Reliability Analysis of Cold-Wave Resistance Connectivity of Underground Municipal Water Supply Networks

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Abstract: To explore the related problems of the reliability of cold-wave resistance connectivity of underground-based municipal water supply network, this paper, taking a city’s water supply network as an example, mainly utilizes the First Order Second Moment method (FOSM) to calculate the reliability with the change of temperature. Based on this, it is concluded that the reliability of the water supply network is related to the temperature during the cold-wave period. When the temperature is different, the reliability of the water supply network is also different. Therefore, when designing the water supply network, the influence of the cold wave should be taken into account, and the freeze stress of the network should also be taken into account when analyzing the reliability of the water supply network during the cold-wave period.

1. Introduction

The municipal water supply network directly affects the normal life of residents. During the cold-wave period, the underground municipal water supply network will be affected correspondingly, resulting in the pipe explosion in endlessly. The pipe explosion of water supply network has greatly affected the safety of people's water supply, then people's normal life could not be guaranteed [1-2]. Based on this, it is very necessary to strengthen the research on the reliability of cold wave resistance connectivity of municipal water supply network. The operation safety of municipal water supply network could be evaluated comprehensively to ensure the safety of residents' water supply.

2. Reliability Calculation and Analysis of Underground Municipal Water Supply Network Based on the Fosm Method

2.1 The Improvement of the Fosm Method

The improved FOSM method is also called the method of design verification points. In this method, the linearized Taylor’s formula expansion point of structural performance function is determined on the limit state surface, and the probability distribution of variables is included in it. The limit state equation of the structure is $Z=g_x(X)=0$.

2.2 The Calculation of Practical Cases with Fosm Method

Taking water supply network of a city as an example to calculate its reliability. Among them, Q235 welded steel pipes are used for water supply pipe network, 0.26mpa is the working pressure of the pipe, 1600mm is the inner diameter, calculated inner diameter d_0=1614mm, calculated wall thickness t=12mm, wall thickness t=14mm, buried Hs= 1.2m. 18KN/m3 is the original soil weight and 1618KN/m3 is the backfill weight. The Table 1 is for the parameter distribution and value.

Table 1 Conditions of Pipelines and Values

Name of Parameter	Range and values($_{u,Ó}$)
Calculated pipe diameter r_0/mm	Normal Distribution(807,40,35)
Calculated wall thickness t_0/mm	Normal Distribution(12.0.6)
Yield strength $Ó_0$/MPa	Normal Distribution(235,18,8)
Working pressure/MPa	Normal Distribution(0,9,0,135)

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The relationship between the reliability of pipelines and the temperature in cold-wave period can be obtained by combining the values in the above table and formulating a calculation program according to the FOSM method.

2.3 Reliability Analysis of Underground Municipal Water Supply Network during the Cold-Wave Period

The soil will not be frozen when the temperature in the cold-wave period is higher than 0℃, so the freezing stress will not occur. The stresses that need to be considered in the reliability calculation are as follows. For hoop stress, it is necessary to consider the stress caused by the dead weight of the pipeline, the stress caused by the internal pressure of the water supply network, the stress caused by ground traffic load or stack load, the hoop Poisson stress, the stress caused by the overlying soil, etc. For longitudinal stresses, the temperature stress, Poisson stress, and uneven settlement stress need to be considered. Figure 1 is for the reliability probability changes of water supply pipelines under different temperatures in this study.

