RISK-BASED INSPECTION MODEL FOR ATMOSPHERIC STORAGE TANKS

DISSERTATION

By

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CERTIFICATION OF APPROVAL

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Approved by,

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January 2015

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.

MUHAMMAD FARUQI BIN RAHMAD

ABSTRACT

Cost reduction is important in current economic trend and everything is about cost reductions. Furthermore, tougher environmental regulations are driving an upsurge in the application of risk management as the methodology to optimize the plant assets inspection. Risk-based inspection (RBI) planning is a methodology for systematic decision making to identify components which are more like to fail first or damage the environment and causing injuries to the personnel and worse come to worst, leading to production shutdowns [12]. In current situation, priority being given for methodology mitigates risks that involves in the process and forecast the optimal inspections interval by using the risk. Quantitative procedures have been provide by the American Petroleum Institute (API) 581 to establish an inspection program using risk-based methods for several fix equipment including atmospheric storage tank but does not present a systematic understanding or direct application for the methodology [13]. However, the methodology for the RBI analysis is very lengthy and needed to take into account with a lot of different preset values as well as different parameters. Hence, the procedure is very complicated and messy to be applied in the industry. Besides that, traditional approach still being applied by many companies when it comes to inspection activity. Thus repetitive inspection disregard the AST's condition cause significant amount of wastage resources. From all the problem above, this project aims to develop an Excel based RBI for atmospheric storage tank. This software is developed based on the synthesis of API 581, API 580 standard. The scope of the application however would be limited on determining the risk value of the AST instead of providing the next inspection date as well. Nevertheless, with the risk value obtained, the analysts could prioritize the inspection interval effectively.

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1. INTRODUCTION

1.1 Background of study

Atmospheric Storage tanks (AST) in refineries and chemical plants contain large volumes of flammable and hazardous chemicals. The main function of AST is to store large quantity of property loss and a few days of production interruption[1]. A large accident results in lawsuits, stock devaluation, or company bankruptcy. Therefore, AST can be describing as one of the importance equipment in any plant or refinery.

Nowadays, a new trend involving the determination of best inspection intervals for related equipment especially storage tank based on calculated risk has been introduced. It is known as Risk Based Inspection (RBI). RBI is a method for using risk as a basis to prioritize and manage the efforts of an inspection program and focused on loss of containment of pressurized equipment in processing facilities due to material deterioration[2] .

RBI is the combination between the probability of some event occurring during a time period of interest and the consequences generally negative is associated with the event in order to estimate the risk to develop inspection plan[2]. Overall, it is a methodology to improve the management of risk through the examination on the critical areas of the plant while reducing the inspection interval on the less critical areas.

Inspection activities are a compulsory routine for any plant in order to get the actual data on the condition of any equipment. With old inspection method, the intervals were solely time based and do not take into account the actual condition or the environmental exposure of the AST. RBI methodology could provide accurate predictive time frame and provide a higher level of coverage on the high-risk equipment and an appropriate effort on lower risk equipment[3]. Without a doubt, RBI analysis can be used to determine the most optimum combination of equipment inspection methods, scopes and frequencies.

1.2 Problem Statement

The American Petroleum Institute (API) 581 standard has come out with quantitative procedures to conduct an inspection program using risk-based methods for several fix equipment including atmospheric storage tank. However, it does not present a systematic understanding or direct application for the methodology. Moreover, the methodology for the RBI analysis is very lengthy and needed to take into account with a lot of different preset values as well as different parameters. Hence, the procedure is very complicated and messy to be applied in the industry. Besides that, a lot of companies still practicing traditional approach when it comes to inspection activity. Repetitive inspection disregard the AST's condition eventually leads to significant amount of wastage resources. To solve the issues mentioned above, this project aims to develop an Excel based RBI for atmospheric storage tank. This software is developed based on the synthesis of API 581, API 580 standard.

1.3 Objective

The objective of this project is to develop an Excel-based RBI model which able to determine the risk value and risk level for atmospheric storage tank.

1.4 Scope of Study

The scope of the project would be developing the RBI model which limited on determining the risk value of the AST instead of providing the next inspection date as well. However, with the risk value obtained, the analysts could prioritize the inspection interval effectively.

2. LITERATURE REVIEW

2.1 Three Type of Atmospheric Storage Tank

External floating roof tank consist of cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid. It have roof that can move up and down according to the liquid level inside the tank. This movement can reduce the evaporative loss of the stored liquid and preserve the quantity of the liquid[4]. The main function is to provide safe, efficient storage of volatile products with minimum vapor loss to the environment.

Fixed roof storage tanks have roofs that are permanently attached to the tank shell. It usually fully welded and designed for both liquid and vapor tight. A typical fixed-roof tank consists of a cylindrical steel shell with a cone or dome shaped roof that is permanently affixed to the tank shell[4]. Domed external fixed roof tanks have self-supporting aluminum dome roof attach to the tank shell and coned roof tank have aluminum cone roof which attach to the tank shell.

Internal floating roof tank has both permanent fixed roof and a floating roof inside. There are two basic types of internal floating roof tanks which the fixed roof is supported by vertical columns within the tank and tanks with a self-supporting fixed roof and no internal support columns[5]. Fixed roof tanks that have been retrofitted to employ an internal floating roof are typically of the first type, while external floating roof tanks that have been converted to an internal floating roof tank typically have a self-supporting roof. The internal floating roof rises and falls with the liquid level.

2.2 Atmospheric storage tank failure

AST failures are frequently caused by tank shell or tank bottom. Catastrophic failures could lead to possibility of sudden tank failure. Studies have shown that in the event of such failures the secondary containment can be of insufficient design to withstand the impacting surge wave and associated tank debris[6]. This is demonstrated in the incident, which occurred at the Azotas Fertilizer Plant, Lithuania in 1989. In this case, an Ammonia storage tank failed that caused by overpressurisation, the tank split open releasing its contents and subsequently the tank separated from its foundations and crashed through the surrounding reinforced concrete bund[6].

Fortunately, catastrophic failure of tanks used for storing hazardous liquids is rare. However, the consequences to the local community and the environment are devastating. Such failures have occurred in the USA, in Greece and in Lithuania, for example and can involve millions of gallons being lost[7]. History has shown that when failure occur, a large proportion of the liquid is likely to escape over the surrounding bund wall or embankment, even if the force of the wave impact does not damage the retaining structures. The recent events at the Buncefield site, Hertfordshire on Sunday 11th December 2005 involving one of the biggest explosions in Europe since the Second World War, indicates the need for adequate assessment of risk[7]. All these accident can be prevented if good inspection practice is implementing in the plant or refinery.

Table 1: Cause of atmospheric storage tank failure [1]

Cause of atmospheric storage tank failure

Maintenance Error	Tank Crack/Rupture	Piping Rupture/Leak	Equipment/ Instrument Failure	Operational Error
• Sparks • Non explosion-Proof Motor And Tools Used • Circuit Shortcut • Welding • Transformer Spark • Poor Grounding of Soldering Equipment	• Poor Soldering • Shell Distortion • Poor Fabrication • Subsidence • High Pressure Liquid from Downstream Vessels Back up • Corrosion • Microbiological Sulfate Reducing Bacteria	• Low Temp • Pump Leak • Cut by Oil Stealers • Cut Accidently by a Contractor • Flammable Liquid Leak from a Gasket • Propane Line Broken by an ATV	• O2 Analyzer Failure • Thermostat Failure • Floating Roof Sunk • Relief Valves Failure • Accidentally Opened • Heater Failure • Discharge Valve Rupture • Frozen LPG Valve • Overheated by Steam • Heater • Level Indicator • Rust Vent Valve not Open	• Drain Valves Left Open • Accidentally Overfill • SOP Not Followed • Tankcars Moved Accidentally during Loading • Vent Closed During Loading • Oil Leaks due to Operators Errors • High Inlet Temp

2.3 Risk assessment method of Risk-based inspection (RBI)

Risk is the combination of the probability of some event occurring during a time period of interest and the consequences generally negative is associated with the event[8]. Risk assessment is the process of identifying the sources of hazards, estimating the risk and evaluating the results[9]. The probability of failure and consequences of failure are combined to produce an estimate of risk[2].

Risk = Probability of Failure (POF) X Consequence of failure (COF)
(Equation 1)

COF can be defined as a result or effect, typically one that related to fatalities or cost for example damage area, item repair and Injury[2]. In RBI, the probability of failure is computed by Equation (2).

POF = Generic Failure Frequency x damage factor x Management Systems Factor
(Equation 2)

Generic Failure Frequency represents a POF and developed for specific type of component, but do not reflect the true failure frequency for a specific component subject to a specific damage mechanism[10]. Damage factor is an adjustment factor applied to account for damage mechanisms that are active in a component, which modifies the industry Generic Failure Frequency and makes it specific to the component under evaluation.

Table 2: Probability and financial-based consequence categories in API RBI [8]

Probability category		Consequence category	
Category	Range	Category	Range ($)
1	$D_f(t) \leq 2$	A	$FC \leq 10\,000$
2	$2 < D_f(t) \leq 20$	B	$10\,000 < FC \leq 100\,000$
3	$20 < D_f(t) \leq 100$	C	$100\,000 < FC \leq 1\,000\,000$
4	$100 < D_f(t) \leq 1000$	D	$1\,000\,000 < FC \leq 10\,000\,000$
5	$D_f(t) > 1000$	E	$FC > 10\,000\,000$

Management Systems Factor represents the effect of the facility's management system on the mechanical integrity of the plant equipment[10]. Probability and Consequence Categories in API 581 are shown in Table (2), in which Probability Categories are divided by the magnitude of the total damage factor. API 581 uses a risk matrix showed in Figure (1) to present the risk distribution of different components.

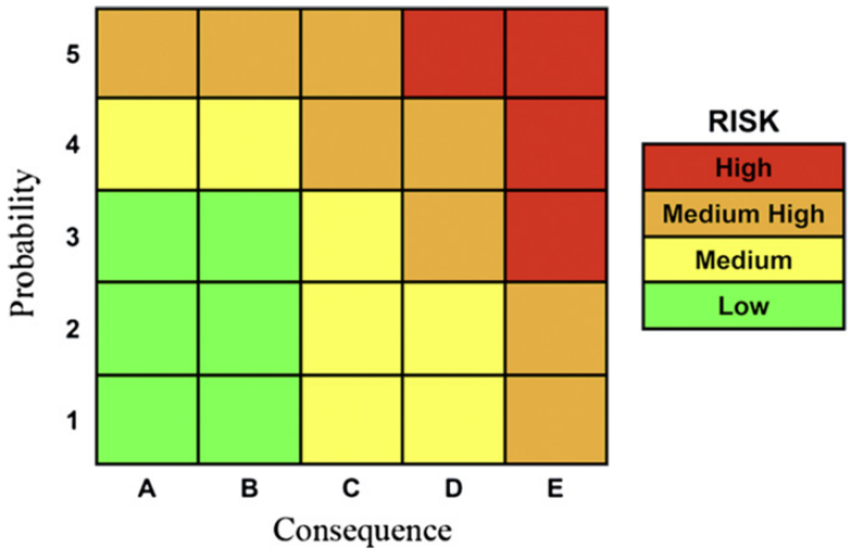


Figure 1: Risk matrix [2]

The setting of inspection frequency within RBI is not a rigid process with fixed, predetermined inspection intervals. Inspection intervals for any given component may change throughout the life of the asset as risk increases or decreases[9]. The frequencies that RBI derives are aligned to the needs of the component or situation and the risks associated. General logic to the inspections and frequency of the inspections are the higher risk components generally have the shorter frequencies of inspection and have potentially larger inspection population requirements whereas lower risk components often have extended inspection frequency and have reduced inspection population requirements[9].

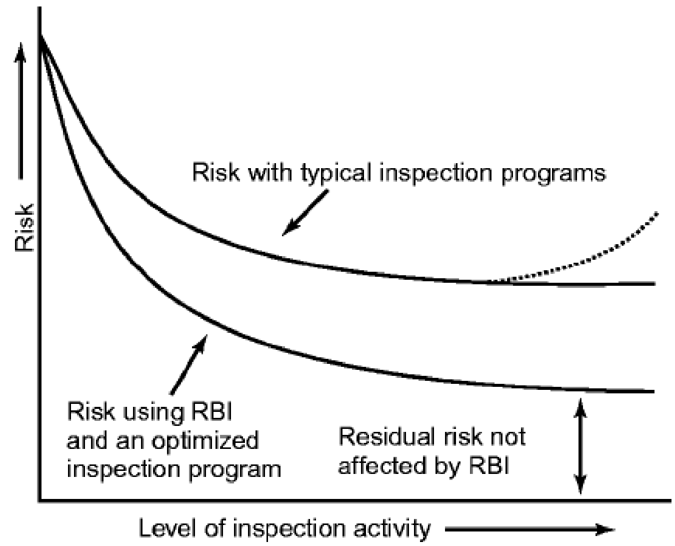


Figure 2: Management of Risk Using RBI [8]

2.4 Type of RBI

There are three methods to perform the RBI which are Quantitative, Qualitative and Semi-Quantitative method. Qualitative approach requires data inputs based on description information such as user own experience and engineering judgment as the input data. These inputs usually resulted in qualitative term such as ranging from low to high instead of numerical values. Quantitative approach relies on comprehensive information such as facility design, operating history, equipment reliability and so on. Besides, this approach also uses logic models to depict the combinations of events that could lead to severe incidents. As for the semi-quantitative approach, this analysis is comprised both the qualitative and quantitative analysis by utilizing both of the approaches advantage. As a remark, semi-quantitative method is used for the development of the software. In all the approaches, the end results are the same which is the risk matrix. Risk matrix basically comprises of both the likelihood and consequence category[2].

2.5 Corrosion rate

The amount of corrosion produced by a unit of surface area when referred to a specific period of time is known as the corrosion rate [14]. As was previously mentioned, this parameter may be measured by weight differences before and after having submitted the metal to the corrosive environment. It is an integral and an averaged indicator.

The simplest way of measuring the corrosion rate of a metal is to expose the sample to the test medium and measure the loss of weight of the material as a function of time. The research done by the Metal Sample Corrosion Monitoring System also stated that the weight loss analysis is the simplest and longest-established method of estimating corrosion losses. The relation between weight loss and corrosion rate are as follow:

$$Corrosion\,rate\;(CR) = \frac{Weight\;loss\;\times K}{Alloy\;density \times exposed\;area \times exposure\;time}$$

Pitting corrosion occur in certain conditions, such as low concentrations of oxygen or high concentrations of species such as chloride which complete as anions, can interfere with a given alloy's ability to re-form a passivating film. In the worst case, almost all of the surface will remain protected, but tiny local fluctuations will degrade the oxide film in a few critical points. Corrosion at these points will be greatly amplified, and can cause corrosion pits of several types, depending upon conditions [15]. While the corrosion pits only nucleate under fairly extreme circumstances, they can continue to grow even when conditions return to normal, since the interior of a pit is naturally deprived of oxygen and locally the pH decreases to very low values and the corrosion rate increases due to an autocatalytic process. In extreme cases, the sharp tips of extremely long and narrow corrosion pits can cause stress concentration to the point that otherwise tough alloys can shatter. A thin film pierced by an invisibly small hole can hide a thumb sized pit from view. These problems are especially dangerous because they are difficult to detect before a part or structure fails. Pitting remains among the most common and damaging forms of corrosion in passivated alloys but it can be prevented by control of the alloy's environment [14].

Pitting results when a small hole, or cavity, forms in the metal, usually as a result of de-passivation of a small area. This area becomes anodic, while part of the remaining metal becomes cathodic, producing a localized galvanic reaction. The deterioration of this small area penetrates the metal and can lead to failure. This form of corrosion is often difficult to detect due to the fact that it is usually relatively small and may be covered and hidden by corrosion-produced compounds.

3. METHODOLOGY

3.1 Research Methodology (Programme flow chart)

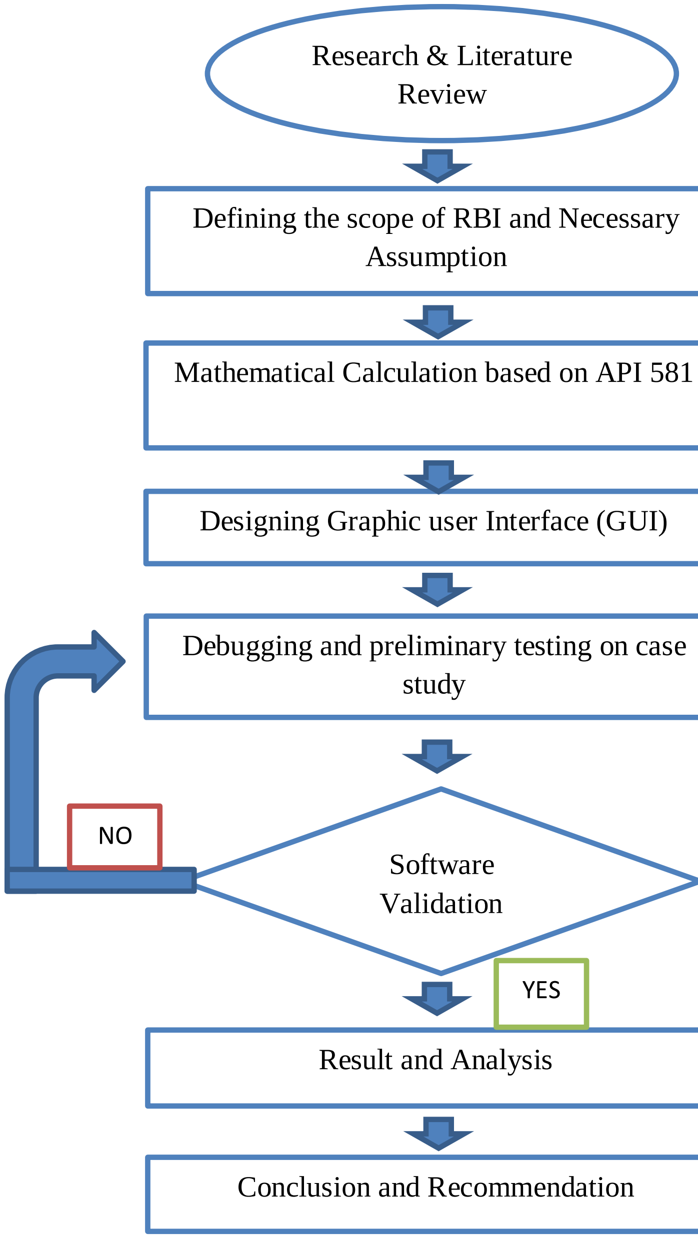


Figure 3 : Programme flowchart

3.2 Overall Calculation Methodology

In this project, the final result will be presented in term of risk matrix and it is an effective way of showing the distribution of risks for different components in a process unit without numerical values. Two items that need to be calculated in order to get the risk value are consequences and probability of failure which is represent as the damage factor. In the risk matrix, the consequence and probability categories are arranged such that the highest risk components are toward the upper right-hand corner.

3.2.1 Damage factor calculation step

The damage factor is determined based on the applicable damage mechanisms relevant to the materials of construction and the process service, the physical condition of the component, and the inspection techniques used to quantify damage. The damage factor modifies the industry generic failure frequency and makes it specific to the component under evaluation. The basic function of the damage factor is to statistically evaluate the amount of damage that may be present as a function of time in service and the effectiveness of an inspection activity to quantify that damage.

Damage factor is cause by many damage mechanisms such as thinning, component linings, external damage, stress corrosion cracking, high temperature hydrogen attack, mechanical fatigue and brittle fracture. However only thinning damage mechanism are utilized for tank risk calculation.

