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# Impact of Internal and External Defects on Ultimate Load of Large Diameter X80 Steel Pipelines: An ABAQUS FEA Study

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**Abstract:**This study focuses on the D1016 × 18.4 X80 pipeline segment in the river crossing section of the Myanmar-China natural gas pipeline project, examining its ultimate internal pressure load. To determine this load, both the plastic failure criterion and the double elastic slope criterion are employed. Utilizing the ABAQUS finite element analysis software, the research investigates the impacts of internal and external defect depth, length, and width on the pipeline's ultimate load.

**Keywords:**Large Diameter Pipeline; Ultimate Load; X80 Pipeline Steel; Internal And External Defects; Interference.

## 1. Introduction

Oil and natural gas promote the development of the world economy, which is of great significance to the national economy and national development. At present, the pace of development of China's oil and natural gas industry is speeding up, and the construction of oil and gas pipelines has entered a high-speed development period. There are many reasons for pipeline corrosion, moreover the mechanism is complex and the location of corrosion is random. The appearance of corrosion defects will affect the failure form and ultimate pressure of pipeline. The long-distance oil and gas pipeline passes through a wide area where the terrain is complex. Furthermore, there are different soil properties, diverse pipeline structure and various transmission medium properties, thus it is easy to cause a large number of internal and external defects of the long-distance pipeline. The pipeline with inner and outer wall defects does not necessarily lose the bearing capacity. Repair and replace the pipeline when the pipeline does not completely lose the bearing capacity,which will force to stop pipeline transmission, causing unnecessary economic losses to a certain extent.

Based on the finite element method, X.Li et al. [1] (2016) proposed an evaluation method for the interference between adjacent corrosion, which has better accuracy and applicability, especially for the axial long corrosion defects. S.s.al-owaisi et al. [2] (2016) used finite element software to analyze X60 with adjacent defects of different shapes. It was found that the adjacent defects of two shapes (ellipse and rectangle) will interact when the axial distance is not more than 3 times of the wall thickness or the circumferential distance is not more than 0.5 times of the wall thickness. In GB / T19624 safety assessment of pressure vessels with defects in service (2004) [3], considering the mutual influence of multiple cracks, a crack merging method is proposed aiming at multiple adjacent cracks, in which the internal and external crack defects are treated as penetrating crack defects, but this method does not propose the treatment method of internal and external volume crack defects.

To sum up, there are few research results on the limit load of double defect pipeline at present, except for the research of crack defects on the inner and outer walls of the pipeline.

Furthermore there are few research on the limit load of the pipeline with internal and external volume defects. At present, the research on the limit load of the pipeline with double defects is mainly aimed at the same surface defects, whereas there is no way to avoid the existence and interaction of internal and external wall defects in actual working condition. Adopting the current pipeline safety evaluation system to determine the pipeline with internal and external defects will result in relatively conservative judgment results, thus increasing the pipeline operation risk. Therefore, it is necessary to further study the ultimate load of pipeline under the interference of internal and external double defects.

## 2. Literature References

The process of pipeline material failure is relatively complex. Through the comparative analysis of the existing theory and method of pipeline ultimate load and pipeline failure criterion, this paper finally selects the plastic failure criterion to analyze the ultimate bearing capacity of pipeline, and chooses the double elastic slope method as the determination criterion of pipeline ultimate load.

### 2.1. Plastic Failure Criterion

$P_{L0}$——Plastic limit internal pressure of flawless pipeline under internal pressure, MPa;

$R_0$——Outer radius of pipe, mm;

$R_i$——Inner radius of pipe, mm.

The X80 steel studied in this paper belongs to high-strength steel grade, which has great toughness. In order to exert the bearing capacity of the material and obtain the limit load with engineering practical significance, the local and controllable plastic deformation of the pipeline is allowed. In conclusion, the failure state of the pipeline with internal and external defects is analyzed by using the plastic failure criterion in this paper.

### 2.2. Limit Load Determination Criteria

According to the different criteria of significant plastic flow when the steel reaches the plastic limit, there are many criteria to determine the ultimate load in engineering. In this paper, the double elastic slope criterion is used as the criteria to determine the ultimate load, as shown in Figure 1 , make an internal pressure-strain curve, and make a straight line through the origin, so that its slope is twice the slope of the elastic section of the load deformation curve. The load value corresponding to the intersection of the straight line and the internal pressure-strain curve is the limit load.

