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A new shape design method of salt cavern used as underground gas storage

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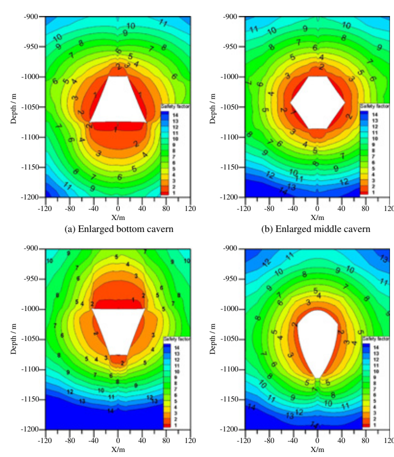
HIGHLIGHTS

- ▶ We propose a new model to design the shape of salt cavern gas storage.
- ▶ The concepts of slope instability and pressure arch are introduced into the shape design.
- ▶ The max. gas pressure determines the shapes and dimensions of cavern lower structure.
- ▶ The min. gas pressure decides the shapes and dimensions of cavern upper structure.

GRAPHICAL ABSTRACT

Safety factor contours of four salt cavern gas storages after running 10 years.



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ABSTRACT

A new model used to design the shape and dimension of salt cavern gas storage is proposed in the paper. In the new model, the cavern is divided into two parts, namely the lower and upper structures, to design. The concepts of slope instability and pressure arch are introduced into the shape design of the lower and upper structures respectively. Calculating models are established according to the concepts. Field salt cavern gas storage in China is simulated as examples, and its shape and dimension are proposed. The effects of gas pressure, friction angle and cohesion of rock salt on the cavern stability are discussed. Moreover, the volume convergence, displacement, plastic volume rate, safety factor, and effective strain are compared with that of three other existing shapes salt caverns to validate the performance of newly proposed cavern. The results show that the max. gas pressure determines the shape and dimension of cavern lower structure, while the min. gas pressure decides that of cavern upper structure. With the increase of friction angle and cohesion of rock salt, the stability of salt cavern is increased. The newly proposed salt cavern gas storage has more notable advantages than the existing shapes of salt cavern in volume convergence, displacement, plastic volume rate, safety factor, and effective strain under the same conditions.

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1. Introduction

Underground salt cavern is recognized as one of the best places to storage the power sources, such as oil, gas, and compressed air [1–6]. Main reasons are that rock salt comparing to other rock materials has four aspects of advantages [7–12]. (i) Low permeability. The permeability of rock salt is about 10^{-21}–10^{-24} m^2, which can ensure the excellent sealing of salt cavern. (ii) Good mechanical properties. Damage self-recovery capability of rock salt can ensure the safety of salt cavern with frequent changes of gas pressure. (iii) Solution in water. Rock salt is easily dissolved into water, which facilitates the construction and shape control of salt cavern. (iv) Abundant resources. Rock salt resource is a very rich mineral resource with wide distributions and large reserves. Therefore the site used to construct salt cavern gas storage near the oil and gas consumption area can be found conveniently. However, volume shrinkage, excessive displacement, ground subsidence, and even collapse of salt cavern gas storage, etc., have become challengeable problems to the engineers for the typical creep and rheology of salt rock. For example, the Tersanne and Eminence salt cavern gas storages lost about 35% of its volume in 10 years, and 40% in just 2 years, respectively [13], which significantly reduced their peak capacities and availabilities. Meanwhile, several pillars of salt cavern in Hengelo area took place failures [14–19], causing excessive ground subsidences and collapses. It became one of the most intimidatory factors to the safety of salt caverns in that area.

Field engineering experiences and available literatures [20–28] show that rational design of the shape and dimension of salt cavern gas storage can effectively reduce negative effects and improve safety. However, how to design the shape and dimension of salt cavern is a difficult engineering problem because it is greatly influenced by many factors, such as the strata characteristics, strengths of rock salts, rock salt creep characteristics, running parameters, and failure criteria. Fig. 1 shows the shapes and dimensions of typical salt cavern gas storages in the world [13]. It is found that the shapes and dimensions of salt caverns are different from each other significantly, indicating the shapes and dimensions design theories and methods of salt cavern gas storages have not formed a unified view in the academic and engineering fields.

