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Research of Risk Identification and Prevention of Underground Pressure Pipelines Damage Caused by External Disturbance

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Abstract: External disturbance is an important cause of underground pressure pipeline damage, which leads to accidents, and it is crucial to study the risk of damage caused by external disturbance and come up with proper prevention and control measures. We reviewed literature on risk identification of underground pressure pipelines damage due to external disturbance was conducted, and a list of risk factors was formed. Based on the list of risk factors, fault tree analysis was carried out on underground pressure pipelines damage caused by external disturbances, and risk prevention and control measures were proposed through the calculation of minimum cut sets, minimum path sets, and structural importance, in hopes of providing reference for the normal operation of underground pressure pipelines.

Keywords: Underground pressure pipeline damage; External disturbance; Risk identification; Fault tree; Risk prevention and control

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1. Introduction

Urban population is becoming denser with the acceleration of urbanization, and the construction scale of underground pressure pipelines such as gas, water supply, and heat supply are also increasing. Many pipelines are tightly arranged or even intersected, which can easily lead to secondary and derivative accidents, causing significant casualties, economic losses, and adverse social impacts. Therefore, it is crucial to study the risk prevention and control of underground pressure pipelines.

Extensive research has been conducted on risk identification, prevention, and control of underground pressure pipelines, but there is limited systematic analysis on the specific risk identification and prevention of external disturbances to underground pressure pipelines, and the reasons for the risks have not been fully clarified [1-5]. External disturbance is a major cause of underground pressure pipeline accidents. Therefore, based on the accident-causation theory, research was carried out to carefully identify the risk factors of external disturbance damage and a fault tree was created. Prevention and control measures were proposed through fault tree analysis.

2. Overview of accident-causing theory

The accident-causation theory demonstrates the occurrence, development, and results of accidents through accident mechanisms and models [6]. Among them, the accident-causation theory at home and abroad mainly include the accident proneness theory, and Heinrich's Dominos theory (**Figure 1**), theory on unexpected release of energy, and the 24Model theory (**Figure 2**) [7-9].