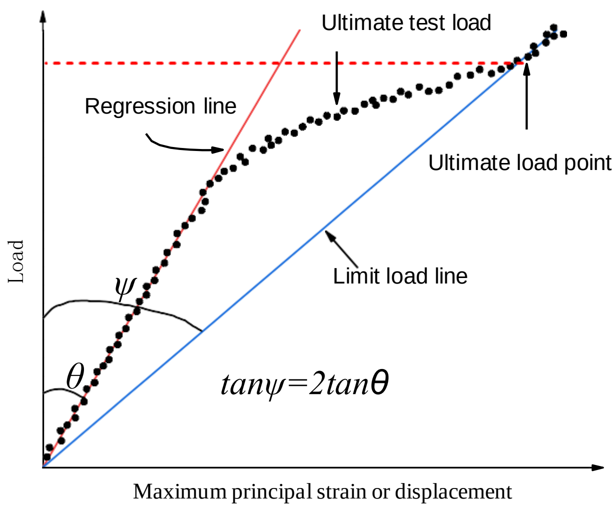



**Figure 1:** schematic diagram of double elastic slope criterion

The double elastic slope criterion is a modern criterion adopted by ASME Boiler and pressure vessel code. It has a relatively good applicability and high accuracy to the mainstream steel in China. Therefore, the double elastic slope criterion is adopted as the determination criterion of ultimate load in this paper.

# 3. Finite Element Analysis of Limit Load of 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 are 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 is used in this paper.

According to Saint Venant's theorem [4], the length of the pipe affected by the end effect is calculated as follows:

It shows that the length of 241.7mm away from the two ends will be affected by the constraints of the two ends. Thus, in order 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 is set as 4m, and the defects are located in the middle of the model. Model parameters are shown in Table 1.

**Table 1:** finite element model parameters of pipe section

| Steels | Yield strength(MPa) | Ultimate tensile strength(MPa) | Young 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 is formed by drawing, the type of defect is set as rectangular volume defect, and the corrosion rectangular pit is formed by rotating cutting. Besides, the model adopts C3D8R eight nodes linear hexahedron reduction integral element. In addition, the structured grid division technology is used to finally form the grid. The grid division results are shown in Figure 1.