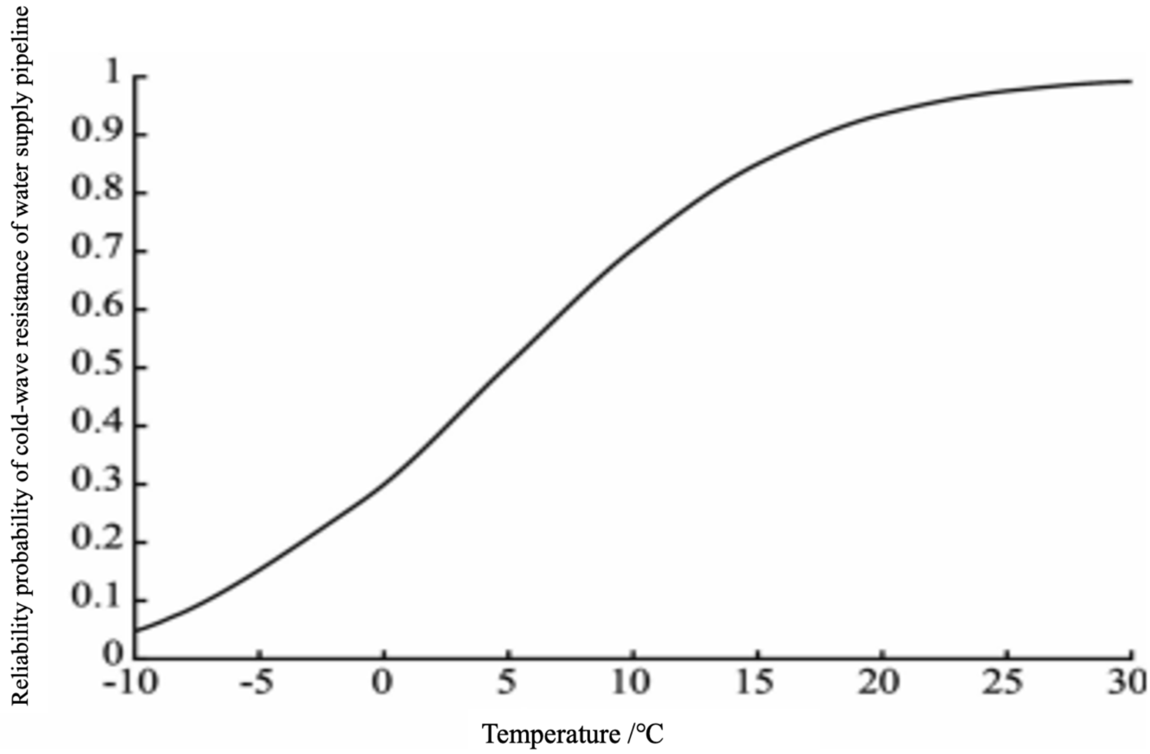

Fig.1 The Reliability Probability Changes of Water Supply Pipelines under Different Temperatures

Because summer is mostly the season of pipeline installation, 30℃ is the fixed value of the mounting temperature. The reliability of the water supply network shows a gradual downward trend with the decrease of the temperature. Once the mounting temperature is the same as the operation temperature, that is, when the temperature difference is 0, 0.9917 is the reliability of cold-wave resistance of the water supply network at this time; when the difference between the mounting temperature and the operation temperature is 15℃, 0.8505 is the reliability of cold-wave resistance of the water supply network at this time.

When the air temperature is below 0℃ in cold-wave period, the soil will be frozen. At this time, the influence of hoop freezing stress should be considered. Combined with the pipeline stress of the municipal water supply network in the cold-wave period, if -9℃ is the lowest temperature during that time, the soil will generate freeze stress, and the frost line is above the water supply pipeline. Once the operating temperature of the water supply pipeline is lower than 0℃, the water in the pipeline will freeze and the pipeline will be damaged. It is assumed that the minimum temperature in the cold-wave period is 0℃. (In order to facilitate the calculation, the minimum temperature of municipal water supply pipeline can be taken as 0℃.) As shown in Figure 1, the reliability of water supply network changes with temperature change. When the temperature is higher than 0℃, the freeze stress will not be produced. In the process of temperature decreasing, the longitudinal temperature difference stress and loop Poisson stress of the water supply network are increasing, and the reliability probability of the water supply network is decreasing. When the temperature is lower than 0℃ in the cold-wave period, there will be freeze stress. In the process of temperature decreasing, the longitudinal temperature difference stress and loop Poisson stress of the water supply network are increasing, and the reliability probability of the water supply network is also decreasing. Under the influence of freeze stress, the inflection point of pipeline reliability probability curve is 0℃. From Figure 1, it can be seen that the temperature could affect the reliability probability of water supply networks, and the reliability probability varies with the temperature. When the temperature is -5℃ and -10℃, the corresponding reliability probability is 0.1506 and 0.0485 respectively. Therefore, it is necessary to consider the influence of cold wave when the municipal government designs the underground water supply network.

