Journal of Rock Mechanics and Geotechnical Engineering 8 (2016) 689–696

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full length article

Design and operation problems related to water curtain system for underground water-sealed oil storage caverns

Zhongkui Li[a,*], Baoqi Lu[b], Jing Zou[a], Bin Xu[a], Zhizeng Zhang[a]

[a] State Key Laboratory of Hydroscience and Engineering, Department of Hydraulic Engineering, Tsinghua University, Beijing, 100084, China
[b] Huangdao National Crude Oil Storage Co., Ltd., Huangdao, 266426, China

A R T I C L E I N F O

Article history:
Received 3 November 2015
Received in revised form
2 June 2016
Accepted 7 June 2016
Available online 26 August 2016

Keywords:
Underground water-sealed oil storage caverns
Water curtain system
Design concept and method
Cavern stability and safety

A B S T R A C T

The underground water-sealed storage technique is critically important and generally accepted for the national energy strategy in China. Although several small underground water-sealed oil storage caverns have been built in China since the 1970s, there is still a lack of experience for large-volume underground storage in complicated geological conditions. The current design concept of water curtain system and the technical instruction for system operation have limitations in maintaining the stability of surrounding rock mass during the construction of the main storage caverns, as well as the long-term stability. Although several large-scale underground oil storage projects are under construction at present in China, the design concepts and construction methods, especially for the water curtain system, are mainly based on the ideal porosity medium flow theory and the experiences gained from the similar projects overseas. The storage projects currently constructed in China have the specific features such as huge scale, large depth, multiple-level arrangement, high seepage pressure, complicated geological conditions, and high in situ stresses, which are the challenging issues for the stability of the storage caverns. Based on years' experiences obtained from the first large-scale (millions of cubic meters) underground water-sealed oil storage project in China, some design and operation problems related to water curtain system during project construction are discussed. The drawbacks and merits of the water curtain system are also presented. As an example, the conventional concept of "filling joints with water" is widely used in many cases, as a basic concept for the design of the water curtain system, but it is immature. In this paper, the advantages and disadvantages of the conventional concept are pointed out, with respect to the long-term stability as well as the safety of construction of storage caverns. Finally, new concepts and principles for design and construction of the underground water-sealed oil storage caverns are proposed.

1. Introduction

China has become the largest net importer of petroleum in the world from October 2012 onward, followed by the USA. Establishing national strategic energy reserve storage is critically important. In this circumstance, storage of energy reserve has been one of the strategic measures in relation to the economy development and security in China (Pan, 2004).

In August 2006, the first phase of the strategic petroleum reserve (SPR) project in China, i.e. Zhenhai ground reserve base, became operational. In the second phase of the SPR project in China, it is of top priority to construct the underground storage caverns. Several candidate sites have been screened, such as Huangdao in Shandong Province, Jinzhou in Liaoning Province, Zhanjiang in Guangdong Province, and Yangpu in Hainan Province. The first large-scale underground water-sealed oil storage project in China, i.e. Huangdao project, started to construct in November 2010, and was put into operation at the end of 2014 (Li et al., 2014; Wang et al., 2015). In 2014, the third phase of the SPR project in China adopted the underground reservoirs for the storage of SPRs.

The concept of underground water-sealed oil storage cavern was pioneered in Sweden in the 1940s (Morfeldt, 1983). After that many countries have carried out intensive studies, such as Norway (Rehbinder et al., 1998; Blindheim et al., 2004), Sweden (Sturk and Stille, 1995), Korea (Lee et al., 1996, 1997; Lee and Song, 2003), Japan (Tezuka and Seoka, 2003), and France. In order to store crude oil in underground rock caverns and to ensure the gas/oil tightness,

* Corresponding author.
E-mail address: LZK-dhh@tsinghua.edu.cn (Z. Li).
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2016.06.003
1674-7755

underground oil reserves in caverns without lining were proposed in Sweden (Morfeldt, 1983). For the purpose of maintaining a stable groundwater level to reach storage requirements using Sweden method, Professor Ingvar Janelid proposed a method using artificial water curtain, i.e. excavating water curtain tunnel in the main caverns and drilling holes for water filling on the water curtain tunnel wall. This can form a water curtain system for the main caverns to maintain a stable groundwater level for ensuring water sealing conditions. The water curtain sealing technology was then formed, which is called hydrodynamic sealing technology. The specific approach is to drill the injection holes in the rock mass at the top or in the both sides of the reservoir. Water is injected through the water curtain holes to maintain the natural groundwater level, and thus exert a required pressure above the base oil and gas pressure to ensure the gas/oil tightness of underground reservoir, as shown in Fig. 1. The storage principle and operation mode of the underground oil storage caverns are that the water infiltrating into the reservoir is collected by the water pit at the bottom of the reservoir, and then is regularly pumped out so that the oil can be stored in a large-scale underground cavern.

