
Circumferential Grooving (CIGR)	112
Circumferential Slotting (CISL)	71
General (GEN)	1220
Pinhole (PINH)	1278
Pitting (PITT)	6108
Total	**9544**

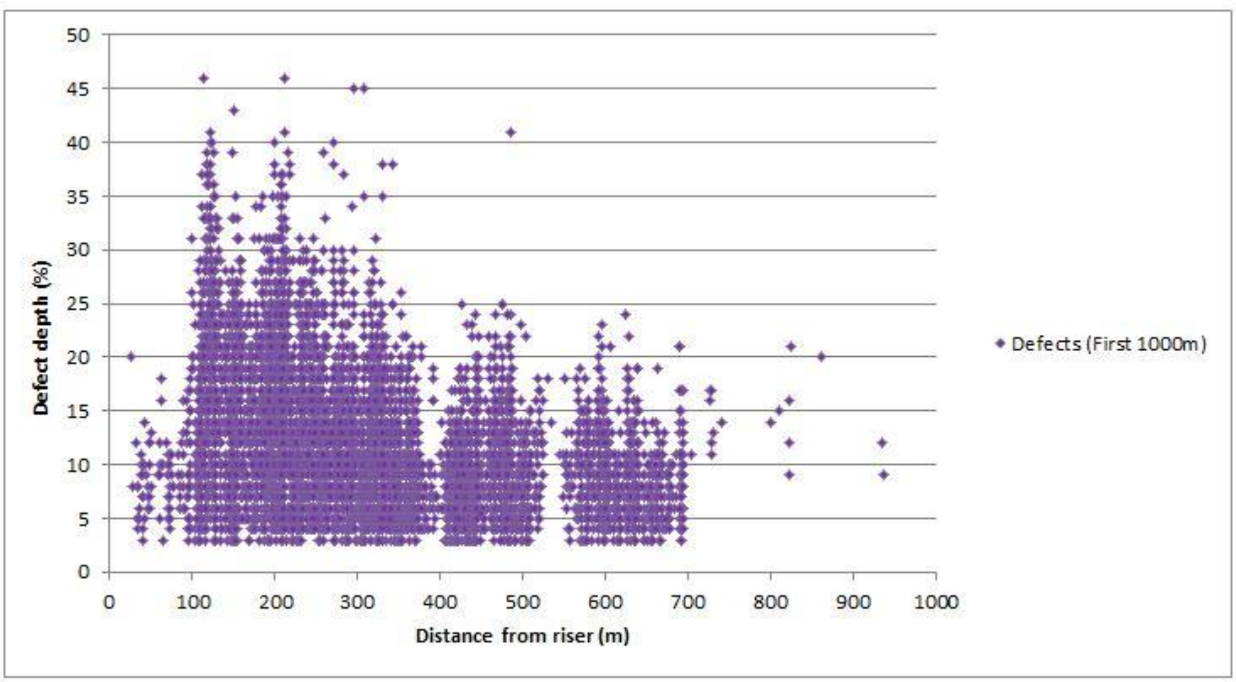


Figure 11: First part (0-1000 m)

The first part which represents the section that has been cut is displayed in Fig. 11. From the graph it can be interpreted that the defect depth have reached as far as 46% of the wall thickness (*t*=11.1mm). However, most of the defect depths concentrated between 3 to 25% of the wall thickness, which suggests that if the updated probability of failure is proven to be lower than reported, the pipeline could still operate for several years before being planned for removal or rejuvenation.

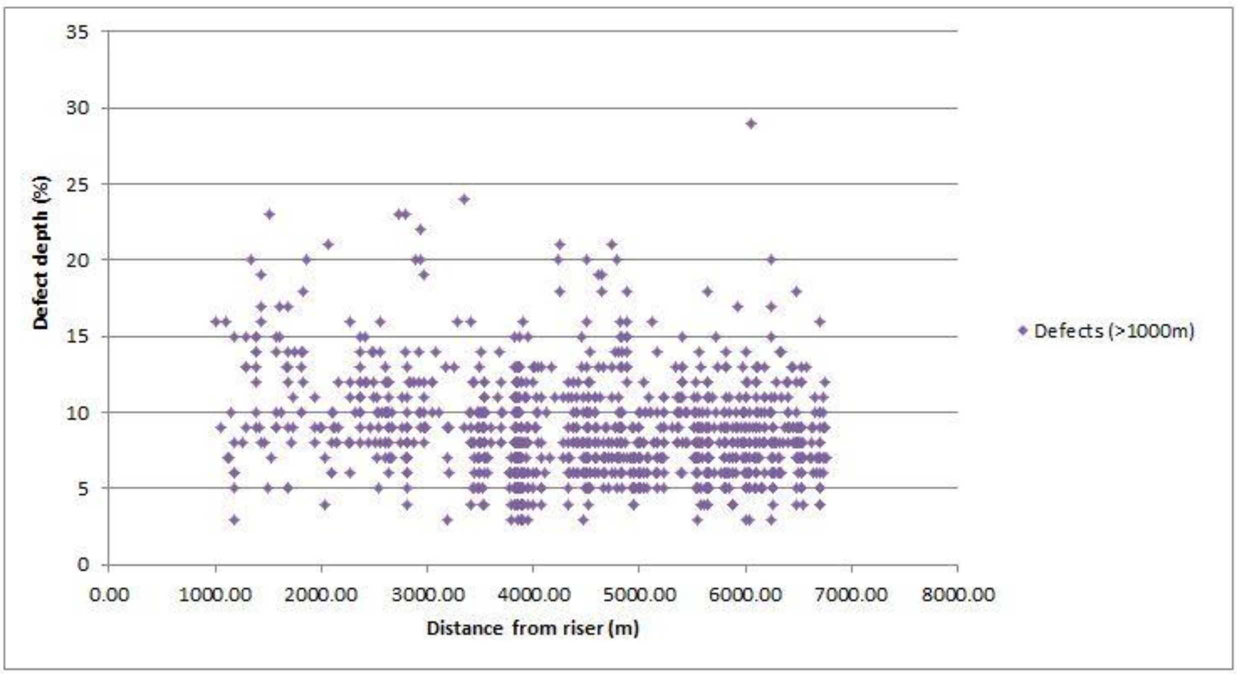


Figure 12: Second part (>1000 m)

The second part as in Fig. 12 shows the defect depths distribution along the log distance of further 6000 m from the riser. The defect distribution concentrated between 3 to 15% of the wall thickness, and this section of pipeline has not been considered for removal.

5.2 Data variables

Tables below show the variables used for evaluating the probability of failure in MATLAB according to respective codes. Since no model uncertainty factor was found available for SHELL 92 code, therefore it is assumed to follow the same model uncertainty factor of B31G, which is evaluated using the Monte Carlo simulation.

Table 6: SHELL 92 variables

Variable	Distribution	Mean	Standard deviation
D	Deterministic	273.05 mm	-
t	Normal	11.1 mm	0.33
TS	Normal	495.95 Mpa	14.879
d/t	Normal	0.41	0.08
X_m	Normal	1.07	0.1
L	Normal	250 mm	0

Table 7: DNV RP-F101 variables

Variable	Distribution	Mean	Standard deviation
D	Deterministic	273.05 mm	-
t	Normal	11.1 mm	0.33
TS	Normal	495.95 Mpa	14.879
d/t	Normal	0.41	0.08
X_m	Normal	1.05	0.1
L	Normal	250 mm	0

Table 8: ASME B31G variables

Variable	Distribution	Mean	Standard deviation
D	Deterministic	273.05 mm	-
t	Normal	11.1 mm	0.33
YS	Normal	390.22 Mpa	10.74
d/t	Normal	0.41	0.08
X_m	Normal	1.07	0.1
L	Normal	250 mm	0

Table 9: List of abbreviation

Variable	Abbreviation
D	Diameter
d	Defect depth
L	Defect length
t	Wall thickness
TS	Tensile Strength
YS	Yield Strength
X_m	Model uncertainty factor

The acceptable probability of failures for different types of safety class is shown in Table 10:

Table 10: Acceptable Probability of Failure

Safety Class	Target Probability of Failure
High	<0.00001
Normal	<0.0001
Low	<0.001

5.3 Results

Evaluation is carried out to find out and compare the effects of ASME B31G, DNV RP-F101 and SHELL 92 code equations on the MAOP and burst test. The data is shown below.

Table 11: MAOP and Burst Test results

Code	Diameter (mm)	Wall thickness (mm)	MAOP (MPa)	Burst Test (MPa)	(Burst test/MAOP) ratio
ASME B31G	273.05	11.1	188.9	326.5	1.73
DNV-RP-F101	273.05	11.1	138.4	326.5	2.36
SHELL 92	273.05	11.1	125.9	326.5	2.59

The MAOP for each code is different, with SHELL 92 having the lowest allowable operating pressure being the most conservative among the three codes. Firstly, probability of failure at maximum allowable operating pressure was determined in MATLAB. By using the ratio of burst test to MAOP which serve as proof load together with the resistance, the probability of failure is updated. The result for each code is shown in the next page.

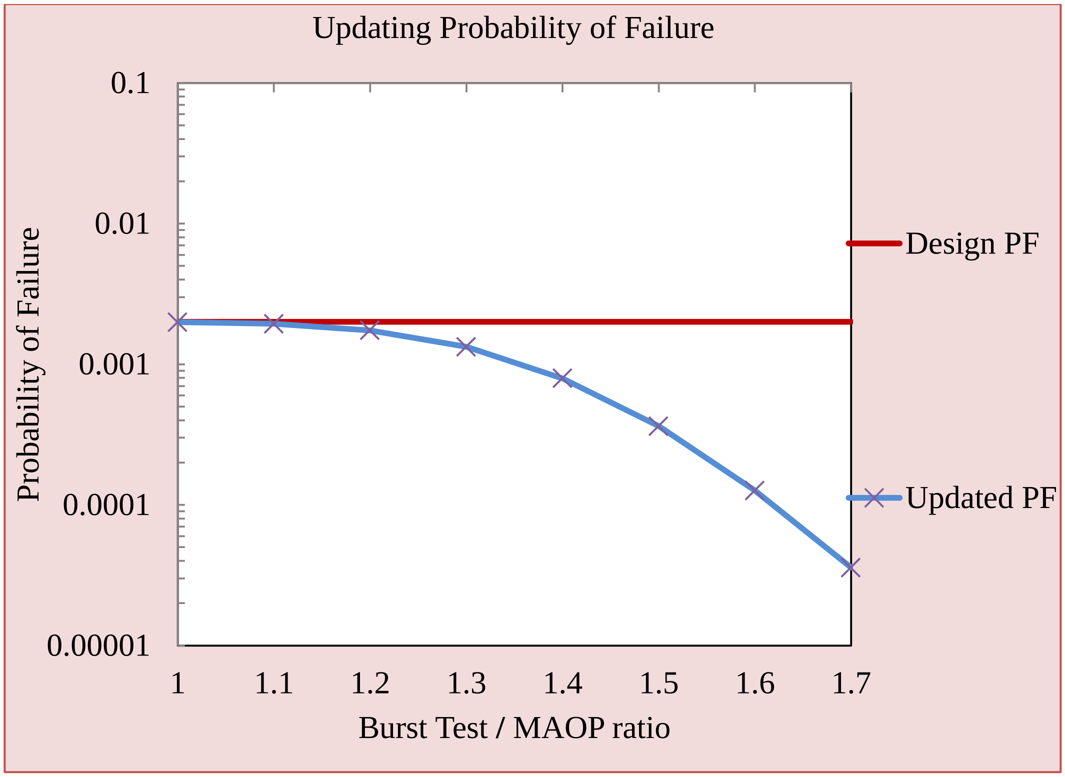


Figure 13: Probability of Failure for ASME B31G code

Fig. 13 shows the ratio of Burst Test and MAOP for ASME B31G code which is 1.7. The design probability of failure is calculated using MATLAB and only one value is found which is 0.002. The Burst Test and MAOP ratio is increased from 1 to 1.7 and for each ratio; it is compared to the design probability of failure. Therefore, it can be seen that as the MAOP which act as the load is decreased, the ratio will increase and therefore the probability of failure will decrease. Here the Burst Test information serves as variable for the Probability of Survival. The design value of probability of failure using MAOP is found out to be 0.002 but with the burst test information, the updated probability of failure decreases to 0.00004.

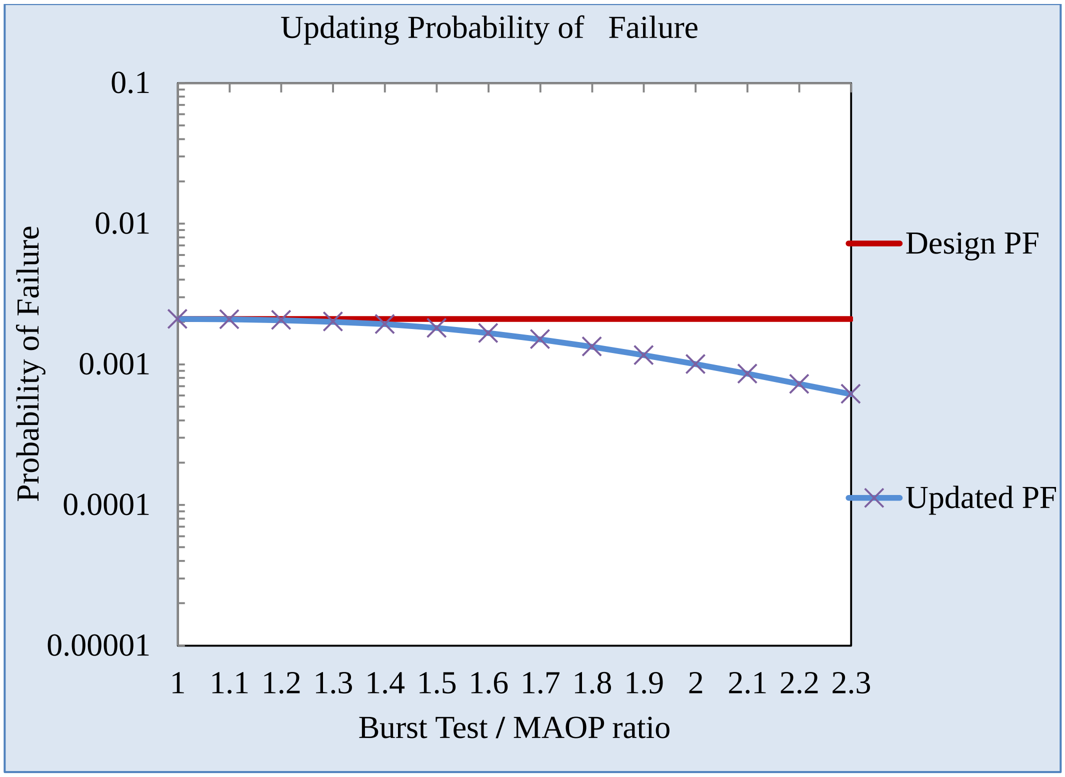


Figure 14: Probability of Failure for DNV RP-F101 code

Fig. 14 shows the ratio of Burst Test and MAOP for DNV RP-F101 code which is 2.3. The design probability of failure is calculated using MATLAB and only one value is found out which is 0.0021. The Burst Test and MAOP ratio is increased from 1 to 2.3. Thus, the design value of probability of failure using MAOP is found out to be 0.0021 but with the burst test information, the updated probability of failure decreases to 0.0006.