In the thinning damage factor calculation, it is assumed that the thinning mechanism has resulted in an average rate of thinning over the time period defined in the basic data that is fairly constant. The probability of failure is estimated by examining the possibility that the rate of thinning is greater than what is expected. The probability of these higher rates is determined by the amount of inspection and on-line monitoring that has been performed. The more thorough the inspection, and the greater the number of inspections and continued use of on-line monitoring, the less likely is the chance that the rate of thinning is greater than anticipated. In the damage factor calculation, it is assumed that thinning damage would eventually result in failure by plastic collapse. Below is the flow chart of the steps required to determine thinning damage factor. All formula used are based on the formula given in API 581. Some of the formulas are stated in the *Appendix D.*

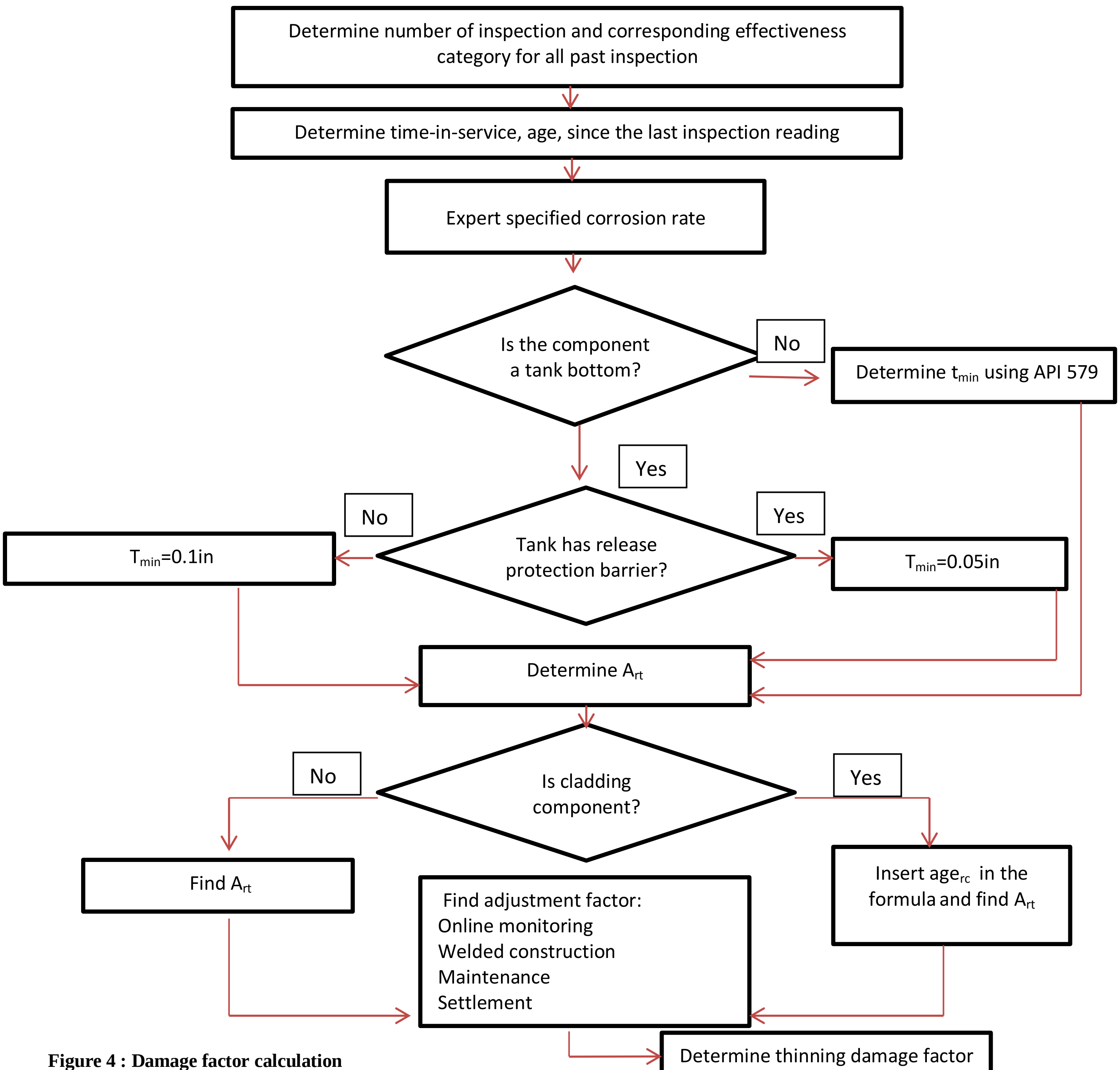
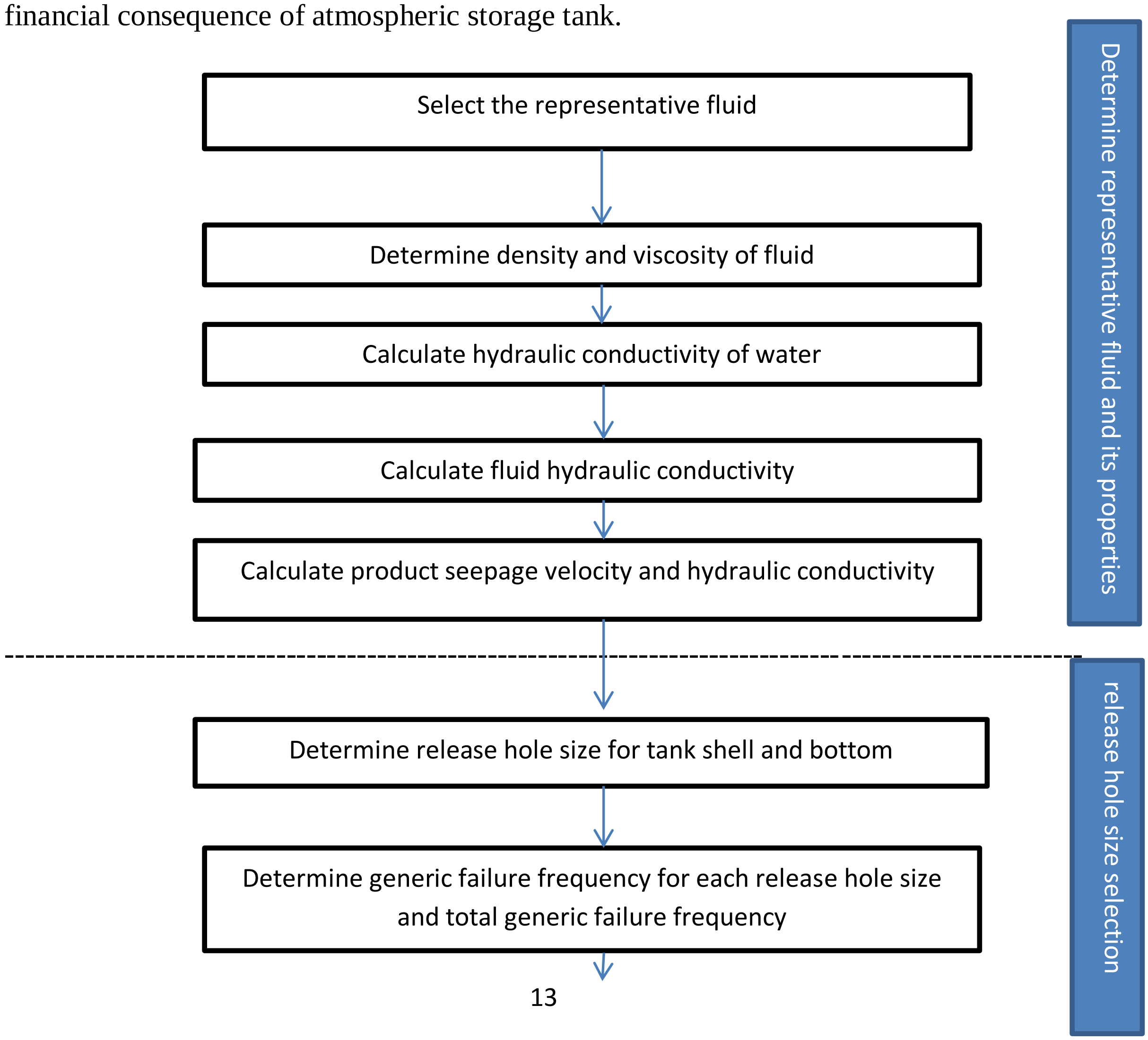


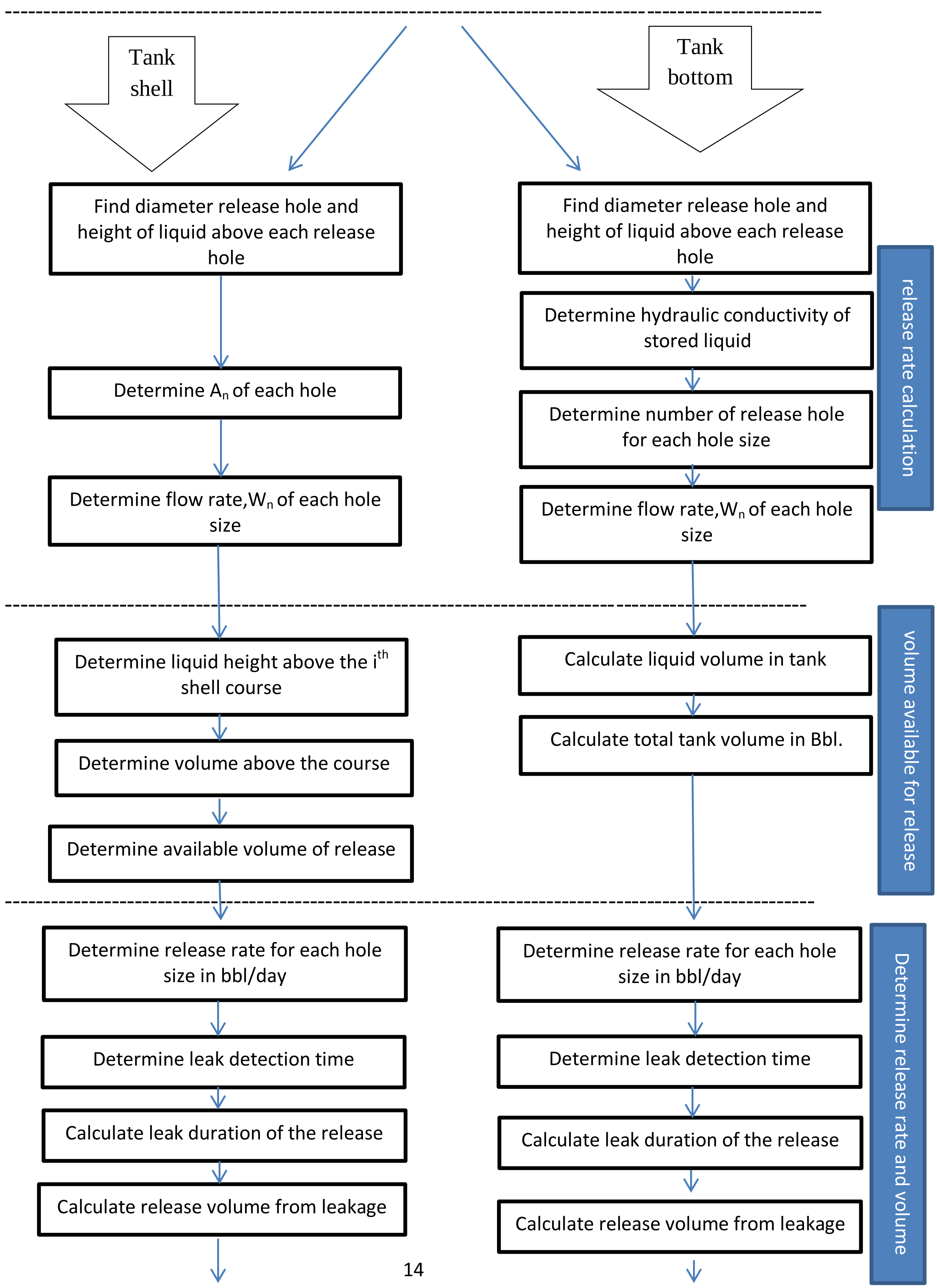
Figure 4 : Damage factor calculation flowchart

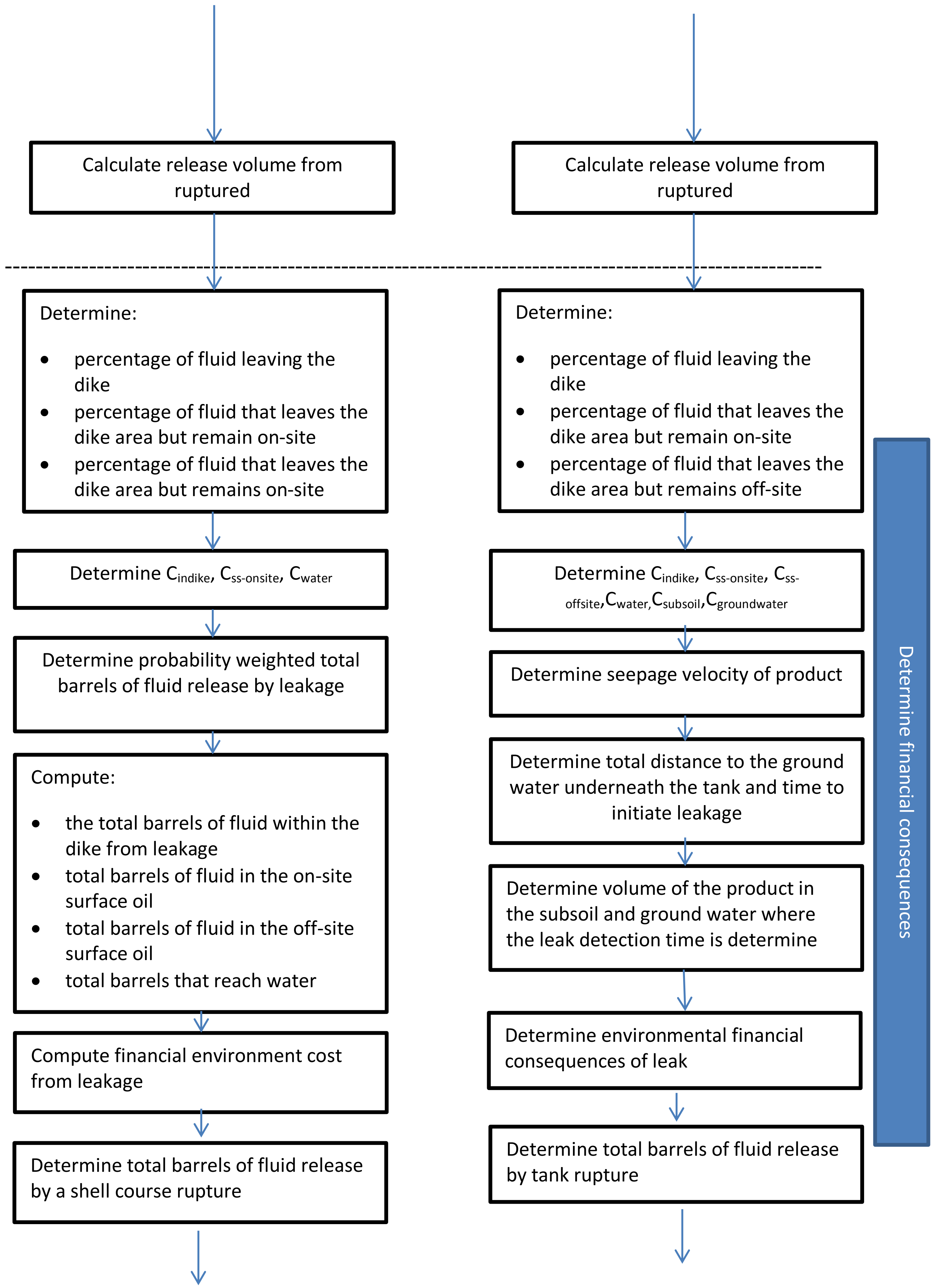
3.2.2 Consequences of failure calculation step

The consequence analysis in an API RBI assessment is performed to aid in establishing a ranking of equipment items on the basis of risk. The consequence measures presented in this part are intended to be used for establishing priorities for inspection programs. Methodologies for two levels of analysis are provided. A Level 1 consequence analysis which is intended to be a simplified workbook method is detailed for a limited number of hazardous fluids. A Level 2 consequence analysis methodology which is intended to be much more rigorous and can be applied to a wider range of hazardous fluids.

Atmospheric Storage tanks have special consequence analysis methodology provided by API. Only Level 1 consequence analysis in financial terms is used for the analysis of tank components. The flow chart below shows the calculation steps for calculation of financial consequence of atmospheric storage tank.




Tank shell
Tank bottom
Find diameter release hole and height of liquid above each release hole
Determine A_n of each hole
Determine flow rate, W_n of each hole size
Find diameter release hole and height of liquid above each release hole
Determine hydraulic conductivity of stored liquid
Determine number of release hole for each hole size
Determine flow rate, W_n of each hole size
release rate calculation
Determine liquid height above the i^{th} shell course
Determine volume above the course
Determine available volume of release
Calculate liquid volume in tank
Calculate total tank volume in Bbl.
volume available for release
Determine release rate for each hole size in bbl/day
Determine leak detection time
Calculate leak duration of the release
Calculate release volume from leakage
Determine release rate for each hole size in bbl/day
Determine leak detection time
Calculate leak duration of the release
Calculate release volume from leakage
Determine release rate and volume


Calculate release volume from ruptured
Determine:
percentage of fluid leaving the dike
percentage of fluid that leaves the dike area but remain on-site
percentage of fluid that leaves the dike area but remains on-site
Determine C_{indike}, $C_{ss\text{-}onsite}$, C_{water}
Determine probability weighted total barrels of fluid release by leakage
Compute:
the total barrels of fluid within the dike from leakage
total barrels of fluid in the on-site surface oil
total barrels of fluid in the off-site surface oil
total barrels that reach water
Compute financial environment cost from leakage
Determine total barrels of fluid release by a shell course rupture
Calculate release volume from ruptured
Determine:
percentage of fluid leaving the dike
percentage of fluid that leaves the dike area but remain on-site
percentage of fluid that leaves the dike area but remains off-site
Determine C_{indike}, $C_{ss\text{-}onsite}$, $C_{ss\text{-}offsite}$, C_{water}, $C_{subsoil}$, $C_{groundwater}$
Determine seepage velocity of product
Determine total distance to the ground water underneath the tank and time to initiate leakage
Determine volume of the product in the subsoil and ground water where the leak detection time is determine
Determine environmental financial consequences of leak
Determine total barrels of fluid release by tank rupture
Determine financial consequences

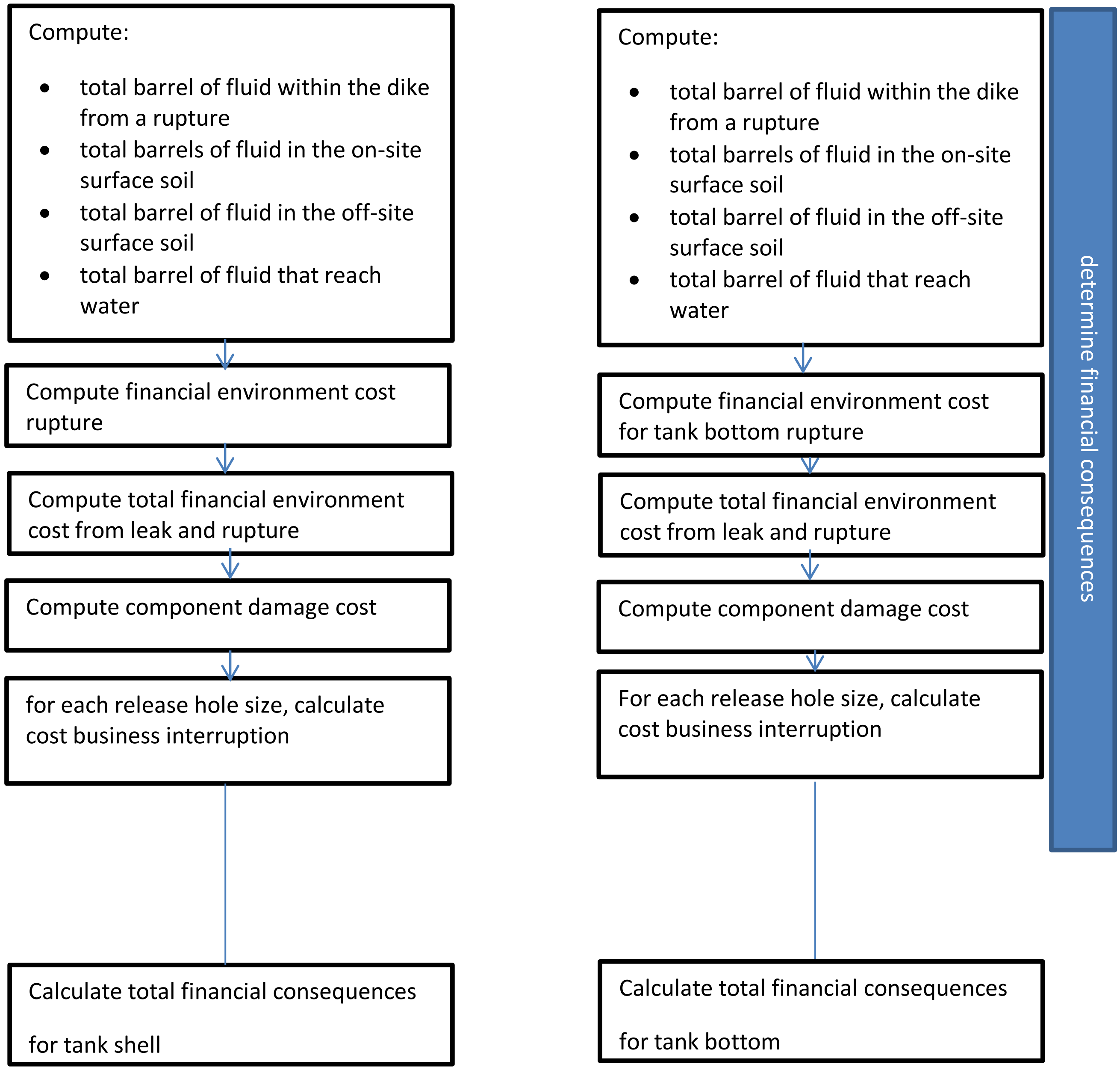


Figure 5: AST financial consequences flowchart

3.3 Software used

3.3.1 Visual Basic Application in Microsoft excel

Visual Basic for Applications (VBA) can define user function and can do verity of calculation. It can enable building user-defined functions, automating processes and accessing Windows API and other low-level functionality through dynamic-link libraries . It supersedes and expands on the abilities of earlier application-specific macro programming languages such as Word's WordBasic