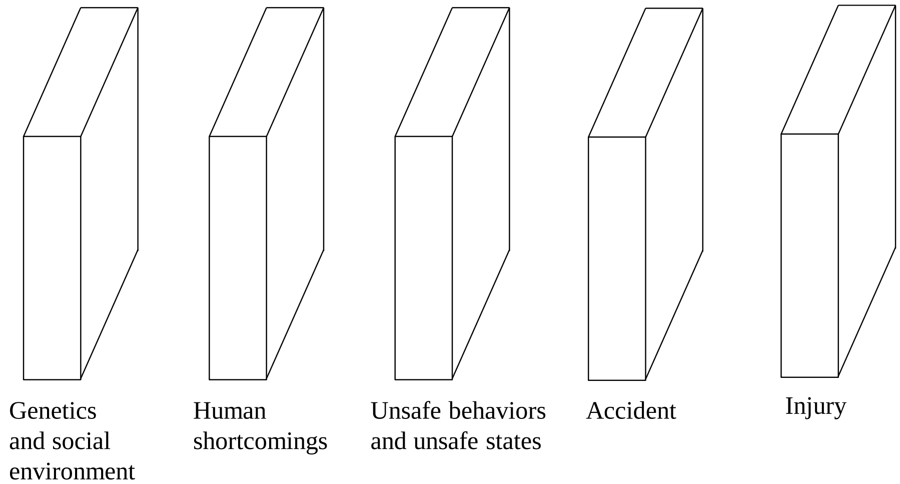

Figure 1. Heinrich's Dominos theory

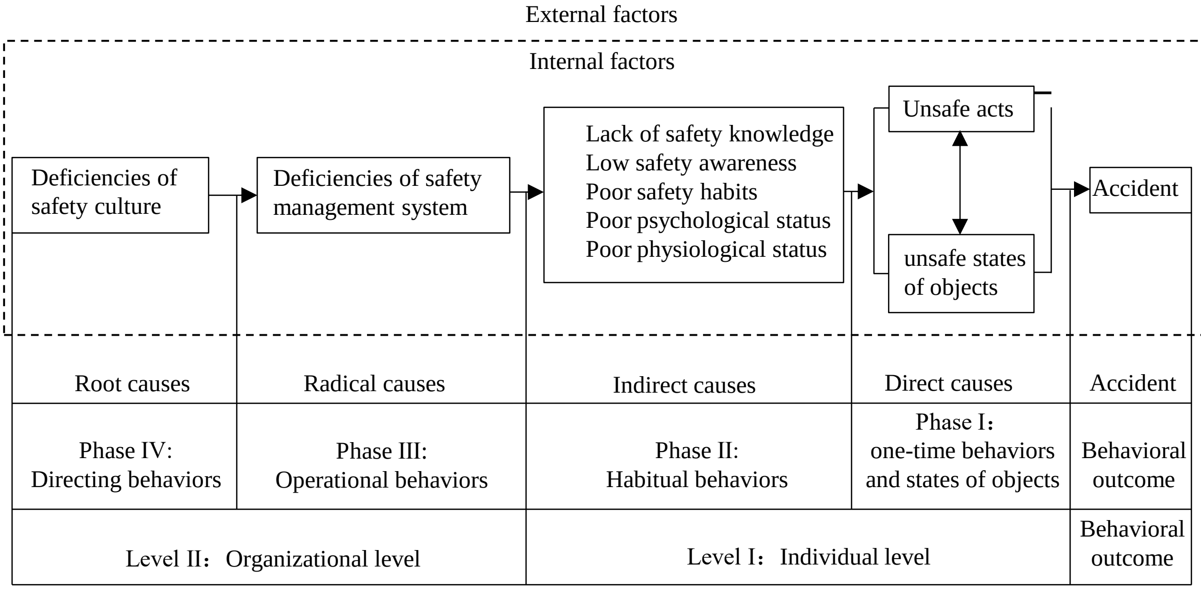

Figure 2. 24Model theory

The accident proneness theory completely attributes the responsibility for accidents to individuals; Heinrich's Dominos theory uses 5 dominoes to represent the mechanism of accidents but does not reflect the complex relationship between accidents; the theory of unexpected release of energy believes that accidents are caused by the accidental release of energy, explaining the physical reasons for accidents; 24Model theory divides the causes of accidents into internal and external factors. The internal factors explained from two levels (organizational level and individual level) and four stages (one-time behaviors and states of objects, habitual behaviors, operational behaviors, and directing behaviors), which better explains the occurrence and development of accidents.

3. Risk identification of external disturbance damage to underground pressure pipelines

Based on Heinrich's Dominos theory and the 24Model theory, the direct cause of accidents is attributed to unsafe behaviors of humans and unsafe states of objects, and then the indirect causes of accidents are explored. However, through research, it was found that risk factors of underground pressure pipelines damage due to external disturbance to not only include the human and "object" factors, but also environmental factors. So, it is necessary to study the causes of risk from three direct risk factors: unsafe behaviors of humans, unsafe states of objects, and unfavorable environmental factors.

3.1. Unsafe behaviors of humans

There are two types of unsafe behaviors of humans: construction/operation damage and vandalism. Construction/operational damage is mainly caused by unstandardized construction, barbaric construction, and operational errors, while vandalism is mainly driven by interests and resentment.

3.2. Unsafe states of objects

The unsafe states of objects can be divided into two types: the impact of the upper load and the unqualified pipeline foundation. The impact of the upper load is mainly caused by insufficient burial depth of pipelines and frequent activities such as rolling and construction. The unqualified pipeline foundation is mainly caused by unstandardized construction and poor construction quality.

3.3. Unfavorable environmental factors

Unfavorable environmental factors mainly include landslides, mud-rock flows, collapses, and earthquakes. Among them, landslides and mud-rock flows are mainly caused by three reasons: geological evolution, deforestation and indiscriminate cultivation, and unreasonable excavation. Collapses are mainly caused by poor protective effects and unreasonable excavation. Earthquakes are mainly caused by crustal movement and large-scale blasting activities.

3.4. List of risk factors

Based on the analysis above, a list of risk factors for underground pressure pipelines damage due to external disturbance is summarized and sorted out in **Table 1**.

Table 1. List of risk factors

Number	First-level risk factors	Second-level risk factors	Third level risk factors	Fourth level risk factors
1	Unsafe behaviors of humans	Construction/operational damage	Unstandardized construction	Lack of professional skills
2				Poor sense of responsibility among construction personnel
3				Lack of supervision and management
4			Barbaric construction	Lack of accurate pipeline location information
5				Poor safety responsibility awareness
6				Lack of supervision and management
7			Operational errors	Lack of professional skills
8				Poor psychological quality
9		Vandalism	Interest driven	–
10			Resentment	Improper handling of social relations
11				Poor economic conditions
12	Unsafe states of objects	Impact of upper load	Insufficient burial depth of pipelines	Pipeline backfilling not in place
13				Rainwater erosion
14			Frequent activities such as rolling and construction	Failure to set warning signs in accordance with regulations for pipelines
15				Lack of supervision and management
16		Unqualified pipeline foundation	Unstandardized construction	Lack of professional skills
17				Poor sense of responsibility among construction personnel
18				Lack of supervision and management
19			Poor construction quality	Lack of professional skills
20				Material defects
21				Poor sense of responsibility among construction personnel
22				Lack of supervision and management