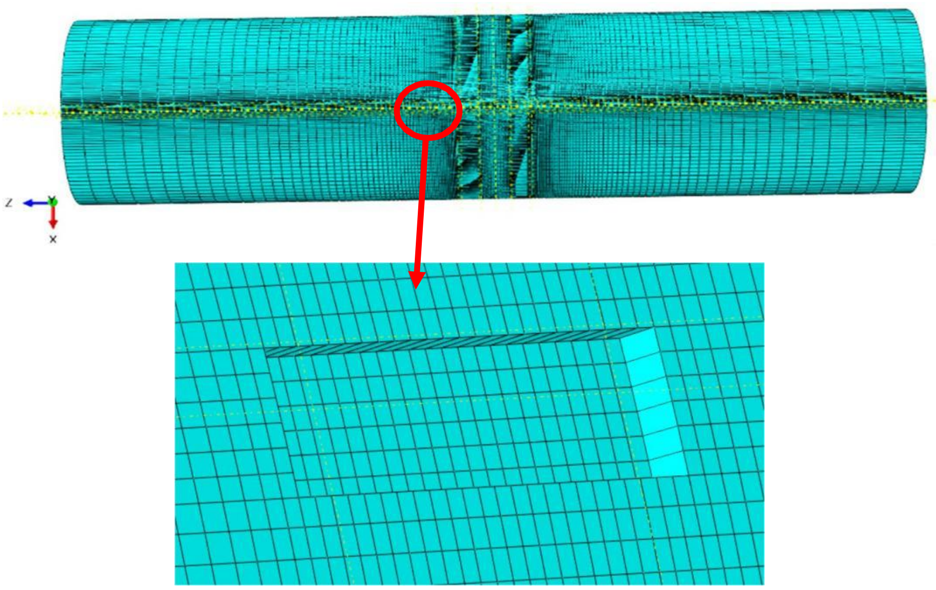



**Figure 2:** schematic diagram of grid division

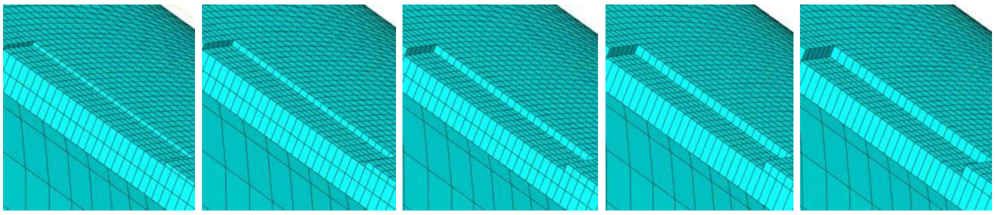
## 3.2. Analysis of the Influence of Internal and External Defect Parameters on the

## Ultimate Load

### 3.2.1. Analysis of the Influence of the Depth of Internal and External Defects on the Ultimate Load of Pipeline

In this section, the influence of different defect depth on the ultimate load will be analyzed. In order to facilitate the analysis and summary of the law, the defect depth will be dimensionless treated, and a/t=0.1 will be used as the defect foundation depth of the study.

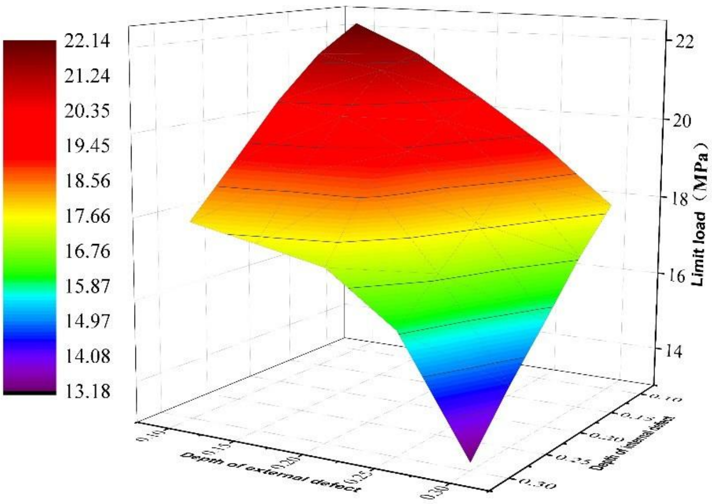
When studying the influence of the depth of internal and external defects on the ultimate load of pipeline, set the length of internal and external defects $b/\sqrt{Rt}=1$, width c=20mm, and the depth a of internal and external defects are a/t=0.1, 0.15, 0.2, 0.25 and 0.3 respectively. There are 25 types of defects in total. As shown in Figure2, based on five kinds of pipe axial spacing of L = 50mm, 150 mm, 250 mm, 350 mm and 450 mm, 125 models with external defects $a_1/t$ and internal defects $a_2/t$ of 0.1, 0.15, 0.2, 0.25 and 0.3, were respectively established.



(a)$a_1/t$=0.1 (b)$a_1/t$=0.15 (c)$a_1/t$=0.2 (d)$a_1/t$=0.25 (e)$a_1/t$=0.3

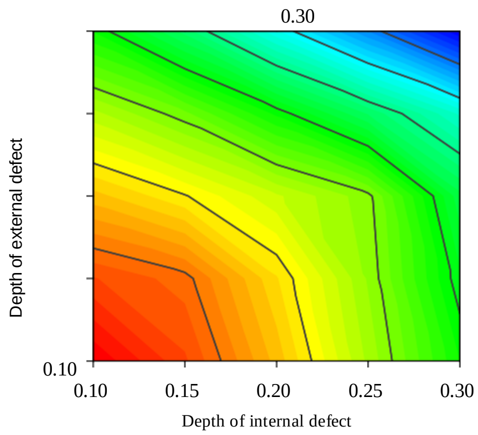
**Figure 3:** schematic diagram of external defect model based on depth change

The above 125 kinds of pipeline models are imported into ABAQUS for finite element analysis, and the corresponding internal pressure-strain curve is obtained. Further, the limit load can be obtained by introducing it into Origin software with the use of the double elastic slope method.




