Dynamic Simulation Research on Operation Safety of Main Canal of South-to-North Water Transfer Based on Risk Input

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Abstract. The South-to-North Water Diversion Project will pose a great threat to the lives and property safety of people along the route once a dangerous situation occurs. Therefore, this paper analyzes the historical risk data of the South-to-North Water Transfer Project to identify risk sources, combs the actual risk occurrence process with the basic structure of "Risk Factor→Destruction Link→Destruction Mode", and builds a main canal system risk interpretation model. At the same time, taking the typical high-fill section of the main canal of the South-to-North Water Transfer Project as an example, a typical failure evolution process is selected to construct a dynamic simulation model based on system dynamics to simulate the failure process of the canal embankment under three kinds of manual intervention, as the channel operation under risk input scheduling decisions provides new ideas.

1. Introduction
As a basic water diversion project to optimize water resources allocation and promote regional coordinated development, the Middle Route Project of South to north water transfer is vulnerable to various risks due to its long canal line, complex terrain conditions. Meanwhile, with the economic and social development of various regions along the line, once there is a danger on the line, it will bring great safety to people's lives and property along the line Big threat. Therefore, how to avoid or reduce the risk has become an urgent issue.

Wang D. [1] pointed out that risk analysis was first widely used in the field of flood control system. Li Q.Y. [2] studied the theory and method of dike engineering safety evaluation, and systematically analyzed the basic factors related to dike engineering safety. There are many kinds of water diversion projects, and the risks are different. Many scholars have carried out a lot of effective research work around the risk analysis of water diversion projects. Chen J. et al. [3] analyzed and proposed the principles of risk classification and classification of water diversion projects from the aspects of hydrology, buildings, economy and society. In 2011, Liu H. et al. [4] proposed to divide the operation risk sources into five aspects: engineering, hydrology, environment, economy and society, and established a relatively complete risk assessment system for the south to North Water Diversion Project.

However, it is very rare for them to consider the risk caused by the internal risk of water diversion system. System dynamics provides a new way for dynamic simulation of system risk.
System dynamics [5] is a comprehensive discipline based on feedback cybernetics, information theory, system theory and decision-making process theory, which studies information feedback system through software simulation, and then solves its internal complex dynamic behavior and structure. It is commonly used to deal with non-linear, high-order and multiple feedback dynamic system problems [6-7]. At present, there is few research on the application of system dynamics to the damage evolution of water conservancy projects, mainly focusing on the management of emergency. For example, Wang S. et al. [8] established a simulation model of emergency management system for large-scale water conservancy projects based on the theory of system dynamics, taking the support system, operation system, incentive system, constraint system and target system as the subsystems of the system model, and studied the complex dynamic change relationship within them.

On the basis of the above research work, this paper analyzes the main failure modes and evolution process of different types of buildings by sorting out the historical dangerous information of the south to North Water Diversion Project, and takes the typical high fill section of the main canal as an example to build a dynamic simulation model based on system dynamics. The model can simulate the process of canal bank failure under the condition of artificial intervention, which provides a new idea for future channel operation and scheduling decision under risk input.

2. Structural model of engineering risk interpretation

2.1. Risk source identification and damage mode sorting

According to the characteristics of the Middle Route Project of South to North Water Transfer and the functions of buildings, the system of the middle route can be divided into two categories: the main canal engineering system with linear distribution and the control building system with point distribution. In this paper, the risk identification and dynamic simulation of the main water conveyance canal system are carried out.

The main canal system is mainly open channel. Due to its long route, it is impossible to analyze section by section. Therefore, the common features in design and operation conditions of each canal section are extracted for classification, which is mainly divided into 7 canal section types. The specific classification is shown in Figure 1. Among them, other canal sections refer to the canal sections or buildings with special operation conditions or involving special safety events, such as sewage treatment plant and Prestressed Concrete Cylinder Pipe, which need to be analyzed separately.

![Central Line Project of South-to-North Water Diversion](Figure 1. System classification of Middle Route Project of South to North Water Diversion.)
According to the field investigation results and historical dangerous information of trunk canal system, the sources of risk can be divided into three categories: environment, engineering and man-made. The engineering factors include two aspects: one is the quality of engineering design and construction; the other is the defects of engineering status quo. The sources are various, which may be the defects that can be observed in the project due to historical danger or accumulation of operation time. The specific risk factors of other types of risk sources are shown in Table 1.

The risk factor is the driving force of the occurrence of dangerous situation, and it will eventually lead to the occurrence of damage after step-by-step evolution. The basic structure of a single failure mode chain is as follows: "Risk Factor→Destruction Link→Destruction Mode". Taking a single building as a system object, the risk factor as the starting point of system damage, the risk function is continuously input into the system, when the system reaches the critical point of risk tolerance, the occurrence of dangerous situation will be triggered, and the final failure mode will be the end after a series of damage links. The main failure modes of dike engineering include overtopping failure, seepage failure and instability failure [9]. On this basis, combined with the characteristics of water diversion project, this paper adds lining panel failure, namely the four typical failure modes in Table 1. It should be noted that the failure modes may evolve with each other, but the final evolution result will not exceed this range.

