Application of Analytical Hierarchy Process in the Risk Assessment of Salt Rock Underground Gas Storage

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Abstract. Based on fuzzy comprehensive evaluation of gas storage risk factors, the paper has established risk analytical hierarchy process of three accidents, destruction, leakage and surface settlement of gas storage in layered salt rock. The model has been used to evaluate operation risk condition of Jintan salt rock underground gas storage in Jiangsu Province. And weights distribution of effected by three accidents risk factors and risk grade of gas storage have been determined.

Keywords: Salt Rock Underground Gas Storage, Risk Factors, Risk Analytical Hierarchy Process, Gas Storage Leakage

1 Introduction

Oil and gas strategic reserve is one of the important means of ensuring energy security and stability of supply. More and more countries pay attention to the method. Salt rock underground gas storage has the features of low permeability, good creep behavior and self-recovery ability of injury, these features can achieve energy strategic reserve safe, reliable, economic, save the land and protect the environment[1-3].

The typical cases of underground oil and gas storage in salt rock indicate that the storage could have catastrophic consequences to the environment and energy reserves safety[4]. Due to the Chinese salt rock has the features of shallow buried depth, stratified distribution, multi-interlayer and lack of construction experience which could cause accident risk easily. Risk source identification and filtration of salt rock underground oil and gas storage are needed to develop. High risk source which the project participants is focus on need to be found to control the risk effectively in order to ensure the safe operation of salt rock underground gas storage.

2 Modeling Of Risk Graded Holography

Hierarchical Holographic Modeling (HHM) is a kind of comprehensive thought and methodology. Its order is to capture and show the inherent characteristics and nature of system. It is used to control the risk for large and complex projects and for development and utilization of the spaceflight, communication, electricity and floodwall [5]. HHM includes scene recognition, scene filter, double
standard filter and evaluation, quantitative rating, risk management, missing important entry protection, operational feedback.

2.1 Risk Source Hierarchical Holography Model

Based on the above-mentioned ideas, gas storage hierarchical holography model can be built, the figure 1 show gas storage hierarchical holography model. Risk source hierarchical filter was carried out from the aspects of project management, environment, surrounding medium, technology, control and function. Based on the hierarchical filter, the risk source which has a small influence on construction and operation of gas storage was filtered. The most possibility and uncertainty of risk source was retained to ensure the validity of risk identification, evaluation and management.

![Fig.1 Salt rock underground gas storage risk hierarchical holography model](image)

2.2 Risk Source Hierarchical Filter

The probability of risk source is classified as possibly, rarely, occasionally, probably and frequently. The consequence of risk is classified as Loss of life / property, overall loss of function, partial loss of function, greater influence on function, slight influence on function.

2.3 Engineering Application

In the construction of Jintan, Jiangsu of China, the thickness of salt rock underground gas storage was 200m. It includes two layers of salt rock intercalation. The thickness of upper interlayer is 2.5 m. The thickness of lower interlayer is 3.0 m. The roof and floor are mudstone layer, those size are 98.095m. The shape of gas storage is standard ellipsoid. Its long and short axes are 70m and 30m respectively. It is located in the middle of the rock, and the thickness of the upper cover is 901.9m.

According to the characteristics of the project and responsibility scenario filter and qualitative serious scenario filter, in the view of project participants, project participants identify the risk source that needs to be focused on.

2.3.1 Responsibility Scenario Filter

By analyzing the Jintan salt rock underground gas storage engineering, after the responsibility scenario filter, 28 risk sources were retained by the designer, 21 risk sources were retained by the constructor, 20 risk sources were retained by the operator.
2.3.2 Qualitative Severity Hierarchical Filter
By the responsibility scenario filter, consequence of construction impact and possibility of occurrence for gas storage construction was considered. Qualitative severity risk matrix was used to carry out the double standard filter. The risk intensity of the qualitative risk matrix cell is increased from the lower left to the upper right. The risk source which was located in a low risk and medium risk matrix area were filtered, the huge risk and high risk were retained.