**L=50mm**

**Figure 4:** 3D rainbow map of inner defect depth outer defect depth ultimate load




**L=50mm**

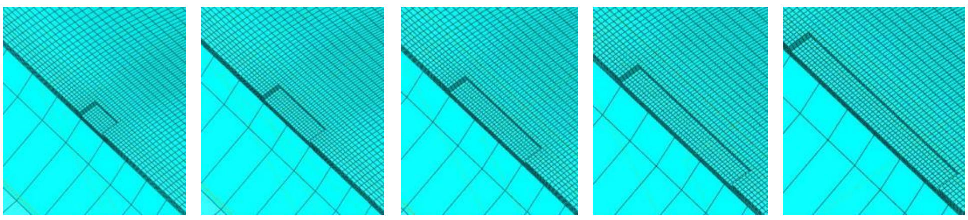
**Figure 5:** contour section of internal defect depth external defect depth ultimate load

It can be seen from Figure 3 and Figure 4 that when L=50mm, with the increase of the depth of internal and external defects, the limit load value of pipeline decreases from 22.13 MPa to 13.19 MPa, with a total decrease of 8.94 MPa and the decrease of 40.40%.

The above analysis shows that when the axial distance between the inner and outer defects is small, the interference effect of the double defects is noticeably strengthened, which leads to the decline of the ultimate load of the pipeline. It can be seen from Figure 4 that the ultimate load of pipeline decreases rapidly with the increase of defect depth, and the rate of change is increasing, which fully shows that the influence of defect depth on the ultimate load of pipeline is significant.

### 3.2.2. Analysis of the Influence of the Length of Internal and External Defects on the Ultimate Load of Pipeline

In this section, the influence of different defect lengths on the ultimate load will be analyzed. In order to facilitate the analysis and summary of the law, the defect length will be dimensionless treated and $b/\sqrt{Rt}$ =0.5 will be used as the basic defect length of the study. When studying the influence of the length of internal and external defects on the ultimate load of the pipeline, set the depth of internal and external defects a/t=0.25, a=4.6mm, width c=20mm, and the length b of internal and external defects are 0.5 $\sqrt{Rt}$ , $\sqrt{Rt}$ ,1.5 $\sqrt{Rt}$ ,2 $\sqrt{Rt}$ , 2.5 $\sqrt{Rt}$ , respectively. There are 25 types of defects in total. As shown in Figure 5, based on five kinds of pipe axial spacing of L = 50mm, 150 mm, 250 mm, 350 mm and 450 mm, the length of external defect $b_1$ and internal defect $b_2$ as 0.5 $\sqrt{Rt}$ , $\sqrt{Rt}$ ,1.5 $\sqrt{Rt}$ ,2 $\sqrt{Rt}$ , 2.5 $\sqrt{Rt}$ are respectively established, and there are 125 pipe models in total.

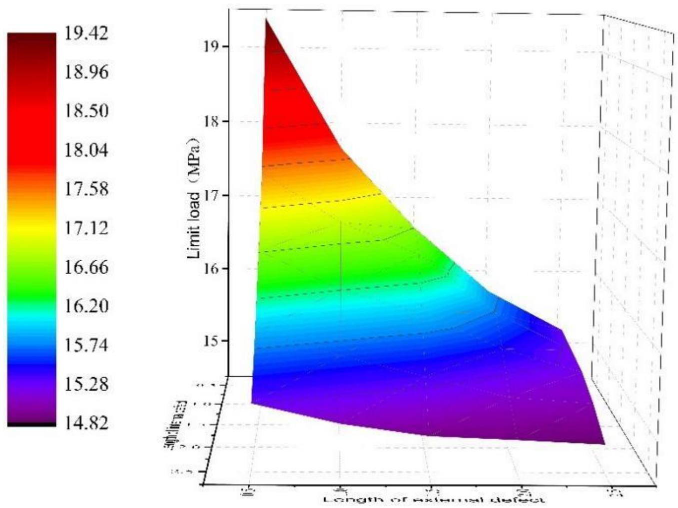


(a) $b_1=0.5\sqrt{Rt}$ $b_1=\sqrt{Rt}$ $b_1=1.5\sqrt{Rt}$ $b_1=2\sqrt{Rt}$ (e) $b_1=2.5$

(b) (c) (d)