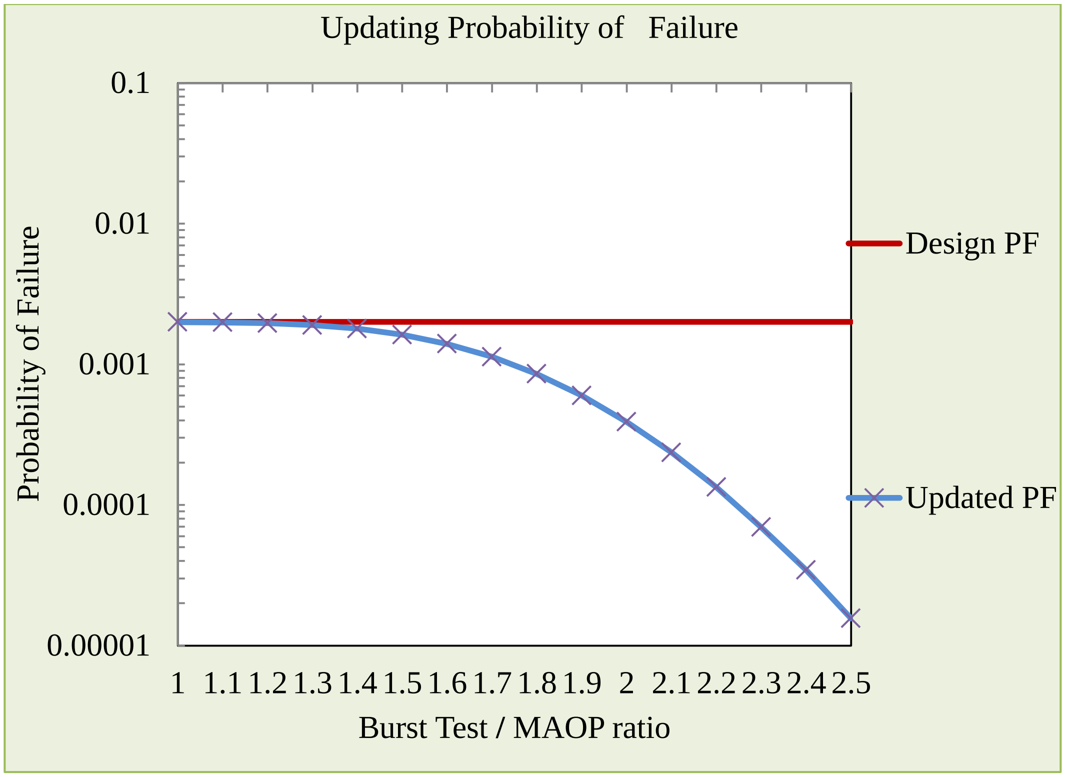


Figure 15: Probability of Failure for SHELL 92 code

Fig. 15 shows the ratio of Burst Test and MAOP for SHELL 92 code which is 2.5. The design probability of failure is calculated using MATLAB and only one value is found out which is 0.002. The Burst Test and MAOP ratio is increased from 1 to 2.5. Thus, the design value of probability of failure using MAOP is found out to be 0.002 but with the burst test information, the updated probability of failure decreases to 0.00002.

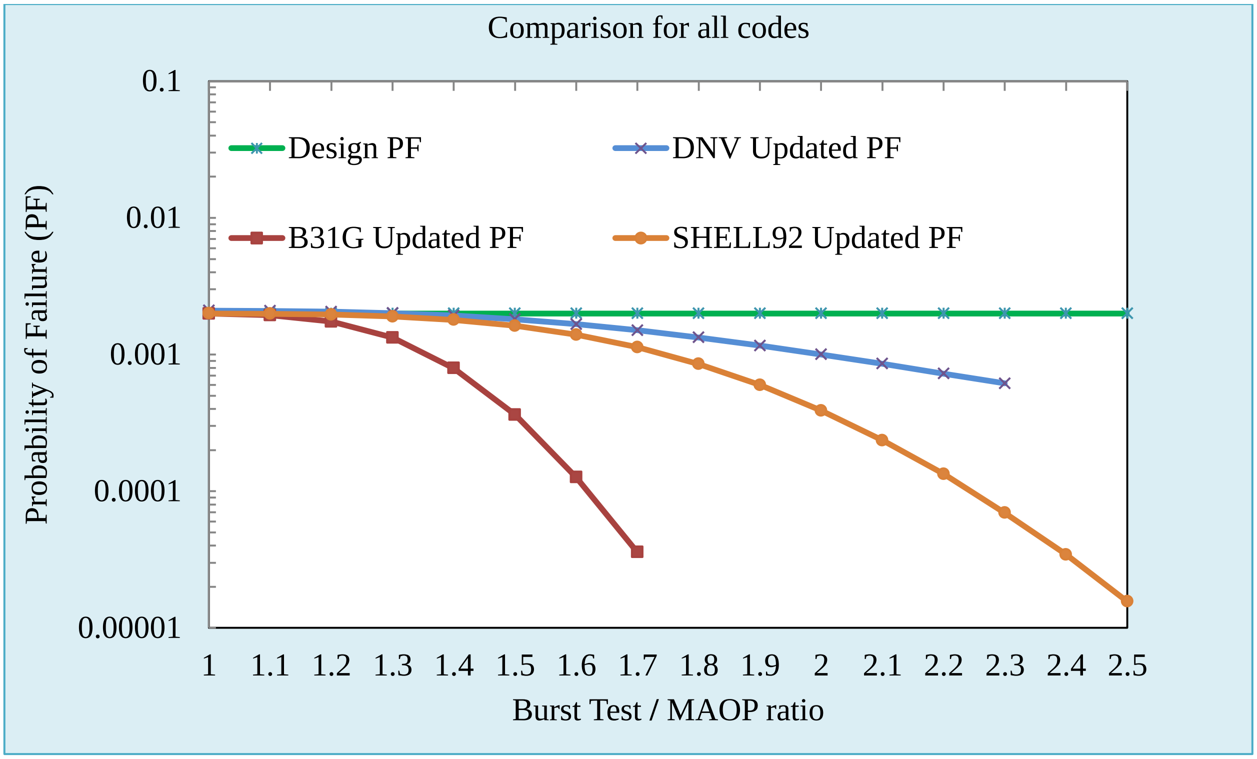


Figure 16: Comparison of Probability of Failure for all codes

Fig. 16 shows the comparison for all codes for ratio of Burst Test and MAOP and the respective probability of failure. The design probability of failure for all codes is calculated using MATLAB and found out to be slightly similar which is around 0.002. Here we can observe that the B31G code predicts well with the actual burst test, followed by the SHELL 92 code, and lastly the DNV code being the most conservative yet still having a reduced probability of failure.

CHAPTER 6 FUTURE CORROSION PREDICTIONS

The corrosion rate of the pipeline was determined after reviewing the inspection record, assessment of ILI inspection findings and application of ECE4 corrosion prediction software.

Based on the ECE4 CO_2 corrosion prediction software, the internal corrosion rate that is applicable to this case is 0.188 mm/yr. By assuming a linear growth rate, the data available from the ILI is used to find out the projection year when it is no longer suitable for service under the updated probability of failure using Bayesian Updating.

6.1 Projection for year 2009

The projection is done in MATLAB by using ASME B31G code, since it predicts well as compared to other codes.

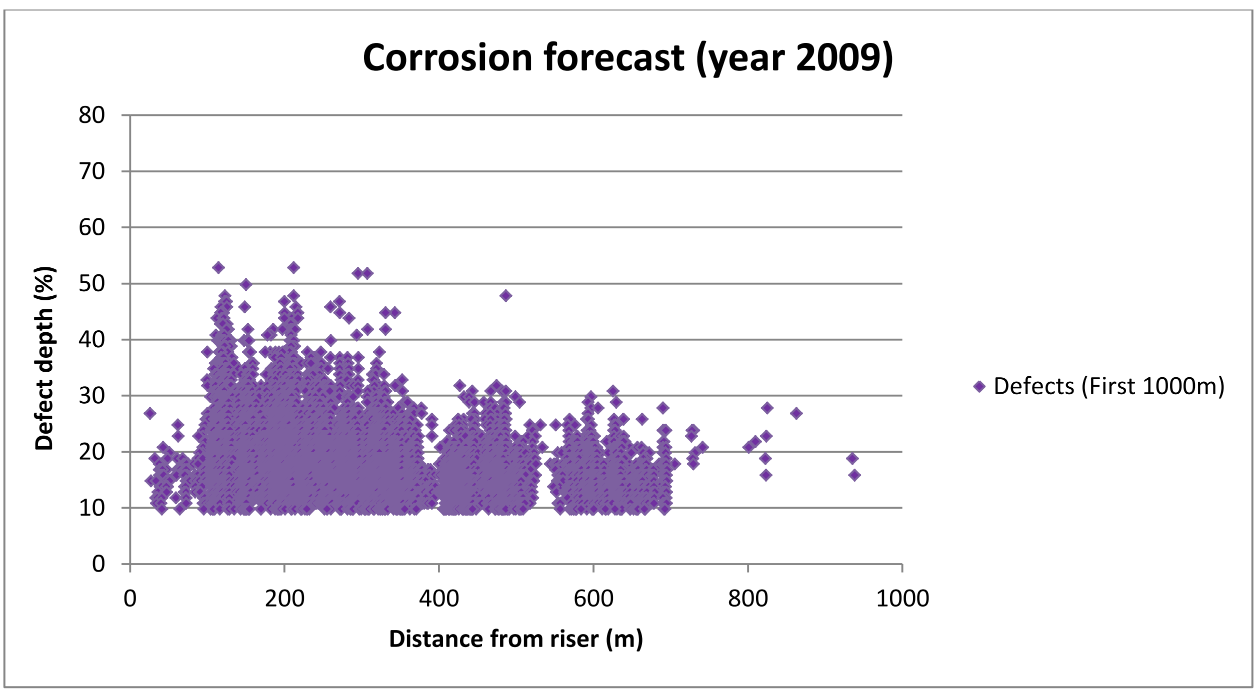


Figure 17: Corrosion forecast for year 2009

The forecast for the first part is shown in Fig. 17 for year 2009. Assuming linear corrosion growth, the defect depth has increased from 46% to 53% and most of the defect depths are concentrated between 10% to 32%.

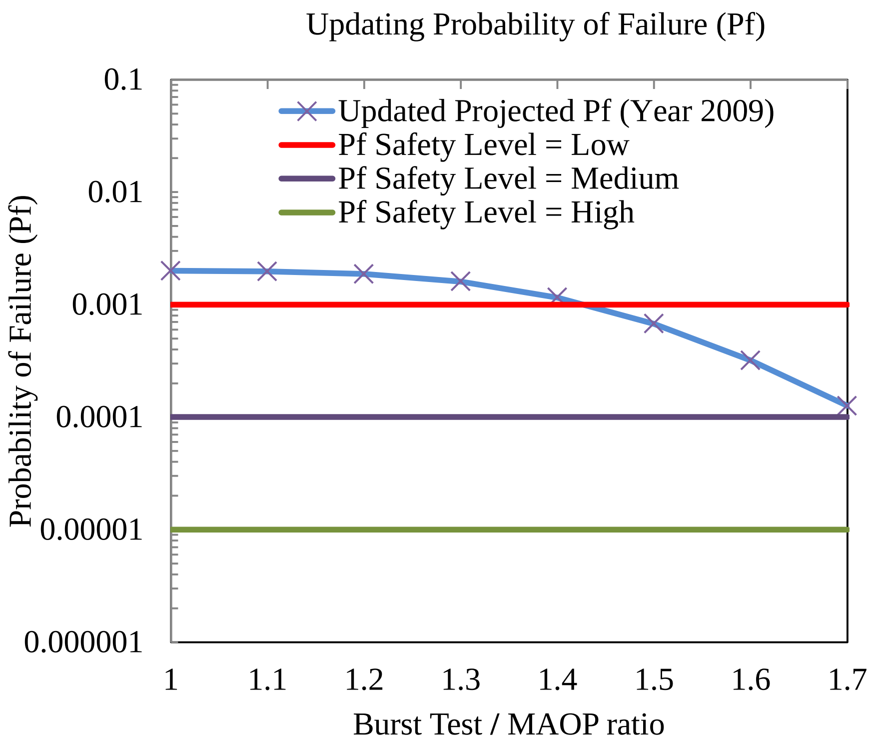


Figure 18: Updated Probability of failure at year 2009

The acceptable probability of failure safety class ranges from High (<0.00001), Medium (<0.0001) and Low (<0.001). The aim of this future projection is to find out the updated probability of failure which does not exceed the Low probability of failure safety level. This is achieved by manipulating the value of d/t in the MATLAB. The value of d increases each year, thus the value of *d/t* will also increase. As *d/t* value increases, the probability of failure will become higher each year, until at some point it will exceed the Low probability of failure safety level.

6.2 Projection for year 2013

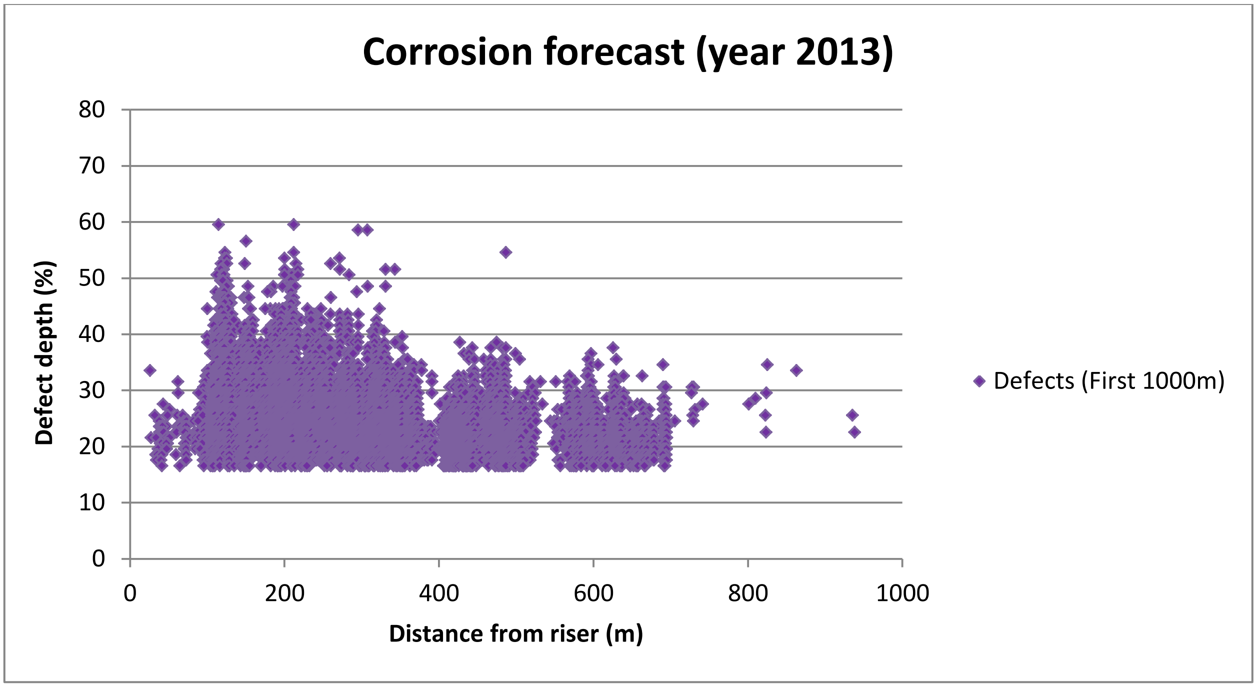


Figure 19: Corrosion forecast for year 2013

The forecast for the first part is shown above for year 2013. Once again, by assuming linear corrosion growth, the defect depth has increased from 53% to 60% and most of the defect depths are concentrated between 17% to 39% of the wall thickness (t=11.1mm).

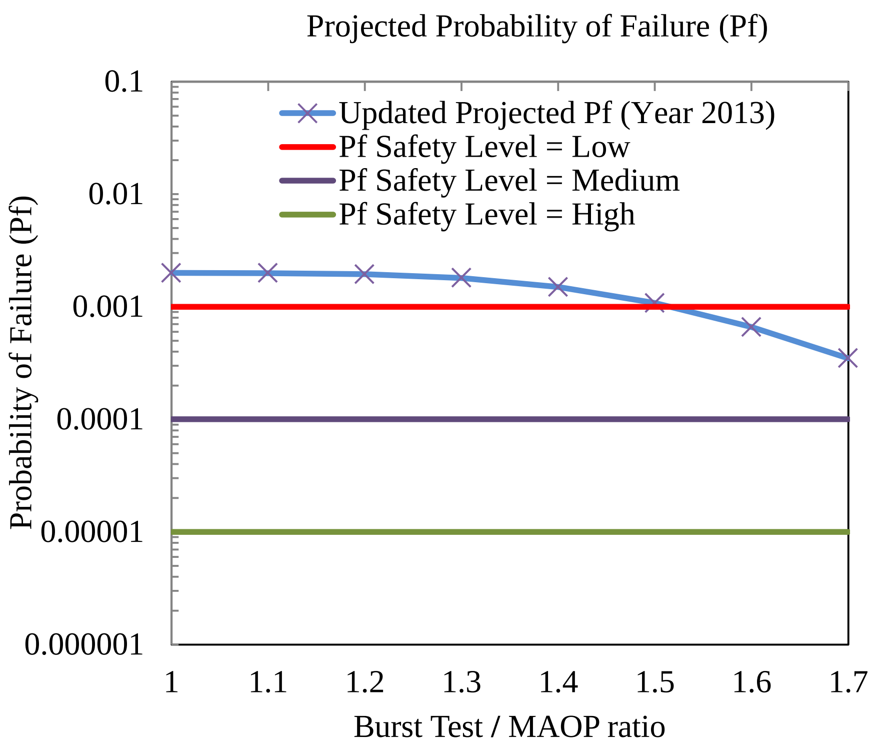


Figure 20: Updated Probability of failure at year 2013

In Fig. 20, the updated probability of failure projected at year 2013 has increased compared to the projection at year 2009. It can be observed that only Burst Test / MAOP ratio of 1.6 and 1.7 are able to produce probability of failure which does not exceed the Low probability of failure safety level.