2.4 The Reliability Calculation of Cold-Wave Resistance Connectivity of Underground Municipal Water Supply Network under the Regulations

In the Regulations, for hoop stress, it is necessary to consider the stress caused by the self-weight of the pipeline, the stress caused by the internal pressure of the water supply network, the stress caused by the ground traffic load or pile load, the stress caused by the water weight in the pipeline, the stress caused by the overlying soil, etc.; the longitudinal stress shall take into account the temperature stress, Poisson stress and the uneven settlement stress. In the Regulations, when the connection form of water supply pipeline is welding, the temperature difference can be 25℃. According to the stress calculation method in the Regulations, 0.7923 is the reliability probability of pipeline. In this study, if the pipeline installation temperature is 30℃, 25℃ is the temperature difference, and the temperature is 5℃, the freeze stress will not be generated. Combining with the stress calculation formula, 0.5059 is the reliability probability, which is lower than the reliability probability stated in the Regulations. This shows that the Regulations overestimates the reliability of the water supply network in the cold-wave period, so all factors affecting the reliability of the pipeline should be considered in the design of the municipal water supply network.

3. Sensitivity Analysis of Related Parameters

3.1 Sensitivity of Parameter Above 0℃ in Cold-Wave Period

If the temperature is above 0℃ in cold-wave period, the freeze stress will not be appeared in the calculation formula of pipeline stress, and the sensitivity of parameters above 0℃ in the cold-wave period is shown in Table 2.

Table 2 Sensitivity of Parameters Above 0℃ in Cold-Wave Period (P=0.9mpa)

Name of Parameter	Increment of parameter change /%	Failure probability change value/%	Sensitive Indicator Value/%	Importance
Pipe diameter	1	0.454	2.273	2
wall thickness	1	0.029	0.147	5
Yield strength	1	2.199	10.992	1
Working pressure	1	0.181	0.905	3
Temperature difference	1	0.078	0.389	4

3.2 Sensitivity of Parameters Below 0℃ during the Cold-Wave Period

The freeze stress will appear in the calculation formula of pipeline stress when the temperature is below 0℃ during the cold-wave period. The sensitivity of parameters below 0℃ during the cold-wave period is shown in Table 3.

Table 3 Sensitivity of Parameters Below 0℃ during the Cold-Wave Period (P=0.9mpa)

Name of Parameter	Increment of parameter change /%	Failure probability change value/%	Sensitive Indicator Value/%	Importance
Pipe diameter	1	0.118	1.252	3
wall thickness	1	0.0468	0.233	4
Yield strength	1	0.901	4.504	1
Working pressure	1	0.3338	1.668	2
Temperature difference	1	0.0196	0.098	5

By analyzing the above table, it can be found that the reliability of water supply pipeline is different due to various parameters, of which the reliability of water supply pipeline is most affected by the yield strength of pipe material. The influence of each parameter on the reliability of water supply pipeline is related to the working pressure. When working pressure is less than 1.8MPa, the order of influence from large to small on pipeline reliability is yield strength, pipe diameter, working pressure and wall thickness; when working pressure is more than 1.8MPa, the order of influence from large to small on pipeline reliability is yield strength, working pressure, pipe diameter and wall thickness.

4. Conclusion

In summary, this paper mainly takes a water supply network in a city as an example, calculates the reliability with the change of air temperature under the FOSM method, and explores the reliability of cold-wave resistance connectivity of underground municipal water supply networks. The following conclusions are drawn: the reliability of water supply pipeline is greatly affected by the lowest temperature of cold wave. When the lowest temperature is different, the reliability of pipeline is different. Municipal governments need to consider the cold wave when designing underground water supply network. When the temperature in the cold-wave period is below 0℃, the stress in various pipelines need to be taken into account during the process of analyzing pipeline reliability. The working pressure affects the reliability of pipeline. It is found that when the working pressure is less than 1.8MPa, the order of influence from large to small on the reliability of pipeline is yield strengthen, pipe diameter, working pressure and wall thickness. When the working pressure is more than 1.8MPa, the order of influence from large to small on the reliability of pipeline is yield strengthen, working pressure, pipe diameter and wall thickness.

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