Although a number of studies have been conducted on underground water-sealing system (e.g. MPCI and WIG, 1977; Gao and Gu, 1997; Li et al., 2005, 2012; Wang and Yang, 2008; Shi and Liu, 2010; He, 2011), the design concept and method for large-scale underground water-sealed oil storage caverns, especially for the water curtain system, were rarely reported in China. The principle and method used in foreign cavern design may not be suitable for the projects in China. The sealing effect of the water curtain system has already been proved to be effective in practice, but the role of the water curtain system in underground oil storage caverns may be overemphasized in the period of the cavern construction. In this regard, the negative impact of the water curtain system on the stability and safety of the main caverns is ignored to some extent. Sometimes, for instance, when the surrounding rock mass is poor and the construction activities including excavation and supporting are performed in unfavorable condition, engineers on site are still asked to keep the water curtain system operation in designed high pressure. In practice, it is mandatory that the water curtain system should be set 20 m ahead of the main cavern excavation face, even though a faulted zone with serious water seepage is encountered during the main cavern excavation, and the designed pressure of the water curtain system should be kept by continuous water supply. Another problem is that the principle of “filling joints with water” is overemphasized without any further analysis, even when the fractures directly connect to the main caverns. To address these problems, the relationship between water curtain system and main storage caverns is discussed in this paper.

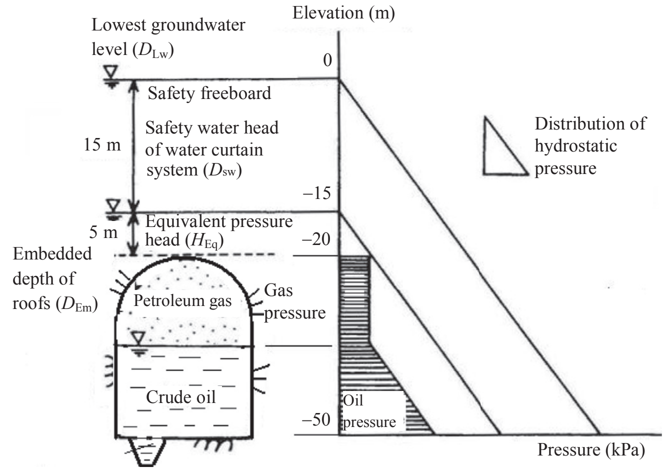

Fig. 2. Location depth of underground water-sealed oil storage cavern.

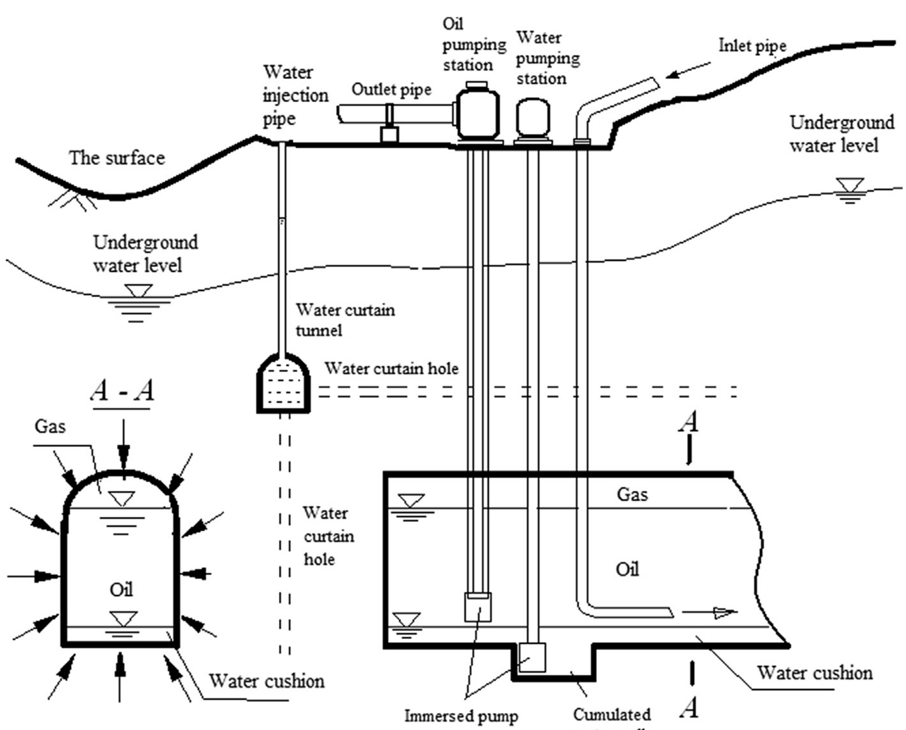

Fig. 1. Operation concept of underground water-sealed oil storage in rock caverns.