6.3 Projection for year 2018

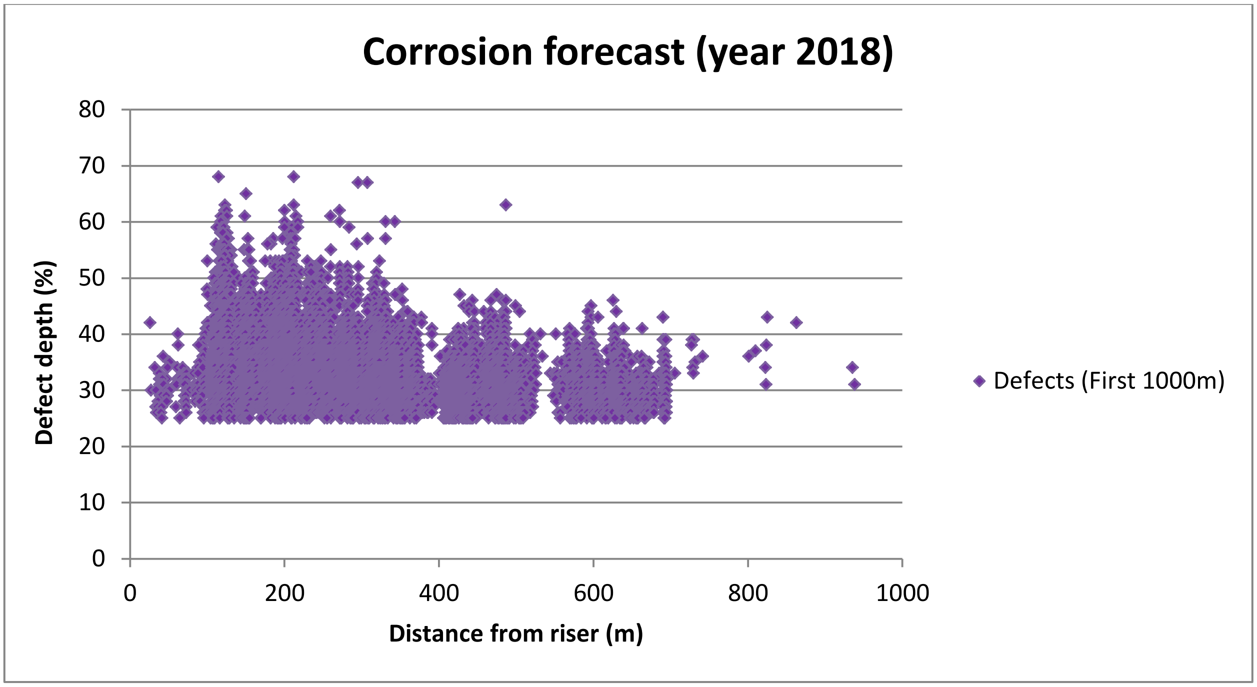


Figure 21: Corrosion forecast for year 2018

The forecast for the first part is shown in Fig. 21 for year 2018. By assuming linear corrosion growth, the defect depth has increased from 60% to 68% and most of the defect depths are concentrated between 25% to 47% of the wall thickness (*t*=11.1mm).

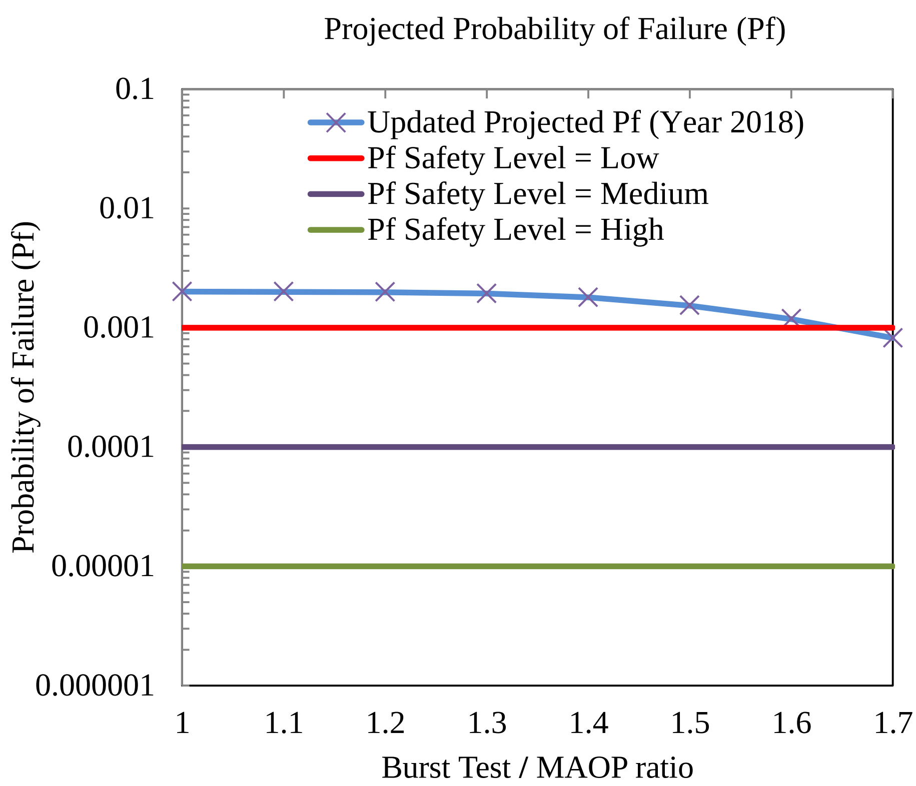


Figure 22: Updated Probability of failure at year 2018

In Fig. 22, the updated probability of failure projected at year 2018 has substantially increased compared to the projection at year 2009 and 2013. It can be observed that only Burst Test / MAOP ratio of 1.7 is able to produce probability of failure which does not exceed the Low probability of failure safety level. Beyond 2018, it is expected that the updated probability of failure will exceed the Low safety level, which means it is no longer safe to operate at given MAOP.

CHAPTER 7 DISCUSSION AND RECOMMENDATIONS

7.1 Discussion

1. The original design probability of failure for B31G, DNV and SHELL 92 is 0.002, 0.0021 and 0.002 respectively. It can be seen that there is not much difference in the design probability of failure for all the codes. However, with reference to Table 10, this probability of failure is ranked as Low in the safety class and therefore is not sufficient. Thus, updating probability of failure for all codes using Bayesian updating was carried out. The B31G code gave probability of failure of 0.00004, the DNV code gave 0.0006, and the SHELL 92 code gave 0.00002. This shows that the pipeline has much lower probability of failure than anticipated.

2. Future corrosion prediction is performed by knowing the internal corrosion rate from the ECE4 software which is 0.188 mm/yr. This information is used together with the updated probability of failure from ASME B31G code to find out the projected year at which the pipeline can still operate at minimum condition; Low probability of failure safety level under minimum loading.

7.2 Recommendations

1. In the future, research can be more comprehensive by including and comparing more design codes with the ones mentioned in this thesis. This can be beneficial as comparison can be made to find out which code is more conservative and which code predicts well with the burst test result.

2. Information from UT scan can be used to perform Bayesian Updating and obtain more accurate result.

CONCLUSIONS

Since it is almost impossible to prevent corrosion, it has become more economical to control the corrosion rate by monitoring the level of inspection activities. The fundamentals of Bayesian Theorem and Limit State Function (LSF) Design and their contributions to the reliability functions have been covered in this research. The conservative value of the design probability of failure is unnecessary and by using the available standard codes, the probability of failure with respect to MAOP can be updated to identify the safest operational pressure of the pipeline before it fails hence reducing the cost.

The updated probability of failure according to the different codes has been worked out. A proper result and comparison of the updated probability of failure between different codes and the actual burst test has been established and it is observed that the ASME B31G code predicted well with the burst test result, followed by the SHELL 92 code, and lastly the DNV RP-F101 code. The future prediction of the corrosion rate for the pipeline based on its historical corrosion data and also its respective updated probability of failure has also been projected and it is found out that the pipeline will run fine up until 2018.

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APPENDIX

Appendix I: Comparison of different codes

CODES	ASME B31G	DNV RP-F101	SHELL-92
Failure Pressure, P_f	$P_f = 1.11\frac{2*SMYS*t}{D}\left[\frac{1-\frac{2d}{3t}}{1-\frac{2d}{3t}\frac{1}{M}}\right]$ for $\frac{L}{\sqrt{D*t}} \le 4.479$ M = $\sqrt{1+\frac{0.8*L^2}{D*t}}$ $P_f = 1.11\frac{2*SMYS*t}{D}\left[1-\frac{d}{t}\right]$ for $\frac{L}{\sqrt{D*t}} \ge 4.479$	$P_f = \frac{2*SMYS*t}{D-t}\left[\frac{1-\frac{d}{t}}{1-\frac{d}{t}\frac{1}{M}}\right]$ M = $\sqrt{1+0.31\frac{L^2}{D*t}}$	$P_f = P_{cap}\left[\frac{1-\frac{d}{t}}{1-\frac{d}{t}*\frac{1}{M}}\right]$ M = $\sqrt{1+0.8\left(\frac{L^2}{D*t}\right)}$
Capacity Equation, P_{cap}	$P_{cap} = \frac{2*SMYS*F*T*t}{D}$	$P_{cap} = 1.05\,\frac{2*SMTS*t}{D-t}\frac{\left(1-\left(\frac{d}{t}\right)\right)}{\left(1-\frac{\left(\frac{d}{t}\right)}{Q}\right)}$ Q = $\sqrt{1+0.31\left(\frac{L}{\sqrt{D*t}}\right)^2}$	$P_{cap} = \frac{2*(0.9*SMTS)*t}{D-t}$
Maximum Allowable Operating Pressure (MAOP), P_{corr}	A = $0.893\left(\frac{L}{\sqrt{D*t}}\right)$ If $A < 4$: $P_{corr} = 1.1P_{cap}\left[\frac{1-\frac{2}{3}\left(\frac{d}{t}\right)}{1-\frac{2}{3}\left(\frac{d}{t\sqrt{A^2+1}}\right)}\right]$ If $A > 4$: $P_{corr} = 1.1P_{cap}\left[1-\frac{d}{t}\right]$	$P_{corr} = 0.74\frac{2*t*SMTS}{D-t}\left[\frac{1-1.28\left(\frac{d}{t}\right)^*}{1-1.28\left(\frac{\left(\frac{d}{t}\right)^*}{Q}\right)}\right]$ $\left(\frac{d}{t}\right)^* = \left(\frac{d}{t}\right)+\varepsilon_d*StD\left[\frac{d}{t}\right]$ ε_d = Fractile value factor $StD\left[\frac{d}{t}\right]$ = Standard deviation of RV	$P_{corr} = 0.72\frac{0.9*SMTS*2*t}{D}$

Appendix II: Pipeline X (PL X)

Appendix III: Original ILI data year 2005 (sorted according to % defect depth)

a) First part (0-1000m)

Distance, m	Depth, %	Depth, mm	WT, mm	d/t	TS	YS
211.94	46	5.106	11.1	0.46	455	358
114.58	46	5.106	11.1	0.46	455	358
295.42	45	4.995	11.1	0.45	455	358
307.32	45	4.995	11.1	0.45	455	358
150.34	43	4.773	11.1	0.43	455	358
122.89	41	4.551	11.1	0.41	455	358
212.23	41	4.551	11.1	0.41	455	358
486.83	41	4.551	11.1	0.41	455	358
122.73	40	4.44	11.1	0.4	455	358
125.01	40	4.44	11.1	0.4	455	358
200.01	40	4.44	11.1	0.4	455	358
271.51	40	4.44	11.1	0.4	455	358
118.16	39	4.329	11.1	0.39	455	358
125.38	39	4.329	11.1	0.39	455	358
148.59	39	4.329	11.1	0.39	455	358
215.11	39	4.329	11.1	0.39	455	358
259.71	39	4.329	11.1	0.39	455	358
217.35	38	4.218	11.1	0.38	455	358
343.03	38	4.218	11.1	0.38	455	358
117.44	38	4.218	11.1	0.38	455	358
121.52	38	4.218	11.1	0.38	455	358
200.33	38	4.218	11.1	0.38	455	358
271.73	38	4.218	11.1	0.38	455	358
331.1	38	4.218	11.1	0.38	455	358
117.44	38	4.218	11.1	0.38	455	358
207.92	37	4.107	11.1	0.37	455	358
118.75	37	4.107	11.1	0.37	455	358
112.63	37	4.107	11.1	0.37	455	358
120.39	37	4.107	11.1	0.37	455	358
121.84	37	4.107	11.1	0.37	455	358
209.49	37	4.107	11.1	0.37	455	358
283.69	37	4.107	11.1	0.37	455	358
200.18	37	4.107	11.1	0.37	455	358
217.32	37	4.107	11.1	0.37	455	358
117.31	36	3.996	11.1	0.36	455	358
120.61	36	3.996	11.1	0.36	455	358
125.73	36	3.996	11.1	0.36	455	358
207.32	36	3.996	11.1	0.36	455	358
208.35	36	3.996	11.1	0.36	455	358
120.45	36	3.996	11.1	0.36	455	358
127.58	35	3.885	11.1	0.35	455	358
125.07	35	3.885	11.1	0.35	455	358
125.15	35	3.885	11.1	0.35	455	358
153	35	3.885	11.1	0.35	455	358

185.43	35	3.885	11.1	0.35	455	358
203.7	35	3.885	11.1	0.35	455	358
207.84	35	3.885	11.1	0.35	455	358
210.76	35	3.885	11.1	0.35	455	358
213.62	35	3.885	11.1	0.35	455	358
197.59	35	3.885	11.1	0.35	455	358
307.62	35	3.885	11.1	0.35	455	358
331.16	35	3.885	11.1	0.35	455	358
182.5	34	3.774	11.1	0.34	455	358
111.52	34	3.774	11.1	0.34	455	358
118.9	34	3.774	11.1	0.34	455	358
121.51	34	3.774	11.1	0.34	455	358
121.99	34	3.774	11.1	0.34	455	358
208.54	34	3.774	11.1	0.34	455	358
177.92	34	3.774	11.1	0.34	455	358
293.48	34	3.774	11.1	0.34	455	358
120.45	33	3.663	11.1	0.33	455	358
113.54	33	3.663	11.1	0.33	455	358
115.2	33	3.663	11.1	0.33	455	358
116.1	33	3.663	11.1	0.33	455	358
121.67	33	3.663	11.1	0.33	455	358
116.34	33	3.663	11.1	0.33	455	358
118.58	33	3.663	11.1	0.33	455	358
118.97	33	3.663	11.1	0.33	455	358
122.59	33	3.663	11.1	0.33	455	358
122.66	33	3.663	11.1	0.33	455	358
122.96	33	3.663	11.1	0.33	455	358
131.02	33	3.663	11.1	0.33	455	358
147.88	33	3.663	11.1	0.33	455	358
151.46	33	3.663	11.1	0.33	455	358
154.06	33	3.663	11.1	0.33	455	358
260.01	33	3.663	11.1	0.33	455	358
127.60	33	3.663	11.1	0.33	455	358
207.49	33	3.663	11.1	0.33	455	358
208.71	33	3.663	11.1	0.33	455	358
211.91	33	3.663	11.1	0.33	455	358
131.35	32	3.552	11.1	0.32	455	358
207.56	32	3.552	11.1	0.32	455	358
121.43	32	3.552	11.1	0.32	455	358
124.5	32	3.552	11.1	0.32	455	358
129.28	32	3.552	11.1	0.32	455	358
208.82	32	3.552	11.1	0.32	455	358
208.96	32	3.552	11.1	0.32	455	358
210.22	32	3.552	11.1	0.32	455	358
213.17	32	3.552	11.1	0.32	455	358
129.28	32	3.552	11.1	0.32	455	358
122.65	32	3.552	11.1	0.32	455	358
208.80	32	3.552	11.1	0.32	455	358
198.81	31	3.441	11.1	0.31	455	358

