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Research on the Limit Interference Influence Distance of X80 Pipeline with Internal and External Defects

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Abstract

In this paper, the D1016 × 18.4 X80 pipeline of a river crossing section of Myanmar-China natural gas pipeline project was taken as the research object. Through the calculation of the limit interference influence distance of 50 groups of different defect parameters, the interference influence range of internal and external defects were studied. Besides, sensitivity analysis was carried out for the depth and length of defects respectively, and the rules were summarized. The calculation formula of the limit interference distance of internal and external defects was obtained by the multi nonlinear regression fitting of MATLAB software.

Keywords

Internal and external defects; interference; X80 pipeline.

1. Introduction

Oil and natural gas play an important role in national energy industry, which are of great significance to the national economy and national development. With the development of China's oil and gas pipeline construction, a large number of high-grade and large-diameter natural gas pipelines are in service. Certain corrosion defects will inevitably occur on the internal and external walls of the pipelines. Furthermore, interference will occur under certain conditions of the internal and external walls defects, affecting the failure mode and ultimate load of the pipelines. Nevertheless the occurrence of internal and external defects does not necessarily mean that the pipeline has completely lost its bearing capacity, while the conservative pipeline safety assessment will increase the maintenance and replacement of the pipeline, to a certain extent, causing unnecessary economic waste.

According to the research of fengziyan (2015) [1], with the increase of axial distance coefficient of double corrosion defects, the failure pressure of pipes with different length and depth of double corrosion defects presents obvious logarithmic function change. While when the axial distance coefficient of double corrosion is more than 2.5, the interaction phenomenon of double corrosion with different length and depth disappears. S. S.al-owaisi et al. [2] (2016) found that the adjacent defects of two shapes (ellipse and rectangle) will interact when the axial distance is less than 3 times of the wall thickness or the circumferential distance is not more than 0.5 times of the wall thickness. So did the rectangular defects with the oblique distance less than 0.5 times of the wall thickness. In addition, Mu Huai (2016) [3] found that the interference limit influence distance of double defects should consider the mutual influence of defect length and axial distance. Meanwhile he fitted the limit distance influence formula of corrosion defects under different length, which can be used to effectively judge whether there is mutual interference between two corrosion defects.

To sum up, there are few research on the limit interference distance of double defect pipeline at present. Furthermore, currently, the research on the limit interference distance of double defect pipeline is mainly focused on the same surface defects, while rarely on the limit interference effect of internal and external double defects. Whereas, it is impossible to avoid the existence and interaction of internal and external defects in the actual project. The risk of pipeline operation will be increased, if the current pipeline safety evaluation system is adopted to determine the pipeline with internal and external defects. Thus, it is necessary to further study the interference of internal and external defects.

2. A Method to Determine the Limit Interference Distance Between Internal and External Defects

The existing research shows that the limit load of the pipeline will augment with the increase of the axial distance between the internal and external defects, and finally tend to the fixed value, which is equal to the limit load of the more serious one of the internal and external defects, indicating that the interference effect of the internal and external defects will be weaken with the increase of the axial distance. In order to define the influence range of the interference effect of internal and external defects in pipes more accurately, the calculation method of the limit interference distance of internal and external defects is as follow

2.1. Criterion for Interference of Internal and External Defects

Foremost, the relation diagram was obtained by ABAQUS, and the limit load Pi was obtained by double elastic slope method, which was compared with the single defect limit load P0 of which the more serious one in the internal and external defects. So that formula (1) was taken to determine the minimum limit axial distance between internal and external defects that there is no interference between the two corrosion defects.

$$\omega = \frac{|\Delta P|}{P_i} \times 100\% = \frac{|P_i - P_0|}{P_i} \times 100\% \le 5\% \tag{1}$$

Where ω——Limiting influence factor;

P_i—— Finite element calculation of the limit internal pressure of the pipeline with double defects, MPa;

P_0——Finite element calculation of the limit internal pressure of the pipeline with single defect, MPa;

When the error between the limit load of internal and external defects and the limit load of the more serious one of the internal and external defects is less than 5%, it can be considered in engineering that there is no interaction between the two defects and no interference [3,4], which can be regarded as two single defect which are independent of each other.

