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Geotechnical monitoring on the stability of a pilot underground crude-oil storage facility during the construction phase in China

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A B S T R A C T

Geotechnical monitoring is one of the important means for the control of safety of underground structure in both construction and operation phase. In this study, geotechnical monitoring on the stability was performed on a pilot underground crude-oil storage facility during the construction phase in China. Considering the engineering characteristics and geological conditions of the caverns, this study proposed a monitoring scheme for the stability of the underground oil storage caverns during the construction phase. This study systematically summarizes the results of geotechnical monitoring on a pilot underground water-sealed crude-oil storage caverns during construction phase in China. The monitoring results of the deformation of the surrounding rock showed that the convergence of the surrounding rocks, the crown settlement and the internal displacement of the caverns were within the ranges of 4–8 mm, 3–6 mm and 4–8 mm, respectively. The monitoring results of the stress on rockbolts show that the stresses were mostly less than 50 MPa. The spatial and time dependent effects of the excavation face and the effect of the geological conditions on the rock mass deformation and on the rockbolt stress were analyzed using the geotechnical monitoring data. This study compared the data from the pilot underground crude-oil storage caverns with those from underground powerhouse caverns of hydropower stations. The comparison showed that the stability of the underground pilot crude-oil storage caverns during the construction phase was relatively superior to that of the underground powerhouse caverns of the hydropower stations due to the relatively good quality of the rock masses.

1. Introduction

Petroleum is the "blood" of the modern industry and is an important resource for the survival and development of a country. Oil reserves play an immeasurable role in ensuring the economic and social development of a country. Underground storage caverns are being constructed all over the world to meet the fluctuant need of carbonate fuels. As a safe, environmentally friendly, economical option for oil storage, underground water-sealed crude-oil storage caverns have been used in many countries [13,7,9,2,15]. Underground water-sealed crude-oil storage caverns are characterized by their large scales, multiply excavation faces and long construction periods. Therefore, research on the stability of underground water-sealed crude-oil storage caverns during their construction and operation phases is important. The geotechnical monitoring on the stability of an underground engineering project can provide information on the real-time stability and its dependency on time and space for the underground engineering project. Additionally, the monitoring on the

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stability of an underground engineering project can also provide important data for back analysis of the deformation and strength parameters of rock mass. Thus, the geotechnical monitoring on the stability of an underground engineering project is important.

In the research on the stability of underground water-sealed crude-oil storage caverns during their construction phases, Gnirk and Fossum [4] established a numerical simulation model to evaluate the stability of caverns and discussed the stability of a large-scale underground cavern in hard rocks that stored compressed air energy. Sturk and Stille [17] summarized the problems of the stability of the surrounding rock encountered during the design and construction process of an underground storage cavern. The general stability and expected deformations were calculated using finite element program. The calculation results implied that stable conditions with very limited plastic zones. Lee et al. [9,8] analyzed the effects of the advancement of the tunnel face and blasting on the stress and deformation states of the surrounding rock around storage caverns. The results of numerical analysis and measurement on the effect of face advance show a rather reasonable agreement in the trend of behavior, but a little discrepancy in the magnitude. Based on the hydro-mechanical coupling theory of discrete media, Li et al. [10] evaluated the effect of joints on the stability of an underground water-sealed crude-oil storage cavern. It was found that crown settlements from numerical simulations are lower than those predicted using empirical equations. This could be induced by the fact that there is no consideration of the interaction between neighboring caverns. Wang et al. [18,19] studied the characteristics of the effect of construction on the stability of the underground water-sealed crude-oil storage cavern using finite element modeling. It was found that the extent of plastic zones, horizontal convergence and crown settlement under permeable condition are lower than those under impermeable condition due to the different stress paths in the rock mass experienced during excavation.

Many researchers in the fields of both oil/gas storage and water conservancy and hydropower have also conducted extensive studies on the stability of large-scale underground caverns. Sturk and Stille [17] used both finite element program and block-stability analysis to investigate the stability of rock caverns for fuel storage in Zimbabwe. Lee et al. [9] performed both filed measurements and numerical analysis on the stress and deformation behavior of oil storage caverns during excavation. It was concluded that the behavior of the rock mass around underground caverns is complex at the time of several stages of excavation due to the face advance and the blasting effect. Monsen and Barton [14] investigated the separate effect of different physical conditions such as jointing, stress anisotropy and depth on the stability of cryogenic storage in underground excavations with emphasis on the rock joint response. Sitharam and Latha [16] analyzed the deformation and failure of an underground cavern using the equivalent continuum model and found that the simulation results were relatively consistent with field observations. Wu et al. [20] studied the pattern and characteristics of the deformation of the surrounding rock during the excavation and support process of a deeply buried water-diversion tunnel under high-groundwater conditions. Zhu et al. [22] analyzed the stability of a typical underground cavern group and proposed an empirical equation to describe the settlement of the crown. Li et al. [11] monitored the underground cavern of the Baishan Hydropower Station during the construction phase and recorded data such as the displacement of the rock surrounding the cavern, the stress on the supports of the cavern and the range of the excavation damage zone, which played an important role in the safety control during the cavern's construction. From the perspectives of the high ground stress and the characteristics of the rock deformation, Li et al. [12] analyzed the engineering problems that occurred in an underground powerhouse cavern group at the Jinping-I Hydropower Station. Feng et al. [3] proposed an intelligent analytical method for evaluating the stability of large-scale underground cavern groups and used that method in the design and construction of the underground workshop of the Jinping-II Hydropower Station. Using both continuous and discontinuous methods, Yazdani et al. [21] conducted a back analysis of parameters, such as geomechanical properties of rocks, stress ratio and joints parameters based on the displacement of the underground cavern of Siah Bisheh hydropower station.

Compared with water conservancy caverns and hydropower caverns, the underground water-sealed crude-oil storage caverns are characterized with multiply excavation faces. The excavation is usually performed in several caverns simultaneously. The interaction between neighboring caverns could be significant. Based on the first large-scale underground water-sealed oil storage cavern construction project in China, this study introduces a geotechnical monitoring scheme that is suitable for large-scale underground water-sealed crude-oil storage caverns. The storage capacity of the facility is much higher than those existing facilities [18,19]. In the proposed monitoring scheme, the engineering characteristics, geological conditions and economic applicability are fully taken into consideration. In addition, this study analyzes the monitoring results of the deformation of the surrounding rock and the stress on the supports of the cavern during the construction phase of the caverns. The results of the analysis show that the underground water-sealed crude-oil storage caverns have good overall stability during the construction phase. The spatial and time dependent effects of the excavated face were identified and the effect of the geological conditions on the deformation of the surrounding rock and the stress on the supports of the cavern was clarified using the geotechnical monitoring data.

2. General information of the engineering project

2.1. General

The underground water-sealed cavern project investigated in this study is the first large-scale underground water-sealed crude-oil storage cavern project constructed in China. The storage caverns are aligned parallel to one