3 Risk control
The risk control of salt rock underground gas storage was carried out for different implementation stages of the project. In the design phase, design scheme was optimized from the angle of safety and stability of guarantee structure. In the construction phase, construction was controlled dynamically from the angle of ensuring the cavity form. In the operation phase, operating condition parameters was optimized from the angle of ensuring the airtightness and stability of long-term safe operation.

3.1 Optimization of Design Scheme
In the aspect of optimization design of underground gas storage in salt rock, the relationship of damage safety index and cavity size for salt rock was built by R.Stenven[6] ; Chunhe YANG build [7] researched the mechanical properties of layered salt rock and key technical problems of construction. The constitutive relation of lamellar salt rock was built and the key parameters of gas storage in lamellar salt rock were determined. Lijuan CHENG[8] researched layout optimization and linkage destruction of dense gas storage in salt rock.

3.2 Construction Dynamic Control
Building gas storage in layered salt rock in China, because of existence of dissoluble intercalation, the difficult of construction was improved further. The dissolution rate of dissoluble intercalation lagged behind the dissolution rate of salt rock, which lead to the flow field of the brine in the cavity is disorganized and the cavity shape is difficult to control or even lead to the discarding of the cavity. Under the action of self-weight, the collapse of insoluble interlayer will lead to secondary accidents such as casing bending, breaking, partial necking, failure of oil cushion, and out of control of cavity shape. Therefore, it should carry out dynamic control from the aspects of roof protection, cavity shape, interlayer collapse, and well bore tightness, surface subsidence and equipment operation in order to ensure the quality and safety of building.

3.3 Optimization of Operation Conditions
In order to ensure long-term safe operation of gas storage, numerical analysis, failure probability analysis, model test and field detection are needed to analyze and compare the stability, airtightness and usability of gas storage under different operation conditions, so as to determine the best operation mode.

(1) Destructive impact analysis of operating parameters on the gas storage
The improper selection of operation parameters lead to destruction of gas storage, the form of performance were roof damage, flex floor uplift, lateral wall spalling, and pillar failure and the collapse of whole storage.

Based on the jinant salt rock underground gas storage, the research conclusion were got by Chunhe YANG under the operating pressure of 6.0MPa ~ 14.5MPa: The fastest growth rate of salt rock appears to the top of salt rock at low voltage (6.0MPa) runtime. It began to enter the accelerated creep period in about 3 months. The second is the bottom of the cavity, and the last is the loin. When the pressure of the gas storage is more than 7.0MPa, the plastic zone decreases obviously and the internal pressure is 14.5MPa, there is no obvious dense plastic zone. In order to ensure the long-term safety gas storage, the continuous low pressure operation time should not exceed 3 months, and the long run internal pressure should be maintained about 11.0MPa.
Based on the improved first order two moment method, the probability of "chip failure" in each part of Jintan salt rock underground gas storage under 0MPa ~ 30.0MPa operating pressure is numerically calculated. The failure probability distribution of each part of the storage is shown in Figure 2.

**Fig.2** Probability distribution diagram of failure of gas storage

The main cause of the failure of the gas storage group pillar is that the salt rock stress in the middle part of the pillar is more than its ultimate strength and causes damage. Lijuan CHENG[8] studied the layout optimization and chain failure of salt rock intensive storage group. The conclusion is that under the premise of reasonable safety pillar, the sudden loss of pressure will cause the side wall rock to deform to the surface of the pressure loss and even collapse; Based on the three-dimensional rheological model test, Qiangyong ZHANG came to the conclusion that when the pressure difference between the gas storage cavity at 9.0MPa, surrounding cavity appeared to phenomenon of accelerated creep. When the cavity suddenly loses pressure, the radial displacement and radial strain of the storage increase suddenly.

