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FAILURE PROBABILITY OF CORRODED PIPELINE ANASYS WITH CORRELATED INPUT PARAMETERS

Changsong Jiang[1]；PengZhang[2]

[1.] School of Mechanical Engineering, Southwest Petroleum University, Chengdu 610500, China

[2.] School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu 610500, China

Abstract

At present, scholars have done a lot of research work on pipeline reliability. In pipeline reliability calculations, traditional methods often assume that each random variable is independent of each other. It is easy to get wrong results when the variables are assumed to be independent of each other. In view of this limitation this paper considers the influence of the correlation between several sets of variables on the probability of pipeline failure. The Monte Carlo simulation method was used to calculate the influence of correlation between variables on several pipeline blasting failure stress models. Research indicates, the correlation between radial corrosion rate and axial corrosion rate has great influence on the failure probability of DNV-RP-F101, modified B31G and PCORRC calculation models. The correlation between yield strength and tensile strength has little effect on the failure probability of the three models. The gap between the upper and lower limits of modified B31G increases first and then decreases and then increases with time. However, the difference between DNV-RP-F101 and PCORRC failure upper and lower limits gradually increased with time.

Keywords: failure probability; reliability; correlation; corroded pipeline; Monte carlo simulation

Introduction

Pipelines are extensively used for transportation of water, crude oil and natural gas. In a sense, the pipeline is a clean, efficient, low-cost way of transporting oil and gas. Metal corrosion is one of the ways of pipeline failure, Metal-loss corrosion is a major integrity threat to oil and gas pipelines. Pipeline managers need to assess the safety of the pipeline in order to repair and replace the pipeline in a timely manner to avoid casualties and economic losses. But in fact, pipeline managers usually fail to take correct protective measures in time to cause pipeline failure[i].

At present, scholars have done a lot of research work on pipeline reliability, but for the convenience of scientific research, it is often assumed that the variables are independent of each other. There are some limitations in the results that are if the variables are assumed to be independent of each other[ii]. Qian G have studied the influence of the correlation between defect depth and length, pipe diameter and wall thickness, yield strength and tensile strength on the failure probability of FITNET FFS calculation[iii]. De Leon and Macia have studied the pipe segment correlation on failure probability[iv].

The failure standard of corroded pipeline

There are many methods for calculating the failure pressure of pipelines containing corrosion defects. ASME B31G[v], Modified ASME B31G[vi], DNV-RP-F101[vii],PCORRC[viii]. In this paper, Monte Carlo simulation method is used to analyze the effect of the correlation between pipe diameter and wall thickness, radial corrosion rate and axial corrosion rate, defect depth and length, yield strength and tensile strength on the failure probability of the failure pressure model of DNV-RP-101, improved B31G, PCORRC.

The DNV-RP-F101 standard was developed by Det Norske Veritas (DNV) and British Gas Company (BG) in 1999 based on more than 70 full-size defective pipelines. At the same time, a large number of nonlinear finite element analysis results are combined, the formula is as follows [vii]:

$$p_b = \frac{2\sigma_u t}{D-t}\left(\frac{1-\frac{d(T)}{t}}{1-\frac{d(T)}{t}M^{-1}}\right) \quad (1)$$

$$M = \sqrt{1+0.31\frac{L(T)^2}{Dt}} \quad (2)$$

The Modified ASME B31Gstandard was introduced by the American Gas Association for the blasting test of 86 pipes containing different defects. The standard is widely accepted in the industry, the formula is as follows [v]:

$$p_b = \frac{2\left(\sigma_y + 68.95\right)t}{D}\left(\frac{1-0.85\frac{d(T)}{t}}{1-0.85\frac{d(T)}{t}M^{-1}}\right) \quad (3)$$

$$M = \begin{cases} \sqrt{1+0.6275\frac{L(T)^2}{Dt}-0.003375\left(\frac{L^2(T)}{Dt}\right)^2}, & \frac{L(T)^2}{Dt} \le 50 \\ 0.032\frac{L^2(T)}{Dt}+3.3, & \frac{L(T)^2}{Dt} > 50 \end{cases} \quad (4)$$