It has a programming aspect allowing the user to employ a wide variety of numerical methods, for example, for solving differential equations of mathematical physics, and then reporting the results back to the spreadsheet[11]. In this project, some of the coding is shown in *Appendix A, Appendix B, Appendix C.*

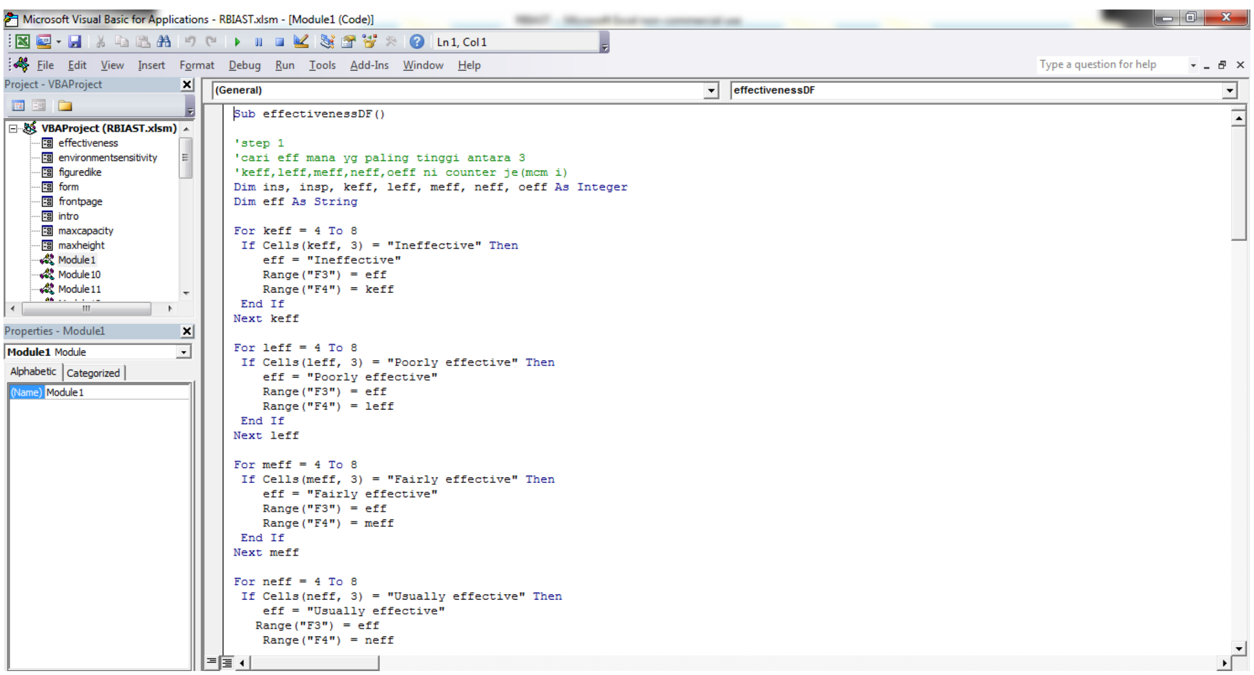


Figure 6 : Example VBA coding

3.4 Gantt Chart

To ensure the project can be delivered on time within the specified period, Gantt Chart and milestone are constructed as per below:

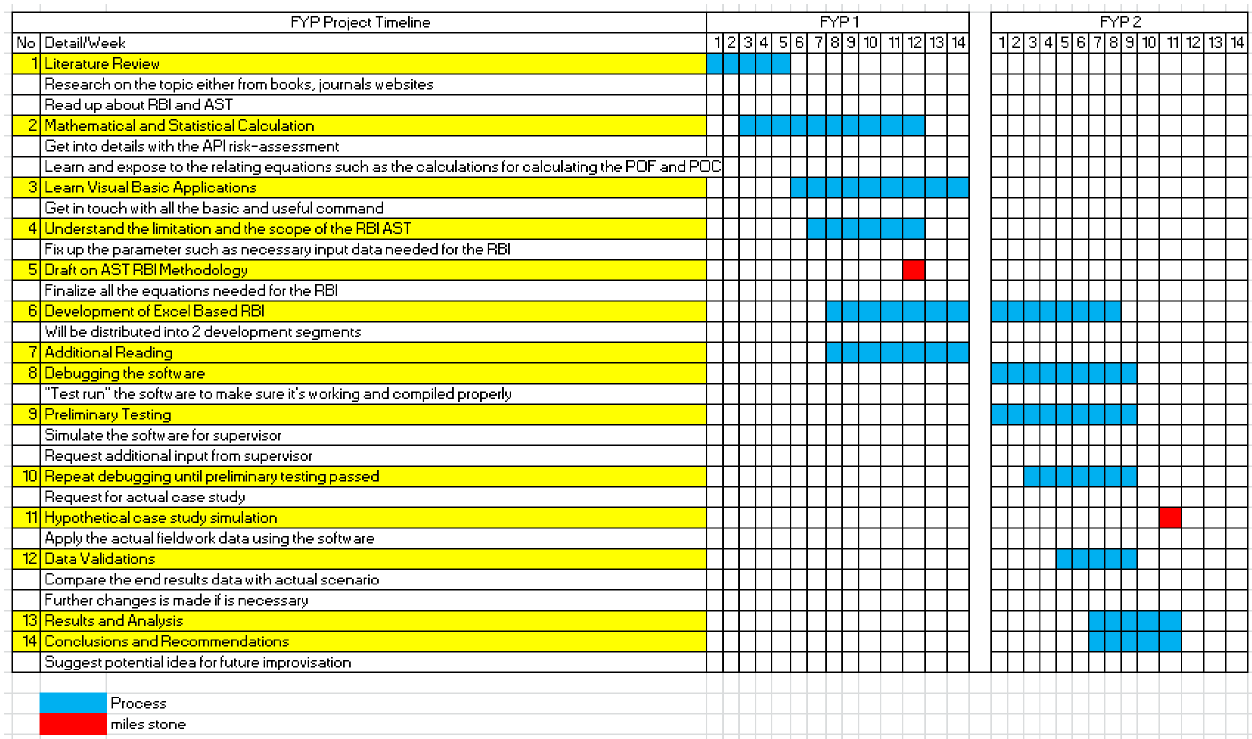


Figure 7 : Gantt chart and milestone

4. RESULT AND DISCUSSION

4.1 Algorithm

Algorithm is a process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer.

4.1.1 Algorithm for thinning damage factor calculation

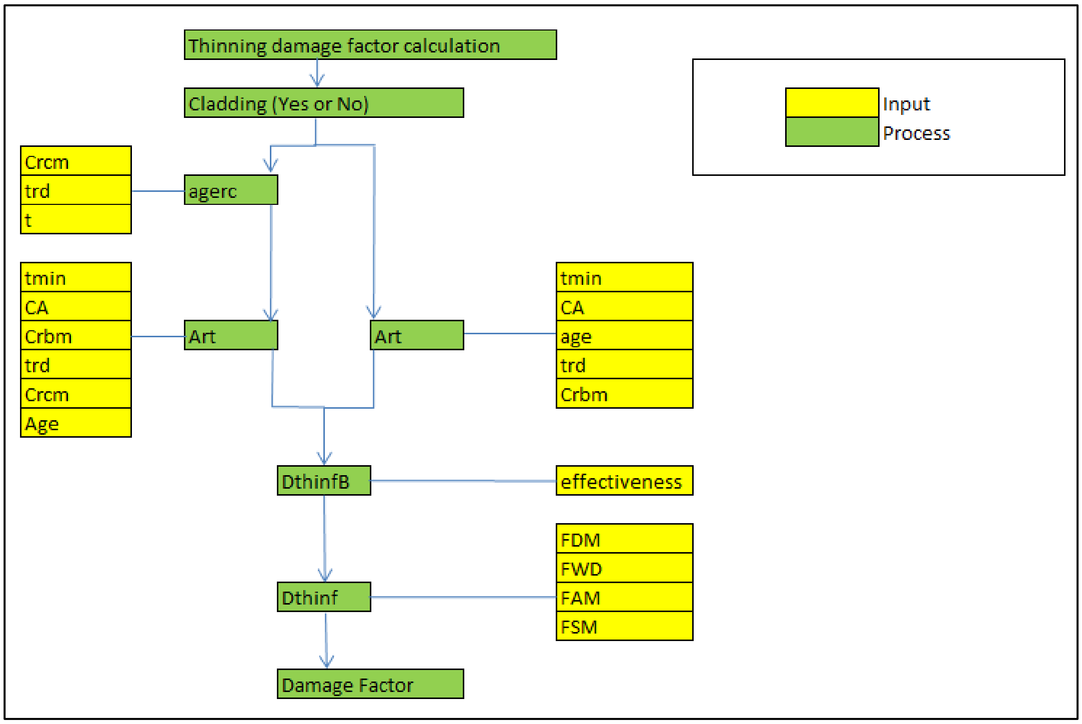


Figure 8: Algorithm for thinning damage factor

Table 3: Algorithm nomenclature description

	Nomenclature	**Description**
1	age	is the time since the last thickness reading
2	agerc	is the time required or age from the last inspection date when the cladding is corroded away
3	Art	is the damage factor parameter
4	Cr	is the corrosion rate
5	Crbm	is the corrosion rate for the base metal
6	Crcm	is the corrosion rate for the cladding
7	CA	is the corrosion allowance
8	DFthinf	is the damage factor for thinning
9	DFthinfB	is the base value of the damage factor for thinning
10	FAM	is the damage factor adjustment for tank maintenance per API 653
11	FOM	is the damage factor adjustment for online monitoring
12	FSM	is the damage factor adjustment for settlement
13	FWD	is the damage factor adjustment for welded construction
14	tmin	is the minimum required wall thickness based on the applicable construction code
15	t	is the furnished thickness of the component base metal
16	trc	is the remaining thickness of the cladding
17	trd	is the thickness reading

4.1.2 Algorithm for Consequence of Failure calculation

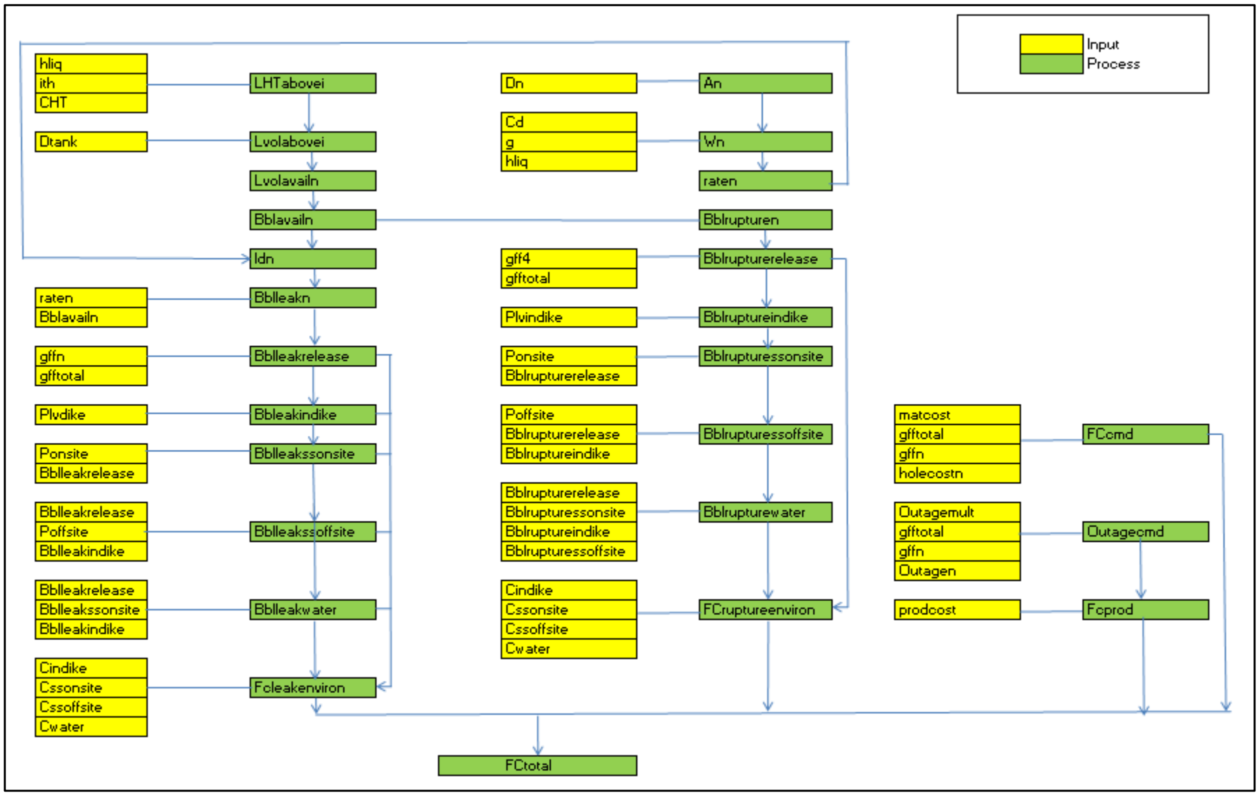


Figure 9: Algorithm for COF of tank shell

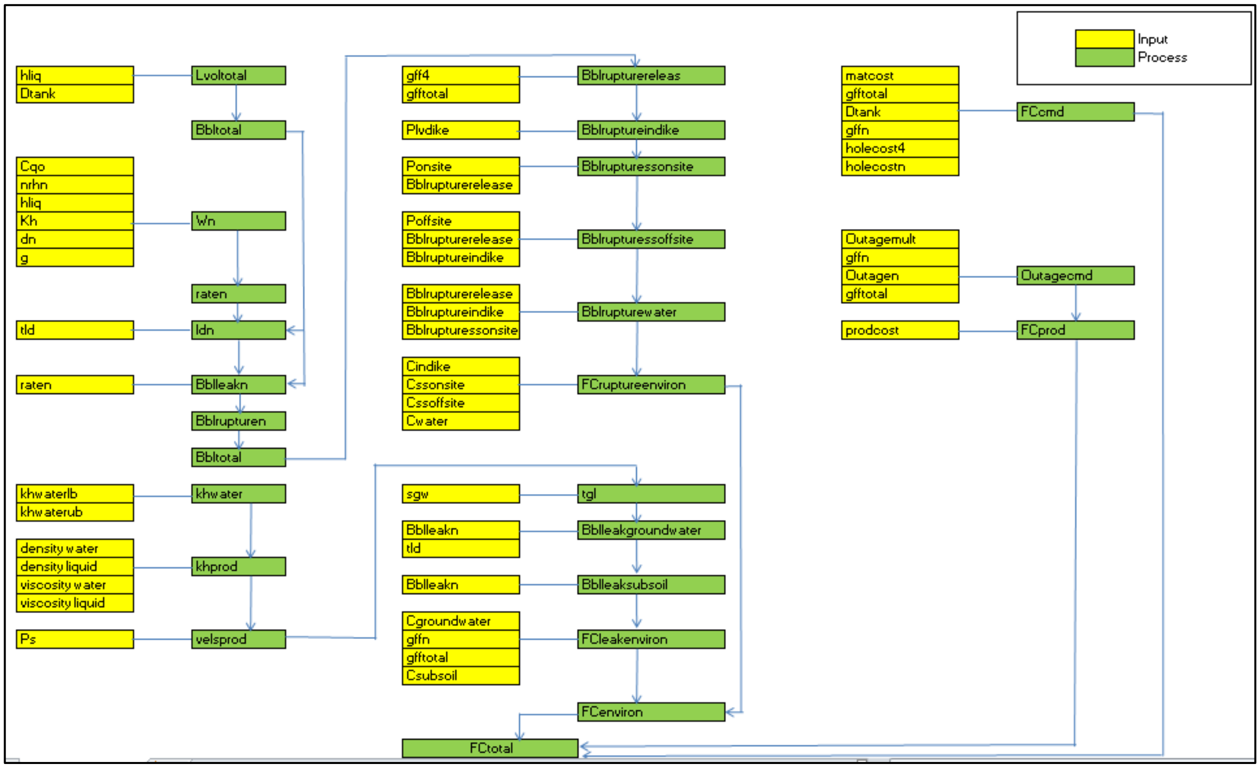


Figure 10: Algorithm for COF of tank bottom

Table 4: Algorithm nomenclature description

	Nomenclature	Description
1	An	is the hole area associated with the *nth* release hole size
2	Bbltotal	is the product volume in the tank
3	Bblavailn	is the available product volume for the *nth* release hole size due to a leak
4	Bblleakgroundwatern	is the product volume for the *nth* release hole size due to a leak in the groundwater
5	Bblleaksubsoiln	is the product volume for the *nth* release hole size due to a leak in the subsoil
6	Bblleakn	is the product volume for the *nth* release hole size due to a leak
7	Bblleakgroundwater	is the total product volume in the groundwater due to a leak
8	Bblleakindike	is the total product volume in the dike due to a leak
9	Bblleakrelease	is the total product volume released due to a leak
10	Bblleakssonsite	is the total product volume released on the surface located on-site due to a leak
11	Bblleakssoffsite	is the total product volume released on the surface located off-site due to a leak
12	Bblleaksubsoil	is the total product volume in the subsoil due to a leak
13	Bblleakwater	is the total product volume in the water due to a leak
14	Bblrupturen	is the product volume for the *nth* release hole size due to a rupture
15	Bblruptureindike	is the product volume in the dike due to a rupture
16	Bblrupturerelease	is the product volume in released due to a rupture
17	Bblrupturessonsite	is the product volume on the surface located on-site due to a rupture
18	Bblrupturessoffsite	is the product volume on the surface located off-site due to a rupture
19	Bblrupturewater	is the total product volume in the water due to a rupture
20	CHT	is the course height of the tank
21	Cd	is the discharge coefficient
22	Cindike	is the environmental cost for product in the dike area
23	Cssonsite	is the environmental cost for product on the surface located on-site

24	Cssoffsite	is the environmental cost for product on the surface located off-site
25	Cwater	is the environmental cost for product in water
26	Csubsoil	is the environmental cost for product in the subsoil
27	Cgroundwater	is the environmental cost for product in the groundwater
28	Cqo	is the adjustment factor for degree of contact with soil
29	dn	is the diameter of the *nth* release hole
30	Dtank	is the tank diameter,
31	FCenviron	is the financial consequence of environmental clean-up,
32	FCcmd	is the financial consequence of component damage,
33	FCprod	is the financial consequence of lost production on the unit
34	FCtotal	is the total financial consequence
35	FCleakenviron	is the financial consequence of environmental cleanup for leakage
36	FCruptureenviron	is the financial consequence of environmental cleanup for leakage
37	g	is the acceleration due to gravity on earth at sea level = 9.81 m/s2
38	gffn	are the generic failure frequencies for each of the *n* release hole sizes selected for the type of equipment being evaluated
39	gfftotal	is the sum of the individual release hole size generic frequencies
40	hliq	is the maximum fill height in the tank
41	kh	is the soil hydraulic conductivity,
42	Khprod	is the soil hydraulic conductivity based on the tank product,
43	Khwater	is the soil hydraulic conductivity based on water
44	Khwaterlb	is the lower bound soil hydraulic conductivity based on water
45	Khwaterub	is the upper bound soil hydraulic conductivity based on water
46	ldn	is the actual leak duration of the release based on the available mass and the calculated release rate, associated with the *nth* release hole size
47	Lvolaboven	is the total liquid volume for the *nth* release hole size
48	Lvolavailn	is the available liquid volume for the *nth* release hole size
49	Lvolabovei	is the total liquid volume above the *ith* tank shell course
50	Lvoltotal	is the total liquid volume in the tank,
51	LHTabovei	is the liquid height above the *ith* tank shell course
52	Matcost	is the material cost factor
53	Nc	is the total number of tank shell courses
54	Viscosity liquid	is the dynamic viscosity
55	Outageaffa	is the numbers of days of downtime required to repair damage to the surrounding equipment, days
56	Outagen	is the number of downtime days to repair damage associated with the *nth* release hole size
57	Ps	is the soil porosity
58	Plvdike	is the percentage of fluid leaving the dike
59	Ponsite	is the percentage of fluid that leaves the dike area but remains on-site
60	Poffsite	is the percentage of fluid that leaves the dike area but remains off-site
61	Density liquid	is the liquid density at storage or normal operating conditions
62	Density water	is the density of water at storage or normal operating conditions
63	raten	is the adjusted or mitigated discharge rate used in the consequence calculation associated with the *nth* release hole size
64	sgw	is the distance to the groundwater underneath the tank
65	Tgl	is the time required for the product to reach the groundwater through a leak in the tank bottom
66	Tld	is the leak detection time
67	Velsprod	is the seepage velocity
68	Wn	is the discharge rate of the tank product through a hole in the shell course

4.2 Risk-based Inspection for Atmospheric Storage Tank (RAST)

After a month of coding and graphic user interface designing, the Excel-based software is successfully developed and named as **RAST** that based on the short form of Risk-based Inspection for Atmospheric Storage Tank (AST). Once the software is launched, *figure 11* would then pop out providing the user of four alternatives including **Introduction**, **Launch software**, **Data recorded** and **Exit**. **Exit** button used to close the software when it is click by the user. This whole interface develops using user form application inside the VBA that allow user to design user friendly software by only using Microsoft excel.