208.71	31	3.441	11.1	0.31	455	358
115.46	31	3.441	11.1	0.31	455	358
120.17	31	3.441	11.1	0.31	455	358
121.01	31	3.441	11.1	0.31	455	358
126.77	31	3.441	11.1	0.31	455	358
153.83	31	3.441	11.1	0.31	455	358
153.83	31	3.441	11.1	0.31	455	358
156.17	31	3.441	11.1	0.31	455	358
181.89	31	3.441	11.1	0.31	455	358
202.63	31	3.441	11.1	0.31	455	358
203.53	31	3.441	11.1	0.31	455	358
208.06	31	3.441	11.1	0.31	455	358
209.15	31	3.441	11.1	0.31	455	358
230.05	31	3.441	11.1	0.31	455	358
206.64	31	3.441	11.1	0.31	455	358
100.10	31	3.441	11.1	0.31	455	358
118.44	31	3.441	11.1	0.31	455	358
175.20	31	3.441	11.1	0.31	455	358
188.53	31	3.441	11.1	0.31	455	358
192.99	31	3.441	11.1	0.31	455	358
197.56	31	3.441	11.1	0.31	455	358
247.36	31	3.441	11.1	0.31	455	358
323.04	31	3.441	11.1	0.31	455	358
118.04	30	3.33	11.1	0.3	455	358
210.47	30	3.33	11.1	0.3	455	358
213.57	30	3.33	11.1	0.3	455	358
121.25	30	3.33	11.1	0.3	455	358
132.13	30	3.33	11.1	0.3	455	358
187.55	30	3.33	11.1	0.3	455	358
190.74	30	3.33	11.1	0.3	455	358
213.45	30	3.33	11.1	0.3	455	358
238.17	30	3.33	11.1	0.3	455	358
271.76	30	3.33	11.1	0.3	455	358
209.27	30	3.33	11.1	0.3	455	358
121.25	30	3.33	11.1	0.3	455	358
187.55	30	3.33	11.1	0.3	455	358
195.99	30	3.33	11.1	0.3	455	358
212.19	30	3.33	11.1	0.3	455	358
234.42	30	3.33	11.1	0.3	455	358
259.71	30	3.33	11.1	0.3	455	358
281.87	30	3.33	11.1	0.3	455	358
295.58	30	3.33	11.1	0.3	455	358
195.75	29	3.219	11.1	0.29	455	358
229.76	29	3.219	11.1	0.29	455	358
110.45	29	3.219	11.1	0.29	455	358
237.95	29	3.219	11.1	0.29	455	358
246.9	29	3.219	11.1	0.29	455	358
248.3	29	3.219	11.1	0.29	455	358
113.56	29	3.219	11.1	0.29	455	358

115.42	29	3.219	11.1	0.29	455	358
123.70	29	3.219	11.1	0.29	455	358
127.24	29	3.219	11.1	0.29	455	358
128.16	29	3.219	11.1	0.29	455	358
129.3	29	3.219	11.1	0.29	455	358
158.74	29	3.219	11.1	0.29	455	358
159.69	29	3.219	11.1	0.29	455	358
197.67	29	3.219	11.1	0.29	455	358
203.64	29	3.219	11.1	0.29	455	358
212.19	29	3.219	11.1	0.29	455	358
213.87	29	3.219	11.1	0.29	455	358
218.22	29	3.219	11.1	0.29	455	358
221.93	29	3.219	11.1	0.29	455	358
117.39	29	3.219	11.1	0.29	455	358
118.73	29	3.219	11.1	0.29	455	358
121.87	29	3.219	11.1	0.29	455	358
123.62	29	3.219	11.1	0.29	455	358
134.45	29	3.219	11.1	0.29	455	358
156.97	29	3.219	11.1	0.29	455	358
158.74	29	3.219	11.1	0.29	455	358
158.97	29	3.219	11.1	0.29	455	358
194.05	29	3.219	11.1	0.29	455	358
207.67	29	3.219	11.1	0.29	455	358
210.66	29	3.219	11.1	0.29	455	358
221.93	29	3.219	11.1	0.29	455	358
229.60	29	3.219	11.1	0.29	455	358
234.26	29	3.219	11.1	0.29	455	358
271.76	29	3.219	11.1	0.29	455	358
282.50	29	3.219	11.1	0.29	455	358
319.22	29	3.219	11.1	0.29	455	358
319.44	28	3.108	11.1	0.28	455	358
246.7	28	3.108	11.1	0.28	455	358
115.32	28	3.108	11.1	0.28	455	358
115.46	28	3.108	11.1	0.28	455	358
122.86	28	3.108	11.1	0.28	455	358
124.35	28	3.108	11.1	0.28	455	358
183.04	28	3.108	11.1	0.28	455	358
185.61	28	3.108	11.1	0.28	455	358
188.45	28	3.108	11.1	0.28	455	358
195.7	28	3.108	11.1	0.28	455	358
211.42	28	3.108	11.1	0.28	455	358
213.4	28	3.108	11.1	0.28	455	358
244.34	28	3.108	11.1	0.28	455	358
248.15	28	3.108	11.1	0.28	455	358
280.16	28	3.108	11.1	0.28	455	358
295.64	28	3.108	11.1	0.28	455	358
108.58	28	3.108	11.1	0.28	455	358
119.70	28	3.108	11.1	0.28	455	358
125.49	28	3.108	11.1	0.28	455	358

128.66	28	3.108	11.1	0.28	455	358
140.96	28	3.108	11.1	0.28	455	358
148.78	28	3.108	11.1	0.28	455	358
158.96	28	3.108	11.1	0.28	455	358
193.88	28	3.108	11.1	0.28	455	358
195.85	28	3.108	11.1	0.28	455	358
204.41	28	3.108	11.1	0.28	455	358
205.56	28	3.108	11.1	0.28	455	358
207.68	28	3.108	11.1	0.28	455	358

b) Second part (>1000m)

	Distance, m	Depth, %	Depth, mm	WT, mm	d/t	TS
PITT	6057.16	29	3.219	11.1	0.29	455
PITT	3342.10	24	2.664	11.1	0.24	455
PITT	1514.85	23	2.553	11.1	0.23	455
PITT	2788.67	23	2.553	11.1	0.23	455
AXGR	2727.89	23	2.553	11.1	0.23	455
PITT	2944.16	22	2.442	11.1	0.22	455
PITT	2067.26	21	2.331	11.1	0.21	455
PITT	4247.47	21	2.331	11.1	0.21	455
PITT	4737.33	21	2.331	11.1	0.21	455
PITT	4231.79	20	2.22	11.1	0.2	455
PITT	4509.78	20	2.22	11.1	0.2	455
PITT	4794.01	20	2.22	11.1	0.2	455
PITT	6245.60	20	2.22	11.1	0.2	455
GENE	1343.1	20	2.22	11.1	0.2	455
GENE	1859.32	20	2.22	11.1	0.2	455
GENE	2885.70	20	2.22	11.1	0.2	455
GENE	2944.11	20	2.22	11.1	0.2	455
PITT	1441.33	19	2.109	11.1	0.19	455
PITT	4616.42	19	2.109	11.1	0.19	455
GENE	4640.62	19	2.109	11.1	0.19	455
PINH	2975.97	19	2.109	11.1	0.19	455
PITT	1827.07	18	1.998	11.1	0.18	455
PITT	4247.16	18	1.998	11.1	0.18	455
PITT	4640.59	18	1.998	11.1	0.18	455
PITT	4880.09	18	1.998	11.1	0.18	455
PITT	6489.00	18	1.998	11.1	0.18	455
PINH	5635.59	18	1.998	11.1	0.18	455
PITT	1441.17	17	1.887	11.1	0.17	455
PITT	1600.95	17	1.887	11.1	0.17	455
PITT	1680.69	17	1.887	11.1	0.17	455
PITT	5922.09	17	1.887	11.1	0.17	455
PITT	6248.92	17	1.887	11.1	0.17	455
PITT	1006.70	16	1.776	11.1	0.16	455
PITT	1097.59	16	1.776	11.1	0.16	455
PITT	1429.05	16	1.776	11.1	0.16	455
PITT	2551.53	16	1.776	11.1	0.16	455
PITT	3897.95	16	1.776	11.1	0.16	455
PITT	4509.58	16	1.776	11.1	0.16	455
PITT	4827.64	16	1.776	11.1	0.16	455
PITT	4880.15	16	1.776	11.1	0.16	455
PITT	5120.23	16	1.776	11.1	0.16	455
PITT	6708.89	16	1.776	11.1	0.16	455
PINH	2276.76	16	1.776	11.1	0.16	455
PINH	3282.15	16	1.776	11.1	0.16	455
PINH	3416.87	16	1.776	11.1	0.16	455

PITT	1181.44	15	1.665	11.1	0.15	455
PITT	1289.41	15	1.665	11.1	0.15	455
PITT	1381.14	15	1.665	11.1	0.15	455
PITT	1383.74	15	1.665	11.1	0.15	455
PITT	1386.09	15	1.665	11.1	0.15	455
PITT	1601.15	15	1.665	11.1	0.15	455
PITT	2363.95	15	1.665	11.1	0.15	455
PITT	2416.05	15	1.665	11.1	0.15	455
PITT	4827.35	15	1.665	11.1	0.15	455
PITT	4879.91	15	1.665	11.1	0.15	455
PITT	4880.02	15	1.665	11.1	0.15	455
PITT	5726.41	15	1.665	11.1	0.15	455
GENE	4448.95	15	1.665	11.1	0.15	455
AXSL	1573.16	15	1.665	11.1	0.15	455
PINH	3821.00	15	1.665	11.1	0.15	455
PINH	3870.75	15	1.665	11.1	0.15	455
PINH	3955.88	15	1.665	11.1	0.15	455
PINH	4829.37	15	1.665	11.1	0.15	455
PINH	5401.62	15	1.665	11.1	0.15	455
PINH	6247.29	15	1.665	11.1	0.15	455
PITT	1381.60	14	1.554	11.1	0.14	455
PITT	1382.64	14	1.554	11.1	0.14	455
PITT	1571.96	14	1.554	11.1	0.14	455
PITT	1744.17	14	1.554	11.1	0.14	455
PITT	2788.65	14	1.554	11.1	0.14	455
PITT	2921.17	14	1.554	11.1	0.14	455
PITT	4536.37	14	1.554	11.1	0.14	455
PITT	4805.62	14	1.554	11.1	0.14	455
PITT	4839.29	14	1.554	11.1	0.14	455
PITT	4880.20	14	1.554	11.1	0.14	455
PITT	5168.76	14	1.554	11.1	0.14	455
PITT	6318.12	14	1.554	11.1	0.14	455
PITT	6343.34	14	1.554	11.1	0.14	455
GENE	1819.7	14	1.554	11.1	0.14	455
GENE	5815.24	14	1.554	11.1	0.14	455
CIGR	1826.55	14	1.554	11.1	0.14	455
AXSL	1680.61	14	1.554	11.1	0.14	455
PINH	2363.29	14	1.554	11.1	0.14	455
PINH	2483.29	14	1.554	11.1	0.14	455
PINH	2491.72	14	1.554	11.1	0.14	455
PINH	2552.01	14	1.554	11.1	0.14	455
PINH	3083.34	14	1.554	11.1	0.14	455
PINH	3503.66	14	1.554	11.1	0.14	455
PINH	3680.05	14	1.554	11.1	0.14	455
PINH	4772.33	14	1.554	11.1	0.14	455
PINH	5557.59	14	1.554	11.1	0.14	455
PINH	6002.39	14	1.554	11.1	0.14	455
PITT	1293.91	13	1.443	11.1	0.13	455
PITT	1682.71	13	1.443	11.1	0.13	455

PITT	1819.19	13	1.443	11.1	0.13	455
PITT	2811.40	13	1.443	11.1	0.13	455
PITT	3180.89	13	1.443	11.1	0.13	455
PITT	3484.97	13	1.443	11.1	0.13	455
PITT	3844.24	13	1.443	11.1	0.13	455
PITT	3848.83	13	1.443	11.1	0.13	455
PITT	3871.81	13	1.443	11.1	0.13	455
PITT	3871.97	13	1.443	11.1	0.13	455
PITT	3872.28	13	1.443	11.1	0.13	455
PITT	4173.28	13	1.443	11.1	0.13	455
PITT	4463.55	13	1.443	11.1	0.13	455
PITT	4511.75	13	1.443	11.1	0.13	455
PITT	4616.50	13	1.443	11.1	0.13	455
PITT	4734.76	13	1.443	11.1	0.13	455
PITT	4880.04	13	1.443	11.1	0.13	455
PITT	4880.10	13	1.443	11.1	0.13	455
PITT	5400.14	13	1.443	11.1	0.13	455
PITT	5574.41	13	1.443	11.1	0.13	455
PITT	5742.44	13	1.443	11.1	0.13	455
PITT	5816.83	13	1.443	11.1	0.13	455
PITT	6110.40	13	1.443	11.1	0.13	455
PITT	6454.67	13	1.443	11.1	0.13	455
PITT	6535.02	13	1.443	11.1	0.13	455
PITT	6584.67	13	1.443	11.1	0.13	455
GENE	3251.68	13	1.443	11.1	0.13	455
GENE	3995.58	13	1.443	11.1	0.13	455
GENE	4044.58	13	1.443	11.1	0.13	455
AXSL	1679.22	13	1.443	11.1	0.13	455
PINH	1287.86	13	1.443	11.1	0.13	455
PINH	1381.24	13	1.443	11.1	0.13	455
PINH	2362.75	13	1.443	11.1	0.13	455
PINH	2609.36	13	1.443	11.1	0.13	455
PINH	3820.40	13	1.443	11.1	0.13	455
PINH	3849.19	13	1.443	11.1	0.13	455
PINH	4014.26	13	1.443	11.1	0.13	455
PINH	4018.97	13	1.443	11.1	0.13	455
PINH	4079.73	13	1.443	11.1	0.13	455
PINH	4660.15	13	1.443	11.1	0.13	455
PINH	4823.12	13	1.443	11.1	0.13	455
PINH	4829.22	13	1.443	11.1	0.13	455
PINH	5341.50	13	1.443	11.1	0.13	455
PINH	5401.18	13	1.443	11.1	0.13	455
PINH	5814.84	13	1.443	11.1	0.13	455
PINH	5815.60	13	1.443	11.1	0.13	455
PINH	5977.76	13	1.443	11.1	0.13	455
PINH	6106.85	13	1.443	11.1	0.13	455
PINH	6110.23	13	1.443	11.1	0.13	455
PINH	6181.41	13	1.443	11.1	0.13	455
PINH	6436.23	13	1.443	11.1	0.13	455

PITT	1381.64	12	1.332	11.1	0.12	455
PITT	1681.94	12	1.332	11.1	0.12	455
PITT	2156.78	12	1.332	11.1	0.12	455
PITT	2365.23	12	1.332	11.1	0.12	455
PITT	2365.83	12	1.332	11.1	0.12	455
PITT	2491.79	12	1.332	11.1	0.12	455
PITT	2633.47	12	1.332	11.1	0.12	455
PITT	2634.13	12	1.332	11.1	0.12	455
PITT	2826.08	12	1.332	11.1	0.12	455
PITT	2836.34	12	1.332	11.1	0.12	455
PITT	2867.76	12	1.332	11.1	0.12	455
PITT	2921.05	12	1.332	11.1	0.12	455
PITT	3848.35	12	1.332	11.1	0.12	455
PITT	3886.86	12	1.332	11.1	0.12	455
PITT	3930.55	12	1.332	11.1	0.12	455
PITT	4333.67	12	1.332	11.1	0.12	455
PITT	4525.58	12	1.332	11.1	0.12	455
PITT	4533.49	12	1.332	11.1	0.12	455
PITT	4879.79	12	1.332	11.1	0.12	455
PITT	5637.94	12	1.332	11.1	0.12	455
PITT	6012.42	12	1.332	11.1	0.12	455
PITT	6535.89	12	1.332	11.1	0.12	455
PITT	6747.81	12	1.332	11.1	0.12	455
AXGR	4419.12	12	1.332	11.1	0.12	455
CISL	6484.16	12	1.332	11.1	0.12	455
PINH	1827.72	12	1.332	11.1	0.12	455
PINH	2279.04	12	1.332	11.1	0.12	455
PINH	2415.52	12	1.332	11.1	0.12	455
PINH	2430.25	12	1.332	11.1	0.12	455
PINH	2612.22	12	1.332	11.1	0.12	455
PINH	2616.72	12	1.332	11.1	0.12	455
PINH	2972.31	12	1.332	11.1	0.12	455
PINH	3047.86	12	1.332	11.1	0.12	455
PINH	3048.57	12	1.332	11.1	0.12	455
PINH	3434.75	12	1.332	11.1	0.12	455
PINH	3444.50	12	1.332	11.1	0.12	455
PINH	3538.80	12	1.332	11.1	0.12	455
PINH	3538.80	12	1.332	11.1	0.12	455
PINH	3695.55	12	1.332	11.1	0.12	455
PINH	3842.27	12	1.332	11.1	0.12	455
PINH	3842.70	12	1.332	11.1	0.12	455
PINH	3847.19	12	1.332	11.1	0.12	455
PINH	3860.84	12	1.332	11.1	0.12	455
PINH	3888.06	12	1.332	11.1	0.12	455
PINH	3999.23	12	1.332	11.1	0.12	455
PINH	4376.84	12	1.332	11.1	0.12	455
PINH	4514.46	12	1.332	11.1	0.12	455
PINH	5043.62	12	1.332	11.1	0.12	455
PINH	5401.74	12	1.332	11.1	0.12	455