The PCORRC standard was found by Stephens and Leis in 1997 that pipeline bursting pressure was related to pipeline yield limit. Its calculation standard is applicable to medium and high-strength ductile pipes, and its calculation formula is as follows[viii]:

$$p_b = \frac{2\sigma_u t}{D}\left[1-\frac{d(T)}{t}\left(1-\exp\left(-0.157\frac{L(T)}{\sqrt{D\left(t-d(T)\right)/2}}\right)\right)\right] \quad (4)$$

Where P_b-Corrosion pipeline failure pressure, MP a;

σ_u -Pipe yield tensile strength, MP a;

M -expansion factor;

d-corrosion depth of pipeline, mm;

L-defect length, mm;

t-pipe wall thickness, mm;

D-pipe outer diameter, mm;

According to the statistical analysis of the previous test data, we obtain that the assumption on linear growth of corrosion rate is reasonable. the initial value of the length, the depth can be indicated by L0,d0. The defect length and depth at T moment is given by:

$$L = L_0 + V_a(T - T_0)$$
$$d = d_0 + V_r(T - T_0) \tag{5}$$

For a given crack, some of the random variables are correlated due to the same environment exposed to. The correlation coefficient $\gamma_{XY}(-1 \le \gamma_{XY} \le 1)$ between two random variables X and Y is defined as

$$\gamma_{XY} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \tag{6}$$

where E is the expected value operator. The larger the absolute value of the correlation coefficient is, the stronger the dependency of the variable X on the other varable Y will be.

Based on reliability theory, a limit state function z can be defined as the difference between the pipeline failure pressure and the pipeline operating pressure P

$$z = P_b - P \tag{7}$$

The pipeline failure probability can be written as:

$$P_f = prob(z \le 0) \tag{8}$$

Meto Calo simulation

For related random variables, Generate random numbers by the following method[ix]:

1) First generate a sample of the independent standard normal distribution random variable Z.
2) Transform the independent standard normal random variable Z into a related standard normal random variable Y by linear transformation.
3) Generate the required random variable X by equal probability inverse normal transformation.

where the linear transformation：Cholesky decomposition of the covariance matrix C_X of X

$$C_X = LL^T \tag{9}$$

Where L is the lower triangular matrix, then the relation between the normal distribution random variable X and the independent standard normal distribution variable Yes follows:

$$X = LY + \mu_X \tag{10}$$

Equal probability normal transformation: Use the cumulative probability function to be equal, The non-normal distribution random variable can be transformed into normal distribution random variable.

$$F_{X_i}(X_i) = \phi(Y_i) \quad (11)$$

where X is an arbitrarily distributed random variable and Y is a normally distributed random variable. The probability density distribution function is equal.

$$f_{X_i}(X_i)dX_i = \varphi(Y_i)dY_i \quad (12)$$

Repeat the sampling calculation many times, obtained the pipeline failure probability, the number of calculations is above 5×10^6.

Results and discussion

Take the pipeline from the literature[x][xi].The random evaluation parameters data are shown in Table 1

Tabel 1.Basic parameters of corroded pipeline

Parameters	Symbol	Dimension	Distribution	Mean	cov
fluid pressure	P	MPa	Extreme value distribution	7.056	0.05
wall thichness	t	mm	lognormal	7.925	0.05
diameter	D	mm	normal	610	0.03
defect depth	d_0	mm	normal	1.59	0.389
defect length	L_0	mm	normal	50	0.156
radial corrosion rate	vd	mm/a	normal	0.15	0.6
axial corrosion rate	va	mm/a	normal	3	0.5
yield strength	σ	MPa	lognormal	425	0.056
tensile strength	σ_u	MPa	normal	496	0.03
Material rated for minimum yield strength	σ_{min}	MPa	—	359	—

Calculate the influence of the correlation between pipe diameter and wall thickness, defect length and depth, radial corrosion rate and axial corrosion rate on several failure models

At time T=10 years, Calculate the correlation coefficient between the diameter and depth of the pipe, the length and depth of the defect, the radial corrosion rate and the axial corrosion rate, yield strength and tensile strength from 0 to 1, which affects the failure probability of the pipeline.