3. Analysis of the Limit Interference Influence Distance Between Internal and External Defects

3.1. Model Establishment and Parameter Setting

In this paper, the parameters of a river crossing section of Myanmar-China natural gas pipeline project were used for modeling and finite element analysis. In engineering practice, the pipeline is affected by many factors. In order to accurately analyze the pipeline, the full-size D1016 × 18.4 steel pipe model were studied n this paper.

According to Saint-Venant theorem [5], the length of the pipe affected by the end effect is calculated as:

$$\Delta L \geq 2.5\sqrt{Rt} = 2.5\times\sqrt{\frac{1016}{2}\times 18.4} = 241.7 \text{ mm} \tag{2}$$

It suggests that the length of 241.7mm from both ends will be affected by the constraint of both ends. Thus, so as to fully avoid the influence of the end effect of the pipe section, better modeling and analysis, the length of the finite element model in this paper was set as 4m, and the defects were located in the middle of the model. The model parameters are shown in table 1.

Table 1. Parameters of finite element model of pipe section

Steel	Yield strength (MPa)	Limit tensile strength (MPa)	Young's modulus (GPa)	Poisson's ratio	Length(m)	External diameter(mm)	Wall thickness(mm)
API5L SPEC X80	555	625	210	0.3	4	1016	18.4

The model of pipe section was formed by drawing. The type of defect was set as rectangular volume defect, and the corrosion rectangular pit was formed by rotating cutting. Besides, C3D8R eight node linear hexahedron reduction integral element was used in the model.

Meanwhile, in the defect location, the grid was locally densified by the way of "laying the edge". In addition, the structured grid division technology was used to finally form the grid. The grid division results are shown in Figure 1.

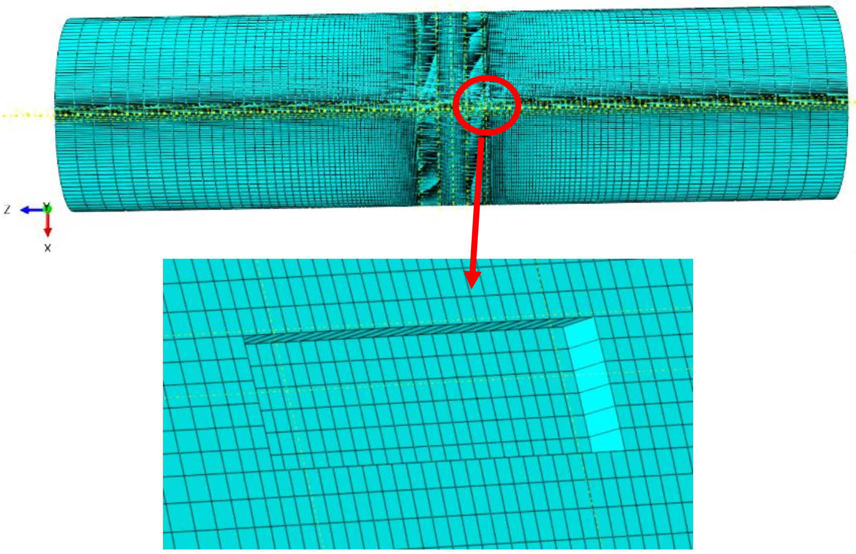

Figure 1. Schematic diagram of grid division

3.2. Analysis of the Influence of Internal and External Defect Parameters on the Limit Interference Influence Distance

3.2.1 Analysis of the influence of the depth of internal and external defects on the limit interference influence distance

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According to the calculation formula of the limit interference influence distance of double defects above, the limit interference influence distance of double defects under the change of the depth of internal and external defects was analyzed.