PINH	5404.87	12	1.332	11.1	0.12	455
PINH	5405.49	12	1.332	11.1	0.12	455
PINH	5527.42	12	1.332	11.1	0.12	455
PINH	5650.48	12	1.332	11.1	0.12	455
PINH	6019.57	12	1.332	11.1	0.12	455
PINH	6106.17	12	1.332	11.1	0.12	455
PINH	6107.84	12	1.332	11.1	0.12	455
PINH	6293.76	12	1.332	11.1	0.12	455

Appendix IV: Projected ILI data year 2006 (sorted according to % defect depth)

First part (0-1000m)

	Distance, m	Depth, %	Depth, mm	Projected Depth, mm	Projected Depth, %	WT, mm	d/t	TS	YS
GENE	211.94	46	5.106	5.294	48	11.1	0.48	455	358
PINH	114.58	46	5.106	5.294	48	11.1	0.48	455	358
GENE	295.42	45	4.995	5.183	47	11.1	0.47	455	358
PITT	307.32	45	4.995	5.183	47	11.1	0.47	455	358
GENE	150.34	43	4.773	4.961	45	11.1	0.45	455	358
GENE	122.89	41	4.551	4.739	43	11.1	0.43	455	358
GENE	212.23	41	4.551	4.739	43	11.1	0.43	455	358
GENE	486.83	41	4.551	4.739	43	11.1	0.43	455	358
GENE	122.73	40	4.44	4.628	42	11.1	0.42	455	358
GENE	125.01	40	4.44	4.628	42	11.1	0.42	455	358
GENE	200.01	40	4.44	4.628	42	11.1	0.42	455	358
GENE	271.51	40	4.44	4.628	42	11.1	0.42	455	358
GENE	118.16	39	4.329	4.517	41	11.1	0.41	455	358
GENE	125.38	39	4.329	4.517	41	11.1	0.41	455	358
GENE	148.59	39	4.329	4.517	41	11.1	0.41	455	358
GENE	215.11	39	4.329	4.517	41	11.1	0.41	455	358
GENE	259.71	39	4.329	4.517	41	11.1	0.41	455	358
AXGR	217.35	38	4.218	4.406	40	11.1	0.40	455	358
AXGR	343.03	38	4.218	4.406	40	11.1	0.40	455	358
GENE	117.44	38	4.218	4.406	40	11.1	0.40	455	358
GENE	121.52	38	4.218	4.406	40	11.1	0.40	455	358
GENE	200.33	38	4.218	4.406	40	11.1	0.40	455	358
GENE	271.73	38	4.218	4.406	40	11.1	0.40	455	358
GENE	331.1	38	4.218	4.406	40	11.1	0.40	455	358
PITT	117.44	38	4.218	4.406	40	11.1	0.40	455	358
AXGR	207.92	37	4.107	4.295	39	11.1	0.39	455	358

CISL	118.75	37	4.107	4.295	39	11.1	0.39	455	358
GENE	112.63	37	4.107	4.295	39	11.1	0.39	455	358
GENE	120.39	37	4.107	4.295	39	11.1	0.39	455	358
GENE	121.84	37	4.107	4.295	39	11.1	0.39	455	358
GENE	209.49	37	4.107	4.295	39	11.1	0.39	455	358
GENE	283.69	37	4.107	4.295	39	11.1	0.39	455	358
PITT	200.18	37	4.107	4.295	39	11.1	0.39	455	358
PITT	217.32	37	4.107	4.295	39	11.1	0.39	455	358
GENE	117.31	36	3.996	4.184	38	11.1	0.38	455	358
GENE	120.61	36	3.996	4.184	38	11.1	0.38	455	358
GENE	125.73	36	3.996	4.184	38	11.1	0.38	455	358
GENE	207.32	36	3.996	4.184	38	11.1	0.38	455	358
GENE	208.35	36	3.996	4.184	38	11.1	0.38	455	358
PITT	120.45	36	3.996	4.184	38	11.1	0.38	455	358
CIGR	127.58	35	3.885	4.073	37	11.1	0.37	455	358
GENE	125.07	35	3.885	4.073	37	11.1	0.37	455	358
GENE	125.15	35	3.885	4.073	37	11.1	0.37	455	358
GENE	153	35	3.885	4.073	37	11.1	0.37	455	358
GENE	185.43	35	3.885	4.073	37	11.1	0.37	455	358
GENE	203.7	35	3.885	4.073	37	11.1	0.37	455	358
GENE	207.84	35	3.885	4.073	37	11.1	0.37	455	358
GENE	210.76	35	3.885	4.073	37	11.1	0.37	455	358
GENE	213.62	35	3.885	4.073	37	11.1	0.37	455	358
PITT	197.59	35	3.885	4.073	37	11.1	0.37	455	358
PITT	307.62	35	3.885	4.073	37	11.1	0.37	455	358
PITT	331.16	35	3.885	4.073	37	11.1	0.37	455	358
AXGR	182.5	34	3.774	3.962	36	11.1	0.36	455	358
GENE	111.52	34	3.774	3.962	36	11.1	0.36	455	358
GENE	118.9	34	3.774	3.962	36	11.1	0.36	455	358
GENE	121.51	34	3.774	3.962	36	11.1	0.36	455	358
GENE	121.99	34	3.774	3.962	36	11.1	0.36	455	358
GENE	208.54	34	3.774	3.962	36	11.1	0.36	455	358

PITT	177.92	34	3.774	3.962	36	11.1	0.36	455	358
PITT	293.48	34	3.774	3.962	36	11.1	0.36	455	358
AXGR	120.45	33	3.663	3.851	35	11.1	0.35	455	358
AXSL	113.54	33	3.663	3.851	35	11.1	0.35	455	358
CIGR	115.2	33	3.663	3.851	35	11.1	0.35	455	358
CIGR	116.1	33	3.663	3.851	35	11.1	0.35	455	358
CIGR	121.67	33	3.663	3.851	35	11.1	0.35	455	358
GENE	116.34	33	3.663	3.851	35	11.1	0.35	455	358
GENE	118.58	33	3.663	3.851	35	11.1	0.35	455	358
GENE	118.97	33	3.663	3.851	35	11.1	0.35	455	358
GENE	122.59	33	3.663	3.851	35	11.1	0.35	455	358
GENE	122.66	33	3.663	3.851	35	11.1	0.35	455	358
GENE	122.96	33	3.663	3.851	35	11.1	0.35	455	358
GENE	131.02	33	3.663	3.851	35	11.1	0.35	455	358
GENE	147.88	33	3.663	3.851	35	11.1	0.35	455	358
GENE	151.46	33	3.663	3.851	35	11.1	0.35	455	358
GENE	154.06	33	3.663	3.851	35	11.1	0.35	455	358
GENE	260.01	33	3.663	3.851	35	11.1	0.35	455	358
PITT	127.60	33	3.663	3.851	35	11.1	0.35	455	358
PITT	207.49	33	3.663	3.851	35	11.1	0.35	455	358
PITT	208.71	33	3.663	3.851	35	11.1	0.35	455	358
PITT	211.91	33	3.663	3.851	35	11.1	0.35	455	358
AXGR	131.35	32	3.552	3.74	34	11.1	0.34	455	358
AXGR	207.56	32	3.552	3.74	34	11.1	0.34	455	358
GENE	121.43	32	3.552	3.74	34	11.1	0.34	455	358
GENE	124.5	32	3.552	3.74	34	11.1	0.34	455	358
GENE	129.28	32	3.552	3.74	34	11.1	0.34	455	358
GENE	208.82	32	3.552	3.74	34	11.1	0.34	455	358
GENE	208.96	32	3.552	3.74	34	11.1	0.34	455	358
GENE	210.22	32	3.552	3.74	34	11.1	0.34	455	358
GENE	213.17	32	3.552	3.74	34	11.1	0.34	455	358
PINH	129.28	32	3.552	3.74	34	11.1	0.34	455	358

PITT	122.65	32	3.552	3.74	34	11.1	0.34	455	358
PITT	208.80	32	3.552	3.74	34	11.1	0.34	455	358
AXGR	198.81	31	3.441	3.629	33	11.1	0.33	455	358
AXGR	208.71	31	3.441	3.629	33	11.1	0.33	455	358
GENE	115.46	31	3.441	3.629	33	11.1	0.33	455	358
GENE	120.17	31	3.441	3.629	33	11.1	0.33	455	358
GENE	121.01	31	3.441	3.629	33	11.1	0.33	455	358
GENE	126.77	31	3.441	3.629	33	11.1	0.33	455	358
GENE	153.83	31	3.441	3.629	33	11.1	0.33	455	358
GENE	153.83	31	3.441	3.629	33	11.1	0.33	455	358
GENE	156.17	31	3.441	3.629	33	11.1	0.33	455	358
GENE	181.89	31	3.441	3.629	33	11.1	0.33	455	358
GENE	202.63	31	3.441	3.629	33	11.1	0.33	455	358
GENE	203.53	31	3.441	3.629	33	11.1	0.33	455	358
GENE	208.06	31	3.441	3.629	33	11.1	0.33	455	358
GENE	209.15	31	3.441	3.629	33	11.1	0.33	455	358
GENE	230.05	31	3.441	3.629	33	11.1	0.33	455	358
PINH	206.64	31	3.441	3.629	33	11.1	0.33	455	358
PITT	100.10	31	3.441	3.629	33	11.1	0.33	455	358
PITT	118.44	31	3.441	3.629	33	11.1	0.33	455	358
PITT	175.20	31	3.441	3.629	33	11.1	0.33	455	358
PITT	188.53	31	3.441	3.629	33	11.1	0.33	455	358
PITT	192.99	31	3.441	3.629	33	11.1	0.33	455	358
PITT	197.56	31	3.441	3.629	33	11.1	0.33	455	358
PITT	247.36	31	3.441	3.629	33	11.1	0.33	455	358
PITT	323.04	31	3.441	3.629	33	11.1	0.33	455	358
AXGR	118.04	30	3.33	3.518	32	11.1	0.32	455	358
AXGR	210.47	30	3.33	3.518	32	11.1	0.32	455	358
AXGR	213.57	30	3.33	3.518	32	11.1	0.32	455	358
AXSL	121.25	30	3.33	3.518	32	11.1	0.32	455	358
GENE	132.13	30	3.33	3.518	32	11.1	0.32	455	358
GENE	187.55	30	3.33	3.518	32	11.1	0.32	455	358

GENE	190.74	30	3.33	3.518	32	11.1	0.32	455	358
GENE	213.45	30	3.33	3.518	32	11.1	0.32	455	358
GENE	238.17	30	3.33	3.518	32	11.1	0.32	455	358
GENE	271.76	30	3.33	3.518	32	11.1	0.32	455	358
PINH	209.27	30	3.33	3.518	32	11.1	0.32	455	358
PITT	121.25	30	3.33	3.518	32	11.1	0.32	455	358
PITT	187.55	30	3.33	3.518	32	11.1	0.32	455	358
PITT	195.99	30	3.33	3.518	32	11.1	0.32	455	358
PITT	212.19	30	3.33	3.518	32	11.1	0.32	455	358
PITT	234.42	30	3.33	3.518	32	11.1	0.32	455	358
PITT	259.71	30	3.33	3.518	32	11.1	0.32	455	358
PITT	281.87	30	3.33	3.518	32	11.1	0.32	455	358
PITT	295.58	30	3.33	3.518	32	11.1	0.32	455	358
AXGR	195.75	29	3.219	3.407	31	11.1	0.31	455	358
AXGR	229.76	29	3.219	3.407	31	11.1	0.31	455	358
AXSL	110.45	29	3.219	3.407	31	11.1	0.31	455	358
AXSL	237.95	29	3.219	3.407	31	11.1	0.31	455	358
CISL	246.9	29	3.219	3.407	31	11.1	0.31	455	358
CISL	248.3	29	3.219	3.407	31	11.1	0.31	455	358
GENE	113.56	29	3.219	3.407	31	11.1	0.31	455	358
GENE	115.42	29	3.219	3.407	31	11.1	0.31	455	358
GENE	123.70	29	3.219	3.407	31	11.1	0.31	455	358
GENE	127.24	29	3.219	3.407	31	11.1	0.31	455	358
GENE	128.16	29	3.219	3.407	31	11.1	0.31	455	358
GENE	129.3	29	3.219	3.407	31	11.1	0.31	455	358
GENE	158.74	29	3.219	3.407	31	11.1	0.31	455	358
GENE	159.69	29	3.219	3.407	31	11.1	0.31	455	358
GENE	197.67	29	3.219	3.407	31	11.1	0.31	455	358
GENE	203.64	29	3.219	3.407	31	11.1	0.31	455	358
GENE	212.19	29	3.219	3.407	31	11.1	0.31	455	358
GENE	213.87	29	3.219	3.407	31	11.1	0.31	455	358
GENE	218.22	29	3.219	3.407	31	11.1	0.31	455	358

GENE	221.93	29	3.219	3.407	31	11.1	0.31	455	358
PITT	117.39	29	3.219	3.407	31	11.1	0.31	455	358
PITT	118.73	29	3.219	3.407	31	11.1	0.31	455	358
PITT	121.87	29	3.219	3.407	31	11.1	0.31	455	358
PITT	123.62	29	3.219	3.407	31	11.1	0.31	455	358
PITT	134.45	29	3.219	3.407	31	11.1	0.31	455	358
PITT	156.97	29	3.219	3.407	31	11.1	0.31	455	358
PITT	158.74	29	3.219	3.407	31	11.1	0.31	455	358
PITT	158.97	29	3.219	3.407	31	11.1	0.31	455	358
PITT	194.05	29	3.219	3.407	31	11.1	0.31	455	358
PITT	207.67	29	3.219	3.407	31	11.1	0.31	455	358
PITT	210.66	29	3.219	3.407	31	11.1	0.31	455	358
PITT	221.93	29	3.219	3.407	31	11.1	0.31	455	358
PITT	229.60	29	3.219	3.407	31	11.1	0.31	455	358
PITT	234.26	29	3.219	3.407	31	11.1	0.31	455	358
PITT	271.76	29	3.219	3.407	31	11.1	0.31	455	358
PITT	282.50	29	3.219	3.407	31	11.1	0.31	455	358
PITT	319.22	29	3.219	3.407	31	11.1	0.31	455	358
AXGR	319.44	28	3.108	3.296	30	11.1	0.30	455	358
CISL	246.7	28	3.108	3.296	30	11.1	0.30	455	358
GENE	115.32	28	3.108	3.296	30	11.1	0.30	455	358
GENE	115.46	28	3.108	3.296	30	11.1	0.30	455	358
GENE	122.86	28	3.108	3.296	30	11.1	0.30	455	358
GENE	124.35	28	3.108	3.296	30	11.1	0.30	455	358
GENE	183.04	28	3.108	3.296	30	11.1	0.30	455	358
GENE	185.61	28	3.108	3.296	30	11.1	0.30	455	358
GENE	188.45	28	3.108	3.296	30	11.1	0.30	455	358
GENE	195.7	28	3.108	3.296	30	11.1	0.30	455	358
GENE	211.42	28	3.108	3.296	30	11.1	0.30	455	358
GENE	213.4	28	3.108	3.296	30	11.1	0.30	455	358
GENE	244.34	28	3.108	3.296	30	11.1	0.30	455	358
GENE	248.15	28	3.108	3.296	30	11.1	0.30	455	358