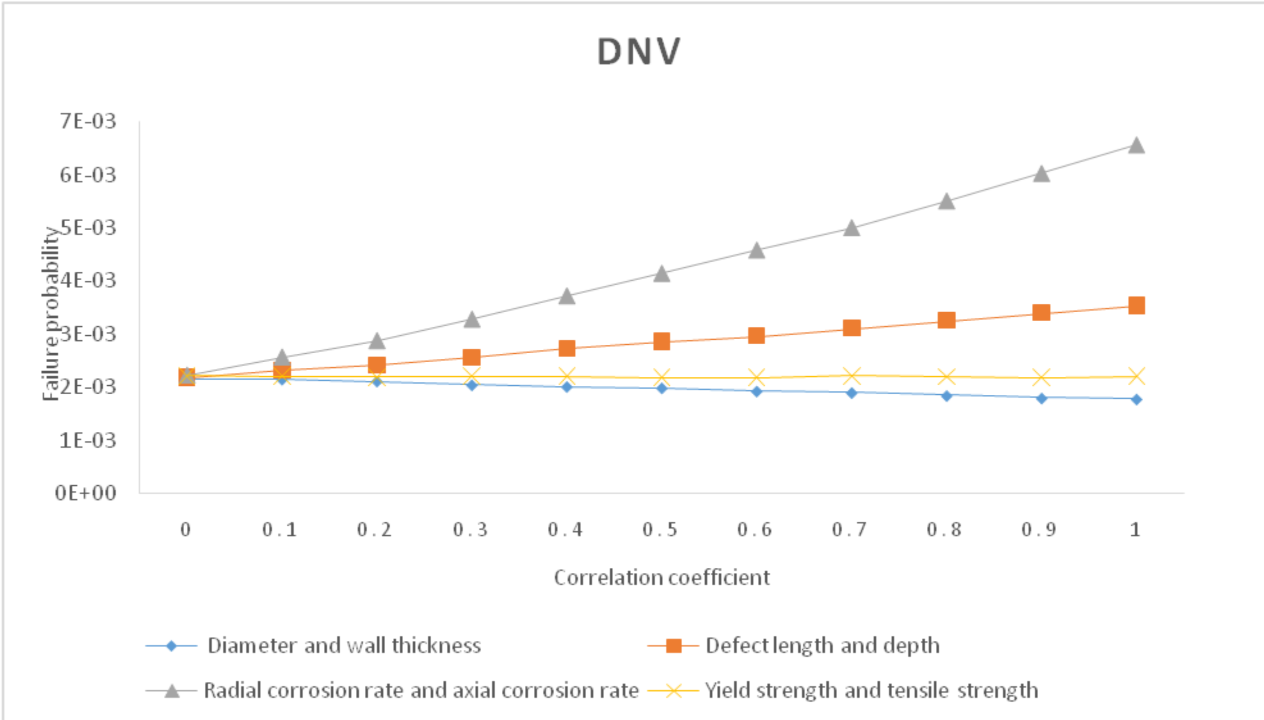

Figure 1 The influence of the correlation of each group on the probability of failure of DNV-RP-F101