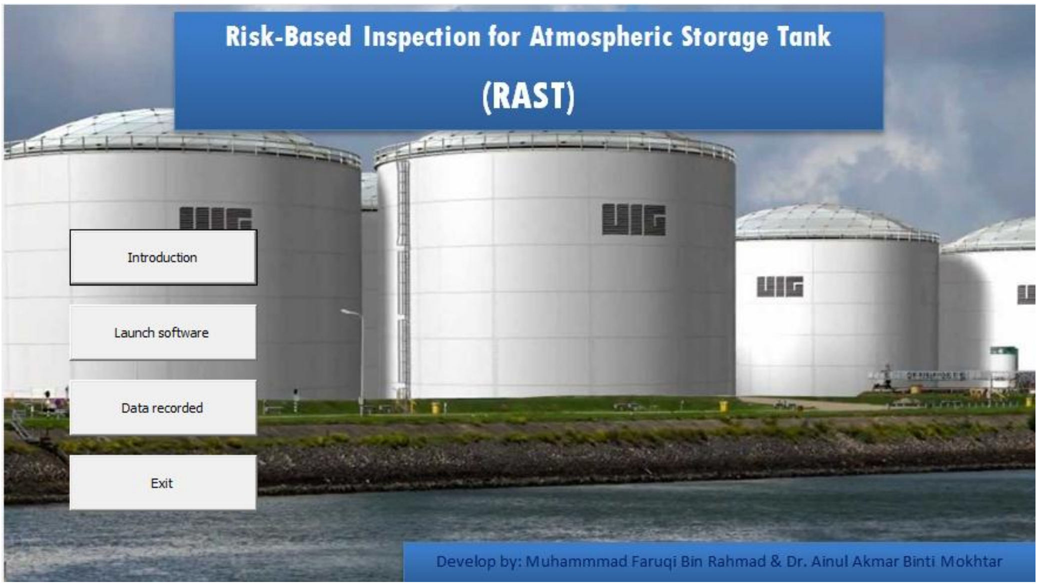
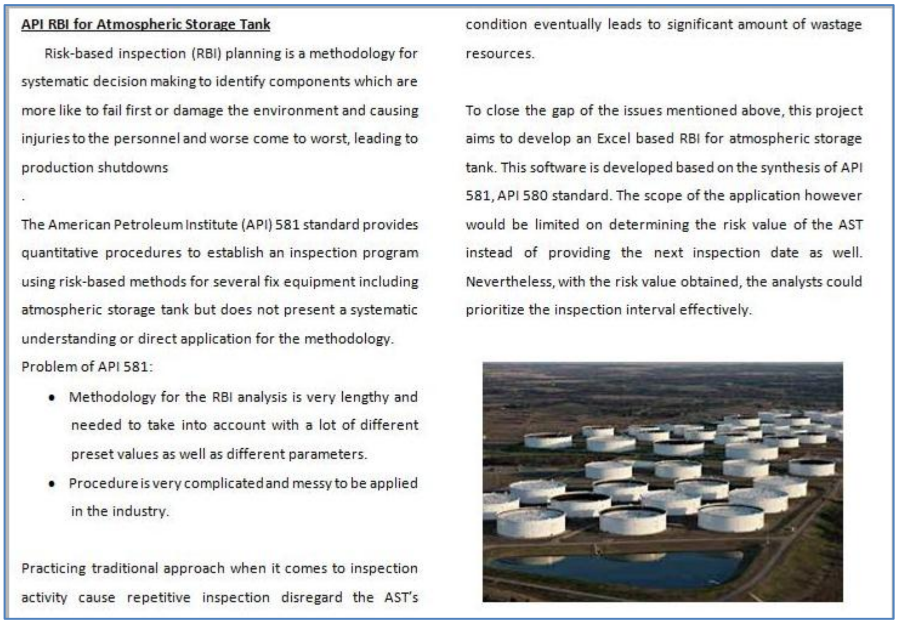


Figure 11: RAST Loading Screen

4.2.1 Introduction

When user click the first command button that shows "**Introduction**", *figure 12* would then appear giving a brief introduction regarding RBI technology and its advantages.



API RBI for Atmospheric Storage Tank

Risk-based inspection (RBI) planning is a methodology for systematic decision making to identify components which are more like to fail first or damage the environment and causing injuries to the personnel and worse come to worst, leading to production shutdowns

.

The American Petroleum Institute (API) 581 standard provides quantitative procedures to establish an inspection program using risk-based methods for several fix equipment including atmospheric storage tank but does not present a systematic understanding or direct application for the methodology.

Problem of API 581:

- Methodology for the RBI analysis is very lengthy and needed to take into account with a lot of different preset values as well as different parameters.
- Procedure is very complicated and messy to be applied in the industry.

Practicing traditional approach when it comes to inspection activity cause repetitive inspection disregard the AST's condition eventually leads to significant amount of wastage resources.

To close the gap of the issues mentioned above, this project aims to develop an Excel based RBI for atmospheric storage tank. This software is developed based on the synthesis of API 581, API 580 standard. The scope of the application however would be limited on determining the risk value of the AST instead of providing the next inspection date as well. Nevertheless, with the risk value obtained, the analysts could prioritize the inspection interval effectively.

Figure 12 : Introduction to RBI

Introduction is important for the user to get the rough idea on the RBI and important of RBI is in the industry especially for the first time user. It also states brief definition of RBI and explaining how RBI system works. The information above is based on the API Risk-based inspection. "**Home**" used to close the introduction windows to go back to main page.

4.2.2 Launch Software

The second button, "**Launch Software**" button will direct user to input window. When the button is click, interface will appear consist of five different categories of input data that needed to be entered in by user. Six categories namely are:

a) General information of atmospheric storage tank
b) Select component want to be evaluate
c) Inspection data history
d) Thinning and corrosion history
e) Construction and maintenance information
f) Financial consequences

Before started entering the input, user need to aware that special **" ? "** help buttons are created as help button for the user. User can press them if having any unclear statement or unable to understand the question given in the software. Pop out as shown in *figure 13* is the example when the button is click. This interface will pop when help button is click and can be closed by pressing "**Close**" button. However, only a few questions are equip with these special help button depending on the level of difficulties of question.

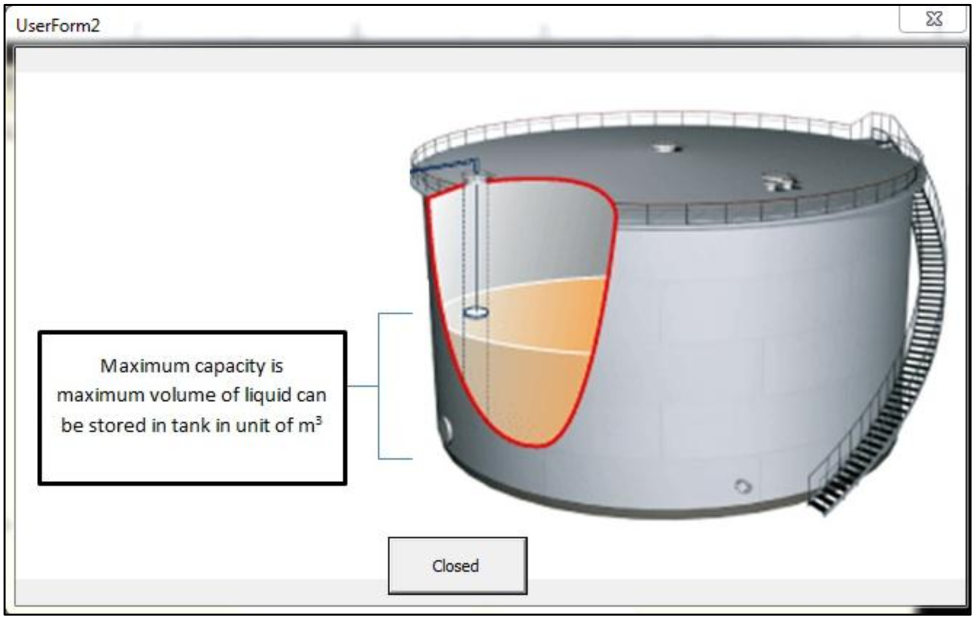


Figure 13: Special help button interface

All respective categories needed different type of parameters which required in the RBI analysis. For the first category requires the user to input general information of AST at the empty boxes such as the equipment number, diameter, height, maximum capacity and total tank shell course. These can be seen from *figure 14*. All these information either in value or wording form are essential data needed by the program to continue the analysis. For "**Type of content**", "**Type of soil**", "**Type of tank shell material**" and "**Type of bottom material**" questions, list of answers can only being select when the user click at the empty blank space .

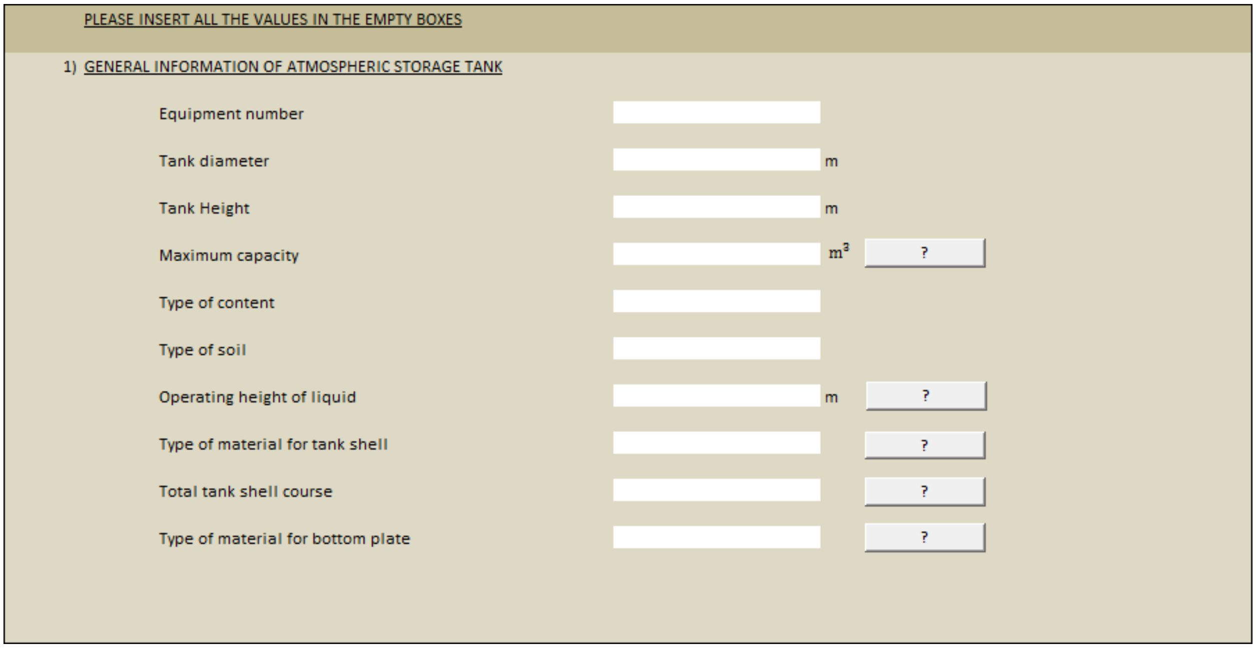


Figure 14: General information of AST

On the other hand, the second category is the selections of AST component that wanted to be evaluated which are **Internal tank shell course**, **External tank shell course** or **Tank bottom**. User can only select one component to be analyzed from these lists. AST being evaluate and analyze separately due to their large structure and consist of different type of other large components. By analyze it separately, it will produce more accurate analysis and more reliable result compared to the result that analyze AST as one component. The selection of AST component can be seen from *figure 15.*

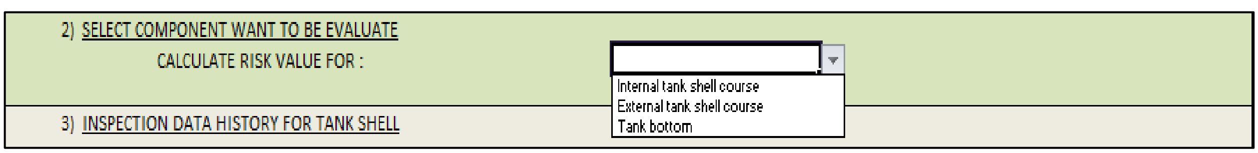


Figure 15: Selection of AST component

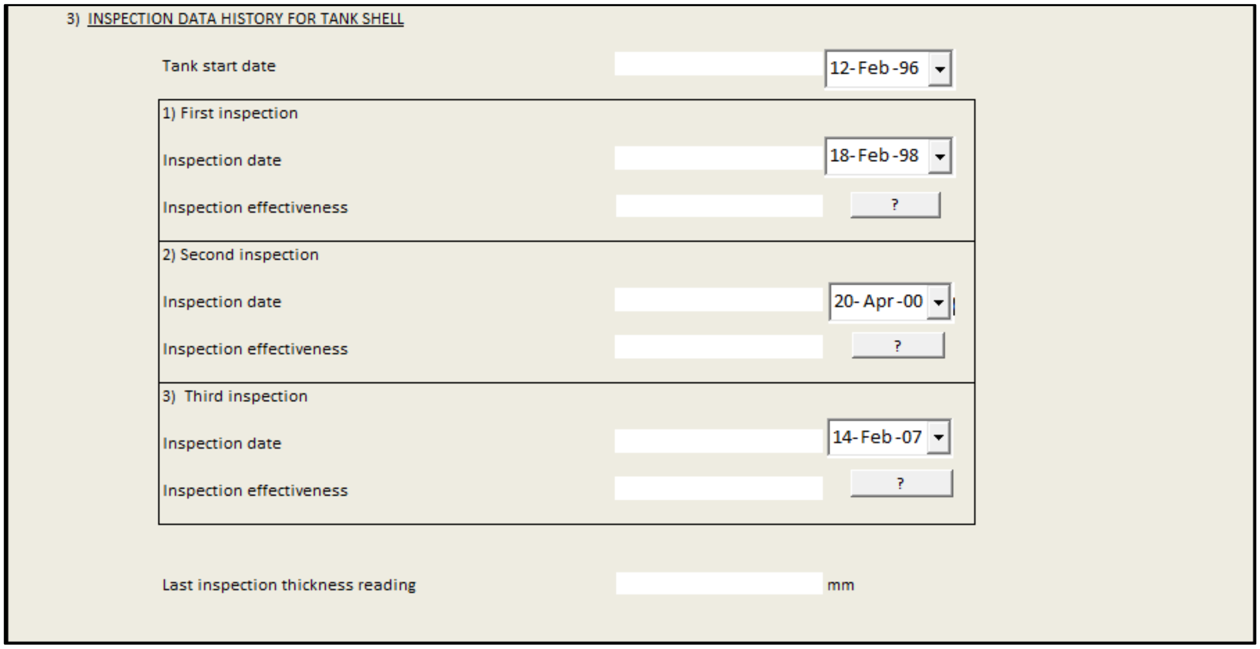


Figure 16: Inspection data history

AST Inspection data history as shown in *figure 16* which is the third category allows user to enter previous AST inspection information for example **Tank start date**, **Inspection effectiveness** and **Last inspection thickness reading**. The effectiveness of each inspection performed within he designated time period must be choose within this characterized **Highly effective**, **Usually effective**, **Fairy effective**, **Poorly effective** and **Ineffective**. User can refer *table 5, table 6 and table 7,* as guidance for the user to decide and enter inspection effectiveness level. The highest effectiveness inspection will be used to determine the damage factor.

