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THE APPLICATION OF MONTE CARLO SIMULATION IN STRUCTURE RELIABILITY ASSESSMENT (CASE STUDY OF OFFSHORE PIPELINES)

WAN NAJIHAH FARHANAH BT WAN HASSAN

A report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Civil Engineering (Civil - Structure)

Faculty of Civil Engineering
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Untuk abah dan mama, Wan Hassan bin Wan Ismail, Nor Mariah bt Embong jutaan terima kasih diatas segala sokongan dan pengorbanan serta adik-adik, Naqiyyah, Amiruddin, Hidayah, Syahirah, Fadhilah dan Arifuddin.

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ABSTRACT

Reliability assessment is one of the important research issues in structure analysis. However, to conduct such evaluation, engineers faced problems in gaining better information and understanding for inherent uncertainties associated with human error, inspection tool, environment properties. Thus, this study aims to demonstrate the application of the Monte Carlo simulation method in structure reliability assessment (offshore pipeline). Monte Carlo simulation is a numerical technique developed on the basis of statistic and probability fundamental which consists of three different stages named statistical analysis, probability analysis and numerical simulation. The statistical analysis involved a construction of histogram which will be used to determine the distribution type i.e. in our case the data represent a normal, Weibull and exponential distribution. Probability analysis phase can be divided into two different methods to determine the distribution parameter which is probability plot and modified moment estimator. To verify the parameter gain from both method, the chi-square goodness-of-fit test and graphical test was applied. Monte Carlo simulation was conducted using modified ASME B31G, original ASME B31G, SHELL 92, DNV RP-F101 and PCORRC models to assess the probability of failure which is in our case for oil and gas pipelines. As a results, a simulation using PCORRC shows a better result compared to other method using processed data. As a conclusion, we successfully proposed a simpler assessment procedure using Monte Carlo simulation compared to manual assessment which is time-consuming and error-prone. We assumed such procedure could also be implemented in other structures as well.

ABSTRAK

Penilaian kebolehpercayaan adalah salah satu isu penyelidikan penting dalam analisa struktur. Walau bagaimanapun, jurutera-jurutera masih menghadapi masalah dalam mengendalikan penilaian seumpama itu, mendapatkan maklumat lebih baik dan persefahaman untuk ketidakpastian sedia ada bersekutu dengan kesilapan manusia, alat pemeriksaan, dan ciri-ciri alam sekitar. Oleh itu, kajian ini bertujuan untuk menunjukkan penambahbaikan kaedah simulasi Monte Carlo dalam kebolehpercayaan struktur penilaian (saluran paip luar pesisir). Simulasi Monte Carlo adalah satu teknik yang berangka ke atas dasar statistik dan kebarangkalian asas yang mengandungi tiga peringkat berbeza iaitu, menganalisis, menentukan kebarangkalian dan simulasi berangka. Analisis statistik melibatkan sebuah binaan histogram yang akan digunakan untuk menentukan jenis taburan iaitu dalam kes ini data mewakili taburan normal, taburan Weibull dan taburan eksponen. Fasa analisa kebarangkalian boleh dibahagikan kepada dua kaedah yang berbeza untuk menentukan parameter iaitu pengedaran yang mengandungi kumpulan kebarangkalian dan penganggar momen diubahsuai. Untuk mengesahkan ketepatan parameter yang diperolehi, dua kaedah yang digunakan ialah, Pengujian Khi kuasa dua dan kaedah grafik telah diaplikasikan. Simulasi Monte Carlo telah dijalankan dengan menggunakan ASME B31G Pengubahsuai, ASME B31G asli, SHELL 92, DNV RP-F101 dan model-model PCORRC untuk menilai kebarangkalian kegagalan yang berada dalam kes bagi talian paip gas dan minyak. Hasilnya, penggunaan model-model PCORRC menunjukkan keputusan yang lebih baik dan selaras berbanding dengan cara lain yang menggunakan data yang diproses. Sebagai satu keputusan, kita berjaya mengetengahkan satu prosedur penilaian yang lebih mudah menggunakan simulasi Monte Carlo berbanding dengan taksiran manual yang memakan masa dan lebih cenderung kepada ralat. Prosedur yang diandaikan seumpama ini boleh juga dilaksanakan dalam struktur-struktur lain juga.