GENE	280.16	28	3.108	3.296	30	11.1	0.30	455	358
GENE	295.64	28	3.108	3.296	30	11.1	0.30	455	358
PITT	108.58	28	3.108	3.296	30	11.1	0.30	455	358
PITT	119.70	28	3.108	3.296	30	11.1	0.30	455	358
PITT	125.49	28	3.108	3.296	30	11.1	0.30	455	358
PITT	128.66	28	3.108	3.296	30	11.1	0.30	455	358
PITT	140.96	28	3.108	3.296	30	11.1	0.30	455	358
PITT	148.78	28	3.108	3.296	30	11.1	0.30	455	358
PITT	158.96	28	3.108	3.296	30	11.1	0.30	455	358
PITT	193.88	28	3.108	3.296	30	11.1	0.30	455	358
PITT	195.85	28	3.108	3.296	30	11.1	0.30	455	358
PITT	204.41	28	3.108	3.296	30	11.1	0.30	455	358
PITT	205.56	28	3.108	3.296	30	11.1	0.30	455	358
PITT	207.68	28	3.108	3.296	30	11.1	0.30	455	358

Appendix V: Projected ILI data year 2009 (sorted according to % defect depth)

First part (0-1000m)

	Distance, m	Depth, %	Depth, mm	Projected Depth, mm	Projected Depth, %	WT, mm	d/t	TS	YS
GENE	211.94	46	5.106	5.858	53	11.1	0.53	455	358
PINH	114.58	46	5.106	5.858	53	11.1	0.53	455	358
GENE	295.42	45	4.995	5.747	52	11.1	0.52	455	358
PITT	307.32	45	4.995	5.747	52	11.1	0.52	455	358
GENE	150.34	43	4.773	5.525	50	11.1	0.50	455	358
GENE	122.89	41	4.551	5.303	48	11.1	0.48	455	358
GENE	212.23	41	4.551	5.303	48	11.1	0.48	455	358
GENE	486.83	41	4.551	5.303	48	11.1	0.48	455	358
GENE	122.73	40	4.44	5.192	47	11.1	0.47	455	358

GENE	125.01	40	4.44	5.192	47	11.1	0.47	455	358
GENE	200.01	40	4.44	5.192	47	11.1	0.47	455	358
GENE	271.51	40	4.44	5.192	47	11.1	0.47	455	358
GENE	118.16	39	4.329	5.081	46	11.1	0.46	455	358
GENE	125.38	39	4.329	5.081	46	11.1	0.46	455	358
GENE	148.59	39	4.329	5.081	46	11.1	0.46	455	358
GENE	215.11	39	4.329	5.081	46	11.1	0.46	455	358
GENE	259.71	39	4.329	5.081	46	11.1	0.46	455	358
AXGR	217.35	38	4.218	4.97	45	11.1	0.45	455	358
AXGR	343.03	38	4.218	4.97	45	11.1	0.45	455	358
GENE	117.44	38	4.218	4.97	45	11.1	0.45	455	358
GENE	121.52	38	4.218	4.97	45	11.1	0.45	455	358
GENE	200.33	38	4.218	4.97	45	11.1	0.45	455	358
GENE	271.73	38	4.218	4.97	45	11.1	0.45	455	358
GENE	331.1	38	4.218	4.97	45	11.1	0.45	455	358
PITT	117.44	38	4.218	4.97	45	11.1	0.45	455	358
AXGR	207.92	37	4.107	4.859	44	11.1	0.44	455	358
CISL	118.75	37	4.107	4.859	44	11.1	0.44	455	358
GENE	112.63	37	4.107	4.859	44	11.1	0.44	455	358
GENE	120.39	37	4.107	4.859	44	11.1	0.44	455	358
GENE	121.84	37	4.107	4.859	44	11.1	0.44	455	358
GENE	209.49	37	4.107	4.859	44	11.1	0.44	455	358
GENE	283.69	37	4.107	4.859	44	11.1	0.44	455	358
PITT	200.18	37	4.107	4.859	44	11.1	0.44	455	358
PITT	217.32	37	4.107	4.859	44	11.1	0.44	455	358
GENE	117.31	36	3.996	4.748	43	11.1	0.43	455	358
GENE	120.61	36	3.996	4.748	43	11.1	0.43	455	358
GENE	125.73	36	3.996	4.748	43	11.1	0.43	455	358
GENE	207.32	36	3.996	4.748	43	11.1	0.43	455	358
GENE	208.35	36	3.996	4.748	43	11.1	0.43	455	358
PITT	120.45	36	3.996	4.748	43	11.1	0.43	455	358
CIGR	127.58	35	3.885	4.637	42	11.1	0.42	455	358

GENE	125.07	35	3.885	4.637	42	11.1	0.42	455	358
GENE	125.15	35	3.885	4.637	42	11.1	0.42	455	358
GENE	153	35	3.885	4.637	42	11.1	0.42	455	358
GENE	185.43	35	3.885	4.637	42	11.1	0.42	455	358
GENE	203.7	35	3.885	4.637	42	11.1	0.42	455	358
GENE	207.84	35	3.885	4.637	42	11.1	0.42	455	358
GENE	210.76	35	3.885	4.637	42	11.1	0.42	455	358
GENE	213.62	35	3.885	4.637	42	11.1	0.42	455	358
PITT	197.59	35	3.885	4.637	42	11.1	0.42	455	358
PITT	307.62	35	3.885	4.637	42	11.1	0.42	455	358
PITT	331.16	35	3.885	4.637	42	11.1	0.42	455	358
AXGR	182.5	34	3.774	4.526	41	11.1	0.41	455	358
GENE	111.52	34	3.774	4.526	41	11.1	0.41	455	358
GENE	118.9	34	3.774	4.526	41	11.1	0.41	455	358
GENE	121.51	34	3.774	4.526	41	11.1	0.41	455	358
GENE	121.99	34	3.774	4.526	41	11.1	0.41	455	358
GENE	208.54	34	3.774	4.526	41	11.1	0.41	455	358
PITT	177.92	34	3.774	4.526	41	11.1	0.41	455	358
PITT	293.48	34	3.774	4.526	41	11.1	0.41	455	358
AXGR	120.45	33	3.663	4.415	40	11.1	0.40	455	358
AXSL	113.54	33	3.663	4.415	40	11.1	0.40	455	358
CIGR	115.2	33	3.663	4.415	40	11.1	0.40	455	358
CIGR	116.1	33	3.663	4.415	40	11.1	0.40	455	358
CIGR	121.67	33	3.663	4.415	40	11.1	0.40	455	358
GENE	116.34	33	3.663	4.415	40	11.1	0.40	455	358
GENE	118.58	33	3.663	4.415	40	11.1	0.40	455	358
GENE	118.97	33	3.663	4.415	40	11.1	0.40	455	358
GENE	122.59	33	3.663	4.415	40	11.1	0.40	455	358
GENE	122.66	33	3.663	4.415	40	11.1	0.40	455	358
GENE	122.96	33	3.663	4.415	40	11.1	0.40	455	358
GENE	131.02	33	3.663	4.415	40	11.1	0.40	455	358
GENE	147.88	33	3.663	4.415	40	11.1	0.40	455	358

GENE	151.46	33	3.663	4.415	40	11.1	0.40	455	358
GENE	154.06	33	3.663	4.415	40	11.1	0.40	455	358
GENE	260.01	33	3.663	4.415	40	11.1	0.40	455	358
PITT	127.60	33	3.663	4.415	40	11.1	0.40	455	358
PITT	207.49	33	3.663	4.415	40	11.1	0.40	455	358
PITT	208.71	33	3.663	4.415	40	11.1	0.40	455	358
PITT	211.91	33	3.663	4.415	40	11.1	0.40	455	358
AXGR	131.35	32	3.552	4.304	39	11.1	0.39	455	358
AXGR	207.56	32	3.552	4.304	39	11.1	0.39	455	358
GENE	121.43	32	3.552	4.304	39	11.1	0.39	455	358
GENE	124.5	32	3.552	4.304	39	11.1	0.39	455	358
GENE	129.28	32	3.552	4.304	39	11.1	0.39	455	358
GENE	208.82	32	3.552	4.304	39	11.1	0.39	455	358
GENE	208.96	32	3.552	4.304	39	11.1	0.39	455	358
GENE	210.22	32	3.552	4.304	39	11.1	0.39	455	358
GENE	213.17	32	3.552	4.304	39	11.1	0.39	455	358
PINH	129.28	32	3.552	4.304	39	11.1	0.39	455	358
PITT	122.65	32	3.552	4.304	39	11.1	0.39	455	358
PITT	208.80	32	3.552	4.304	39	11.1	0.39	455	358
AXGR	198.81	31	3.441	4.193	38	11.1	0.38	455	358
AXGR	208.71	31	3.441	4.193	38	11.1	0.38	455	358
GENE	115.46	31	3.441	4.193	38	11.1	0.38	455	358
GENE	120.17	31	3.441	4.193	38	11.1	0.38	455	358
GENE	121.01	31	3.441	4.193	38	11.1	0.38	455	358
GENE	126.77	31	3.441	4.193	38	11.1	0.38	455	358
GENE	153.83	31	3.441	4.193	38	11.1	0.38	455	358
GENE	153.83	31	3.441	4.193	38	11.1	0.38	455	358
GENE	156.17	31	3.441	4.193	38	11.1	0.38	455	358
GENE	181.89	31	3.441	4.193	38	11.1	0.38	455	358
GENE	202.63	31	3.441	4.193	38	11.1	0.38	455	358
GENE	203.53	31	3.441	4.193	38	11.1	0.38	455	358
GENE	208.06	31	3.441	4.193	38	11.1	0.38	455	358

GENE	209.15	31	3.441	4.193	38	11.1	0.38	455	358
GENE	230.05	31	3.441	4.193	38	11.1	0.38	455	358
PINH	206.64	31	3.441	4.193	38	11.1	0.38	455	358
PITT	100.10	31	3.441	4.193	38	11.1	0.38	455	358
PITT	118.44	31	3.441	4.193	38	11.1	0.38	455	358
PITT	175.20	31	3.441	4.193	38	11.1	0.38	455	358
PITT	188.53	31	3.441	4.193	38	11.1	0.38	455	358
PITT	192.99	31	3.441	4.193	38	11.1	0.38	455	358
PITT	197.56	31	3.441	4.193	38	11.1	0.38	455	358
PITT	247.36	31	3.441	4.193	38	11.1	0.38	455	358
PITT	323.04	31	3.441	4.193	38	11.1	0.38	455	358
AXGR	118.04	30	3.33	4.082	37	11.1	0.37	455	358
AXGR	210.47	30	3.33	4.082	37	11.1	0.37	455	358
AXGR	213.57	30	3.33	4.082	37	11.1	0.37	455	358
AXSL	121.25	30	3.33	4.082	37	11.1	0.37	455	358
GENE	132.13	30	3.33	4.082	37	11.1	0.37	455	358
GENE	187.55	30	3.33	4.082	37	11.1	0.37	455	358
GENE	190.74	30	3.33	4.082	37	11.1	0.37	455	358
GENE	213.45	30	3.33	4.082	37	11.1	0.37	455	358
GENE	238.17	30	3.33	4.082	37	11.1	0.37	455	358
GENE	271.76	30	3.33	4.082	37	11.1	0.37	455	358
PINH	209.27	30	3.33	4.082	37	11.1	0.37	455	358
PITT	121.25	30	3.33	4.082	37	11.1	0.37	455	358
PITT	187.55	30	3.33	4.082	37	11.1	0.37	455	358
PITT	195.99	30	3.33	4.082	37	11.1	0.37	455	358
PITT	212.19	30	3.33	4.082	37	11.1	0.37	455	358
PITT	234.42	30	3.33	4.082	37	11.1	0.37	455	358
PITT	259.71	30	3.33	4.082	37	11.1	0.37	455	358
PITT	281.87	30	3.33	4.082	37	11.1	0.37	455	358
PITT	295.58	30	3.33	4.082	37	11.1	0.37	455	358
AXGR	195.75	29	3.219	3.971	36	11.1	0.36	455	358
AXGR	229.76	29	3.219	3.971	36	11.1	0.36	455	358

AXSL	110.45	29	3.219	3.971	36	11.1	0.36	455	358
AXSL	237.95	29	3.219	3.971	36	11.1	0.36	455	358
CISL	246.9	29	3.219	3.971	36	11.1	0.36	455	358
CISL	248.3	29	3.219	3.971	36	11.1	0.36	455	358
GENE	113.56	29	3.219	3.971	36	11.1	0.36	455	358
GENE	115.42	29	3.219	3.971	36	11.1	0.36	455	358
GENE	123.70	29	3.219	3.971	36	11.1	0.36	455	358
GENE	127.24	29	3.219	3.971	36	11.1	0.36	455	358
GENE	128.16	29	3.219	3.971	36	11.1	0.36	455	358
GENE	129.3	29	3.219	3.971	36	11.1	0.36	455	358
GENE	158.74	29	3.219	3.971	36	11.1	0.36	455	358
GENE	159.69	29	3.219	3.971	36	11.1	0.36	455	358
GENE	197.67	29	3.219	3.971	36	11.1	0.36	455	358
GENE	203.64	29	3.219	3.971	36	11.1	0.36	455	358
GENE	212.19	29	3.219	3.971	36	11.1	0.36	455	358
GENE	213.87	29	3.219	3.971	36	11.1	0.36	455	358
GENE	218.22	29	3.219	3.971	36	11.1	0.36	455	358
GENE	221.93	29	3.219	3.971	36	11.1	0.36	455	358
PITT	117.39	29	3.219	3.971	36	11.1	0.36	455	358
PITT	118.73	29	3.219	3.971	36	11.1	0.36	455	358
PITT	121.87	29	3.219	3.971	36	11.1	0.36	455	358
PITT	123.62	29	3.219	3.971	36	11.1	0.36	455	358
PITT	134.45	29	3.219	3.971	36	11.1	0.36	455	358
PITT	156.97	29	3.219	3.971	36	11.1	0.36	455	358
PITT	158.74	29	3.219	3.971	36	11.1	0.36	455	358
PITT	158.97	29	3.219	3.971	36	11.1	0.36	455	358
PITT	194.05	29	3.219	3.971	36	11.1	0.36	455	358
PITT	207.67	29	3.219	3.971	36	11.1	0.36	455	358
PITT	210.66	29	3.219	3.971	36	11.1	0.36	455	358
PITT	221.93	29	3.219	3.971	36	11.1	0.36	455	358
PITT	229.60	29	3.219	3.971	36	11.1	0.36	455	358
PITT	234.26	29	3.219	3.971	36	11.1	0.36	455	358

PITT	271.76	29	3.219	3.971	36	11.1	0.36	455	358
PITT	282.50	29	3.219	3.971	36	11.1	0.36	455	358
PITT	319.22	29	3.219	3.971	36	11.1	0.36	455	358
AXGR	319.44	28	3.108	3.86	35	11.1	0.35	455	358
CISL	246.7	28	3.108	3.86	35	11.1	0.35	455	358
GENE	115.32	28	3.108	3.86	35	11.1	0.35	455	358
GENE	115.46	28	3.108	3.86	35	11.1	0.35	455	358
GENE	122.86	28	3.108	3.86	35	11.1	0.35	455	358
GENE	124.35	28	3.108	3.86	35	11.1	0.35	455	358
GENE	183.04	28	3.108	3.86	35	11.1	0.35	455	358
GENE	185.61	28	3.108	3.86	35	11.1	0.35	455	358
GENE	188.45	28	3.108	3.86	35	11.1	0.35	455	358
GENE	195.7	28	3.108	3.86	35	11.1	0.35	455	358
GENE	211.42	28	3.108	3.86	35	11.1	0.35	455	358
GENE	213.4	28	3.108	3.86	35	11.1	0.35	455	358
GENE	244.34	28	3.108	3.86	35	11.1	0.35	455	358
GENE	248.15	28	3.108	3.86	35	11.1	0.35	455	358
GENE	280.16	28	3.108	3.86	35	11.1	0.35	455	358
GENE	295.64	28	3.108	3.86	35	11.1	0.35	455	358
PITT	108.58	28	3.108	3.86	35	11.1	0.35	455	358
PITT	119.70	28	3.108	3.86	35	11.1	0.35	455	358
PITT	125.49	28	3.108	3.86	35	11.1	0.35	455	358
PITT	128.66	28	3.108	3.86	35	11.1	0.35	455	358
PITT	140.96	28	3.108	3.86	35	11.1	0.35	455	358
PITT	148.78	28	3.108	3.86	35	11.1	0.35	455	358
PITT	158.96	28	3.108	3.86	35	11.1	0.35	455	358
PITT	193.88	28	3.108	3.86	35	11.1	0.35	455	358
PITT	195.85	28	3.108	3.86	35	11.1	0.35	455	358
PITT	204.41	28	3.108	3.86	35	11.1	0.35	455	358
PITT	205.56	28	3.108	3.86	35	11.1	0.35	455	358
PITT	207.68	28	3.108	3.86	35	11.1	0.35	455	358