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Number	First-level risk factors	Second-level risk factors	Third level risk factors	Fourth level risk factors
23	Unfavorable environmental factors	Landslides	Geological evolution	–
24			Deforestation and indiscriminate cultivation	Interest driven
25				Weak legal awareness
26				Lack of supervision and management
27			Unreasonable excavation	Poor technical solutions
28				Lack of supervision and management
29		Mud-rock flows	Geological evolution	–
30			Deforestation and indiscriminate cultivation	Interest driven
31				Weak legal awareness
32				Lack of supervision and management
33			Unreasonable excavation	Poor technical solutions
34				Lack of supervision and management
35		Collapses	Poor protective effects	Poor technical solutions
36				Lack of professional skills
37				Material defects
38			Unreasonable excavation	Poor technical solutions
39				Lack of supervision and management
40		Earthquakes	Crustal movement	–
41			Large-scale blasting activities	–

4. Drawing of fault tree for external disturbance damage to underground pressure pipelines

Based on the risk factors listed in **Table 1**, the risk factors were converted into events in the fault tree as shown in **Table 2**. The logical relationships between events were expressed by "AND" and "OR" gates, and a fault tree was drawn, as shown in **Figures 3** and **4**.

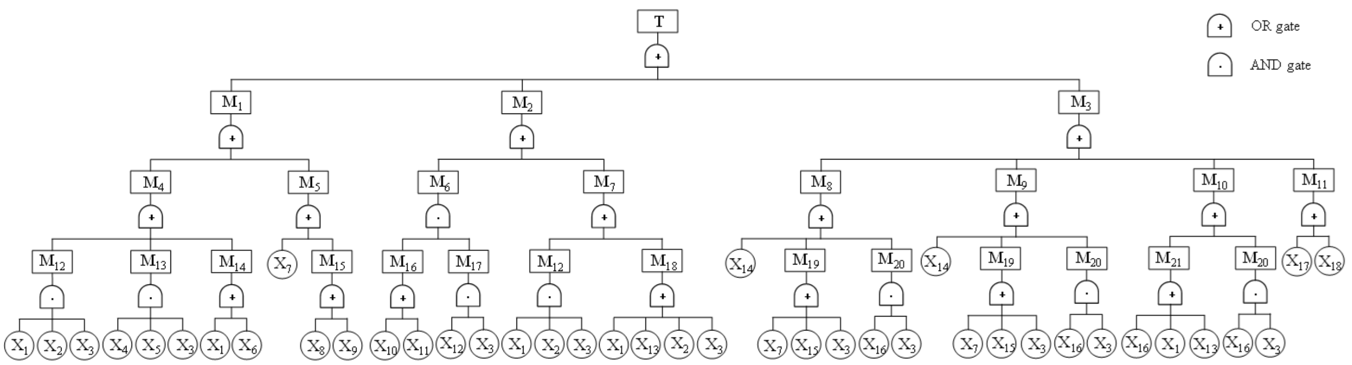

Figure 3. Fault tree of external disturbance damage to underground pressure pipelines

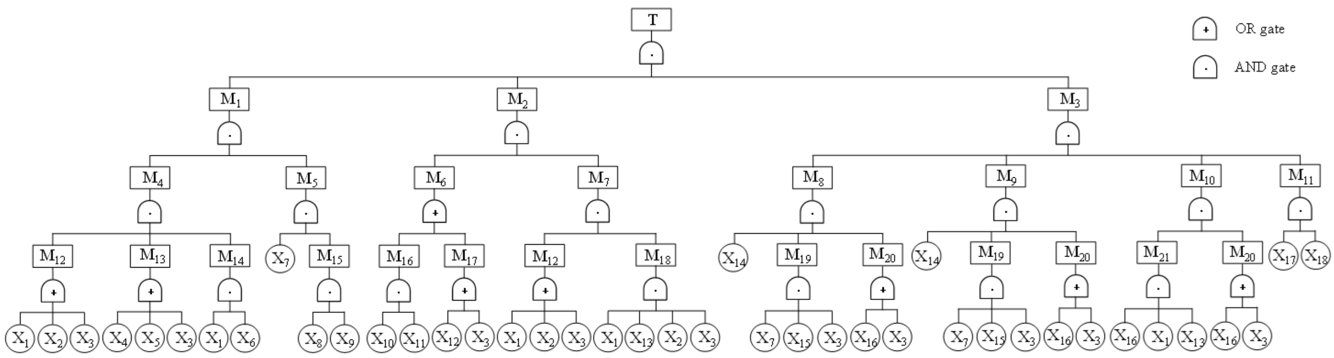

Figure 4. Success tree of external disturbance damage to underground pressure pipelines