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NOMENCLATURES

$\Gamma( )$	=	Gamma function
Γi	=	incomplete Gamma function.
β	=	shape parameter ($0<\beta<\infty$).
βi	=	reliability index for failure element.
χ^2	=	chi-square value.
δ	=	location parameter ($-\infty<\delta<\infty$).
ε_d	=	factor for defining a fractile value for the corrosion depth.
ϕ	=	standard Normal probability.
$\phi[]$	=	standard normal cumulative distribution function.
γ_d	=	partial safety factor for corrosion depth.
γ_m	=	partial safety factor for prediction model and safety class.
η	=	usage factor.
η_{new}	=	new usage factor.
λ	=	exponential parameter or known as failure rate.
λ_x	=	lognormal parameter.
μ	=	mean of defect tolerance distribution.
μ	=	sample mean.
μ_x	=	mean of the random variable X.
μ_x	=	mean value.
μx	=	mean of corrosion rate.
θ	=	scale parameter ($0<\theta<\infty$).
ρ	=	correlation coefficient.
σ	=	standard deviation of defect tolerance distribution.
σ^2	=	variance of error (ILI tools).
σ^2	=	sample variance.

σ_x	=	standard deviation of the random variable X.
σ_y	=	yield stress.
σ_x	=	standard deviation.
σX	=	standard deviation of corrosion rate.
ξ_x	=	lognormal parameter.
ψ	=	true value.
A	=	projected area of the defect in the longitudinal plane through the wall thickness represented by a parabola (mm^2).
A	=	spiral correction factor.
A_0	=	original cross-sectional area of the pipe at the defect,
a	=	number of bin / class.
C	=	constant parameter.
COV	=	coefficient of variation.
CR	=	corrosion rate.
CR_{cor}	=	corrected corrosion rate.
c	=	y-axis intercept.
D	=	outer diameter.
D_h	=	hydraulic diameter of the pipe. (D-2t).
d	=	depth of corrosion defect.
d	=	degree of freedom.
d_{T1}	=	corrosion depth in year $T_{1.}$
d_{T2}	=	corrosion depth in year $T_{2.}$
d_{T0}	=	corrosion depth during installation (d_{T0}=0).
d_{T1}	=	corrosion depth in year T_1
$\%wt$	=	percentage of pipe wall thickness.
E	=	expected value.
F	=	factor of safety (always taken as 0.72).
$F(x)$	=	cumulative distribution function (CDF).
$F(x_i)$	=	cumulative distribution function (CDF).
F_y	=	yield stress.
f(xi)	=	probability density function (PDF).
G( )	=	limit state function.
$g(x)<0$	=	limit state function (failure state).

h	=	defect depth.
i	=	failure order (counted from 1 to the largest order).
K	=	reverse rank order (from largest order to 1).
k	=	number of classes.
L	=	defect length of metal defect along the axis of the pipe.
L	=	measured length of corrosion defect
L	=	length of beam span.
L	=	longitudinal extent of corrosion.
Loc.	=	location of corrosion either internal or external.
M	=	folias or bulging factor, accounting for effect of stress concentration at notch.
m	=	slope.
N	=	sample size.
N	=	number of trials.
N	=	number of trial
n	=	number of observation.
n	=	total number of observed data.
$n(G(x)\leq 0$	=	number of trials which violated limit state function.
O	=	observed value.
P_n	=	probability of failure according to the numbers of defects.
P_f	=	probability of failure.
P_f	=	expected probability of failure.
P_a	=	applied fluid pressure.
P_p	=	calculated allowable pressure using failure model equation.
R	=	pipeline radius.
R	=	resistance/demand.
r	=	number of data (counted from 1 to the largest order).
r	=	random number.
r	=	real rate interest.
S	=	load.
S_p	=	hoop stress level at failure (MPa).
S_f	=	flow stress of the material (MPa).
SMTS	=	specified minimum tensile stress.
SMTS	=	specified minimum tensile strength.