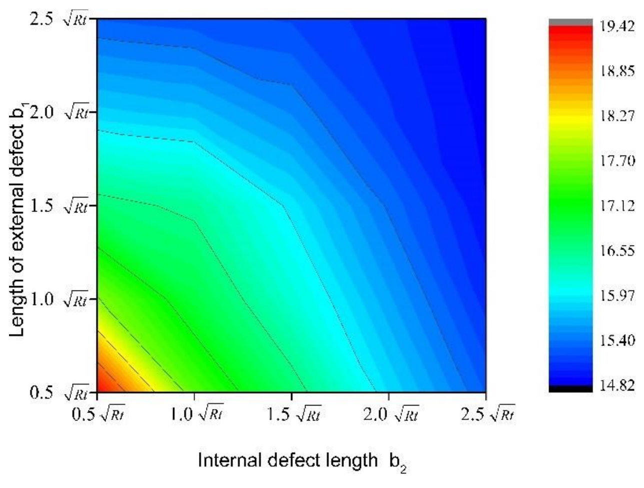
**Figure 6:** schematic diagram of external defect model based on length change

The above 125 kinds of pipeline models are imported into ABAQUS for finite element analysis, and the corresponding internal pressure-strain curve is obtained. Further, the limit load can be obtained by introducing it into Origin software with the use of the double elastic slope method.




**L=50mm**

**Figure 7:** 3D rainbow map of inner defect depth outer defect depth ultimate load




**L=50mm**

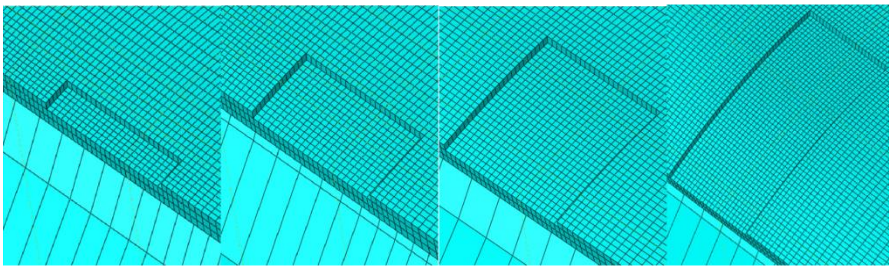
**Figure 8:** contour section of internal defect depth external defect depth ultimate load

It can be seen from Figure 6 that when L=50mm, with the increase of the length of internal and external defects, the ultimate load value of the pipeline decreases from 19.41 MPa to 14.83 MPa, with a total of 4.58 MPa and the decrease of 23.60%. Thus, the ultimate load of pipeline will decrease with the increase of defect length, but the change rate will be smaller and smaller. Besides, as shown in Figure 7, the contour distribution becomes sparser with the increase of the length, indicating that when the defect length is longer, its influence on the ultimate load of the pipeline decreases gradually.

### 3.2.3. Analysis of the Influence of the Width of Internal and External Defects on the Ultimate Load of Pipeline

This section will analyze the influence of different defect width on the ultimate load. In order to facilitate the analysis and summary of the law, width c=20mm is used as the width of defect foundation.

When studying the influence of the width of internal and external defects on the ultimate load of the pipeline, set the depth of internal and external defects a/t=0.1, a=1.84mm, length b/ $\sqrt{Rt}$ =1, b=96.68mm, and the width c of internal and external defects are respectively 20mm, 50mm, 100mm and 200mm. There are 16 types of defects in total. As shown in Figure 8, the models with the width of external defect $c_1$ and internal defect $c_2$ of 20 mm, 50 mm, 100 mm and 200 mm are respectively established by using the axial spacing of L = 50 mm and 150 mm. There are 32 pipeline models in total.