Table 5: Effectiveness category for external tank shell course

Inspection Category	Inspection Effectiveness Category	Inspection
A	Highly Effective	a. Intrusive inspection – good visual inspection with pit depth gage measurements at suspect locations. b. UT scanning follow up on suspect location and as general confirmation of wall thickness
B	Usually Effective	a. External spot UT scanning based on visual information from previous internal inspection of this tank or similar service tanks. b. Internal video survey with external UT follow-up.
C	Fairly Effective	Eternal spot UT scanning based at suspect locations without benefit of any internal inspection information on tank type or service.
D	Poorly Effective	External spot UT based at suspect locations without benefit of any internal inspection information on tank type or service.
E	Ineffective	No inspection

Table 6: Effectiveness category for external category

Inspection Category	Inspection Effectiveness Category	Inspection
A	Highly Effective	a. **Insulated** – >95% external visual inspection prior to removal of insulation b. Remove >90% of insulation at suspect locations, OR >90% pulse eddy current inspection. c. Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required. a. **Non-Insulated** - >95% visual inspection of the exposed surface area with follow-up by UT or pit gauge as required.
B	Usually Effective	a. **Insulated** – >95% external visual inspection prior to removal of insulation b. Remove >30% of insulation at suspect locations, OR >30% pulse eddy current inspection. c. Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required. a. **Non-Insulated** - >50% visual inspection of the exposed surface area with follow-up by UT or pit gauge as required.
C	Fairly Effective	a. **Insulated** – >95% external visual inspection prior to removal of insulation b. Remove >10% of insulation at suspect locations, OR >10% pulse eddy current inspection. c. Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required. a. **Non-Insulated** - >25% visual inspection of the exposed surface area with follow-up by UT or pit gauge as required.
D	Poorly Effective	a. **Insulated** – >95% external visual inspection prior to removal of insulation b. Remove >5% of insulation at suspect locations, OR >5% pulse eddy current inspection. c. Visual inspection of the exposed surface area with follow-up by UT or pit gauge as required. a. **Non-Insulated** - >10% visual inspection of the exposed surface area with follow-up by UT or pit gauge as required.
E	Ineffective	a. **Insulated** – No visual inspection of insulation surface area or removal of insulation. a. **Non-Insulated** - <5% visual of the exposed surface area

Table 7: Effectiveness category for tank bottom

Inspection Category	Inspection Effectiveness Category	Soil Side	Product Side
A	Highly Effective	a. Floor scan 90+% & UT follow-up b. Include welds if warranted from the results on the plate scanning c. Hand scan of the critical zone	a. Commercial blast b. Effective supplementary light c. Visual 100% (API 653) d. Pit depth gauge e. 100% vacuum box testing of suspect welded joints <u>Coating or Liner</u>: a. Sponge test 100% b. Adhesion test c. Scrape test
B	Usually Effective	a. Floor scan 50+% & UT follow-up OR b. EVA or other statistical method with Floor scan follow-up if warranted by the result	a. Brush blast b. Effective supplementary light c. Visual 100% (API 653) d. Pit depth gauge <u>Coating or Liner</u>: a. Sponge test >75% b. Adhesion test c. Scrape test
C	Fairly Effective	a. Floor scan 5-10+% plates; supplement with scanning near Shell & UT follow-up; Scan circle and X pattern b. Progressively increase if damage found during scanning c. Helium/Argon test d. Hammer test e. Cut coupons	a. Broom swept b. Effective supplementary light c. Visual 100% d. Pit depth gauge <u>Coating or Liner</u>: a. Sponge test 50 – 75% b. Adhesion test c. Scrape test
D	Poorly Effective	a. Spot UT b. Flood test	a. Broom swept b. No effective supplementary lighting c. Visual 25-50% <u>Coating or Liner</u>: a. Sponge test <50
E	Ineffective	None	None

The forth category is the thinning and corrosion information, *figure 17*. This interface asks for information regarding corrosion rate and thinning effect that being faced by the component. The information includes the type of equipment, operating condition, representative process fluid and financial properties. Corrosion rate data input is in unit of millimeter per year. Cladding is defined as a covering or coating on a structure of AST. If user clicks “**Yes**” at the cladding question, one more question will pop out asking for corrosion rate of cladding. However, it is difficult to have AST that used metal as a cladding component in the industry. Corrosion allowance is the additional thickness to the wall thickness to compensate for the metal expected to be lost over the life of the equipment. Thus its value is very small compared to the thickness of base metal. All of the parameters are necessary in the calculation for the damage factor and consequences of failure.

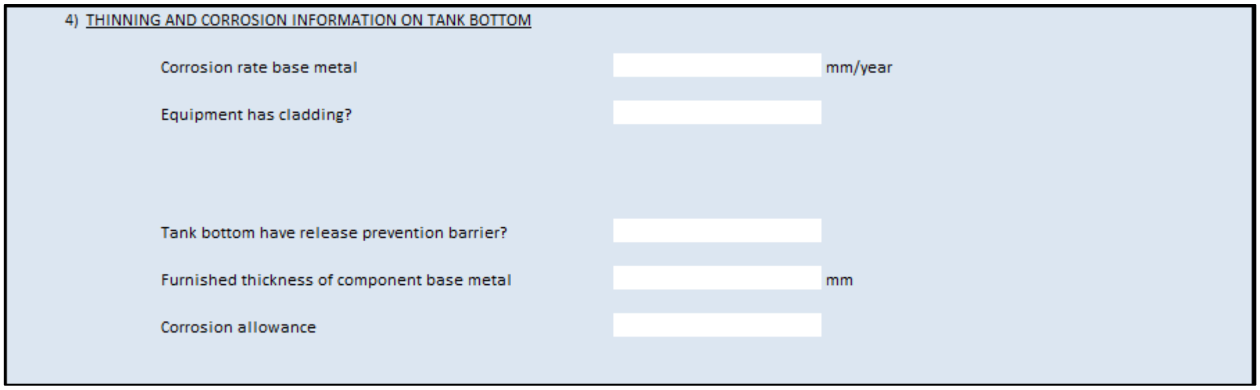


Figure 17: Thinning and corrosion information

The fifth category is the **construction and maintenance information** as shown in figure 18. The information includes the adjustment to damage factor for online monitoring value, adjustment for tank settlement and maintenance method.

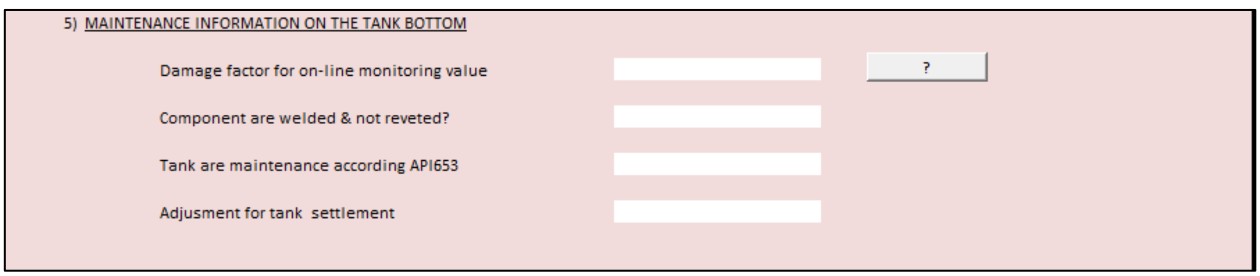


Figure 18: Construction and maintenance information

Adjustment for on-line monitoring of corrosion or key process variables affecting corrosion is commonly used in many processes to prevent corrosion failures. The advantage of on-line monitoring is that changes in corrosion rates as a result of process changes can be detected long before they would be detected with normal periodic inspections. This earlier detection usually permits more timely action to be taken that should decrease the probability of failure. Various methods are employed, ranging from corrosion probes, corrosion coupons, and monitoring of key process variables. If on-line monitoring is employed, then credit should be given to reflect higher confidence in the predicted thinning rate. However, these methods have a varying degree of success depending on the specific thinning mechanism. Using knowledge of the thinning mechanism and the type of on-line monitoring, users can determine the on-line monitoring factor base from *table 8*.

Table 8: Online monitoring factor

Thinning Mechanism	Adjustment Factors as a Function of On-Line Monitoring, F_{OM}		
	Key Process Variable	Electrical Resistance Probes (See Note 3)	Corrosion Coupons (See Note 3)
Hydrochloric Acid (HCl) Corrosion	10 (20 if in conjunction with Probes)	10	2
High Temperature Sulfidic/Naphthenic Acid Corrosion	10	10	2
High Temperature H_2S/H_2 Corrosion	1	10	1
Sulfuric Acid (H_2S/H_2) Corrosion			
Low Velocity ≤ 3 ft/s for CS, ≤ 5 ft/s for SS, ≤ 7 ft/s for higher alloys	20	10	2
High Velocity > 3 ft/s for CS, > 5 ft/s for SS, > 7 ft/s for higher alloys	10 (20 if in conjunction with Probes)	10	1
Hydrofluoric Acid (HF) Corrosion	10	1	1
Sour Water Corrosion			
Low Velocity ≤ 20 ft/s	20	10	2
High Velocity > 20 ft/s	10	2	2
Amine			
Low Velocity	20	10	2
High Velocity	10	10	1
Other Corrosion Mechanism	1	1	1

Adjustment for Welded Construction is depending whether the component is welded or not. Welded component give value of 1 where else non welded give value 10. Adjustment for Maintenance asks the user whether AST is maintained or not maintained according to API. If the AST is maintained in accordance with API 653, it gives value of 1 where else if not maintained according to API653 it will give value of 5. Finally adjustment for settlement need information on the settlement information such as **exceed API 653**, **not exceed API 653**, **not evaluate** or **no settlement**.

The last category is the financial consequences information that asks regarding effect of AST leak or rupture towards the financial of the company as shown in *figure 19*. The consequences associated with atmospheric storage tanks is concerned primarily with the financial losses due to loss of containment and leakage through the tank floor as well as leakage or rupture of a tank shell course .The information includes the position of release hole, percentage of fluid leaves the AST, environmental sensitivity and course of production due to repair.

Position of release hole is defined as the position of release hole at the tank shell course level. The user enter level of shell course that having small, medium, large and rupture type release hole. Percentage of fluid leaving the dike, fluid leaves dike area but remain onsite and fluid leaves dike area but remain offsite are the assumption need to be made by the user when the tank shell and tank bottom having leakage or rupture. Dike area, onsite and offsite are defining base on the *figure 20.*

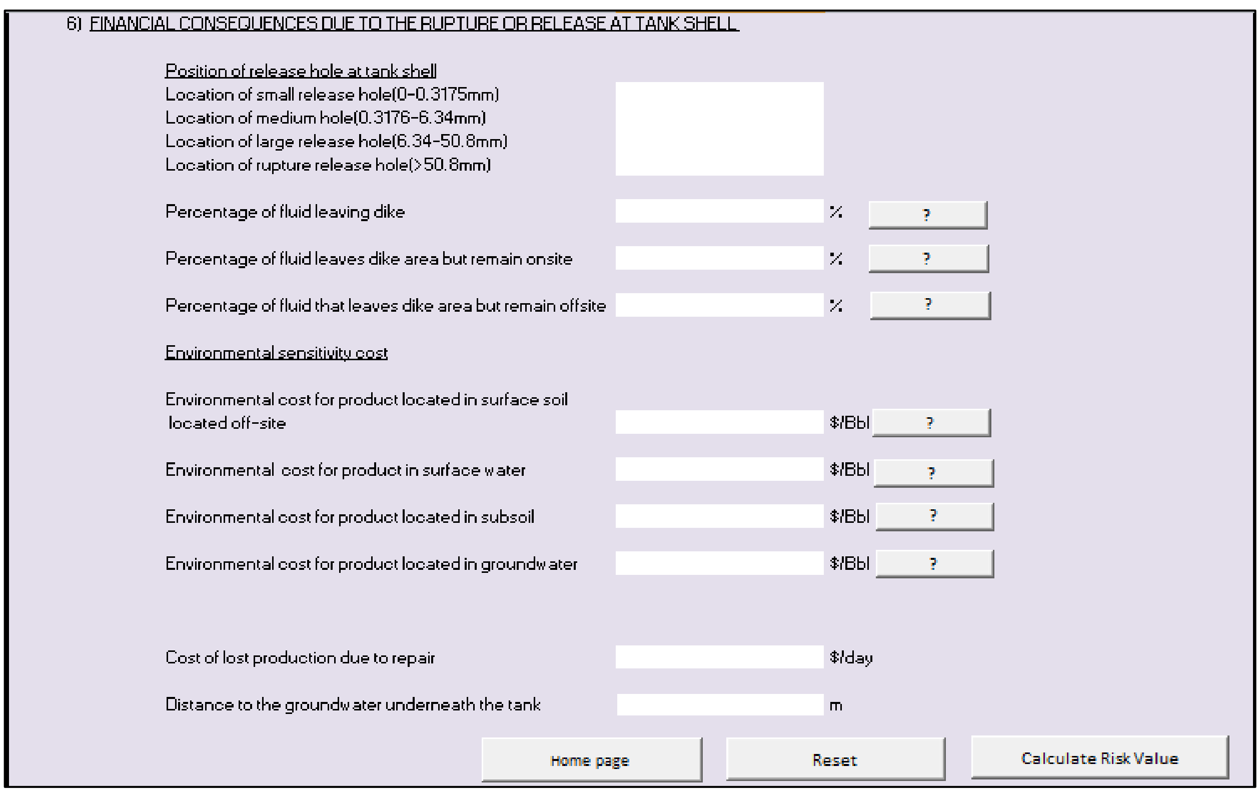


Figure 19: Financial consequences

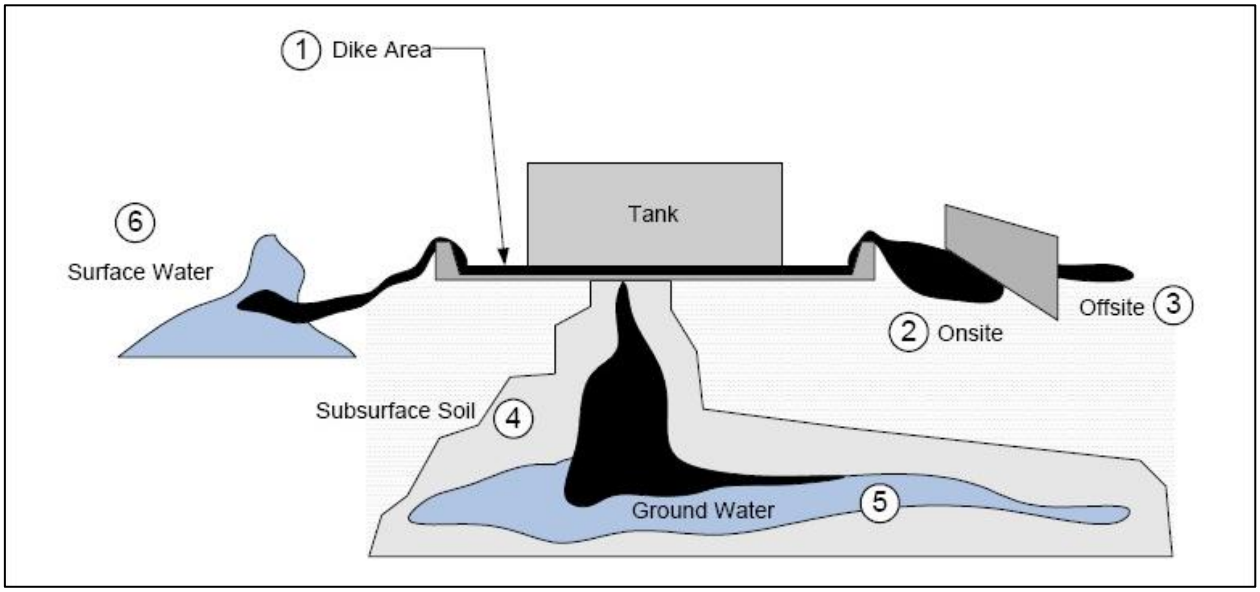


Figure 20: Dike, onsite and offsite area

Environmental sensitivity is the cost to clean and purify product that leak to the environment. It is calculated using USD currency base on their universal usage and the user can decide according *table 9.* Adjustment factor for degree of contact with soil will only appear when the user selecting select tank bottom as the component to be analyze. Higher value of indicate poor contact where else lower value indicate good contact between the bottom plate and soil.

Table 9: Environmental sensitivity

Location (1)	Description	Environmental Sensitivity Low (US$/bbl)	Medium (US$/bbl)	High (US$/bbl)
1	C_{indike} – Environmental cost for product located in the dike area	10	10	10
2	$C_{ss-onsite}$ – Environmental cost for product located in surface soil located on-site	50	50	50
3	$C_{ss-offsite}$ – Environmental cost for product located in surface soil located off-site	100	250	500
4	$C_{subsoil}$ – Environmental cost for product located in subsoil	500	1500	3000
5	$C_{groundwater}$ – Environmental cost for product located in groundwater	1000	5000	10000
6	C_{water} – Environmental cost for product in surface water	500	1500	5000

Once all the information are key in into the interface, the user may then proceed to the risk calculation or reset input value there is any correction need to be made by clicking button as shown in bottom of *figure 19.*

Figure 21 below shows the example result that will be shown by this software. Risk level is assign based on the damage factor value and consequences of failure value. The result window gives the type of AST currently evaluating, additional descriptions such as AST equipment number as well as the risk value in term of financial-based. The highlighted column beside risk level represents the risk category of the risk value falls into. For instance, green represents low risk while yellow represents medium risk, orange represent medium high risk and red indicates high risk. Risk matrix diagram is added to give more understanding to the user.

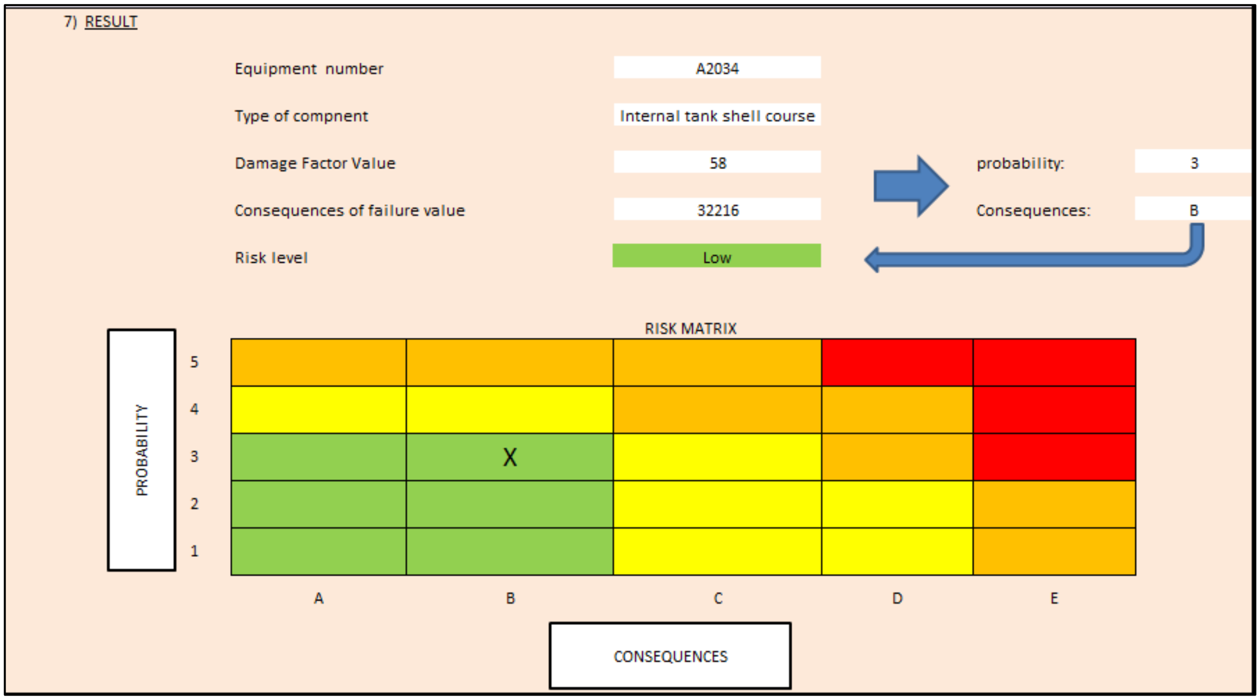


Figure 21: RBI result

4.2.3 Data recorded

The third button, “**Data recorded**” button will direct user to the list of all the data that have been key in by user as shown in *figure 22*. This data might be used in the future to keep tract the condition of the AST.

INPUT DATA HISTORY

Home page

Bil	Input	Unit	Data1	Data2	Data3
1	Equipment number	-	A2034	A2034	
2	Tank diameter	m	100	100	
3	Tank height	m	50	50	
4	Maximum capacity	m^3	1213	1213	
5	Type of content	-	Heavy Crude Oil	Heavy Crude Oil	
6	Type of soil	-	Coarse Sand	Coarse Sand	
7	Operating height of liquid	m	40	40	
8	Type of material for tank shell course	-	1.25Cr-0.5Mo	1.25Cr-0.5Mo	
9	Total tank shell course	-	10	10	
10	Type of material for bottom plate	-	Carbon Steel	Carbon Steel	
11	Height of each cell course	m	5	5	
12	type of material to be analize	-	Tank bottom	Tank bottom	
13	Tank start date	-	02-12-96	02-12-96	
14	Inspection date insp 1	-	18-02-1998	18-02-1998	
15	Inspection effectiveness insp 1	-	Usually effective	Usually effective	
16	Inspection date insp 2	-	20-04-2000	20-04-2000	
17	Inspection effectiveness insp2	-	Fairly effective	Fairly effective	
18	Inspection date insp 3	-	14-02-2007	14-02-2007	
19	Inspection effectiveness insp 3	-	Usually effective	Usually effective	
20	Time since last inspection reading	yr	8.27	8.27	
21	Last inspection thickness reading	mm	10	10	
22	Corrosion rate base metal	mm/yr	1	1	
23	Equipment has cladding?	-	No	No	
24	Corrosion rate for cladding	mm/yr			
25	Minimum required wall thickness according API579	-			
26	Tank bottom have release prevention barrier?	-	Yes	Yes	
27	Furnished thickness of component base metal	mm	10	10	
28	Corrosion allowance	-	0.1	0.1	
29	Damage factor for on-line monitoring value	-	1	1	
30	Component are welded & not reveted?	-	Yes	Yes	
31	Tank are maintenance according API653	-	Yes	Yes	
32	Adjusment for tank settlemet	-	ettlement exceeds API 653 criter	ent exceeds API 653 criteria	
33	Location of small release hole(0-0.3175mm)	mm			
34	Location of medium hole(0.3176-6.34mm)	mm			
35	Location of large release hole(6.34-50.8mm)	mm			
36	Location of rupture release hole(>50.8mm)	mm			
37	Percentage of fluid leaving dike	%	10	10	
38	Percentage of fluid leaves dike area but remain onsite	%	10	10	
39	Percentage of fluid that leaves dike area but remain offsite	%	10	10	

Figure 22: Recorded input data

4.2.4 Data validation

Due to the absence of actual case study, data validation could not be carrying out. The reason is because most of the plants are yet to implement the RBI technology. The alternative would be actual simulation on a plant directly but the process exceeds the time frame available to conduct this study. Hence, the remaining choice would be validating the functionality and availability of the software by comparing between results obtains from software and the result obtains from manual calculation. For the software validation purpose, two sets of hypothetical data are used as shown in figure *23* and figure *24*. Both figures show different list of input data and risk level obtain based on the software and manual calculation.