When studying the relationship between the depth of internal and external defects and the limit interference influence distance of double defects, set the length of internal and external defects b= $\sqrt{Rt}$, namely 96.68mm, width c=20mm. Besides, the depth a of internal and external defects were respectively a/t=0.1, 0.15, 0.2, 0.25, 0.3. There were 25 types of defects in total. Based on five kinds of pipe axial distances namely L=50mm, 150mm, 250mm, 350mm and 450mm to calculate of limit influence factor ω, drawing $L-\omega$ relation diagram, employing $\omega = 5\%$ as standard, ultimately, the limit interference influence distance data of double defects were obtained.

So as to make explicit the relationship between the depth of internal and external defects and the limit interference distance of double defects, combined with finite element simulation results, importing the data from the above table into origin to draw a 3D rainbow mapping surface of internal defect depth, external defect depth and the limit interference influence distance, which is shown in Figure 2.

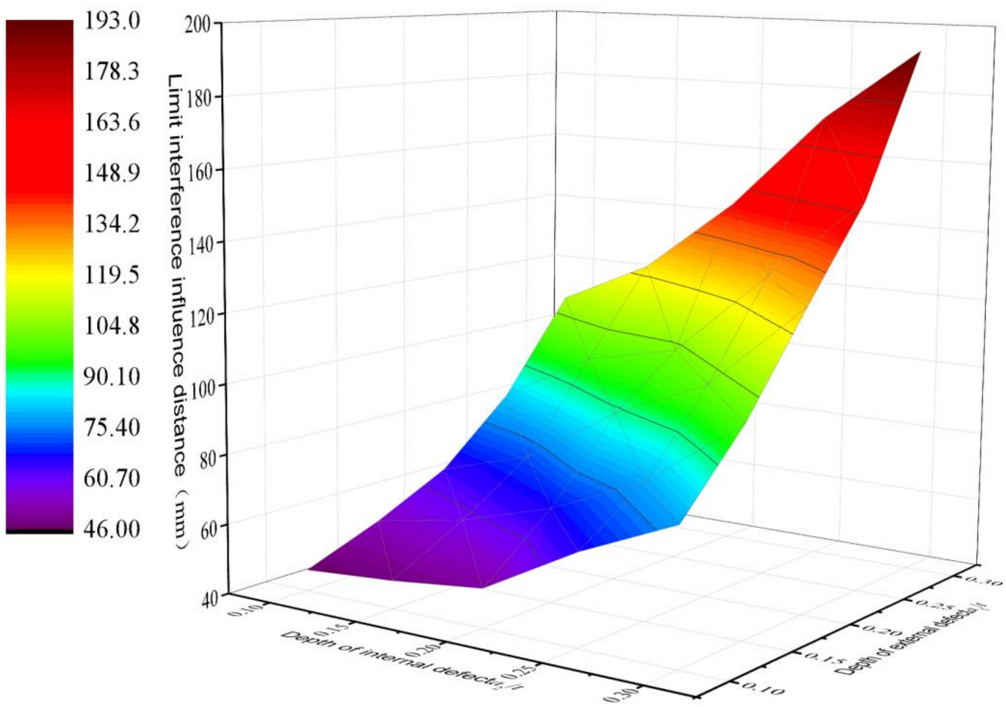

Figure 2. 3D rainbow mapping surface of internal defect depth-external defect depth limit interference influence distance

As shown in Figure 2, in the range of defect depth a1 and a2 from 0.1 to 0.3, the range of limit interference influence distance of double defects is from 46mm to 193mm. Furthermore, with the increase of defect depth a1 and a2, the limit interference influence distance of double defect augment significantly, and the change rate is also expanding. As the increase of the depth of internal and external defects, will accelerate the attenuation of the limit load of the pipeline.

Thus, the influence of the depth of defects on the ultimate load of the pipeline can only be counteracted in a larger range of axial distance. So that, with the increase of the depth of the double defects, the change rate of the distance of the double defects is enhancing.