(2) Analysis of the effect of operating parameters on the leakage of gas storage

When the pressure of the gas storage is too high, the salt rock will be damaged, which leads to the expansion of the fracture of the surrounding rock to produce oil and gas leakage.

According to the salt rock damage expansion capacity boundary equation and the maximum tensile stress criterion, the first two moment method is used to calculate the leakage failure probability of different underground parts of Jintan salt rock underground gas storage under different operating pressures, as shown in Figure 3. The internal pressure value corresponding to the failure probability less than 0.01% is shown in table 7.

**Fig.3** Gas storage leakage failure probability with pressure change curve
Internal pressure of gas storage reduced to stable state (pressure 6.0MPa), the maximum equivalent stress of the casing and the maximum shear stress increases, the safety margin decreased. Gas injection is the normal working state of voltage regulator (internal pressure 10.0MPa), the maximum equivalent stress of the casing and the maximum shear stress decreases, it has considerable safety margin.

(3) Analysis of the influence of operating parameters on the surface settlement of gas storage

The first order two moment method is applied to establish the volumetric convergence function of the gas storage. It is concluded that the volume convergence failure probability of the storage decreases with the increase of the internal pressure under the long-term internal pressure condition, and the minimum internal pressure limit increases with the prolongation of the running time. In each flooding cycle, the volume convergence failure probability has reduction as the internal pressure increases, the minimum operating pressure should be maintained at more than 4.2Mpa.

4 Conclusions

(1) Based on project management, environment, technology, surrounding rock medium, storage body, control and function, the risk classification holography model of salt rock underground gas storage was established. The technology of situational filter and qualitative severe scenario filter were adopted to determine the source of risk that the project participants should focus on and create the conditions for risk assessment.

(2) A risk control method for the optimization of the design scheme, the dynamic control of the construction and the optimization of the operating conditions of the underground gas storage of the salt rock were proposed. Determination of ellipsoidal cavity and key design parameters of layered salt rock underground gas storage; Put forward the target of risk control and the dynamic control method in the period of the construction of the storage; According to the results of the failure probability analysis of the three major accidents, the safety value range of the pressure, time, injection and gas recovery rate under different operating conditions of the storage gas storage were determined. Design method of peak regulation scheme for gas storage (Group) was proposed.

References
[1] Thomas R. L., Gehle R. M. A brief history of salt cavern use[C]. The 8th World Salt Symposium, Volume 1. Elsevier, 2000, 207-214.
[2] Guosheng DING, Ping XIE. The present situation and development prospect of underground gas storage in China[J]. Natural gas industry, 2006,26(6):111-113.
[3] Yunfei TAN, Leming LIAN. Technology and development of underground gas storage in foreign country [J]. Oil & Gas Storage, 1997, 16 (12):17-19.
[4] B. Ehgartner, J. Neal, and T. Hinkebein. Gas releases from salt[C]. SMRI Spr. Mtg: 1998, 5: 68.
[5] Y.Y. Haimes, S. Kaplan, and J. H. Lambert. Risk filtering, ranking, and management framework using hierarchical holographic modeling[J]. Risk Analysis, 2001(22):381-395.
[6] Steven R. Sobolik and Brian L., Ehgartner. Analysis of Cavern Shapes for the Strategic Petroleum Reserve [R]. SAND 2006-1974, Sandia National Laboratories.
[7] Yang Chunhe, Zeng Yijun, Wu Wen. CONSTITUTIVE RELATIONSHIP OF DEEP SALT ROCK AND ITS APPLICATION TO PETROLEUM DRILLING ENGINEERING [J]. Chinese Journal of Rock Mechanics and Engineering, 2002, 21(11):1602-1604.
[8] CHENG Lijuan, LI Zhongkui, XU Bin. STUDY OF LAYOUT OPTIMIZATION AND CHAIN DESTRUCTION OF DENSE STORAGE GROUP IN SALT ROCK [J]. Chinese Journal of Rock Mechanics and Engineering, 2011, 30(2): 296-305.