Bil	Input	Unit	Data34	Data34
1	Equipment number	-	A2034	A2034
2	Tank diameter	m	50	50
3	Tank height	m	50	50
4	Maximum capacity	m^3	80000	80000
5	Type of content	-	Gasoline	Gasoline
6	Type of soil	-	Silt	Silt
7	Operating height of liquid	m	40	40
8	Type of material for tank shell course	-	1.25Cr-0.5Mo	1.25Cr-0.5Mo
9	Total tank shell course	-	10	10
10	Type of material for bottom plate	-	Carbon Steel	Carbon Steel
11	Height of each cell course	m	5	5
12	type of material to be analize	-	External tank shell course	External tank shell course
13	Tank start date	-	02-12-96	02-12-96
14	Inspection date insp 1	-	18-02-1998	18-02-1998
15	Inspection effectiveness insp 1	-	Highly effective	Highly effective
16	Inspection date insp 2	-	20-04-2000	20-04-2000
17	Inspection effectiveness insp2	-	Fairly effective	Fairly effective
18	Inspection date insp 3	-	22-08-2013	22-08-2013
19	Inspection effectiveness insp 3	-	Highly effective	Highly effective
20	Time since last inspection reading	yr	1.69	1.69
21	Last inspection thickness reading	mm	10	10
22	Corrosion rate base metal	mm/yr	0.001	0.001
23	Equipment has cladding?	-	No	No
25	Minimum required wall thickness according API579	-	8	8
26	Tank bottom have release prevention barrier?	-	No	No
27	Furnished thickness of component base metal	mm	1	1
28	Corrosion allowance	-	3.17	3.17
29	Damage factor for on-line monitoring value	-	1	1
30	Component are welded & not reveted?	-	Yes	Yes
31	Tank are maintenance according API653	-	Yes	Yes
32	Adjusment for tank settlemet	-	settlement exceeds API 653 criteria	settlement exceeds API 653 criteria
33	Location of small release hole(0-0.3175mm)	mm	2	2
34	Location of medium hole(0.3176-6.34mm)	mm	3	3
35	Location of large release hole(6.34-50.8mm)	mm	2	2
36	Location of rupture release hole(>50.8mm)	mm	2	2
37	Percentage of fluid leaving dike	%	20	20
38	Percentage of fluid leaves dike area but remain onsite	%	20	20
39	Percentage of fluid that leaves dike area but remain offsite	%	20	20
40	Environmental cost for product located in surface soil located offs	$/Bbl	100	100
41	Environmental cost for product in surface water	$/Bbl	500	500
42	Environmental cost for product located in subsoil	$/Bbl	500	500
43	Environmental cost for product located in groundwater	$/Bbl	1000	1000
44	Adjustment factor for degree of contact with soil	-		
45	Cost of lost production due to repair	$/Bbl	1000	1000
46	Distance to the groundwater underneath the tank	m	100	100
47	Damage factor value		270	270
48	Probability		4	4
49	Consequences of failure value		116179	116178
50	Consequences		C	C
51	Risk level		Medium high	Medium high

Result base on the sofware

Result base on the manual calculaition

Figure 23: RBI result for first data set

Bil	Input	Unit	Data36	Data36
1	Equipment number	-	A2034	A2034
2	Tank diameter	m	50	50
3	Tank height	m	50	50
4	Maximum capacity	m^3	90000	90000
5	Type of content	-	Heavy Crude Oil	Heavy Crude Oil
6	Type of soil	-	Silt	Silt
7	Operating height of liquid	m	40	40
8	Type of material for tank shell course	-	405 SS	405 SS
9	Total tank shell course	-	10	10
10	Type of material for bottom plate	-	Carbon Steel	Carbon Steel
11	Height of each cell course	m	5	5
12	type of material to be analize	-	Internal tank shell course	Internal tank shell course
13	Tank start date	-	02-12-96	02-12-96
14	Inspection date insp 1	-	18-02-1998	18-02-1998
15	Inspection effectiveness insp 1	-	Highly effective	Highly effective
16	Inspection date insp 2	-	20-04-2000	20-04-2000
17	Inspection effectiveness insp2	-	Fairly effective	Fairly effective
18	Inspection date insp 3	-	22-08-2013	22-08-2013
19	Inspection effectiveness insp 3	-	Highly effective	Highly effective
20	Time since last inspection reading	yr	1.69	1.69
21	Last inspection thickness reading	mm	10	10
22	Corrosion rate base metal	mm/yr	0.001	0.001
23	Equipment has cladding?	-	No	No
25	Minimum required wall thickness according API579	-	8	8
26	Tank bottom have release prevention barrier?	-	No	No
27	Furnished thickness of component base metal	mm	1	1
28	Corrosion allowance	-	3.17	3.17
29	Damage factor for on-line monitoring value	-	1	1
30	Component are welded & not reveted?	-	Yes	Yes
31	Tank are maintenance according API653	-	Yes	Yes
32	Adjusment for tank settlemet	-	settlement exceeds API 653 criteria	settlement exceeds API 653 criteria
33	Location of small release hole(0-0.3175mm)	mm	2	2
34	Location of medium hole(0.3176-6.34mm)	mm	3	3
35	Location of large release hole(6.34-50.8mm)	mm	2	2
36	Location of rupture release hole(>50.8mm)	mm	2	2
37	Percentage of fluid leaving dike	%	20	20
38	Percentage of fluid leaves dike area but remain onsite	%	20	20
39	Percentage of fluid that leaves dike area but remain offsite	%	20	20
40	Environmental cost for product located in surface soil located off	$/Bbl	100	100
41	Environmental cost for product in surface water	$/Bbl	500	500
42	Environmental cost for product located in subsoil	$/Bbl	500	500
43	Environmental cost for product located in groundwater	$/Bbl	1000	1000
44	Adjustment factor for degree of contact with soil	-		
45	Cost of lost production due to repair	$/Bbl	1000	1000
46	Distance to the groundwater underneath the tank	m	100	100
47	Damage factor value		270	270
48	Probability		4	4
49	Consequences of failure value		127489	127489
50	Consequences		C	C
51	Risk level		Medium high	Medium high

Result base on the sofware

Result base on manual calculation

Figure 24: RBI result for second data set

From figure above, only *figure 23* have slightly different consequences of failure values obtain from software and manual calculation. **116179** obtain form software whereas **116178** obtain from manual calculation. However, the different are very small and still give similar risk level since the risk level is the main concern in this project. Different result obtain might be due to the round off error by the excel system. Figure 24 shows similar result from both methods. From the result above, it is clear that the software developed is functioning accordingly and perform as it should. Unfortunately in term of data accuracy validation wise, it was not verified.

5. CONCLUSION AND RECOMMENDATION

Based from the results, the goal can be said was successfully by develop an Excel-based Risk-based inspection model which capable of determining the risk value. Since the software is Excel based, no installation would be required and most importantly it does not cost a single dime compare with the expensive software available in the market. Besides that, any operator with little computing knowledge would know how to use it in a short time. Without a doubt if the software could be validated with an actual case study, the result comparison would be more convincing. Thus, the result from this study is expected to help in planning the inspection interval thus saving tremendous amount of cost such as the redundant inspection cost and unnecessary production shutdown. Indirectly, the plant production efficiency could be increase as well. On the other hand, this could overcome the gap between the conventional inspection techniques with the current risk management technique.

This system can be improve by widen the scope of equipment and not just only for atmospheric storage tank. Next, graphical result presentation and statistics can be added into this software to increase its function. Last but not least, it can be improve by extend the capability of system to for generating next inspection date of equipment.

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APPENDICES

Appendix A: Coding for Damage factor

```
Sub DFrespectedtoMAIN()

Dim typecomp As String
typecomp = Range("G30")

'STEP1

'step 1
'cari eff mana yg paling tinggi antara 3
'keff,leff,meff,neff,oeff ni counter je(mcm i)
Dim ins, insp, keff, leff, meff, neff, oeff As Integer
Dim eff As String

For keff = 40 To 52
 If Cells(keff, 7) = "Ineffective" Then
    eff = "Ineffective"
    Range("P6") = eff
    Range("P7") = keff
 End If
Next keff

For leff = 40 To 52
 If Cells(leff, 7) = "Poorly effective" Then
    eff = "Poorly effective"
    Range("P6") = eff
    Range("P7") = leff
 End If
Next leff

For meff = 40 To 52
 If Cells(meff, 7) = "Fairly effective" Then
    eff = "Fairly effective"
    Range("P6") = eff
    Range("P7") = meff
 End If
Next meff

For neff = 40 To 52
 If Cells(neff, 7) = "Usually effective" Then
    eff = "Usually effective"
   Range("P6") = eff
    Range("P7") = neff
 End If
Next neff

For oeff = 40 To 52
 If Cells(oeff, 7) = "Highly effective" Then
    eff = "Highly effective"
   Range("P6") = eff
    Range("P7") = oeff
 End If
Next oeff


'cari inspection keberapa yg paling tinggi
ins = Range("P7")

    If ins = 40 Then
    insp = 1
    ElseIf ins = 46 Then
    insp = 2
```

```
   ElseIf ins = 52 Then
   insp = 3
   End If

 Range("P7") = insp

'klu tank bottom nyer selection lain
If Range("G30") = "Tank bottom" Then
   If Range("G40") = "Highly effective" Then
   eff = "Highly effective"
   ElseIf Range("G40") = "Usually effective" Then
   eff = "Usually effective"
   ElseIf Range("G40") = "Fairly effective" Then
   eff = "Fairly effective"
   ElseIf Range("G40") = "Poorly effective" Then
   eff = "Poorly effective"
   ElseIf Range("G40") = "Ineffective" Then
   eff = "Ineffective"
   End If

   insp = 1
End If

Range("P6") = eff
Range("P7") = insp

'samakan effectiveness dgn huruf(ABCDE)

Dim effhuruf As String

If eff = "Highly effective" Then
effhuruf = "A"
ElseIf eff = "Usually effective" Then
effhuruf = "B"
ElseIf eff = "Fairly effective" Then
effhuruf = "C"
ElseIf eff = "Poorly effective" Then
effhuruf = "D"
ElseIf eff = "Ineffective" Then
effhuruf = "E"
End If

Range("P8") = effhuruf

'cari thinning damage factor kat dalam table

'Range("F7") = insp

Dim effhuruf2 As String

'gabung insp dengan gred absd
If insp = 1 And effhuruf = "D" Then
effhuruf2 = "Done"
ElseIf insp = 1 And effhuruf = "C" Then
effhuruf2 = "Cone"
ElseIf insp = 1 And effhuruf = "B" Then
effhuruf2 = "Bone"
ElseIf insp = 1 And effhuruf = "A" Then
effhuruf2 = "Aone"
ElseIf insp = 2 And effhuruf = "D" Then
effhuruf2 = "Dtwo"
ElseIf insp = 2 And effhuruf = "C" Then
effhuruf2 = "Ctwo"
ElseIf insp = 2 And effhuruf = "B" Then
effhuruf2 = "Btwo"
ElseIf insp = 2 And effhuruf = "A" Then
```

```
effhuruf2 = "Atwo"
ElseIf insp = 3 And effhuruf = "D" Then
effhuruf2 = "Dthree"
ElseIf insp = 3 And effhuruf = "C" Then
effhuruf2 = "Cthree"
ElseIf insp = 3 And effhuruf = "B" Then
effhuruf2 = "Bthree"
ElseIf insp = 3 And effhuruf = "A" Then
effhuruf2 = "Athree"
Else
effhuruf2 = "Eone"
End If

Range("P9") = effhuruf2

'STEP2
Dim age, trd As Double
trd = Range("G56")
age = Range("G54")

'STEP3
Dim Crbm  As Double
Crbm = Range("G61")

Dim CLADcomp As String
CLADcomp = Range("G63")

Dim Crcm As Double
Crcm = Range("G64")

'STEP4(tanya protection barrrier)

Dim tmin As Double
tmin = Range("G66")
Dim PROTECTIONbarrier As String
PROTECTIONbarrier = Range("G68")

'If typecomp = "Internal tank shell course" Or "External tank shell course " Then"
'tmin = tmin

If typecomp = "Tank bottom" Then
 If PROTECTIONbarrier = "Yes" Then
  tmin = 3.2 'mm
 ElseIf PROTECTIONbarrier = "No" Then
  tmin = 6.4 'mm
 End If
End If

Range("P10") = typecomp
Range("P11") = tmin

'STEP5(find ageRC)

Dim agerc, t As Double
t = Range("G70")

    If CLADcomp = "Yes" Then
     agerc = (trd - t) / Crcm
        If agerc > 0 Then
            agerc = agerc
        Else
            agerc = 0
        End If
    End If

Range("P12") = agerc
```

```
'STEP6(find aRT,need CA)
Dim Art As Double
Dim CA As Double

CA = Range("G72")

If CLADcomp = "No" Then
Art = 1 - ((trd - (Crbm * age)) / (tmin + CA))

        If Art > 0 Then
        Art = Art
        Else
        Art = 0
        End If

ElseIf CLADcomp = "Yes" Then
Art = 1 - ((trd - (Crcm * agerc) - (Crbm * (age - agerc))) / (tmin + CA))

        If Art > 0 Then
        Art = Art
        Else
        Art = 0
        End If
End If


Dim Artsebelumround As Double
Artsebelumround = Art

Art = Round(Art, 1)

Range("P13") = Artsebelumround
Range("P14") = Art

'STEP7(find DthinfB),sheet lain


Dim DthinfB As Double
Dim iTDF, jTDF As Integer

For iTDF = 2 To 20 'kebawah
    If Cells(iTDF, 30) = Art Then
      For jTDF = 31 To 43 'kekanan
       If Cells(1, jTDF) = effhuruf2 Then
       Range("P17") = Cells(iTDF, jTDF)
       End If
        Next jTDF
    End If
 Next iTDF

If Range("G30") = "Tank bottom" Then
 For iTDF = 24 To 43 'kebawah
    If Cells(iTDF, 33) = Art Then
      For jTDF = 34 To 38 'kekanan
       If Cells(23, jTDF) = effhuruf2 Then
       Range("P17") = Cells(iTDF, jTDF)
       End If
        Next jTDF
    End If
 Next iTDF
End If

Range("P15") = Art
Range("P16") = effhuruf2
DthinfB = Range("P17")
```

```
'STEP8(find Dthinf)
Dim Dthinf, FWD, FAM, FSM, FOM As Double
Dim FWDvariable, FAMvariable, FSMvariable As String

FOM = Range("G77")
 If DthinfB = 1 Then
        FOM = 1
 End If
Range("P18") = FOM

FWDvariable = Range("G79")
If FWDvariable = "Yes" Then
        FWD = 1
        Else
        FWD = 10
        End If
Range("P19") = FWD

FAMvariable = Range("G81")
 If FAMvariable = "Yes" Then
        FAM = 1
        Else
        FAM = 5
        End If
Range("P20") = FAM


If Range("G30") = "Tank bottom" Then

 FSMvariable = Range("G83")
 If FSMvariable = "settlement exceeds API 653 criteria" Then
        FSM = 2
 ElseIf FSMvariable = "settlement meets API 653 criteria" Then
        FSM = 1
 ElseIf FSMvariable = "settelment never evaluated" Then
        FSM = 1.5
 ElseIf FSMvariable = "concrete foundation,no settlement" Then
        FSM = 1
 End If
Else
 FSM = 1
End If

'Range("P21") = FSM

Dthinf = (DthinfB * FWD * FAM * FSM) / FOM
Range("P22") = Dthinf
Range("G125") = Dthinf


End Sub
```