SMYS	=	specified Minimum Yield Strength.
SUTS	=	specified Ultimate Tensile Stress.
T	=	prediction interval in year.
T_1	=	year of inspection T_1
T_1	=	year of inspection in year T_1
T_2	=	year of inspection T_2
T_i	=	time of inspection.
t	=	nominal pipeline thickness.
t	=	nominal pipe wall thickness.
t	=	time.
U	=	liquid flow velocity (m/s).
u	=	generated pseudo random numbers (0,1).
V_{cr}	=	corrosion rate (mm/year).
Var(x)	=	variance.
x_i	=	random variable.
x_o	=	an offset, which is assumed to be known a priori (the smallest value).
$\hat{x}$	=	independent variable.
y	=	dependent variable.
y	=	y-axis intercept.
Z	=	section modulus.
z	=	characteristic corrosion depth.

LIST OF APPENDIX

CHAPTER I

INTRODUCTION

1.1 Overview

Over the last decade, the use of statistical analysis techniques has become more prominent in the field of reliability engineering. Complement to statistical analysis technique, a Monte Carlo simulation, can be useful in studying a reliability assessment process. Monte Carlo simulation was developed in the 1940s as part of the atomic bomb program. Scientists at the Los Alamos National Laboratory originally used it to model the random diffusion of neutrons. The scientists who developed this simulation technique gave it the name "Monte Carlo" after the city in Monaco and its many casinos.

The Monte Carlo simulation, a third level approach under the reliability method is used to pick random values from a specified probability distribution in order to estimate the probability of failure [Dodson, 1994]. This method can be described as a statistical simulation method that utilizes sequences of random numbers to simulate the actual process of the particular system and has found application in various fields of science and engineering. With the development of computer technology, this method can be easily constructed and has great capabilities. The Monte Carlo simulation can be used for many types of purposes such as estimating the probability of failure, and estimating the confidence limits for the population parameters [Bryan, 1991].

1.2 Problems Background

Combinations of statistical methods and reliability analyses to obtained better information and understanding from inspections have been suggested for many years in order to cater for the inherent uncertainties associated with human error, inspection tool, environment and material properties. Monte Carlo simulation is a numerical technique developed on the basis of statistic and probability fundamental [Haldar and Mahadevan, 2000]. As such, its application in civil engineering field may not attract the attention of the engineers since the whole procedure is not readily available in simplified form nor easily understood.

Assessment on the corroding pipelines is one of the case study which is full of uncertainties. The degree of accuracy of inspection, the real condition of the structure, the actual rate of degrading and the performance of structure in the future are not known. This uncertainty can be analyzed using structural reliability method. This method is used to assess the corroding pipelines where Monte Carlo simulation is used to quantify the probability that the pipeline will not perform its desired function. Using reliability-based assessment, the interval to the next inspection is determined based on the likelihood of pipeline failure by corrosion. Five pipelines integrity assessment models i.e. modified ASME B31G, original ASME B31G, SHELL 92, DNV RP-F101 and PCORRC used in predicting the probability of failure are compared.

1.3 Aim and Objectives

The main goal of this research is to demonstrate the use of Monte Carlo simulation in structural reliability assessment. The following objectives were identified as steps towards this goal.

(a) To investigate the implementation of statistical, probability analysis and Monte Carlo simulation in reliability assessment and determine the processed inspection data pattern using histogram distribution.

(b) To develop and verify probability analysis using probability plot, modified moment estimator and graphical test, chi-square goodness of fit test.

(c) To produce a simpler presentation of Structural assessment using Monte Carlo simulation to suit the need of engineer and inspection personnel.

1.4 Scope Of Study

The study will be focusing on the application of Monte Carlo simulation in structure reliability assessment. The simulation is used to predict the time to failure of an offshore pipeline subjected to internal corrosion. The assessment on the pipeline integrity is based on real inspection data gained through pigging inspection. The study will cover the following scopes:

(a) This study is using processed data from pigging inspection data of offshore pipeline.

(b) Statistical and probability approach used consists of estimation of distribution parameter using probability plot and modified moment estimator and verification of probability distribution by using chi-square goodness of fit test and graphical test.

(c) Five models of pipeline assessment was used as a basis of reliability study which is modified ASME B31G, original ASME B31G, SHELL 92, DNV RP-F101 and PCORRC.

(d) MATLAB software is applied as a tool to run the simulation program based on Monte Carlo simulation procedure in order to calculate the probability of failure of the corroded pipeline.