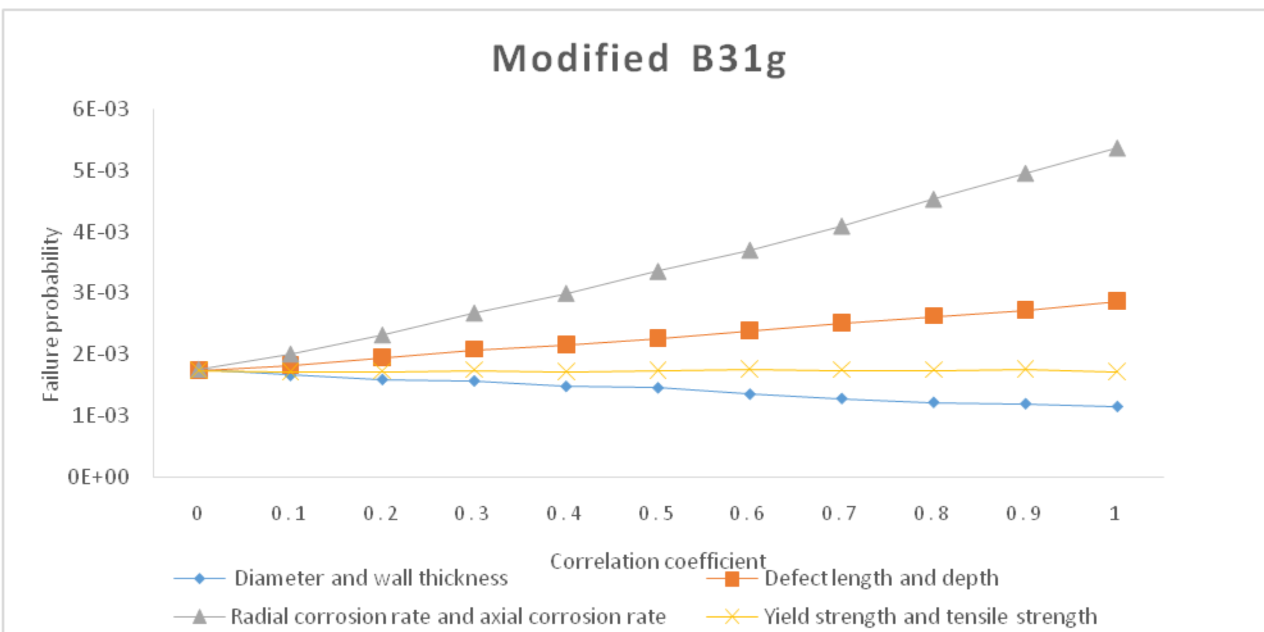

Figure 2 The influence of the correlation of each group on the probability of failure of ModifiedB31G

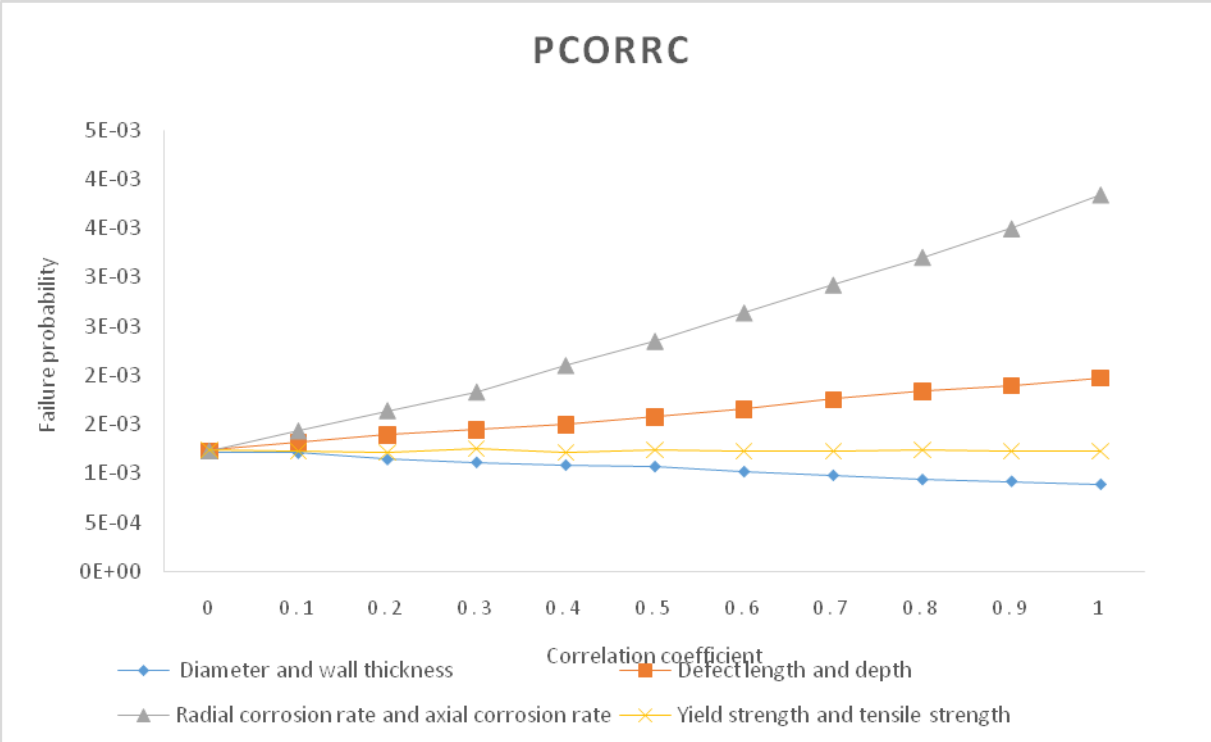

Figure 3 The influence of the correlation of each group on the probability of failure of PCORRC

As can be seen from the above figure, the failure probability of three failure standard of pipeline increases with the correlation between depth and length of defect, radial corrosion rate and axial corrosion rate. The correlation between radial corrosion rate and axial corrosion rate has a greater impact on the failure probability of the three models. The failure probability of three failure modes of pipelines decreases with the correlation coefficient between pipe diameter and wall thickness. The correlation between yield strength and tensile strength has little effect on the failure probability of

Three pipeline failure models. The correlation between the variables of each group on the three failure models from large to small is: the relationship between radial corrosion rate and axial corrosion rate, initial defect depth and length, pipe diameter and wall thickness.