Table 2. Event meanings of fault tree

Event symbols	Event meanings	Event symbols	Event meanings
T	Underground pressure pipelines damage due to external disturbance	M_{20}	Unreasonable excavation
M_1	Unsafe behaviors of humans	M_{21}	Poor protective effects
M_2	Unsafe states of objects	X_1	Lack of professional skills
M_3	Unfavorable environmental factors	X_2	Poor sense of responsibility among construction personnel
M_4	Construction/operational damage	X_3	Lack of supervision and management
M_5	Vandalism	X_4	Lack of accurate pipeline location information
M_6	Impact of upper load	X_5	Poor safety responsibility awareness
M_7	Unqualified pipeline foundation	X_6	Poor psychological quality
M_8	Landslides	X_7	Interest driven
M_9	Mud-rock flows	X_8	Improper handling of social relations
M_{10}	Collapses	X_9	Poor economic conditions
M_{11}	Earthquakes	X_{10}	Pipeline backfilling not in place
M_{12}	Unstandardized construction	X_{11}	Rainwater erosion
M_{13}	Barbaric construction	X_{12}	Failure to set warning signs in accordance with regulations for pipelines
M_{14}	Operational errors	X_{13}	Material defects
M_{15}	Resentment	X_{14}	Geological evolution
M_{16}	Insufficient burial depth of pipelines	X_{15}	Weak legal awareness
M_{17}	Frequent activities such as rolling and construction	X_{16}	Poor technical solutions
M_{18}	Poor construction quality	X_{17}	Crustal movement
M_{19}	Deforestation and indiscriminate cultivation	X_{18}	Large-scale blasting activities

5. Risk prevention and control of external disturbance damage to underground pressure pipelines

5.1. Minimum cut sets

The minimum cut sets represent the minimum combination of elementary event that lead to the top event. The Boolean algebra method was used to calculate the fault tree, and 13 minimum cut sets were obtained, as shown in **Table 3**.

Table 3. Minimum cut sets of fault tree

Code	Composition
K_1	X_1
K_2	X_2
K_3	X_3
K_4	X_6
K_5	X_7
K_6	X_8
K_7	X_9
K_8	X_{13}
K_9	X_{14}
K_{10}	X_{15}
K_{11}	X_{16}
K_{12}	X_{17}
K_{13}	X_{18}

It can be seen from **Table 3** that all 13 minimum cut sets are first-order cut sets, and there are 18 "OR" gates and 8 "AND" gates in the fault tree; the OR gates account for 69.23% of the total number of logic gates. Therefore, it is clear that there are many ways external disturbance can cause damage to underground pressure pipelines damage, and the risk is relatively high.

5.2. Minimum path sets

The fault tree was converted into a success tree, and the minimum path sets of the fault tree were obtained by calculating the minimum cut sets of the success tree. The minimum path sets were also calculated by the Boolean algebra method, and the minimum path set is represented by P = {X_1, X_2, X_3, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}, X_{18}}.

There is only one minimum path set, indicating that there is only one way to suppress the occurrence of top events in the fault tree analysis. Moreover, this path set is a 13-order path set with a higher order, and it is necessary to simultaneously prevent and control 13 risk factors in order to suppress external disturbance damage to underground pressure pipelines. Even if geological evolution (X_{14}) and crustal movement (X_{17}), which are two natural factors that are difficult to control, are not considered, there are still 11 risk factors that need to be controlled simultaneously, which is difficult.