Table 1. Results of Risk Source Identification and Failure Mode.

| Type of Building | Failure Mode | Risk Sources | Risk Factors |
|-----------------|-------------|--------------|--------------|
| Water main canal system | 1. Leakage Damage | Environmental Factors | Rainstorm and Flood |
| | 2. The Top of the Mountain Burst | | Earthquake |
| | 3. Landslide | | Formation Lithology |
| | 4. Lining Panel Failure | Engineering Factors | Construction Quality |
| | | | Defects of Current engineering Situation |
| | | Human Factors | Management Factors |
| | | | Human Activity |

2.2. Structural model of risk interpretation for main canal system

In fact, Interpretative Structural Model is to analyze the subsystems or elements of a complex system, and to express the relationship between the elements of the system with a directed connection graph, which presents the complex system as a multi-level hierarchical structure, and further clarifies the hierarchy and overall structure of the system. According to the "Risk Factor→Destruction Link→Destruction Mode" mentioned above, the risk interpretation structural model of the main canal system failure mode chain is listed in Figure 2. Among them, the arrow represents the direction of the evolution of the failure mode chain. As the source of the elements of the destruction link layer is the historical dangerous situation of the canal section, it is targeted and representative.
3. Dynamic simulation of operation safety of main canal system

3.1. Model building

Figure 3 shows a typical section of clay canal section in the main canal system. The channel height is 10m, the slope is 1:2, the canal top width is 5m, and the water level is 9.00m during normal operation. A typical failure mode chain is selected: rainstorm flood → water level backup → slope scouring → overtopping and breaking. Based on the model chain, the dynamic simulation model is established through the system dynamics simulation software Vensim.

In order to establish the simulation model, it is necessary to understand the basic mechanism of overtopping breach. In this paper, referring to the overtopping breach model described in the relevant references [10-11], overflow occurs when the water level reaches the top of the canal, and it is assumed that for the section in this paper, the scour pit appears at the toe of the slope first, and then "scarp" erosion occurs, and when the trailing edge of the "scarp" soil passes through the top of the canal, the breach occurs. Then the scene setting is carried out, assuming that a heavy rainstorm occurs in the area, and the rainfall reaches 480 mm. In order to reflect the role of human intervention in the project operation, three intervention schemes are assumed: releasing 75% and 25% of the incoming water by regulating the control gate and not conducting manual intervention. The software is used to draw the flow inventory diagram, including state variables, auxiliary variables, rate variables and constants. The simulation time is set at 72 hours. The input equation of the model is shown in Table 2, and the dynamic model is shown in Figure 4.

Table 2. Description of model variable attribute and derived equation input.

| Variable name | attribute   | Value/Derivation equation | Unit |
|---------------|-------------|----------------------------|------|
| Rainstorm and Flood | Auxiliary variable | 480 | mm |
| Variable name          | attribute          | Value/Derivation equation                                                                 |
|-----------------------|--------------------|-------------------------------------------------------------------------------------------|
| Intervene             | Auxiliary variable | 1. IF THEN ELSE(Time>10,360,0)                                                           |
|                       |                    | 2. IF THEN ELSE(Time>10,120,0)                                                            |
|                       |                    | 3. 0                                                                                        |
| Rate of Rise          | Rate variable      | (55 * Rainstorm and Flood - 55 * Intervene) / (2 * (600.25 + 2 * (55 * Rainstorm and Flood - 55 * Intervene) * Time) ^ 0.5) | mm/h |
| Water Level in Canal  | State variable     | INTEG (Rate of Rise, Initial Value of Water Level in Canal)                                | m    |
| Channel Velocity      | Auxiliary variable | (55 * Intervene) / (Water Level in Canal * (15 + Water Level in Canal * 2))                | m/s  |
| Backward Speed of Scarp | Auxiliary variable | IF THEN ELSE(Water Level in Canal <=10, 0,(0.0007355)*(( Water Level in Canal -10)^(1/3))*60*60) | m/h  |
| Break                 | State variable     | INTEG (- Backward Speed of Scarp, Width of Canal Top)                                       | m    |

Figure 4. Dynamic simulation model under three intervention schemes.

3.2. Simulation results

Under the input of rainstorm and flood risk, the dynamic simulation results of the trunk canal system with the section in Fig. 3 as an example are shown in Figure 5. It can be seen from the figure that it is difficult to control the water level when the water level (a) is reduced. Due to the failure to reach 100% discharge, the water level in the channel in figure (b) is still rising. Without intervention, the dike overtopping occurred at 47h and burst at 53h; the artificial control of 25% inflow was delayed compared with the time of breach, and overtopping occurred at 58h and outburst occurred at 64H, while the release of 75% inflow did not occur until the end of simulation.
4. Conclusion
This paper analyzes and summarizes the main risk sources of the main canal system by sorting out the dangerous information of the Middle Route Project of the south to North Water Diversion Project, sorts out the actual dangerous situation occurrence process with the basic structure of "Risk Factor→Destruction Link→Destruction Mode", and constructs the risk interpretation model of the main canal system, which provides a theoretical basis for further construction of the operation safety model.

On the basis of risk source identification and damage mode sorting, the development process of overtopping breach is simulated by constructing a dynamic operation safety model under the condition of given rainstorm flood risk input. According to the dynamic simulation model, we can simulate the break time under the influence of different human intervention. Because the model is simplified in this paper for the convenience of calculation, the simulation accuracy needs to be further improved, but the dynamic simulation of the actual engineering system has great research significance. On the one hand, it makes up for the lack of single static thinking when considering the system risk of water diversion project, on the other hand, it can be used as one of the decision-making basis for emergency disposal of engineering.

Acknowledgments
This paper was supported by the National Key Research and Development Program of China (Grants No. 2017YFC0405006, 2016YFC0401809), the National Natural Science Foundation of China (Grants No. 51579154), the Water Conservancy Science and Technology Project of Jiangsu Province (Grants No. 2017005).

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