Correlation between radial corrosion rate and axial corrosion rate has a great influence on pipeline failure probability. As the correlation coefficient between radial corrosion rate and axial corrosion rate increases, the failure probability of DNV-RP-F101, improved B31G and PCORRC failure models increases. Its influence on the three failure models from large to small is: modified B31G,DNV-RP-F101,PCORRC. Correlation between pipe diameter and wall thickness has little effect on pipeline failure probability. As the correlation coefficient between pipe diameter and wall thickness increases, the failure probability of the three failure models decreases. Its influence on the three failure models from large to small is: modified B31G, PCORRC, DNV-RP-F101.

when all variables are completely independent of each other. The failure probabilities of DNV-RP-F101, modified B31g and PCORRC are$0.22x10^{-2}$,$0.18x10^{-2}$,$0.12x10^{-2}$respectively.When the radial corrosion rate is completely related to the axial corrosion rate (correlation coefficient is 1), the failure probability is0.67x10^{-2},0.54x10^{-2},0.38x10^{-2}respectively. Increased by 197%,207%,213% respectively.

When the defect depth is completely related to the length (correlation coefficient is 1), the failure probability is0.35x10^{-2},0.29x10^{-2},0.20x10^{-2}. Increased by 62%,65%,60% respectively.

When the pipe diameter is completely related to the wall thickness (correlation coefficient is 1), the failure probability is0.18x10^{-2},0.12x10^{-2},0.89x10^{-2}.Decreased by 17%,34%,26% respectively.

The relationship between yield strength and tensile strength has little effect on pipeline failure probability.

Calculate the influence of failure upper and lower limits on the failure probability of pipelines

According to the above analysis, the failure probability calculated by the three failure models decreases with the increase of the correlation coefficient between the pipe diameter and the wall thickness, and increases with the increase of the correlation coefficient between the initial defect length and depth, the same as the coefficient between the radial corrosion rate and the axial corrosion rate. When the pipe diameter and wall thickness are independent of each other, defect length is completely related to depth, radial corrosion rate is completely related to axial corrosion rate($\rho_{Dw}=0,\rho_{L_0d_0}=1,\rho_{v_dv_l}=1$),and then we get the upper limit of the failure probability. When pipe diameter is completely related to thickness, defect length and depth, the radial corrosion rate and the axial corrosion rate are independent of each other($\rho_{Dw}=1,\rho_{L_0d_0}=0,\rho_{v_dv_l}=0$), at this point, we get the lower limit of failure probability.