Many scholars studied the problems in relative fields, e.g., Dennis [20] had built up the shape model of salt cavern gas storage based on the property parameters of rock salt in Alberta of Canada. He thought the salt cavern with a shape of ellipsoid was more conducive to keep its stability and to reduce volume shrinkage than the caverns with other shapes. However, he neither gave the mechanism of cavern with ellipsoid shape nor optimized its dimensions. Staudtmeister and Rokahr [21] divided the design process of salt cavern gas storage into four steps and gave the corresponding design criteria. They thought the salt cavern with a shape of slender cylinder was reasonable in keeping stability. Sobolik and Ehgartner [22] studied the safety factor, volume shrinkage, displacement, and ground subsidence of salt cavern gas storages with shapes of cylinder, enlarged top, enlarged middle, and enlarged bottom by numerical simulations respectively. They pointed out the salt cavern with a shape of enlarged bottom performing the worst of them. Wang et al. [23] studied the max. displacement, plastic volume, pillar width of salt cavern gas storages with shapes of ellipsoid and pear-like under the long-term running conditions respectively. They considered the ellipsoidal cavern performed much better than pear-like cavern. Meanwhile, the ratio of long and short axes of ellipsoidal cavern was proposed as 7/3. Heusermann [24] discussed the design process of salt cavern gas storage by numerical simulations. Moreover, he studied the equivalent stresses of salt caverns under different gas pressures based on LUBBY2 rock salt creep law, and pointed out the cavern stability should be checked both under gas pressures and long-term creep loads. Cristescu and Paraschiv [25] simplified the design of underground structure in continuous rock masses as a plane strain problem, and discussed the effects of corner radius and ratio of length/width on the stability of rectangular-like cavern. The optimized dimensions of rectangular cavern were proposed.

As described above, the shape and dimension design of salt cavern gas storage was still a difficult problem, and a unified

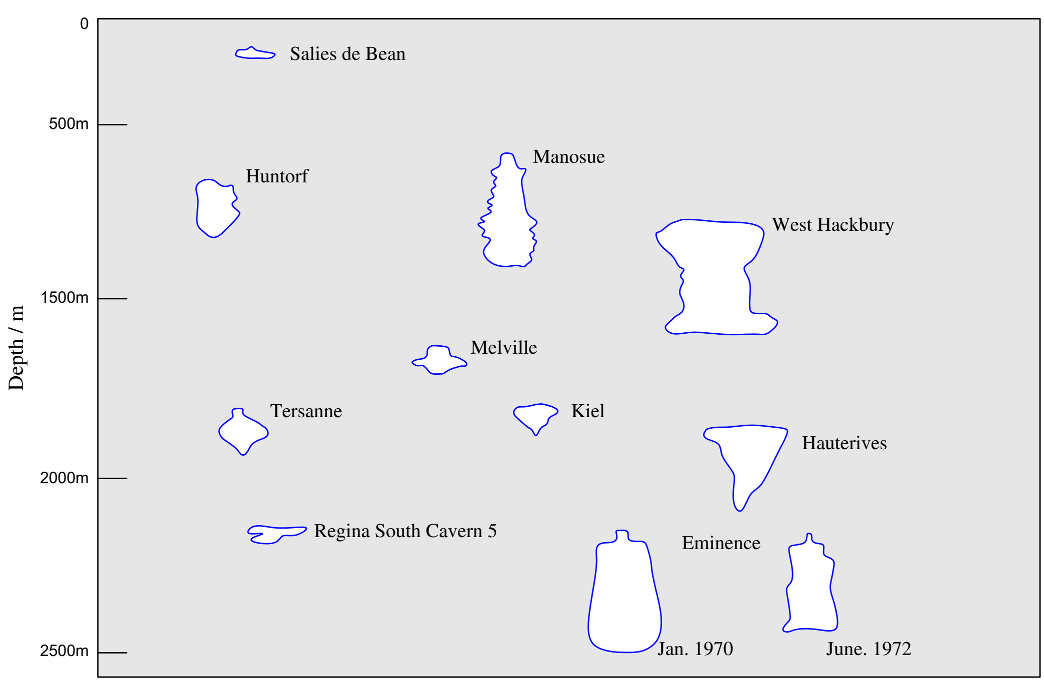

Fig. 1. Shapes of typical salt cavern gas storages.