Appendix B: Coding for Consequences of failure for tank shell

```
Sub cofshellrespectedtoMAIN()

'1.1(pilih fluid)
'base on type of fluid,loop untuk cari density & viscosity kat table
Dim typefluid, typecomp, typesoil As String
typecomp = Range("G30") ''''''''''''''''''''''''''''''''''''''''''''''''
typefluid = Range("G14") ''''''''''''''''''''''''''''''''''''''''''''''''
Dim liquiddensity As Double
Dim liquidviscosity As Double

Range("M5") = typecomp
Range("M6") = typefluid

For itypefluid = 3 To 9 'kebawah
   If Cells(itypefluid, 23) = typefluid Then
   liquiddensity = Cells(itypefluid, 26)
   liquidviscosity = Cells(itypefluid, 27)
   End If
Next itypefluid

Range("M7") = liquiddensity
Range("M8") = liquidviscosity

'1.3(base on type of soil,loop untuk cari hydraulic conductivity kat table)
typesoil = Range("G16") ''''''''''''''''''''''''''''''''''''''''''''''''
Dim khwater As Double
Dim khwaterlb As Double
Dim khwaterub As Double

Range("M9") = typesoil

For itypesoil = 13 To 19 'kebawah
   If Cells(itypesoil, 23) = typesoil Then
   khwaterlb = Cells(itypesoil, 24)
   khwaterub = Cells(itypesoil, 25)
   End If
Next itypesoil

khwater = 864 * ((khwaterlb + khwaterub) / 2)

Range("M10") = khwaterlb
Range("M11") = khwaterub
Range("M12") = khwater

'1.4(calculate khprod)
Dim khprod As Double
Dim waterdensity As Double
Dim waterviscosity As Double
waterdenstiy = 999.97 'kg/m3
waterviscosity = 0.001 'N s/m2

khprod = khwater * (liquiddensity / waterdenstiy) * (waterviscosity / liquidviscosity)
Range("M13") = khprod

'1.5 (cari fluid seepage velocity velsprod)
Dim velsprod As Double
Dim ps As Double

For i = 13 To 19 'kebawah
   If Cells(i, 23) = typesoil Then
   ps = Cells(i, 26)
   End If
Next i
```

```
velsprod = khprod / ps

Range("M14") = ps
Range("M15") = velsprod

'2.1(cari release hole size)
Dim holesize1, holesize2, holesize3, holesize4 As String
Dim d1, d2, d3, d4 As Double
Dim Dtank As Double
Dim releasepreventionbarrier As String

releasepreventionbarrier = Range("G68") '''''''''''''''''''''''''
Dtank = Range("G8") '''''''''''''''''''''''''''''''''

holesize1 = "Small"
holesize2 = "Medium"
holesize3 = "Large"
holesize4 = "Rupture"

If typecomp = "Tank bottom" Then
    If releasepreventionbarrier = "Yes" Then
    d1 = 3.175 'mm
    d2 = 0
    d3 = 0
    d4 = 1000 * (Dtank / 4)


    ElseIf releasepreventionbarrier = "No" Then
    d1 = 12.7 'mm
    d2 = 0
    d3 = 0
    d4 = 1000 * (Dtank / 4)
    End If

Else 'If typecomp = "Internal tank shell course" Or "External tank shell course" Then
   d1 = 3.175 'mm
   d2 = 6.35
   d3 = 50.8
   d4 = 1000 * (Dtank / 4)
End If


Range("M16") = holesize1
Range("M17") = holesize2
Range("M18") = holesize3
Range("M19") = holesize4

Range("M20") = d1
Range("M21") = d2
Range("M22") = d3
Range("M23") = d4

'2.2 (find gff gfftotal)

Dim gff1, gff2, gff3, gff4 As Double
Dim gfftotal As Double

If typecomp = "Tank bottom" Then
    gff1 = 0.00072
    gff2 = 0
    gff3 = 0
    gff4 = 0.000002
    gfftotal = 0.00072

Else 'If typecomp = "Internal tank shell course" Or "External tank shell course" Then
```

```
  gff1 = 0.00007
  gff2 = 0.000025
  gff3 = 0.000005
  gff4 = 0.0000001
  gfftotal = 0.0001
End If


Range("M24") = gff1
Range("M25") = gff2
Range("M26") = gff3
Range("M27") = gff4
Range("M28") = gfftotal

'3.1 hliqn

Dim hliq As Double

hliq = Range("G18") ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


'3.2 An

Dim A1, A2, A3, A4 As Double

A1 = 3.142 * (d1 ^ 2) / 4
A2 = 3.142 * (d2 ^ 2) / 4
A3 = 3.142 * (d3 ^ 2) / 4
A4 = 3.142 * (d4 ^ 2) / 4

Range("M29") = A1
Range("M30") = A2
Range("M31") = A3
Range("M32") = A4

'3.3 find Wn
Dim W1, W2, W3, W4 As Double
W1 = 0.543 * 0.61 * A1 * ((2 * 9.81 * hliq) ^ 0.5)
W2 = 0.543 * 0.61 * A2 * ((2 * 9.81 * hliq) ^ 0.5)
W3 = 0.543 * 0.61 * A3 * ((2 * 9.81 * hliq) ^ 0.5)
W4 = 0.543 * 0.61 * A4 * ((2 * 9.81 * hliq) ^ 0.5)

Range("M33") = W1
Range("M34") = W2
Range("M35") = W3
Range("M36") = W4


'4.1 liq height aboce ith shell course
Dim LHTabove1, LHTabove2, LHTabove3, LHTabove4, LHTabove5 As Double
Dim LHTabove6, LHTabove7, LHTabove8, LHTabove9, LHTabove10 As Double
Dim th1, th2, th3, th4, th5, th6, th7, th8, th9, th10 As Double
Dim CHT As Double
Dim Nc As Double

CHT = Range("G26") '''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


LHTabove1 = hliq - (1 * CHT)
LHTabove2 = hliq - (2 * CHT)
LHTabove3 = hliq - (3 * CHT)
LHTabove4 = hliq - (4 * CHT)
LHTabove5 = hliq - (5 * CHT)
LHTabove6 = hliq - (6 * CHT)
LHTabove7 = hliq - (7 * CHT)
LHTabove8 = hliq - (8 * CHT)
```

```
LHTabove9 = hliq - (9 * CHT)
LHTabove10 = hliq - (10 * CHT)

Range("M37") = LHTabove1
Range("M38") = LHTabove2
Range("M39") = LHTabove3
Range("M40") = LHTabove4
Range("M41") = LHTabove5
Range("M42") = LHTabove6
Range("M43") = LHTabove7
Range("M44") = LHTabove8
Range("M45") = LHTabove9
Range("M46") = LHTabove10


'4.2 find Lvolabovei
Dim Lvolabove1, Lvolabove2, Lvolabove3, Lvolabove4, Lvolabove5 As Double
Dim Lvolabove6, Lvolabove7, Lvolabove8, Lvolabove9, Lvolabove10 As Double

Lvolabove1 = (3.142 * (Dtank ^ 2) / 4) * LHTabove1
Lvolabove2 = (3.142 * (Dtank ^ 2) / 4) * LHTabove2
Lvolabove3 = (3.142 * (Dtank ^ 2) / 4) * LHTabove3
Lvolabove4 = (3.142 * (Dtank ^ 2) / 4) * LHTabove4
Lvolabove5 = (3.142 * (Dtank ^ 2) / 4) * LHTabove5
Lvolabove6 = (3.142 * (Dtank ^ 2) / 4) * LHTabove6
Lvolabove7 = (3.142 * (Dtank ^ 2) / 4) * LHTabove7
Lvolabove8 = (3.142 * (Dtank ^ 2) / 4) * LHTabove8
Lvolabove9 = (3.142 * (Dtank ^ 2) / 4) * LHTabove9
Lvolabove10 = (3.142 * (Dtank ^ 2) / 4) * LHTabove10

If Lvolabove1 <= 0 Then
Lvolabove1 = 0
End If
If Lvolabove2 <= 0 Then
Lvolabove2 = 0
End If
If Lvolabove3 <= 0 Then
Lvolabove3 = 0
End If
If Lvolabove4 <= 0 Then
Lvolabove4 = 0
End If
If Lvolabove5 <= 0 Then
Lvolabove5 = 0
End If
If Lvolabove6 <= 0 Then
Lvolabove6 = 0
End If
If Lvolabove7 <= 0 Then
Lvolabove7 = 0
End If
If Lvolabove8 <= 0 Then
Lvolabove8 = 0
End If
If Lvolabove9 <= 0 Then
Lvolabove9 = 0
End If
If Lvolabove10 <= 0 Then
Lvolabove10 = 0
End If

Range("M47") = Lvolabove1
Range("M48") = Lvolabove2
Range("M49") = Lvolabove3
Range("M50") = Lvolabove4
Range("M51") = Lvolabove5
```

```
Range("M52") = Lvolabove6
Range("M53") = Lvolabove7
Range("M54") = Lvolabove8
Range("M55") = Lvolabove9
Range("M56") = Lvolabove10

'4.3 find Lvolavailn
Dim Lvolavail1, Lvolavail2, Lvolavail3, Lvolavail4 As Double
Dim holeposition1, holeposition2, holeposition3, holeposition4 As Double

holeposition1 = Range("G89") """"""""""""""""""""""""""""
holeposition2 = Range("G90") """"""""""""""""""""""""""
holeposition3 = Range("G91") """"""""""""""""""""""""
holeposition4 = Range("G92") """"""""""""""""""""""""""""

If holeposition1 = 1 Then
Lvolavail1 = Lvolabove1
ElseIf holeposition1 = 2 Then
Lvolavail1 = Lvolabove2
ElseIf holeposition1 = 3 Then
Lvolavail1 = Lvolabove3
ElseIf holeposition1 = 4 Then
Lvolavail1 = Lvolabove4
ElseIf holeposition1 = 5 Then
Lvolavail1 = Lvolabove5
ElseIf holeposition1 = 6 Then
Lvolavail1 = Lvolabove6
ElseIf holeposition1 = 7 Then
Lvolavail1 = Lvolabove7
ElseIf holeposition1 = 8 Then
Lvolavail1 = Lvolabove8
ElseIf holeposition1 = 9 Then
Lvolavail1 = Lvolabove9
ElseIf holeposition1 = 10 Then
Lvolavail1 = Lvolabove10
End If

If holeposition2 = 1 Then
Lvolavail2 = Lvolabove1
ElseIf holeposition2 = 2 Then
Lvolavail2 = Lvolabove2
ElseIf holeposition2 = 3 Then
Lvolavail2 = Lvolabove3
ElseIf holeposition2 = 4 Then
Lvolavail2 = Lvolabove4
ElseIf holeposition2 = 5 Then
Lvolavail2 = Lvolabove5
ElseIf holeposition2 = 6 Then
Lvolavail2 = Lvolabove6
ElseIf holeposition2 = 7 Then
Lvolavail2 = Lvolabove7
ElseIf holeposition2 = 8 Then
Lvolavail2 = Lvolabove8
ElseIf holeposition2 = 9 Then
Lvolavail2 = Lvolabove9
ElseIf holeposition2 = 10 Then
Lvolavail2 = Lvolabove10
End If

If holeposition3 = 1 Then
Lvolavail3 = Lvolabove1
ElseIf holeposition3 = 2 Then
Lvolavail3 = Lvolabove2
ElseIf holeposition3 = 3 Then
Lvolavail3 = Lvolabove3
ElseIf holeposition3 = 4 Then
```

```
Lvolavail3 = Lvolabove4
ElseIf holeposition3 = 5 Then
Lvolavail3 = Lvolabove5
ElseIf holeposition3 = 6 Then
Lvolavail3 = Lvolabove6
ElseIf holeposition3 = 7 Then
Lvolavail3 = Lvolabove7
ElseIf holeposition3 = 8 Then
Lvolavail3 = Lvolabove8
ElseIf holeposition3 = 9 Then
Lvolavail3 = Lvolabove9
ElseIf holeposition3 = 10 Then
Lvolavail3 = Lvolabove10
End If

If holeposition4 = 1 Then
Lvolavail4 = Lvolabove1
ElseIf holeposition4 = 2 Then
Lvolavail4 = Lvolabove2
ElseIf holeposition4 = 3 Then
Lvolavail4 = Lvolabove3
ElseIf holeposition4 = 4 Then
Lvolavail4 = Lvolabove4
ElseIf holeposition4 = 5 Then
Lvolavail4 = Lvolabove5
ElseIf holeposition4 = 6 Then
Lvolavail4 = Lvolabove6
ElseIf holeposition4 = 7 Then
Lvolavail4 = Lvolabove7
ElseIf holeposition4 = 8 Then
Lvolavail4 = Lvolabove8
ElseIf holeposition4 = 9 Then
Lvolavail4 = Lvolabove9
ElseIf holeposition4 = 10 Then
Lvolavail4 = Lvolabove10
End If

Range("M57") = Lvolavail1
Range("M58") = Lvolavail2
Range("M59") = Lvolavail3
Range("M60") = Lvolavail4


'4.4 find Bblavailn
Dim Bblavail1, Bblavail2, Bblavail3, Bblavail4 As Double

Bblavail1 = Lvolavail1 / 6.29
Bblavail2 = Lvolavail2 / 6.29
Bblavail3 = Lvolavail3 / 6.29
Bblavail4 = Lvolavail4 / 6.29

Range("M61") = Bblavail1
Range("M62") = Bblavail2
Range("M63") = Bblavail3
Range("M64") = Bblavail4

'7.1 find raten
Dim rate1, rate2, rate3, rate4 As Double
rate1 = W1
rate2 = W2
rate3 = W3
rate4 = W4

Range("M65") = rate1
Range("M66") = rate2
Range("M67") = rate3
```

```
Range("M68") = rate4

'7.2 find tld
Dim tld1, tld2, tld3, tld4 As Double

 If d1 <= 3.17 Then
 tld1 = 7
 ElseIf d1 > 3.17 Then
 tld1 = 1
 End If

 If d2 <= 3.17 Then
 tld2 = 7
 ElseIf d2 > 3.17 Then
 tld2 = 1
 End If

 If d3 <= 3.17 Then
 tld3 = 7
 ElseIf d3 > 3.17 Then
 tld3 = 1
 End If

 If d4 <= 3.17 Then
 tld4 = 7
 ElseIf d4 > 3.17 Then
 tld4 = 1
 End If

Range("M69") = tld1
Range("M70") = tld2
Range("M71") = tld3
Range("M72") = tld4

'7.3 find ldn
Dim ld1, ld2, ld3, ld4 As Double

ld1 = Bblavail1 / rate1
If ld1 < 7 Then
   ld1 = ld1
Else
  ld1 = 7
End If

ld2 = Bblavail2 / rate2
If ld2 < 7 Then
   ld2 = ld2
Else
  ld2 = 7
End If

ld3 = Bblavail3 / rate3
If ld3 < 7 Then
   ld3 = ld3
Else
  ld3 = 7
End If

ld4 = Bblavail4 / rate4
If ld4 < 7 Then
   ld4 = ld4
Else
  ld4 = 7
End If

If ld1 < 1 Then
```

```
ld1 = 1
End If
If ld2 < 1 Then
ld2 = 1
End If
If ld3 < 1 Then
ld3 = 1
End If
If ld4 < 1 Then
ld4 = 1
End If

Range("M73") = ld1
Range("M74") = ld2
Range("M75") = ld3
Range("M76") = ld4

'7.4 find Bblleakn
Dim Bblleak1, Bblleak2, Bblleak3, Bblleak4 As Double

Bblleak1 = rate1 * ld1
 If Bblleak1 < Bblavail1 Then
    Bblleak1 = Bblleak1
 Else
   Bblleak1 = Bblavail1
 End If

Bblleak2 = rate2 * ld2
 If Bblleak2 < Bblavail2 Then
    Bblleak2 = Bblleak2
 Else
   Bblleak2 = Bblavail2
 End If

 Bblleak3 = rate3 * ld3
 If Bblleak3 < Bblavail3 Then
    Bblleak3 = Bblleak3
 Else
   Bblleak3 = Bblavail3
 End If

Bblleak4 = rate4 * ld4
 If Bblleak4 < Bblavail4 Then
    Bblleak4 = Bblleak4
 Else
   Bblleak4 = Bblavail4
 End If

Range("M77") = Bblleak1
Range("M78") = Bblleak2
Range("M79") = Bblleak3
Range("M80") = Bblleak4

'7.5 find Bblrupturen
Dim Bblrupture1, Bblrupture2, Bblrupture3, Bblrupture4 As Double

Bblrupture1 = Bblavail1
Bblrupture2 = Bblavail2
Bblrupture3 = Bblavail3
Bblrupture4 = Bblavail4

Range("M81") = Bblrupture1
Range("M82") = Bblrupture2
Range("M83") = Bblrupture3
Range("M84") = Bblrupture4
```

```
'12.1 input Plvdike,Ponsite,Poffsite

Dim Plvdike, Ponsite, Poffsite As Double
Plvdike = Range("G94") ''''''''''''''''''''''''''''''''''''
Ponsite = Range("G96") ''''''''''''''''''''''''''''''''''
Poffsite = Range("G98") ''''''''''''''''''''''''''''''''''''

'12.2 find sensitivity

Dim Cindike, Cssonsite, Cssoffsite, Cwater As Double

Cindike = 10
Cssonsite = 50
Cssoffsite = Range("G103") ''''''''''''''''''''''''''''''''''''''
Cwater = Range("G105") ''''''''''''''''''''''''''''''''''''''''''

Range("M85") = Cindike
Range("M86") = Cssonsite
Range("M87") = Cssoffsite
Range("M88") = Cwater

'12.3 find Bblleakrelease
Dim Bblleakrelease As Double
Bblleakrelease = ((Bblleak1 * gff1) + (Bblleak2 * gff2) + (Bblleak3 * gff3)) / gfftotal
Range("M89") = Bblleakrelease

'12.4 find Bblleakindike,Bblleakssonsite,Bblleakssoffsite,Bblleakwater

Dim Bblleakindike, Bblleakssonsite As Double
Dim Bblleakssoffsite, Bblleakwater As Double

Bblleakindike = Bblleakrelease * (1 - (Plvdike / 100))
Bblleakssonsite = (Ponsite / 100) * (Bblleakrelease - Bblleakindike)
Bblleakssoffsite = (Poffsite / 100) * (Bblleakrelease - Bblleakindike - Bblleakssonsite)
Bblleakwater = Bblleakrelease - (Bblleakindike + Bblleakssonsite + Bblleakssoffsite)

Range("M90") = Bblleakindike
Range("M91") = Bblleakssonsite
Range("M92") = Bblleakssoffsite
Range("M93") = Bblleakwater


'12.5 find FCleakenviron

Dim FCleakenviron As Double

FCleakenviron = (Bblleakindike * Cindike) + (Bblleakssonsite * Cssonsite) + (Bblleakssoffsite * Cssoffsite) + (Bblleakwater * Cwater)
Range("M94") = FCleakenviron

'12.6 find Bblrupturerelease

Dim Bblrupturerelease As Double
Bblrupturerelease = Bblrupture4 * gff4 / gfftotal
Range("M95") = Bblrupturerelease

'12.7 find Bblruptureindike,Bblrupturessonsite,Bblrupturessoffsite,Bblrupturewater
Dim Bblruptureindike, Bblrupturessonsite As Double
Dim Bblrupturessoffsite, Bblrupturewater As Double

Bblruptureindike = Bblrupturerelease * (1 - (Plvdike / 100))
Bblrupturessonsite = (Ponsite / 100) * (Bblrupturerelease - Bblruptureindike)
Bblrupturessoffsite = (Poffsite / 100) * (Bblrupturerelease - Bblruptureindike - Bblrupturessonsite)
Bblrupturewater = Bblrupturerelease - (Bblruptureindike + Bblrupturessonsite + Bblrupturessoffsite)

Range("M96") = Bblruptureindike
Range("M97") = Bblrupturessonsite
```

```
Range("M98") = Bblrupturessoffsite
Range("M99") = Bblrupturewater

'12.8 find FCruptureenviron

Dim FCruptureenviron As Double
FCruptureenviron = (Bblruptureindike * Cindike) + (Bblrupturessonsite * Cssonsite) + (Bblrupturessoffsite * Cssoffsite) + (Bblrupturewater * Cwater)

Range("M100") = FCruptureenviron

'12.9 find FCenviron

Dim FCenviron As Double
FCenviron = FCleakenviron + FCruptureenviron
Range("M101") = FCenviron

'12.10 find FCcmd

Dim FCcmd As Double
Dim holecost1, holecost2, holecost3, holecost4 As Double
Dim matcost As Double
Dim shellmaterial As String

shellmaterial = Range("G20") ''''''''''''''''''''''''''''''''''''''''''

 holecost1 = 5000
 holecost2 = 12000
 holecost3 = 20000
 holecost4 = 40000

  For i = 53 To 86 'kebawah
    If Cells(i, 27) = shellmaterial Then
    matcost = Cells(i, 28)
    End If
    Next i

FCcmd = ((gff1 * holecost1) + (gff2 * holecost2) + (gff3 * holecost3) + (gff4 * holecost4)) * matcost / gfftotal

Range("M102") = holecost1
Range("M103") = holecost2
Range("M104") = holecost3
Range("M105") = holecost4
Range("M106") = matcost
Range("M107") = FCcmd

'12.11 (1) find Outagecmd

Dim Outagecmd As Double
Dim Outage1, Outage2, Outage3, Outage4 As Double

 Outage1 = 2
 Outage2 = 3
 Outage3 = 3
 Outage4 = 7

Outagecmd = ((gff1 * Outage1) + (gff2 * Outage2) + (gff3 * Outage3) + (gff4 * Outage4)) / gfftotal * 1 '(Outagemult=1)
Outagecmd = Round(Outagecmd, 0)

Range("M108") = Outage1
Range("M109") = Outage2
Range("M110") = Outage3
Range("M111") = Outage4
Range("M112") = Outagecmd

'12.11 (2) find FCprod
```

```
Dim FCprod As Double
Dim prodcost As Double

prodcost = Range("G113") ''''''''''''''''''''''''''''''''''''
FCprod = Outagecmd * prodcost

Range("M113") = FCprod

'12.12 find FCtotal
Dim FCtotal As Double
FCtotal = FCenviron + FCcmd + FCprod
FCtotal = Round(FCtotal, 0)

Range("G127") = FCtotal
Range("M114") = FCtotal

End Sub
```