1.5 Importance Of Study

The study shows the procedure of Monte Carlo simulation in structure reliability assessment in one of the case study of offshore pipelines. The main finding of the study is to simplify the presentation of Monte Carlo simulation to suit the need of engineer and inspection personnel. It is also reduce the uncertainties of the corrosion data, environmental loading and material properties. The benefit by using Monte Carlo simulation was as listed below:

(a) Monte Carlo simulation is easy to use for engineers who have only limited working knowledge of probability and statistics.

(b) Monte Carlo simulation is feasible to use for virtually any performance functions and distributions.

(c) Monte Carlo simulation is computationally robust; with sufficient number of simulations, it can always converge.

(d) The problem dimension (the number of random variables) does not affect the accuracy of Monte Carlo simulation. This feature is beneficial to large scale engineering problems.

(e) For reliability analysis, Monte Carlo simulation is generally computationally expensive. The higher the reliability is, the larger the simulation size is needed. Because of the accuracy, Monte Carlo simulation is widely used in engineering applications where the model evaluations (deterministic analyses) are not computationally expensive and validating other methods. However, due to its computational inefficiency, Monte Carlo simulation is not commonly used for problems where deterministic analyses are expensive.

1.6 Thesis Organisation

The thesis consists of six chapters. Chapter I is comprises the problem background, research aim and objectives, scope and important of the study. Chapter II covers the literature review which discusses the domain of the study, related works, and fundamental review of Monte Carlo model and simulation and relevance justifications. Chapter III shows the methodology to conduct the reliability assessment which includes the statistical and probability theory. It is also explained the concepts of reliability evaluation followed by introduction to continuous probability distribution theory which includes Normal, Lognormal, Exponential and Weibull distribution. Besides that several approaches to estimate the distribution parameters such as Probability plot and

Modified Moment estimator were also verified. The verification of proposed distribution was performed by implementing the graphical test and chi-square goodness of fit test. Chapter IV present the results for statistical and probability analysis while Chapter V present the results for Monte Carlo simulation. Finally Chapter VI will conclude our study with discussion and future works. This organization can be map via organization chart (Figure 1.1).

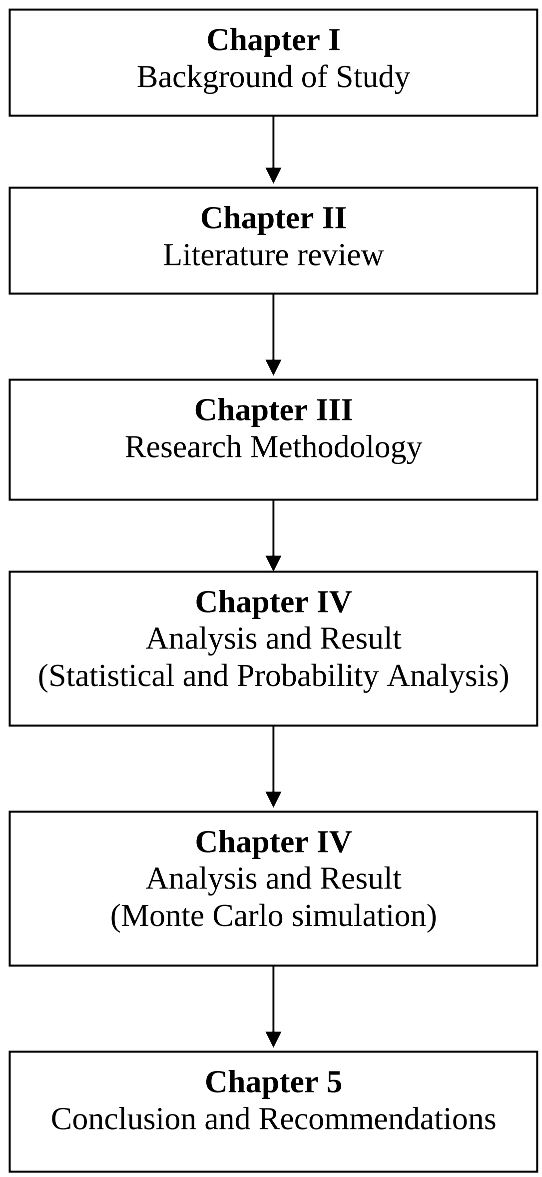

Figure 1.1: Chart of Study Organisations