3.2.2 Analysis of the influence of the length of internal and external defects on the limit interference influence distance

In the previous section, the influence of defect depth on the limit interference influence distance of double defects in pipes has been analyzed and discussed. Next, the influence of the length of internal and external defects on the limit interference influence distance of double defects will be analyzed.

When studying the relationship between the length of internal and external defects and the limit interference influence distance of double defects, set the depth of internal and external defects a/t=0.25, namely 4.6mm, width c=20mm. Besides, the length b of internal and external defects were respectively $0.5\sqrt{Rt}$, $\sqrt{Rt}$, $1.5\sqrt{Rt}$, $2\sqrt{Rt}$, $2.5\sqrt{Rt}$. There were 25 types of defects in total. Based on five kinds of pipe axial distances, namely L=50mm, 150mm, 250mm, 350mm and 450mm to calculate of limit influence factor ω, drawing $L-\omega$ relation diagram, employing $\omega = 5\%$ as standard, ultimately, the limit interference influence distance data of double defects were obtained.

So as to make explicit the relationship between the length of internal and external defects and the limit interference distance of double defects, combined with finite element simulation results, importing the data from the above table into origin to draw a 3D rainbow mapping surface of internal defect length, external defect length and the limit interference influence distance, which is shown in Figure 3.

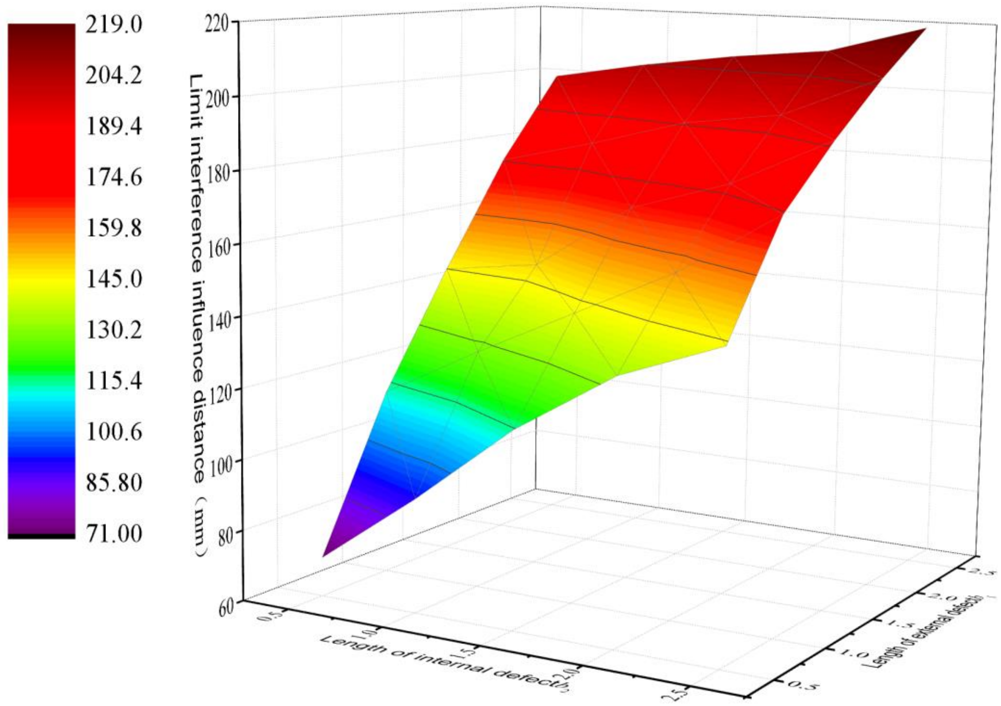

Figure 3. 3D rainbow mapping surface of defect length external defect length limit interference distance

As shown in Figure 3, in the range of defect length b1, b2 from $0.5\sqrt{Rt}$ to $2.5\sqrt{Rt}$ the range of limit interference influence distance of double defects is from 71mm to 219mm. Furthermore, with the increase of defect length b1, b2, the limit interference influence distance between internal and external defects is also enhancing, while the change rate is getting smaller and smaller. Although the increase of the length of the internal and external defects will lead to the decrease of the limit load of the pipeline, its influence degree will gradually diminish. Thus, when the length of the internal and external defects is relatively long, its influence on the limit load of the pipeline is mild, furthermore the limit interference influence distance of the internal and external defects will not change much.