Appendix C: Coding for Consequences of failure for tank bottom

```
Sub COFbottomrepectedtoMAIN()

'1.1(pilih fluid)
'base on type of fluid,loop untuk cari density & viscosity kat table
Dim typefluid, typecomp, typesoil As String
typecomp = Range("G30") """""""""""""""""""""'
typefluid = Range("G14") """"""""""""""""""""'
Dim liquiddensity As Double
Dim liquidviscosity As Double

For itypefluid = 3 To 9 'kebawah
   If Cells(itypefluid, 23) = typefluid Then
   liquiddensity = Cells(itypefluid, 26)
   liquidviscosity = Cells(itypefluid, 27)
   End If
Next itypefluid

'Range("F7") = liquiddensity
'Range("F8") = liquidviscosity

'1.3(base on type of soil,loop untuk cari hydraulic conductivity kat table)
typesoil = Range("G16") """"""""""""""""""""""'
Dim khwater As Double
Dim khwaterlb As Double
Dim khwaterub As Double

For itypesoil = 13 To 19 'kebawah
   If Cells(itypesoil, 23) = typesoil Then
   khwaterlb = Cells(itypesoil, 24)
   khwaterub = Cells(itypesoil, 25)
   End If
Next itypesoil

khwater = 864 * ((khwaterlb + khwaterub) / 2)

'Range("F10") = khwaterlb
'Range("F11") = khwaterub
'Range("F12") = khwater

'1.4(calculate khprod)
Dim khprod As Double
Dim waterdensity As Double
Dim waterviscosity As Double
waterdenstiy = 999.97 'kg/m3
waterviscosity = 0.001 'N s/m2

khprod = khwater * (liquiddensity / waterdenstiy) * (waterviscosity / liquidviscosity)
'Range("F14") = khprod

'1.5 (cari fluid seepage velocity velsprod)
Dim velsprod As Double
Dim ps As Double

For i = 13 To 19 'kebawah
   If Cells(i, 23) = typesoil Then
   ps = Cells(i, 26)
   End If
Next i

velsprod = khprod / ps

'Range("F16") = ps
'Range("F17") = velsprod
```

```
'2.1(cari release hole size)
Dim holesize1, holesize2, holesize3, holesize4 As String
Dim d1, d2, d3, d4 As Double
Dim Dtank As Double
Dim releasepreventionbarrier As String

releasepreventionbarrier = Range("G68") ''''''''''''''''''''
Dtank = Range("G8") ''''''''''''''''''''''''''''''''''''

holesize1 = "Small"
holesize2 = "Medium"
holesize3 = "Large"
holesize4 = "Rupture"

If typecomp = "Tank bottom" Then
   If releasepreventionbarrier = "Yes" Then
   d1 = 3.175 'mm
   d2 = 0
   d3 = 0
   d4 = 1000 * (Dtank / 4)


   ElseIf releasepreventionbarrier = "No" Then
   d1 = 12.7 'mm
   d2 = 0
   d3 = 0
   d4 = 1000 * (Dtank / 4)
   End If

Else 'If typecomp = "Internal tank shell course" Or "External tank shell course" Then
  d1 = 3.175 'mm
  d2 = 6.35
  d3 = 50.8
  d4 = 1000 * (Dtank / 4)
End If


'Range("F19") = holesize1
'Range("F20") = holesize2
'Range("F21") = holesize3
'Range("F22") = holesize4

'Range("K3") = d1
'Range("K4") = d2
'Range("K5") = d3
'Range("K6") = d4

'2.2 (find gff gfftotal)

Dim gff1, gff2, gff3, gff4 As Double
Dim gfftotal As Double

If typecomp = "Tank bottom" Then
   gff1 = 0.00072
   gff2 = 0
   gff3 = 0
   gff4 = 0.000002
   gfftotal = 0.00072

Else 'If typecomp = "Internal tank shell course" Or "External tank shell course" Then
  gff1 = 0.00007
  gff2 = 0.000025
  gff3 = 0.000005
  gff4 = 0.0000001
  gfftotal = 0.0001
End If
```

```
'Range("K8") = gff1
'Range("K9") = gff2
'Range("K10") = gff3
'Range("K11") = gff4
'Range("K13") = gfftotal


'3.1 find hliq

Dim hliq As Double
hliq = Range("G18") ''''''''''''''''''''''''''''''''''''''''''''''''

'3.2 nak nrhn

Dim nrh1, nrh2, nrh3, nrh4 As Double

 If Dtank <= 30.5 Then
 nrh1 = 1
 ElseIf Dtank > 30.5 And Dtank < 91.4 Then
 nrh1 = 4
 ElseIf Dtank >= 91.4 Then
 nrh1 = 9
 End If

nrh2 = 0
nrh3 = 0
nrh4 = 0


'Range("N29") = nrh1
'Range("N30") = nrh2
'Range("N31") = nrh3
'Range("N32") = nrh4


'3.3 nak kh
Dim kh As Double
kh = khprod
'Range("N34") = kh

'3.4 nak Wn

Dim W1, W2, W3, W4 As Double
Dim Cqo As Double

Cqo = Range("G111") ''''''''''''''''''''''''''''''''''''''

Dim aleuto1, aleuto2, aleuto3, aleuto4 As Double
aleuto1 = (86.4 * (d1 ^ 2))
aleuto2 = (86.4 * (d2 ^ 2))
aleuto3 = (86.4 * (d3 ^ 2))
aleuto4 = (86.4 * (d4 ^ 2))

'W1
If kh > aleuto1 Then
   If releasepreventionbarrier = "Yes" Then
   W1 = 0.0815 * 3.142 * d1 * ((2 * 9.81 * 0.0762) ^ 0.5) * nrh1
   ElseIf releasepreventionbarrier = "No" Then
   W1 = 0.0815 * 3.142 * d1 * ((2 * 9.81 * hliq) ^ 0.5) * nrh1
   End If
ElseIf kh <= aleuto1 Then
   If releasepreventionbarrier = "Yes" Then
   W1 = 2.382 * Cqo * (d1 ^ 0.2) * (0.0762 ^ 0.9) * (kh ^ 0.74) * nrh1
   ElseIf releasepreventionbarrier = "No" Then
```

```
    W1 = 2.382 * Cqo * (d1 ^ 0.2) * (hliq ^ 0.9) * (kh ^ 0.74) * nrh1
    End If
End If

'W2
If kh > aleuto2 Then
    If releasepreventionbarrier = "Yes" Then
    W2 = 0.0815 * 3.142 * d2 * ((2 * 9.81 * 0.0762) ^ 0.5) * nrh2
    Else
    W2 = 0.0815 * 3.142 * d2 * ((2 * 9.81 * hliq) ^ 0.5) * nrh2
    End If
ElseIf kh <= aleuto2 Then
    If releasepreventionbarrier = "Yes" Then
    W2 = 2.382 * Cqo * (d2 ^ 0.2) * (0.0762 ^ 0.9) * (kh ^ 0.74) * nrh2
    ElseIf releasepreventionbarrier = "No" Then
    W2 = 2.382 * Cqo * (d2 ^ 0.2) * (hliq ^ 0.9) * (kh ^ 0.74) * nrh2
    End If
End If

'W3
If kh > aleuto3 Then
    If releasepreventionbarrier = "Yes" Then
    W3 = 0.0815 * 3.142 * d3 * ((2 * 9.81 * 0.0762) ^ 0.5) * nrh3
    Else
    W3 = 0.0815 * 3.142 * d3 * ((2 * 9.81 * hliq) ^ 0.5) * nrh3
    End If
ElseIf kh <= aleuto3 Then
    If releasepreventionbarrier = "Yes" Then
    W3 = 2.382 * Cqo * (d3 ^ 0.2) * (0.0762 ^ 0.9) * (kh ^ 0.74) * nrh3
    ElseIf releasepreventionbarrier = "No" Then
    W3 = 2.382 * Cqo * (d3 ^ 0.2) * (hliq ^ 0.9) * (kh ^ 0.74) * nrh3
    End If
End If

'W4
If kh > aleuto4 Then
    If releasepreventionbarrier = "Yes" Then
    W4 = 0.0815 * 3.142 * d4 * ((2 * 9.81 * 0.0762) ^ 0.5) * nrh4
    Else
    W4 = 0.0815 * 3.142 * d4 * ((2 * 9.81 * hliq) ^ 0.5) * nrh4
    End If
ElseIf kh <= aleuto4 Then
    If releasepreventionbarrier = "Yes" Then
    W4 = 2.382 * Cqo * (d4 ^ 0.2) * (0.0762 ^ 0.9) * (kh ^ 0.74) * nrh4
    ElseIf releasepreventionbarrier = "No" Then
    W4 = 2.382 * Cqo * (d4 ^ 0.2) * (hliq ^ 0.9) * (kh ^ 0.74) * nrh4
    End If
End If


'Range("N36") = W1
'Range("N37") = W2
'Range("N38") = W3
'Range("N39") = W4


'4.1 Lvoltotal

Dim Lvoltotal As Double
Lvoltotal = 3.142 * (Dtank ^ 2) * hliq / 4
'Range("N41") = Lvoltotal

'4.2 Bbltotal
Dim Bbltotal As Double
Bbltotal = Lvoltotal / 6.29
'Range("N43") = Bbltotal
```

```
'7.1 raten
Dim rate1, rate2, rate3, rate4 As Double
rate1 = W1
rate2 = W2
rate3 = W3
rate4 = W4

Range("N45") = rate1
Range("N46") = rate2
Range("N47") = rate3
Range("N48") = rate4

'7.2 input tld
Dim tld As Double

If releasepreventionbarrier = "Yes" Then
 tld = 30
ElseIf releasepreventionbarrier = "No" Then
 tld = 360
End If
'Range("N50") = tld

'7.3 find ldn
Dim ld1, ld2, ld3, ld4 As Double

If rate1 = 0 Then
 ld1 = 0
Else
 ld1 = Bbltotal / rate1
 If ld1 < tld Then
 ld1 = ld1
 Else
 ld1 = tld
 End If
End If


If raten2 = 0 Then
 ld2 = 0
Else
  ld2 = Bbltotal / rate2
  If ld2 < tld Then
  ld2 = ld2
  Else
  ld2 = tld
  End If
End If

If raten3 = 0 Then
 ld3 = 0
Else
 ld3 = Bbltotal / rate3
 If ld3 < tld Then
 ld3 = ld3
 Else
 ld3 = tld
 End If
End If

If rate4 = 0 Then
 ld4 = 0
Else
 ld4 = Bbltotal / rate4
 If ld4 < tld Then
 ld4 = ld4
```

```
 Else
 ld4 = tld
 End If
End If

'Range("N52") = ld1
'Range("N53") = ld2
'Range("N54") = ld3
'Range("N55") = ld4

'7.4 Bblleakn

Dim Bblleak1, Bblleak2, Bblleak3, Bblleak4 As Double

If rate1 = 0 Then
 Bbleak1 = 0
Else
 Bblleak1 = rate1 / ld1
 If Bblleak1 < Bbltotal Then
 Bblleak1 = Bblleak1
 Else
 Bblleak1 = Bbltotal
 End If
End If


If rate2 = 0 Then
'Range("Q59") = "kuku"
End If

If rate2 = 0 Then
 Bbleak2 = 0
Else
 Bblleak2 = rate2 / ld2
 If Bblleak2 < Bbltotal Then
 Bblleak2 = Bblleak2
 Else
 Bblleak2 = Bbltotal
 End If
End If

If rate3 = 0 Then
 Bblleak3 = 0
Else
 Bblleak3 = rate3 / ld3
 If Bblleak3 < Bbltotal Then
 Bblleak3 = Bblleak3
 Else
 Bblleak3 = Bbltotal
 End If
End If

If rate4 = 0 Then
 Bbleak4 = 0
Else
 Bblleak4 = rate4 / ld4
 If Bblleak4 < Bbltotal Then
 Bblleak4 = Bblleak4
 Else
 Bblleak4 = Bbltotal
 End If
End If

'Range("N57") = Bblleak1
'Range("N58") = Bblleak2
'Range("N59") = Bblleak3
```

```
'Range("N60") = Bblleak4


'7.5 Bblrupturen

Dim Bblrupture1, Bblrupture2, Bblrupture3, Bblrupture4 As Double
Bblrupture1 = Bbltotal
Bblrupture2 = Bbltotal
Bblrupture3 = Bbltotal
Bblrupture4 = Bbltotal

'Range("N62") = Bblrupture1
'Range("N63") = Bblrupture2
'Range("N64") = Bblrupture3
'Range("N65") = Bblrupture4

'12.1 find Plvdike,Plvdikeonsite,Plvdikeoffsite

Dim Plvdike As Double
Dim Plvdikeonsite As Double
Dim Plvdikeoffsite As Double

Plvdike = Range("G94") ''''''''''''''''''''''''''''
Plvdikeonsite = Range("G96") ''''''''''''''''''''''''
Plvdikeoffsite = Range("G98") ''''''''''''''''''''''''''

'12.2 find Cindike,Cssonsite,Cssoffsite,Cwater,Csubsoil,Cgroundwater

Dim Cindike, Cssonsite, Cssoffsite As Double
Dim Cwater, Csubsoil, Cgroundwater As Double

Cindike = 10
Cssonsite = 50
Cssoffsite = Range("G103") '''''''''''''''''''''''
Cwater = Range("G105") '''''''''''''''''''''''''''''
 Csubsoil = Range("G107") '''''''''''''''''''''''
Cgroundwater = Range("G109") '''''''''''''''''''''''

'Range("N72") = Cindike
'Range("N73") = Cssonsite
'Range("N74") = Cssoffsite
'Range("N75") = Cwater
'Range("N76") = Csubsoil
'Range("N77") = Cgroundwater

'12.3  velsprod

'Range("N79") = velsprod

'12.4 find sgw,tgl

Dim sgw As Double
Dim tgl As Double

sgw = Range("G115") '''''''''''''''''''''''''''''''''''''''
tgl = sgw / velsprod

'Range("N81") = tgl

'12.5 find Bblleakgroundwatern, Bblleaksubsoiln

Dim Bblleakgroundwater1, Bblleakgroundwater2, Bblleakgroundwater3, Bblleakgroundwater4 As Double

If tgl > tld Then
   Bblleakgroundwater1 = Bblleak1 * ((tld - tgl) / tld)
   Bblleakgroundwater2 = Bblleak2 * ((tld - tgl) / tld)
```

```
   Bblleakgroundwater3 = Bblleak3 * ((tld - tgl) / tld)
   Bblleakgroundwater4 = Bblleak4 * ((tld - tgl) / tld)
ElseIf tgl <= tld Then
   Bblleakgroundwater1 = 0
   Bblleakgroundwater2 = 0
   Bblleakgroundwater3 = 0
   Bblleakgroundwater4 = 0
End If

Dim Bblleaksubsoil1, Bblleaksubsoil2, Bblleaksubsoil3, Bblleaksubsoil4 As Double

Bblleaksubsoil1 = Bblleak1 - Bblleakgroundwater1
Bblleaksubsoil2 = Bblleak2 - Bblleakgroundwater2
Bblleaksubsoil3 = Bblleak3 - Bblleakgroundwater3
Bblleaksubsoil4 = Bblleak4 - Bblleakgroundwater4

'Range("N83") = Bblleakgroundwater1
'Range("N84") = Bblleakgroundwater2
'Range("N85") = Bblleakgroundwater3
'Range("N86") = Bblleakgroundwater4

'Range("N88") = Bblleaksubsoil1
'Range("N89") = Bblleaksubsoil2
'Range("N90") = Bblleaksubsoil3
'Range("N91") = Bblleaksubsoil4

'12.6 FCleakenviron

Dim FCleakenviron As Double

FCleakenviron = ((((Bblleakgroundwater1 * Cgroundwater) + (Bblleaksubsoil1 * Csubsoil)) * gff1) + (((Bblleakgroundwater2 * Cgroundwater) + (Bblleaksubsoil2 * Csubsoil)) * gff2) + (((Bblleakgroundwater3 * Cgroundwater) + (Bblleaksubsoil3 * Csubsoil)) * gff3) + (((Bblleakgroundwater4 * Cgroundwater) + (Bblleaksubsoil4 * Csubsoil)) * gff4)) / gfftotal
'Range("N93") = FCleakenviron

'12.7 Bblrupturerelease

Dim Bblrupturerelease As Double
Bblrupturerelease = Bbltotal * gff4 / gfftotal
'Range("N95") = Bblrupturerelease

'12.8 Bblruptureindike, Bblrupturessonsite,Bblrupturessoffsite, Bblrupturewater

Dim Bblruptureindike, Bblrupturessonsite As Double
Dim Bblrupturessoffsite, Bblrupturewater As Double

Bblruptureindike = Bblrupturerelease * (1 - (Plvdike / 100))
Bblrupturessonsite = (Ponsite / 100) * (Bblrupturerelease - Bblruptureindike)
Bblrupturessoffsite = (Poffsite / 100) * (Bblrupturerelease - Bblruptureindike - Bblrupturessonsite)
Bblrupturewater = Bblrupturerelease - (Bblruptureindike + Bblrupturessonsite + Bblrupturessoffsite)

'Range("N97") = Bblruptureindike
'Range("N98") = Bblrupturessonsite
'Range("N99") = Bblrupturessoffsite
'Range("N100") = Bblrupturewater

'12.9 FCruptureenviron

Dim FCruptureenviron As Double
FCruptureenviron = (Bblruptureindike * Cindike) + (Bblrupturessonsite * Cssonsite) + (Bblrupturessoffsite * Cssoffsite) + (Bblrupturewater * Cwater)
'Range("N102") = FCruptureenviron

'12.10 FCenviron
Dim FCenviron As Double
FCenviron = FCleakenviron + FCruptureenviron
```

```
'Range("N104") = FCenviron

'12.11 FCcmd

Dim FCcmd As Double
Dim holecost1, holecost2, holecost3, holecost4 As Double
Dim matcost As Double
Dim bottommaterial As String

bottommaterial = Range("G24") """"""""""""""""""""""""""""""""

 holecost1 = 5000
 holecost2 = 0
 holecost3 = 0
 holecost4 = 120000


  For i = 53 To 86 'kebawah
   If Cells(i, 27) = bottommaterial Then
   matcost = Cells(i, 28)
   End If
   Next i

FCcmd = ((gff1 * holecost1) + (gff2 * holecost2) + (gff3 * holecost3)) + (holecost4 * ((Dtank / 30.5) ^ 2)) * matcost / gfftotal

'Range("N106") = holecost1
'Range("N107") = holecost2
'Range("N108") = holecost3
'Range("N109") = holecost4
'Range("N110") = matcost
'Range("N111") = FCcmd

'12.12(1) Outagecmd

Dim Outagecmd As Double
Dim Outage1, Outage2, Outage3, Outage4 As Double

Outage1 = 5
Outage2 = 0
Outage3 = 0
Outage4 = 50

Outagecmd = ((gff1 * Outage1) + (gff2 * Outage2) + (gff3 * Outage3) + (gff4 * Outage4)) / gfftotal * 1 '(Outagemult=1)

'Range("N113") = Outage1
'Range("N114") = Outage2
'Range("N115") = Outage3
'Range("N116") = Outage4

'Range("N118") = Outagecmd

'12.12(2) FCprod

Dim FCprod As Double
Dim prodcost As Double

prodcost = Range("G113") """""""""""""""""""""""""""""""""""""""""""'
FCprod = Outagecmd * prodcost

'Range("N120") = FCprod

'12.13 FCtotal

Dim FCtotal As Double
FCtotal = FCenviron + FCcmd + FCprod
```

```
FCtotal = Round(FCtotal, 0)

Range("G127") = FCtotal

End Sub
```

Appendix D: Some formula used in the calculation

$$age_{rc} = \max\left[\left(\frac{t_{rd} - t}{C_{r,cm}}\right), \;\; 0.0\right]$$

$$A_{rt} = \max\left[\left(1 - \frac{t_{rd} - C_{r,bm} \cdot age}{t_{\min} + CA}\right), \;\; 0.0\right]$$

$$A_{rt} = \max\left[1 - \frac{t_{rd} - C_{r,cm} \cdot age_{rc} - C_{r,bm} \cdot \left(age - age_{rc}\right)}{t_{\min} + CA}, \;\; 0.0\right]$$

$$D_f^{thin} = \frac{D_{fB}^{thin} \cdot F_{IP} \cdot F_{DL} \cdot F_{WD} \cdot F_{AM} \cdot F_{SM}}{F_{OM}}$$

$$k_{h,prod} = k_{h,water}\left(\frac{\rho_l}{\rho_w}\right)\left(\frac{\mu_w}{\mu_l}\right)$$

$$vel_{s,prod} = \frac{k_{h,prod}}{p_s}$$

$$k_{h,water} = C_{31}\frac{\left(k_{h,water-lb} + k_{h,water-ub}\right)}{2}$$

$$W_n = C_{32} \cdot C_d \cdot A_n \sqrt{2 \cdot g \cdot h_{liq}}$$

$$W_n = C_{33} \cdot \pi \cdot d_n \sqrt{2 \cdot g \cdot h_{liq}} \cdot n_{rh,n} \qquad for\ k_h > C_{34} \cdot d_n^2$$

$$W_n = C_{35} \cdot C_{qo} \cdot d_n^{0.2} \cdot h_{liq}^{0.9} \cdot k_h^{0.74} \cdot n_{rh,n} \qquad for\ k_h \le C_{34} \cdot d_n^2$$