Appendix VI: Projected ILI data year 2013 (sorted according to % defect depth)

First part (0-1000m)

	Distance, m	Depth, %	Depth, mm	Projected Depth, mm	Projected Depth, %	WT, mm	d/t	TS	YS
GENE	211.94	46	5.106	6.61	60	11.1	0.60	455	358
PINH	114.58	46	5.106	6.61	60	11.1	0.60	455	358
GENE	295.42	45	4.995	6.499	59	11.1	0.59	455	358
PITT	307.32	45	4.995	6.499	59	11.1	0.59	455	358
GENE	150.34	43	4.773	6.277	57	11.1	0.57	455	358
GENE	122.89	41	4.551	6.055	55	11.1	0.55	455	358
GENE	212.23	41	4.551	6.055	55	11.1	0.55	455	358
GENE	486.83	41	4.551	6.055	55	11.1	0.55	455	358
GENE	122.73	40	4.44	5.944	54	11.1	0.54	455	358
GENE	125.01	40	4.44	5.944	54	11.1	0.54	455	358
GENE	200.01	40	4.44	5.944	54	11.1	0.54	455	358
GENE	271.51	40	4.44	5.944	54	11.1	0.54	455	358
GENE	118.16	39	4.329	5.833	53	11.1	0.53	455	358
GENE	125.38	39	4.329	5.833	53	11.1	0.53	455	358
GENE	148.59	39	4.329	5.833	53	11.1	0.53	455	358
GENE	215.11	39	4.329	5.833	53	11.1	0.53	455	358
GENE	259.71	39	4.329	5.833	53	11.1	0.53	455	358
AXGR	217.35	38	4.218	5.722	52	11.1	0.52	455	358
AXGR	343.03	38	4.218	5.722	52	11.1	0.52	455	358
GENE	117.44	38	4.218	5.722	52	11.1	0.52	455	358
GENE	121.52	38	4.218	5.722	52	11.1	0.52	455	358
GENE	200.33	38	4.218	5.722	52	11.1	0.52	455	358
GENE	271.73	38	4.218	5.722	52	11.1	0.52	455	358
GENE	331.1	38	4.218	5.722	52	11.1	0.52	455	358
PITT	117.44	38	4.218	5.722	52	11.1	0.52	455	358
AXGR	207.92	37	4.107	5.611	51	11.1	0.51	455	358

CISL	118.75	37	4.107	5.611	51	11.1	0.51	455	358
GENE	112.63	37	4.107	5.611	51	11.1	0.51	455	358
GENE	120.39	37	4.107	5.611	51	11.1	0.51	455	358
GENE	121.84	37	4.107	5.611	51	11.1	0.51	455	358
GENE	209.49	37	4.107	5.611	51	11.1	0.51	455	358
GENE	283.69	37	4.107	5.611	51	11.1	0.51	455	358
PITT	200.18	37	4.107	5.611	51	11.1	0.51	455	358
PITT	217.32	37	4.107	5.611	51	11.1	0.51	455	358
GENE	117.31	36	3.996	5.5	50	11.1	0.50	455	358
GENE	120.61	36	3.996	5.5	50	11.1	0.50	455	358
GENE	125.73	36	3.996	5.5	50	11.1	0.50	455	358
GENE	207.32	36	3.996	5.5	50	11.1	0.50	455	358
GENE	208.35	36	3.996	5.5	50	11.1	0.50	455	358
PITT	120.45	36	3.996	5.5	50	11.1	0.50	455	358
CIGR	127.58	35	3.885	5.389	49	11.1	0.49	455	358
GENE	125.07	35	3.885	5.389	49	11.1	0.49	455	358
GENE	125.15	35	3.885	5.389	49	11.1	0.49	455	358
GENE	153	35	3.885	5.389	49	11.1	0.49	455	358
GENE	185.43	35	3.885	5.389	49	11.1	0.49	455	358
GENE	203.7	35	3.885	5.389	49	11.1	0.49	455	358
GENE	207.84	35	3.885	5.389	49	11.1	0.49	455	358
GENE	210.76	35	3.885	5.389	49	11.1	0.49	455	358
GENE	213.62	35	3.885	5.389	49	11.1	0.49	455	358
PITT	197.59	35	3.885	5.389	49	11.1	0.49	455	358
PITT	307.62	35	3.885	5.389	49	11.1	0.49	455	358
PITT	331.16	35	3.885	5.389	49	11.1	0.49	455	358
AXGR	182.5	34	3.774	5.278	48	11.1	0.48	455	358
GENE	111.52	34	3.774	5.278	48	11.1	0.48	455	358
GENE	118.9	34	3.774	5.278	48	11.1	0.48	455	358
GENE	121.51	34	3.774	5.278	48	11.1	0.48	455	358
GENE	121.99	34	3.774	5.278	48	11.1	0.48	455	358
GENE	208.54	34	3.774	5.278	48	11.1	0.48	455	358

PITT	177.92	34	3.774	5.278	48	11.1	0.48	455	358
PITT	293.48	34	3.774	5.278	48	11.1	0.48	455	358
AXGR	120.45	33	3.663	5.167	47	11.1	0.47	455	358
AXSL	113.54	33	3.663	5.167	47	11.1	0.47	455	358
CIGR	115.2	33	3.663	5.167	47	11.1	0.47	455	358
CIGR	116.1	33	3.663	5.167	47	11.1	0.47	455	358
CIGR	121.67	33	3.663	5.167	47	11.1	0.47	455	358
GENE	116.34	33	3.663	5.167	47	11.1	0.47	455	358
GENE	118.58	33	3.663	5.167	47	11.1	0.47	455	358
GENE	118.97	33	3.663	5.167	47	11.1	0.47	455	358
GENE	122.59	33	3.663	5.167	47	11.1	0.47	455	358
GENE	122.66	33	3.663	5.167	47	11.1	0.47	455	358
GENE	122.96	33	3.663	5.167	47	11.1	0.47	455	358
GENE	131.02	33	3.663	5.167	47	11.1	0.47	455	358
GENE	147.88	33	3.663	5.167	47	11.1	0.47	455	358
GENE	151.46	33	3.663	5.167	47	11.1	0.47	455	358
GENE	154.06	33	3.663	5.167	47	11.1	0.47	455	358
GENE	260.01	33	3.663	5.167	47	11.1	0.47	455	358
PITT	127.60	33	3.663	5.167	47	11.1	0.47	455	358
PITT	207.49	33	3.663	5.167	47	11.1	0.47	455	358
PITT	208.71	33	3.663	5.167	47	11.1	0.47	455	358
PITT	211.91	33	3.663	5.167	47	11.1	0.47	455	358
AXGR	131.35	32	3.552	5.056	46	11.1	0.46	455	358
AXGR	207.56	32	3.552	5.056	46	11.1	0.46	455	358
GENE	121.43	32	3.552	5.056	46	11.1	0.46	455	358
GENE	124.5	32	3.552	5.056	46	11.1	0.46	455	358
GENE	129.28	32	3.552	5.056	46	11.1	0.46	455	358
GENE	208.82	32	3.552	5.056	46	11.1	0.46	455	358
GENE	208.96	32	3.552	5.056	46	11.1	0.46	455	358
GENE	210.22	32	3.552	5.056	46	11.1	0.46	455	358
GENE	213.17	32	3.552	5.056	46	11.1	0.46	455	358
PINH	129.28	32	3.552	5.056	46	11.1	0.46	455	358

PITT	122.65	32	3.552	5.056	46	11.1	0.46	455	358
PITT	208.80	32	3.552	5.056	46	11.1	0.46	455	358
AXGR	198.81	31	3.441	4.945	45	11.1	0.45	455	358
AXGR	208.71	31	3.441	4.945	45	11.1	0.45	455	358
GENE	115.46	31	3.441	4.945	45	11.1	0.45	455	358
GENE	120.17	31	3.441	4.945	45	11.1	0.45	455	358
GENE	121.01	31	3.441	4.945	45	11.1	0.45	455	358
GENE	126.77	31	3.441	4.945	45	11.1	0.45	455	358
GENE	153.83	31	3.441	4.945	45	11.1	0.45	455	358
GENE	153.83	31	3.441	4.945	45	11.1	0.45	455	358
GENE	156.17	31	3.441	4.945	45	11.1	0.45	455	358
GENE	181.89	31	3.441	4.945	45	11.1	0.45	455	358
GENE	202.63	31	3.441	4.945	45	11.1	0.45	455	358
GENE	203.53	31	3.441	4.945	45	11.1	0.45	455	358
GENE	208.06	31	3.441	4.945	45	11.1	0.45	455	358
GENE	209.15	31	3.441	4.945	45	11.1	0.45	455	358
GENE	230.05	31	3.441	4.945	45	11.1	0.45	455	358
PINH	206.64	31	3.441	4.945	45	11.1	0.45	455	358
PITT	100.10	31	3.441	4.945	45	11.1	0.45	455	358
PITT	118.44	31	3.441	4.945	45	11.1	0.45	455	358
PITT	175.20	31	3.441	4.945	45	11.1	0.45	455	358
PITT	188.53	31	3.441	4.945	45	11.1	0.45	455	358
PITT	192.99	31	3.441	4.945	45	11.1	0.45	455	358
PITT	197.56	31	3.441	4.945	45	11.1	0.45	455	358
PITT	247.36	31	3.441	4.945	45	11.1	0.45	455	358
PITT	323.04	31	3.441	4.945	45	11.1	0.45	455	358
AXGR	118.04	30	3.33	4.834	44	11.1	0.44	455	358
AXGR	210.47	30	3.33	4.834	44	11.1	0.44	455	358
AXGR	213.57	30	3.33	4.834	44	11.1	0.44	455	358
AXSL	121.25	30	3.33	4.834	44	11.1	0.44	455	358
GENE	132.13	30	3.33	4.834	44	11.1	0.44	455	358
GENE	187.55	30	3.33	4.834	44	11.1	0.44	455	358

GENE	190.74	30	3.33	4.834	44	11.1	0.44	455	358
GENE	213.45	30	3.33	4.834	44	11.1	0.44	455	358
GENE	238.17	30	3.33	4.834	44	11.1	0.44	455	358
GENE	271.76	30	3.33	4.834	44	11.1	0.44	455	358
PINH	209.27	30	3.33	4.834	44	11.1	0.44	455	358
PITT	121.25	30	3.33	4.834	44	11.1	0.44	455	358
PITT	187.55	30	3.33	4.834	44	11.1	0.44	455	358
PITT	195.99	30	3.33	4.834	44	11.1	0.44	455	358
PITT	212.19	30	3.33	4.834	44	11.1	0.44	455	358
PITT	234.42	30	3.33	4.834	44	11.1	0.44	455	358
PITT	259.71	30	3.33	4.834	44	11.1	0.44	455	358
PITT	281.87	30	3.33	4.834	44	11.1	0.44	455	358
PITT	295.58	30	3.33	4.834	44	11.1	0.44	455	358
AXGR	195.75	29	3.219	4.723	43	11.1	0.43	455	358
AXGR	229.76	29	3.219	4.723	43	11.1	0.43	455	358
AXSL	110.45	29	3.219	4.723	43	11.1	0.43	455	358
AXSL	237.95	29	3.219	4.723	43	11.1	0.43	455	358
CISL	246.9	29	3.219	4.723	43	11.1	0.43	455	358
CISL	248.3	29	3.219	4.723	43	11.1	0.43	455	358
GENE	113.56	29	3.219	4.723	43	11.1	0.43	455	358
GENE	115.42	29	3.219	4.723	43	11.1	0.43	455	358
GENE	123.70	29	3.219	4.723	43	11.1	0.43	455	358
GENE	127.24	29	3.219	4.723	43	11.1	0.43	455	358
GENE	128.16	29	3.219	4.723	43	11.1	0.43	455	358
GENE	129.3	29	3.219	4.723	43	11.1	0.43	455	358
GENE	158.74	29	3.219	4.723	43	11.1	0.43	455	358
GENE	159.69	29	3.219	4.723	43	11.1	0.43	455	358
GENE	197.67	29	3.219	4.723	43	11.1	0.43	455	358
GENE	203.64	29	3.219	4.723	43	11.1	0.43	455	358
GENE	212.19	29	3.219	4.723	43	11.1	0.43	455	358
GENE	213.87	29	3.219	4.723	43	11.1	0.43	455	358
GENE	218.22	29	3.219	4.723	43	11.1	0.43	455	358

GENE	221.93	29	3.219	4.723	43	11.1	0.43	455	358
PITT	117.39	29	3.219	4.723	43	11.1	0.43	455	358
PITT	118.73	29	3.219	4.723	43	11.1	0.43	455	358
PITT	121.87	29	3.219	4.723	43	11.1	0.43	455	358
PITT	123.62	29	3.219	4.723	43	11.1	0.43	455	358
PITT	134.45	29	3.219	4.723	43	11.1	0.43	455	358
PITT	156.97	29	3.219	4.723	43	11.1	0.43	455	358
PITT	158.74	29	3.219	4.723	43	11.1	0.43	455	358
PITT	158.97	29	3.219	4.723	43	11.1	0.43	455	358
PITT	194.05	29	3.219	4.723	43	11.1	0.43	455	358
PITT	207.67	29	3.219	4.723	43	11.1	0.43	455	358
PITT	210.66	29	3.219	4.723	43	11.1	0.43	455	358
PITT	221.93	29	3.219	4.723	43	11.1	0.43	455	358
PITT	229.60	29	3.219	4.723	43	11.1	0.43	455	358
PITT	234.26	29	3.219	4.723	43	11.1	0.43	455	358
PITT	271.76	29	3.219	4.723	43	11.1	0.43	455	358
PITT	282.50	29	3.219	4.723	43	11.1	0.43	455	358
PITT	319.22	29	3.219	4.723	43	11.1	0.43	455	358
AXGR	319.44	28	3.108	4.612	42	11.1	0.42	455	358
CISL	246.7	28	3.108	4.612	42	11.1	0.42	455	358
GENE	115.32	28	3.108	4.612	42	11.1	0.42	455	358
GENE	115.46	28	3.108	4.612	42	11.1	0.42	455	358
GENE	122.86	28	3.108	4.612	42	11.1	0.42	455	358
GENE	124.35	28	3.108	4.612	42	11.1	0.42	455	358
GENE	183.04	28	3.108	4.612	42	11.1	0.42	455	358
GENE	185.61	28	3.108	4.612	42	11.1	0.42	455	358
GENE	188.45	28	3.108	4.612	42	11.1	0.42	455	358
GENE	195.7	28	3.108	4.612	42	11.1	0.42	455	358
GENE	211.42	28	3.108	4.612	42	11.1	0.42	455	358
GENE	213.4	28	3.108	4.612	42	11.1	0.42	455	358
GENE	244.34	28	3.108	4.612	42	11.1	0.42	455	358
GENE	248.15	28	3.108	4.612	42	11.1	0.42	455	358

GENE	280.16	28	3.108	4.612	42	11.1	0.42	455	358
GENE	295.64	28	3.108	4.612	42	11.1	0.42	455	358
PITT	108.58	28	3.108	4.612	42	11.1	0.42	455	358
PITT	119.70	28	3.108	4.612	42	11.1	0.42	455	358
PITT	125.49	28	3.108	4.612	42	11.1	0.42	455	358
PITT	128.66	28	3.108	4.612	42	11.1	0.42	455	358
PITT	140.96	28	3.108	4.612	42	11.1	0.42	455	358
PITT	148.78	28	3.108	4.612	42	11.1	0.42	455	358
PITT	158.96	28	3.108	4.612	42	11.1	0.42	455	358
PITT	193.88	28	3.108	4.612	42	11.1	0.42	455	358
PITT	195.85	28	3.108	4.612	42	11.1	0.42	455	358
PITT	204.41	28	3.108	4.612	42	11.1	0.42	455	358
PITT	205.56	28	3.108	4.612	42	11.1	0.42	455	358
PITT	207.68	28	3.108	4.612	42	11.1	0.42	455	358