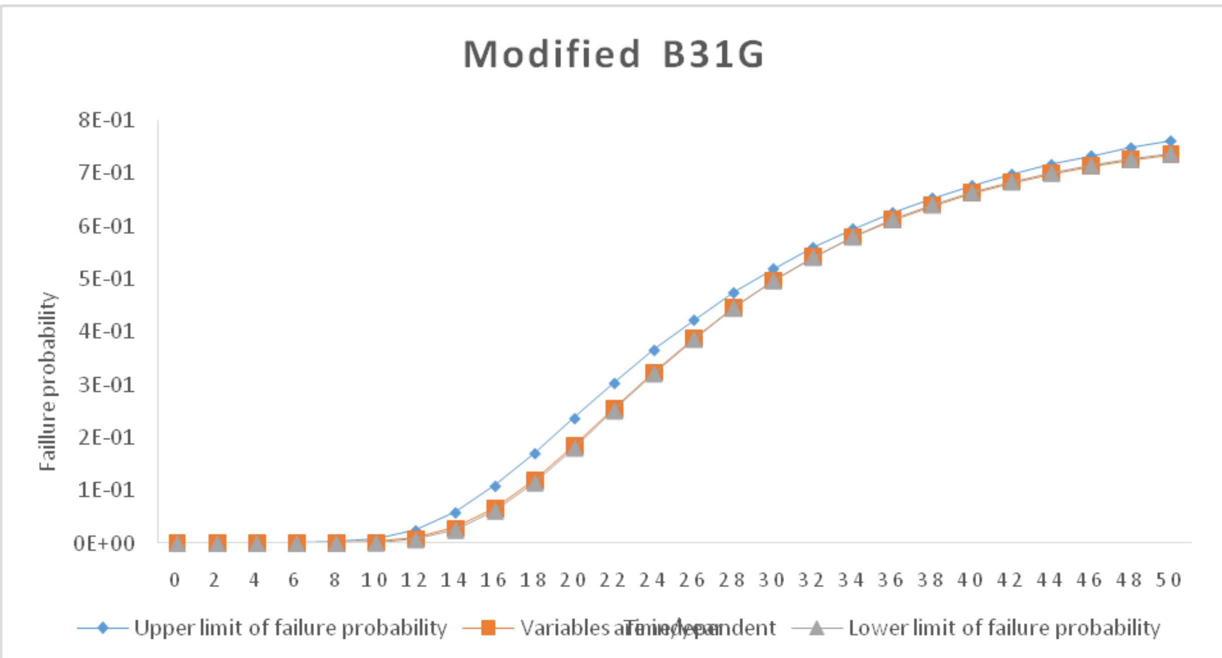

Figure 4 The upper and lower limits of failure of Modified B31G change with time

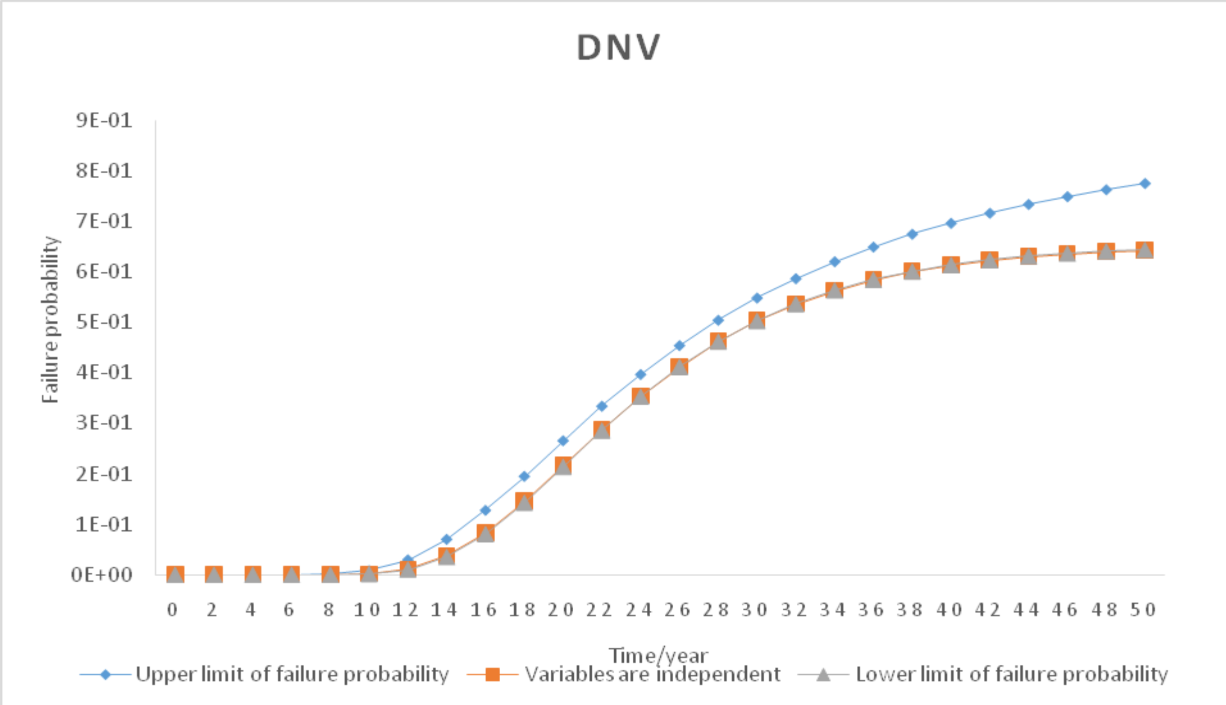

Figure 5 The upper and lower limits of failure of DNV-RP-F101 change with time

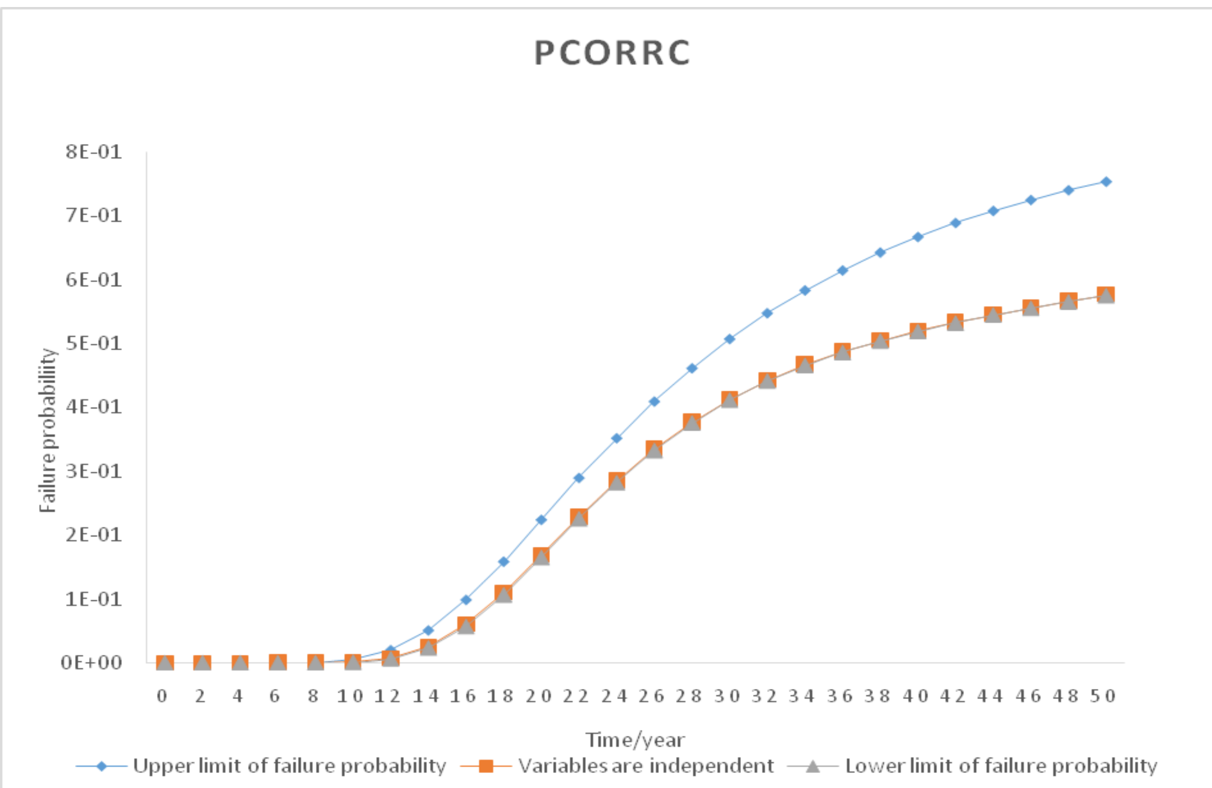

Figure 6 The upper and lower limits of failure of PCORRC change with time

As can be seen from the above figure. the gap between the upper and lower limits of modified B31G increases first and then decreases and then increases with time. The difference between the upper and lower limits reaches the maximum at T=18 year, The maximum value is: $5.07x10^{-2}$. The minimum value is reached at T=38 year, the minimum value is: $1.34x10^{-2}$.

As can be seen from the figure, the difference between upper and lower limits of failure of dnv-pr-f101 and PCORRC gradually increased with time. When the time was 50 years, the difference between upper and lower limits of failure is 0.123 and 0.178 respectively.

Conclusion

The correlation between radial corrosion rate and axial corrosion rate has great influence on three failure models. The correlation between yield strength and tensile strength has little effect on failure probability. As the correlation between radial corrosion rate and axial corrosion rate, defect length and depth increases, the failure probability of all three failure models increases. With the correlation between pipe diameter and wall thickness, the failure probability of three failure models is reduced. As time increases, the gap between the upper and lower limits of DNV-RP-F101 and PCORRC failure probability gradually increases .The gap between the upper and lower limits of modified B31G increases first and then decreases and then increases with time.

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