Postprint: Feasibility Assessment and Analysis of Compressed Air Energy Storage Caverns Integrating Economic and Stability Considerations

Authors: Huang Ran, Zhao Cheng, Zeyuan Sun, Xing Jinquan, Qian Yuan, Jialun Niu, Luo Qinyuan

Date: 2025-07-29T19:11:13+00:00

Abstract

In the construction and operation of compressed air energy storage caverns, the trade-off between economic viability and stability has become increasingly prominent. To address this, this study aims to establish a feasibility evaluation system for compressed air energy storage caverns that simultaneously accounts for both economic and stability considerations. Initially, a comprehensive lifecycle cost function for the cavern was systematically developed, encompassing multi-dimensional elements including construction investment, operation and maintenance expenses, and potential decommissioning costs, which was then integrated with various design parameters to form a logically rigorous and systematically complete economic evaluation framework. For stability assessment, the Hoek-Brown nonlinear strength criterion for rock mass was adopted as the cornerstone, incorporating the Geological Strength Index (GSI) to conduct precise classification and rating of rock mass strength, thereby enabling scientific estimation of the rational burial depth of the cavern. Furthermore, utilizing thick-walled cylinder theory, an intrinsic relationship between the lining thickness and cavern radius was elegantly established under known burial depth conditions, while the economic function and cavern stability parameters were subjected to in-depth fusion and coupled analysis to ensure that the cavern maintains both stability and economic efficiency under various complex operating conditions. The key innovation of this study lies in breaking through traditional single-dimensional evaluation paradigms by innovatively integrating stability and economy within the same analytical framework, constructing a coupled analysis model, and through the establishment of a rigorous collaborative optimization model, accurately screening out optimal solutions that are dually feasible from both economic and technical perspectives among numerous design alternatives, thereby substantially enhancing the credibility and reliability of optimal design determination and providing solid and scientific decision-making

support for the engineering construction of compressed air energy storage caverns. This coupled evaluation and analysis methodology for economy and stability, by virtue of its systematic, scientific, and precise nature, demonstrates the optimality of feasible design schemes for compressed air energy storage caverns and is expected to become a key methodological guideline in the field of feasibility assessment for compressed air energy storage caverns, facilitating the industry's steady advancement under the dual dimensions of economy and safety.

Full Text

Integrated Feasibility Analysis of Compressed Air Energy Storage Caverns Considering Economic Efficiency and Structural Stability

Ran Huang[1], Cheng Zhao[1,2,3,*], Zeyuan Sun[1], Jinquan Xing[1,2], Yuan Qian[4], Jialun Niu[1,2], Qinyuan Luo[1]

[1]Department of Geotechnical Engineering, Tongji University, Shanghai 200092, China
[2]Key Laboratory of Geotechnical and Underground Engineering of Ministry of Education, Tongji University, Shanghai 200092, China
[3]School of Engineering, Tibet University, Lhasa, Tibet 850000, China
[4]Key Laboratory of Geotechnical Mechanics and Engineering of Ministry of Water Resources, Changjiang River Scientific Research Institute, Wuhan, Hubei 430010, China

---

Abstract

During the construction and operation of compressed air energy storage (CAES) caverns, the trade-off between economic efficiency and structural stability has become increasingly prominent. To address this challenge, this study aims to develop a comprehensive feasibility assessment framework that integrates both economic and stability considerations for CAES caverns.

The research systematically constructed a life-cycle cost function encompassing construction investment, operation and maintenance expenses, and potential decommissioning costs, which was integrated with design parameters to form a rigorous economic evaluation framework. For stability assessment, the Hoek-Brown nonlinear strength criterion for rock mass was adopted, incorporating the Geological Strength Index (GSI) to classify rock mass strength and estimate reasonable burial depth. Thick-walled cylinder theory was further employed to establish the relationship between lining thickness and cavern radius under known burial conditions. The economic function and stability parameters were then coupled to ensure both stability and economic efficiency under complex operating conditions.

The key innovation lies in breaking from traditional single-dimensional evaluation by integrating stability and economy into a unified framework. Through a rigorous collaborative optimization model, the framework accurately identifies optimal solutions that are both economically and technically feasible among numerous design alternatives, significantly enhancing the credibility of optimal design determination. This coupled evaluation methodology provides robust scientific decision-making support for CAES cavern engineering and is poised to become a key methodological guideline in feasibility assessment, advancing the industry on both economic and safety fronts.

Keywords: compressed air energy storage cavern; life-cycle cost; Hoek-Brown criterion; thick-walled cylinder theory; coupled stability and economic analysis

Note: Figure translations are in progress. See original paper for figures.