Appendix VII: Projected ILI data year 2018 (sorted according to % defect depth)

First part (0-1000m)

	Distance, m	Depth, %	Depth, mm	Projected Depth, mm	Projected Depth, %	WT, mm	d/t	TS	YS
GENE	211.94	46	5.106	7.55	68	11.1	0.68	455	358
PINH	114.58	46	5.106	7.55	68	11.1	0.68	455	358
GENE	295.42	45	4.995	7.439	67	11.1	0.67	455	358
PITT	307.32	45	4.995	7.439	67	11.1	0.67	455	358
GENE	150.34	43	4.773	7.217	65	11.1	0.65	455	358
GENE	122.89	41	4.551	6.995	63	11.1	0.63	455	358
GENE	212.23	41	4.551	6.995	63	11.1	0.63	455	358
GENE	486.83	41	4.551	6.995	63	11.1	0.63	455	358
GENE	122.73	40	4.44	6.884	62	11.1	0.62	455	358
GENE	125.01	40	4.44	6.884	62	11.1	0.62	455	358
GENE	200.01	40	4.44	6.884	62	11.1	0.62	455	358
GENE	271.51	40	4.44	6.884	62	11.1	0.62	455	358
GENE	118.16	39	4.329	6.773	61	11.1	0.61	455	358
GENE	125.38	39	4.329	6.773	61	11.1	0.61	455	358
GENE	148.59	39	4.329	6.773	61	11.1	0.61	455	358
GENE	215.11	39	4.329	6.773	61	11.1	0.61	455	358
GENE	259.71	39	4.329	6.773	61	11.1	0.61	455	358
AXGR	217.35	38	4.218	6.662	60	11.1	0.60	455	358
AXGR	343.03	38	4.218	6.662	60	11.1	0.60	455	358
GENE	117.44	38	4.218	6.662	60	11.1	0.60	455	358
GENE	121.52	38	4.218	6.662	60	11.1	0.60	455	358
GENE	200.33	38	4.218	6.662	60	11.1	0.60	455	358
GENE	271.73	38	4.218	6.662	60	11.1	0.60	455	358
GENE	331.1	38	4.218	6.662	60	11.1	0.60	455	358
PITT	117.44	38	4.218	6.662	60	11.1	0.60	455	358
AXGR	207.92	37	4.107	6.551	59	11.1	0.59	455	358

CISL	118.75	37	4.107	6.551	59	11.1	0.59	455	358
GENE	112.63	37	4.107	6.551	59	11.1	0.59	455	358
GENE	120.39	37	4.107	6.551	59	11.1	0.59	455	358
GENE	121.84	37	4.107	6.551	59	11.1	0.59	455	358
GENE	209.49	37	4.107	6.551	59	11.1	0.59	455	358
GENE	283.69	37	4.107	6.551	59	11.1	0.59	455	358
PITT	200.18	37	4.107	6.551	59	11.1	0.59	455	358
PITT	217.32	37	4.107	6.551	59	11.1	0.59	455	358
GENE	117.31	36	3.996	6.44	58	11.1	0.58	455	358
GENE	120.61	36	3.996	6.44	58	11.1	0.58	455	358
GENE	125.73	36	3.996	6.44	58	11.1	0.58	455	358
GENE	207.32	36	3.996	6.44	58	11.1	0.58	455	358
GENE	208.35	36	3.996	6.44	58	11.1	0.58	455	358
PITT	120.45	36	3.996	6.44	58	11.1	0.58	455	358
CIGR	127.58	35	3.885	6.329	57	11.1	0.57	455	358
GENE	125.07	35	3.885	6.329	57	11.1	0.57	455	358
GENE	125.15	35	3.885	6.329	57	11.1	0.57	455	358
GENE	153	35	3.885	6.329	57	11.1	0.57	455	358
GENE	185.43	35	3.885	6.329	57	11.1	0.57	455	358
GENE	203.7	35	3.885	6.329	57	11.1	0.57	455	358
GENE	207.84	35	3.885	6.329	57	11.1	0.57	455	358
GENE	210.76	35	3.885	6.329	57	11.1	0.57	455	358
GENE	213.62	35	3.885	6.329	57	11.1	0.57	455	358
PITT	197.59	35	3.885	6.329	57	11.1	0.57	455	358
PITT	307.62	35	3.885	6.329	57	11.1	0.57	455	358
PITT	331.16	35	3.885	6.329	57	11.1	0.57	455	358
AXGR	182.5	34	3.774	6.218	56	11.1	0.56	455	358
GENE	111.52	34	3.774	6.218	56	11.1	0.56	455	358
GENE	118.9	34	3.774	6.218	56	11.1	0.56	455	358
GENE	121.51	34	3.774	6.218	56	11.1	0.56	455	358
GENE	121.99	34	3.774	6.218	56	11.1	0.56	455	358
GENE	208.54	34	3.774	6.218	56	11.1	0.56	455	358

PITT	177.92	34	3.774	6.218	56	11.1	0.56	455	358
PITT	293.48	34	3.774	6.218	56	11.1	0.56	455	358
AXGR	120.45	33	3.663	6.107	55	11.1	0.55	455	358
AXSL	113.54	33	3.663	6.107	55	11.1	0.55	455	358
CIGR	115.2	33	3.663	6.107	55	11.1	0.55	455	358
CIGR	116.1	33	3.663	6.107	55	11.1	0.55	455	358
CIGR	121.67	33	3.663	6.107	55	11.1	0.55	455	358
GENE	116.34	33	3.663	6.107	55	11.1	0.55	455	358
GENE	118.58	33	3.663	6.107	55	11.1	0.55	455	358
GENE	118.97	33	3.663	6.107	55	11.1	0.55	455	358
GENE	122.59	33	3.663	6.107	55	11.1	0.55	455	358
GENE	122.66	33	3.663	6.107	55	11.1	0.55	455	358
GENE	122.96	33	3.663	6.107	55	11.1	0.55	455	358
GENE	131.02	33	3.663	6.107	55	11.1	0.55	455	358
GENE	147.88	33	3.663	6.107	55	11.1	0.55	455	358
GENE	151.46	33	3.663	6.107	55	11.1	0.55	455	358
GENE	154.06	33	3.663	6.107	55	11.1	0.55	455	358
GENE	260.01	33	3.663	6.107	55	11.1	0.55	455	358
PITT	127.60	33	3.663	6.107	55	11.1	0.55	455	358
PITT	207.49	33	3.663	6.107	55	11.1	0.55	455	358
PITT	208.71	33	3.663	6.107	55	11.1	0.55	455	358
PITT	211.91	33	3.663	6.107	55	11.1	0.55	455	358
AXGR	131.35	32	3.552	5.996	54	11.1	0.54	455	358
AXGR	207.56	32	3.552	5.996	54	11.1	0.54	455	358
GENE	121.43	32	3.552	5.996	54	11.1	0.54	455	358
GENE	124.5	32	3.552	5.996	54	11.1	0.54	455	358
GENE	129.28	32	3.552	5.996	54	11.1	0.54	455	358
GENE	208.82	32	3.552	5.996	54	11.1	0.54	455	358
GENE	208.96	32	3.552	5.996	54	11.1	0.54	455	358
GENE	210.22	32	3.552	5.996	54	11.1	0.54	455	358
GENE	213.17	32	3.552	5.996	54	11.1	0.54	455	358
PINH	129.28	32	3.552	5.996	54	11.1	0.54	455	358

PITT	122.65	32	3.552	5.996	54	11.1	0.54	455	358
PITT	208.80	32	3.552	5.996	54	11.1	0.54	455	358
AXGR	198.81	31	3.441	5.885	53	11.1	0.53	455	358
AXGR	208.71	31	3.441	5.885	53	11.1	0.53	455	358
GENE	115.46	31	3.441	5.885	53	11.1	0.53	455	358
GENE	120.17	31	3.441	5.885	53	11.1	0.53	455	358
GENE	121.01	31	3.441	5.885	53	11.1	0.53	455	358
GENE	126.77	31	3.441	5.885	53	11.1	0.53	455	358
GENE	153.83	31	3.441	5.885	53	11.1	0.53	455	358
GENE	153.83	31	3.441	5.885	53	11.1	0.53	455	358
GENE	156.17	31	3.441	5.885	53	11.1	0.53	455	358
GENE	181.89	31	3.441	5.885	53	11.1	0.53	455	358
GENE	202.63	31	3.441	5.885	53	11.1	0.53	455	358
GENE	203.53	31	3.441	5.885	53	11.1	0.53	455	358
GENE	208.06	31	3.441	5.885	53	11.1	0.53	455	358
GENE	209.15	31	3.441	5.885	53	11.1	0.53	455	358
GENE	230.05	31	3.441	5.885	53	11.1	0.53	455	358
PINH	206.64	31	3.441	5.885	53	11.1	0.53	455	358
PITT	100.10	31	3.441	5.885	53	11.1	0.53	455	358
PITT	118.44	31	3.441	5.885	53	11.1	0.53	455	358
PITT	175.20	31	3.441	5.885	53	11.1	0.53	455	358
PITT	188.53	31	3.441	5.885	53	11.1	0.53	455	358
PITT	192.99	31	3.441	5.885	53	11.1	0.53	455	358
PITT	197.56	31	3.441	5.885	53	11.1	0.53	455	358
PITT	247.36	31	3.441	5.885	53	11.1	0.53	455	358
PITT	323.04	31	3.441	5.885	53	11.1	0.53	455	358
AXGR	118.04	30	3.33	5.774	52	11.1	0.52	455	358
AXGR	210.47	30	3.33	5.774	52	11.1	0.52	455	358
AXGR	213.57	30	3.33	5.774	52	11.1	0.52	455	358
AXSL	121.25	30	3.33	5.774	52	11.1	0.52	455	358
GENE	132.13	30	3.33	5.774	52	11.1	0.52	455	358
GENE	187.55	30	3.33	5.774	52	11.1	0.52	455	358

GENE	190.74	30	3.33	5.774	52	11.1	0.52	455	358
GENE	213.45	30	3.33	5.774	52	11.1	0.52	455	358
GENE	238.17	30	3.33	5.774	52	11.1	0.52	455	358
GENE	271.76	30	3.33	5.774	52	11.1	0.52	455	358
PINH	209.27	30	3.33	5.774	52	11.1	0.52	455	358
PITT	121.25	30	3.33	5.774	52	11.1	0.52	455	358
PITT	187.55	30	3.33	5.774	52	11.1	0.52	455	358
PITT	195.99	30	3.33	5.774	52	11.1	0.52	455	358
PITT	212.19	30	3.33	5.774	52	11.1	0.52	455	358
PITT	234.42	30	3.33	5.774	52	11.1	0.52	455	358
PITT	259.71	30	3.33	5.774	52	11.1	0.52	455	358
PITT	281.87	30	3.33	5.774	52	11.1	0.52	455	358
PITT	295.58	30	3.33	5.774	52	11.1	0.52	455	358
AXGR	195.75	29	3.219	5.663	51	11.1	0.51	455	358
AXGR	229.76	29	3.219	5.663	51	11.1	0.51	455	358
AXSL	110.45	29	3.219	5.663	51	11.1	0.51	455	358
AXSL	237.95	29	3.219	5.663	51	11.1	0.51	455	358
CISL	246.9	29	3.219	5.663	51	11.1	0.51	455	358
CISL	248.3	29	3.219	5.663	51	11.1	0.51	455	358
GENE	113.56	29	3.219	5.663	51	11.1	0.51	455	358
GENE	115.42	29	3.219	5.663	51	11.1	0.51	455	358
GENE	123.70	29	3.219	5.663	51	11.1	0.51	455	358
GENE	127.24	29	3.219	5.663	51	11.1	0.51	455	358
GENE	128.16	29	3.219	5.663	51	11.1	0.51	455	358
GENE	129.3	29	3.219	5.663	51	11.1	0.51	455	358
GENE	158.74	29	3.219	5.663	51	11.1	0.51	455	358
GENE	159.69	29	3.219	5.663	51	11.1	0.51	455	358
GENE	197.67	29	3.219	5.663	51	11.1	0.51	455	358
GENE	203.64	29	3.219	5.663	51	11.1	0.51	455	358
GENE	212.19	29	3.219	5.663	51	11.1	0.51	455	358
GENE	213.87	29	3.219	5.663	51	11.1	0.51	455	358
GENE	218.22	29	3.219	5.663	51	11.1	0.51	455	358

GENE	221.93	29	3.219	5.663	51	11.1	0.51	455	358
PITT	117.39	29	3.219	5.663	51	11.1	0.51	455	358
PITT	118.73	29	3.219	5.663	51	11.1	0.51	455	358
PITT	121.87	29	3.219	5.663	51	11.1	0.51	455	358
PITT	123.62	29	3.219	5.663	51	11.1	0.51	455	358
PITT	134.45	29	3.219	5.663	51	11.1	0.51	455	358
PITT	156.97	29	3.219	5.663	51	11.1	0.51	455	358
PITT	158.74	29	3.219	5.663	51	11.1	0.51	455	358
PITT	158.97	29	3.219	5.663	51	11.1	0.51	455	358
PITT	194.05	29	3.219	5.663	51	11.1	0.51	455	358
PITT	207.67	29	3.219	5.663	51	11.1	0.51	455	358
PITT	210.66	29	3.219	5.663	51	11.1	0.51	455	358
PITT	221.93	29	3.219	5.663	51	11.1	0.51	455	358
PITT	229.60	29	3.219	5.663	51	11.1	0.51	455	358
PITT	234.26	29	3.219	5.663	51	11.1	0.51	455	358
PITT	271.76	29	3.219	5.663	51	11.1	0.51	455	358
PITT	282.50	29	3.219	5.663	51	11.1	0.51	455	358
PITT	319.22	29	3.219	5.663	51	11.1	0.51	455	358
AXGR	319.44	28	3.108	5.552	50	11.1	0.50	455	358
CISL	246.7	28	3.108	5.552	50	11.1	0.50	455	358
GENE	115.32	28	3.108	5.552	50	11.1	0.50	455	358
GENE	115.46	28	3.108	5.552	50	11.1	0.50	455	358
GENE	122.86	28	3.108	5.552	50	11.1	0.50	455	358
GENE	124.35	28	3.108	5.552	50	11.1	0.50	455	358
GENE	183.04	28	3.108	5.552	50	11.1	0.50	455	358
GENE	185.61	28	3.108	5.552	50	11.1	0.50	455	358
GENE	188.45	28	3.108	5.552	50	11.1	0.50	455	358
GENE	195.7	28	3.108	5.552	50	11.1	0.50	455	358
GENE	211.42	28	3.108	5.552	50	11.1	0.50	455	358
GENE	213.4	28	3.108	5.552	50	11.1	0.50	455	358
GENE	244.34	28	3.108	5.552	50	11.1	0.50	455	358
GENE	248.15	28	3.108	5.552	50	11.1	0.50	455	358

GENE	280.16	28	3.108	5.552	50	11.1	0.50	455	358
GENE	295.64	28	3.108	5.552	50	11.1	0.50	455	358
PITT	108.58	28	3.108	5.552	50	11.1	0.50	455	358
PITT	119.70	28	3.108	5.552	50	11.1	0.50	455	358
PITT	125.49	28	3.108	5.552	50	11.1	0.50	455	358
PITT	128.66	28	3.108	5.552	50	11.1	0.50	455	358
PITT	140.96	28	3.108	5.552	50	11.1	0.50	455	358
PITT	148.78	28	3.108	5.552	50	11.1	0.50	455	358
PITT	158.96	28	3.108	5.552	50	11.1	0.50	455	358
PITT	193.88	28	3.108	5.552	50	11.1	0.50	455	358
PITT	195.85	28	3.108	5.552	50	11.1	0.50	455	358
PITT	204.41	28	3.108	5.552	50	11.1	0.50	455	358
PITT	205.56	28	3.108	5.552	50	11.1	0.50	455	358
PITT	207.68	28	3.108	5.552	50	11.1	0.50	455	358