3.3. Fitting the Formula of Limit Interference Influence Distance of Internal and External Defects

In order to directly calculate the interference range of the internal and external defects of the pipeline, and quickly determine whether the internal and external defects of the pipeline interfere or not, and facilitate the calculation of the limit load and safety evaluation of the pipeline, combined with the limit interference influence distance of the internal and external defects of the pipeline under different defect depth and defect length, the calculation formula of the limit interference influence distance of the internal and external defects of the pipeline was constructed through MATLAB. Since the influence of the defect width on the limit load can be ignored, the formula fitting of the limit interference influence distance between internal and external defects only considers the influence of depth and length of the defect. In addition,the depth and length of the defect were treated dimensionless.

The polynomial fitting formula was directly used for the limit interference influence distance, furthermore the cubic polynomial fitting effect was found to be optimal through multiple tests. As a result, the fundamental form of the quaternion cubic polynomial constructed is as follows:

$$\begin{aligned} L_{\lim} = {} & m_1 \cdot A_1^3 + m_2 \cdot A_1^2 + m_3 \cdot A_1 + m_4 \cdot A_2^3 + m_5 \cdot A_2^2 + k_6 \cdot A_2 + m_7 \cdot B_1^3 \\ & + m_8 \cdot B_1^2 + m_9 \cdot B_1 + m_{10} \cdot B_2^3 + m_{11} \cdot B_2^2 + m_{12} \cdot B_2 + m_{13} \end{aligned} \tag{3}$$

Where $L_{\lim}$——Limit interference influence distance of internal and external defects, mm:

$m_1 \sim m_{13}$——Undetermined parameters in quaternion cubic polynomials.

A_1——Dimensionless coefficient of external defect depth;

A_2——Dimensionless coefficient of internal defect depth;

B_1——Dimensionless coefficient of external defect length;

B_2——Dimensionless coefficient of internal defect length.

According to 50 groups of interference limit influence distances data of double defects, the nlinfit function of MATLAB software was used for multiple nonlinear regression fitting. After that the best estimation of each undetermined coefficient was calculated, meanwhile 4 decimal places were reserved for the parameters to be determined. The fitting results of each parameter are shown in table 2.

Table 2. Values of fitting parameters

Parameter	m1	m2	m3	m4	m5	m6	m7
Value	3478.0135	-797.9935	318.0556	-2655.3183	2424.8627	-331.7537	0.1447
Parameter	m8	m9	m10	m11	m12	m13	-
Value	-7.4821	69.9249	-2.3887	11.3465	7.5725	-62.2588	-

The square sum of correlation coefficient, residual square sum and mean square error parameters of parameter fitting are shown in table 3, and the parameter function fitting distribution of calculation result is shown in Figure 4.

Table 3. Fitting accuracy index

Index	Sum of squares of correlation coefficients (R2)	Sum of squares of residuals (SSE)	Mean square error(RMSE)
Value	0.9898	0.5361	7.3219

As shown in Figure 4, the discrete type is relatively low, and the data points of the limit interference influence distance are evenly distributed on both sides of the fitting line. Therefore, the deviation value of the fitting result is relatively small, and the overall fitting accuracy is considerably high.