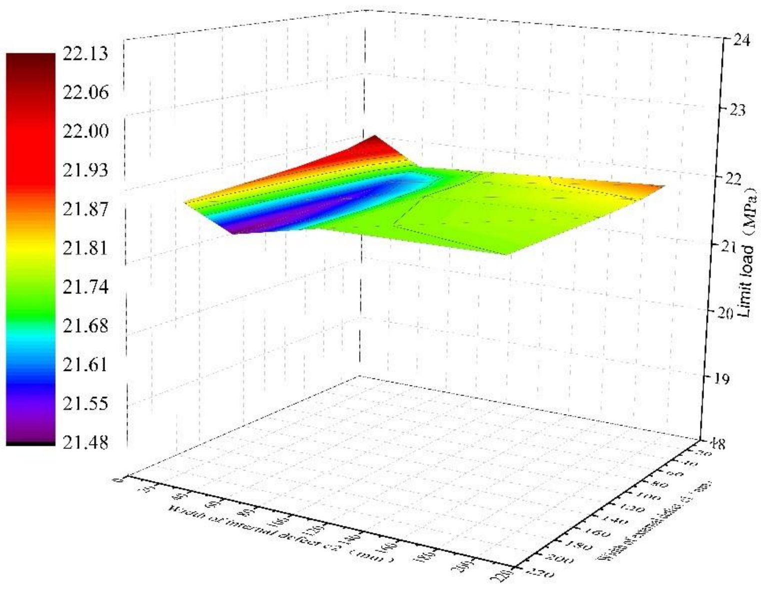
(a)$c_1$=20mm (b)$c_1$=50mm (c)$c_1$=100mm (d)$c_1$=200mm

**Figure 9:** schematic diagram of external defect model based on width change

The above 32 kinds of pipeline models are imported into ABAQUS for finite element analysis, and the corresponding internal pressure-strain curve is obtained. Further, the limit load can be obtained by introducing it into Origin software with the use of the double elastic slope method.

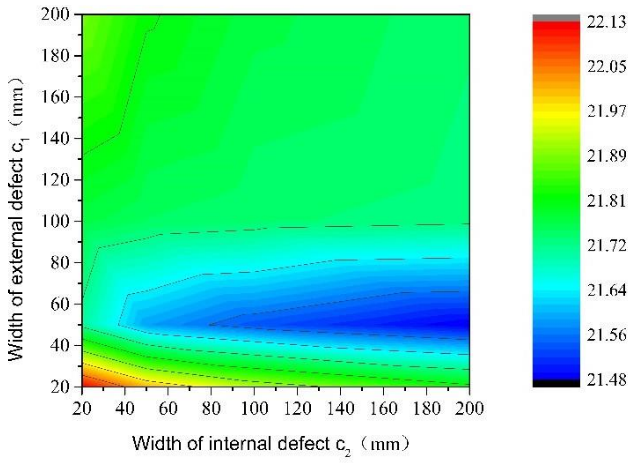
It can be seen from Figure 9 that when L= 50mm, with the increase of the width of internal and external defects, the limit load value of pipeline decreases from 22.13 MPa to 21.48 MPa, with only a total decrease of 0.65 MPa and a decrease of 2.94%. In addition, with the increase of the width of internal and external defects, the limit load of the pipeline decreases slightly, while the overall change is not significant.

Furthermore, it can be seen from Figure 10 that most areas of the ultimate load are in a state of very low rate of change, indicating that the influence of the width of internal and external defects on the ultimate load of the pipeline is insignificant, which can be ignored in engineering.



**L=50mm**

**Figure 10:** 3D rainbow map of inner defect depth outer defect depth ultimate load




**L=50mm**

**Figure 11:** contour section of internal defect width external defect width ultimate load

## 4. Conclusion

In this paper, the D1016 × 18.4 X80 pipeline of a river crossing section of Myanmar China natural gas pipeline project is used as the modeling basis, meanwhile the ABAQUS finite element simulation is used to research on the influence of internal and external defects on the ultimate load of the pipeline under the interference. Besides, the influence of the depth, length and width of internal and external double defects on the ultimate load of the pipeline is analyzed and discussed respectively. The conclusion is as follows:

The ultimate load of pipeline decreases significantly with the increase of the depth of internal and external defects, and the rate of change is increasing. Thus, the depth of defects is the main factor affecting the ultimate load of pipeline. While, the ultimate load of pipeline decreases with the increase of the length of internal and external defects, but the rate of change is getting smaller and smaller, which indicates that the length of defects has an impact on the ultimate load of pipeline to some extent. Furthermore, when the length of defects is longer than 2.5 $\sqrt{Rt}$ , the influence of length on the pipeline can be ignored. Moreover, compared with the depth, the defect length is the secondary influence factor of the ultimate load of the pipeline; at last, the ultimate load of the pipeline is almost constant with the increase of the width of the internal and external defects, indicating that its influence can be ignored.

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