5.3. Structural importance

Considering that solving the structural importance through the minimum cut sets (path sets) is relatively simple, qualitative analysis was mainly conducted, and precise structural importance coefficients were not required. Therefore, in this study, the structural importance was determined based on the minimum cut sets (path sets). Generally, the structural importance can be determined according to the number of elementary events in the minimum cut sets (path sets) and relevant principles [10]. If the situation is relatively complex, the approximate formula of formula (1) [11-12] was usually used to solve the structural importance.

$$I(i) = \sum_{X_i \in K_j} \frac{1}{2^{n_i - 1}} \tag{1}$$

In Equation (1), $I(i)$ represent the structural importance of elementary event X_i; X_i represents elementary events, K_j represents the minimum cut sets or minimum path sets, n_i represents the number of elementary events contained in the minimum path sets or minimum cut sets where the elementary event X_i is located.

Due to the fact that all 13 minimum cut sets were of the first order and there was only one minimum path set, the judgment results were consistent regardless of the method used, and the order of structural importance was I(1) = I(2) = I(3) = I(6) = I(7) = I(8) = I(9) = I(13) = I(14) = I(15) = I(16) = I(17) = I(18). It can be seen that the structural importance of these elementary events are equal, indicating that they are equally important and comprehensive prevention and control are needed. In addition to force majeure factors, the following measures should be taken as a priority: (1) strengthening of professional skills training; (2) strengthening of education on safety responsibility awareness; (3) strengthening of supervision and management, including using technology to strengthen risk monitoring, warning, and prevention and control; (4) strengthening of psychological quality education; (5) strengthening of value education; (6) strengthening of communication and understanding among all parties, and improvement of economic level; (7) strict control of pipeline material quality; (8) strengthening of legal education; (9) discussions on technical solutions to ensure scientific rationality; (10) For large-scale blasting, pipeline relocation or protection measures should be taken in advance. In short, only by taking multiple measures in parallel can the risk of disturbance damage to underground pressure pipelines be prevented.

6. Conclusions

Through a literature review, the risk factors for underground pressure pipelines damage due to external disturbance were identified from three aspects: unsafe behaviors of humans, unsafe states of objects, and unfavorable environmental factors, and the risk factors were listed.

(1) Based on risk factors for underground pressure pipelines damage due to external disturbance, the risk factors were converted into events in the fault tree. The logical relationships between events were expressed by “AND” gates and “OR” gates, and a fault tree was drawn.

(2) By calculating the minimum cut sets, minimum path sets, and structural importance, targeted prevention and control measures were proposed, including strengthening skill training, legal education, psychological quality education, value education, supervision and management, and material control for comprehensive prevention and control.

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Disclosure statement

The author declares no conflict of interest.

References

[1] Wang YZ, 2019, Risk Prevention and Control Strategy of Natural Gas Pipeline. Chemical Engineering Design Communications, 45(8): 55–56.

[2] Lv HQ, Li JF, 2005, Cause and Prevention of Pipeline Third-Party Interference. Natural Gas Industry, 2005(12): 118–120 + 2.

[3] Chen XC, 2013, Analysis on Risk Prevention and Control of Oil and Gas Pipelines. Safety & Security, 34(6): 50–51.

[4] Chen Y, Wang WM, Chen WC, et al. 2011, Risk Assessment of the Buried Pipeline Based on the Fault Tree and Fuzzy Theory. Oil & Gas Storage and Transportation, 30(7): 481–485+473.

[5] Ma YB, 2020, Risk Analysis and Control Measures of Third-Party Construction Damage in High Consequence Area of Natural Gas Pipeline. Technology Supervision in Petroleum Industry, 36(6): 55–58.

[6] Xu XJ, Lv HX, Song JL, 2019, Research on the Development Status of Accident-Causing Theory. Aeronautic Standardization & Quality, 2019(6): 42–45.

[7] Li WB, Xiao DS, 2007, Overview on Accident－Causing Theories. Journal of University of South China (Social Science Edition), 8(1): 57–61.

[8] Suo X, Fu G, Wang CX, et al. 2017, An Application of 24Model to Analyse Capsizing of the Eastern Star Ferry. Polish Maritime Research, 24(S3): 116–122.

[9] Zhou L, Xue YJY, Liu XY, 2016, Literature Review on Organization and Management Causes of Accidents. Journal of Safety Science and Technology, 12(10): 185–190.

[10] Song H, Wang T, Yang ZJ, 2023, Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) of Rigid Fire Curtain on Stage. Mechanical Engineering & Automation 237(2): 138–142.

[11] Wang LY, 2022, Analysis of Wind Resistance Variation Based on Fault Tree Evaluation Method. Gansu Science and Technology, 38(2): 39–41.

[12] Yang YX, Cai HJ, 2020, Research on Fault Tree Analysis of Fire Accidents in Airport Oil Depot. Technology Innovation and Application, 2020(8): 55–56.