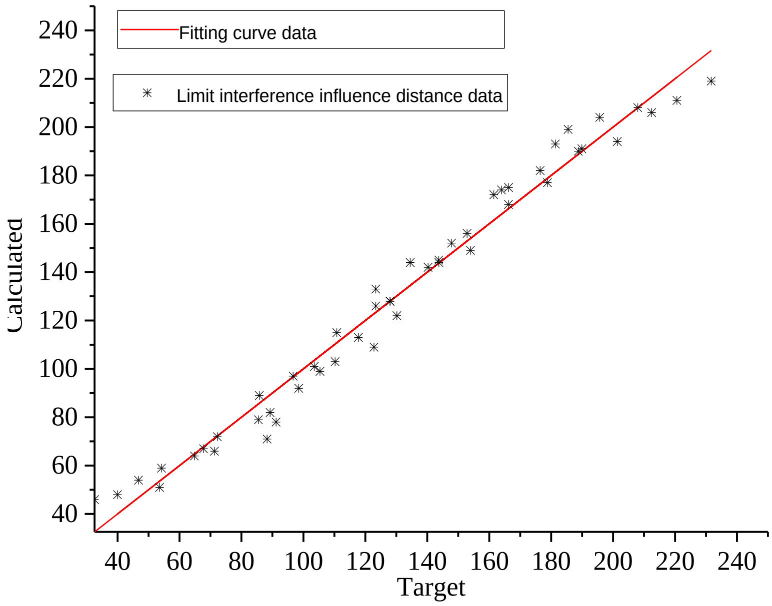

Figure 4. Regression curve X-Y

In order to express the formula more conveniently, the influence function f_{A_1} of dimensionless depth of external defect on the limit distance was introduced, likewise, introducing the influence function f_{A_2} of the depth of inner defect on the limit distance, influence function f_{B_1} of length of external defect on limit distance, influence function f_{B_2} of length of inner defect on limit distance.After integration, the fitting formula of limit interference distance Llim of double defects is obtained as follows:

$$L_{\lim} = f_{A_1} + f_{A_2} + f_{B_1} + f_{B_2} - 62.2588$$

$$\begin{cases} f_{A_1} = 3478.0135 \times A_1^{\ 3} - 797.9935 \times A_1^{\ 2} + 318.0556 \times A_1 \\ f_{A_2} = -2655.3183 \times A_2^{\ 3} + 2424.8627 \times A_2^{\ 2} - 331.7537 \times A_2 \\ f_{B_1} = 0.1447 \times B_1^{\ 3} - 7.4821 \times B_1^{\ 2} + 69.9249 \times B_1 \\ f_{B_2} = -2.3887 \times B_2^{\ 3} + 11.3465 \times B_2^{\ 2} + 7.5725 \times B_2 \end{cases}$$

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4. Conclusion

In this paper, the D1016 × 18.4 X80 pipeline of a river crossing section of Myanmar-China natural gas pipeline project was used as the modeling basis, employing the ABAQUS finite element simulation to study the limit interference influence distance of internal and external defects. Besides, the influence rules of the depth and length of internal and external defects toward the limit interference influence distance of the pipeline were analyzed and discussed respectively. The conclusion is as follows:

With the increase of the depth of internal and external defects, the limit interference influence distances of double defects will increase significantly. Besides, the change rate is continuously enhancing. As the increase of the depth of internal and external defects, will accelerate the attenuation of the limit load of the pipeline. Thus, the influence of the depth of defects on the ultimate load of the pipeline can only be counteracted in a larger range of axial distance.

As the increase of the length of the internal and external defects, the limit interference distance of the internal and external defects will also raise, while the rate of change is gradually diminishing. Although the increase of the length of the internal and external defects will lead to the decrease of the limit load of the pipeline, its influence degree will gradually reduce. Thus, when the length of the internal and external defects is relatively long, its influence on the limit load of the pipeline is mild . Moreover, the limit interference influence distance of the internal and external defects will not change much.

In addition, in this paper, the dimensionless variables and the quaternion cubic polynomials were also constructed. MATLAB software was used for multiple nonlinear regression fitting of data of the limit interference influence distance of each internal and external defect, so that the calculation formula of the limit interference influence distance of internal and external defect on the depth and length of the defects was obtained.

It can be used to calculate the interference range of internal and external defects of pipeline directly, judging whether there is interference between internal and external defects of pipeline effetctively. calculating the limit load of pipeline and evaluating the safety. Moreover, the formula has a considerably high fitting accuracy, which has a certain practical value in production.

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