Engineering Structures 33 (2011) 2554–2562

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Cost optimization of the underground gas storage

Bojan Žlender, Stojan Kravanja *

Faculty of Civil Engineering, University of Maribor, Smetanova ulica 17, SI-2000 Maribor, Slovenia

ARTICLE INFO

Article history:
Received 29 September 2010
Received in revised form
1 May 2011
Accepted 2 May 2011
Available online 11 June 2011

Keywords:
Underground gas storage
Lined rock cavern
Optimization
Non-linear programming
NLP

ABSTRACT

The paper presents the cost optimization of an underground gas storage (UGS), designed from lined rock caverns (LRC). The optimization is performed by the non-linear programming (NLP) approach. For this purpose, the NLP optimization model OPTUGS was developed. The model comprises the cost objective function, which is subjected to geomechanical and design constraints. The geotechnical problem is proposed to be solved simultaneously. Geomechanical rock mass parameters are determined from geological conditions of a selected suitable UGS location and a special FE model is generated. The rock mass strength stability and safety of the system are then analyzed for various combinations between different design parameters like inner gas pressures, cavern depths, cavern diameters and cavern wall thickness. As a result, geomechanical constraints are approximated and put into the optimization model OPTUGS. This way, the optimization enables not only the obtaining of an optimal solution but also that the rock mass achieves sufficient strength stability and safety. The optimization is proposed to be performed for the phase of preliminary design. The numerical example at the end of the paper demonstrates the efficiency of the introduced optimization approach.

1. Introduction

High pressure gas reservoirs are typically designed in a cylindrical form from steel, pre-stressed concrete or composite walls. The construction of these type of structures is relatively difficult and expensive due to high internal pressures. Special care has to be paid to systems' safety. For this reason, an idea to design underground gas storages was raised forty years ago. In the beginning, engineers/researches designed gas or oil storage in deep aquifers or leaved wells. Since such solutions proved to be ineffective, the concept of high pressure underground gas storage (UGS), carried out by the technology of rock caverns, was promptly created and applied in praxis.

There are two types of rock caverns used for this purpose: unlined rock caverns and lined rock caverns (LRC). The main request in the designing and construction of rock caverns is the prevention of gas leaking from the storage. In the unlined rock cavern, gas is kept from escaping by ensuring that groundwater pressure in the surrounding rock exceeds the gas pressure in the storage [1]. The required gas pressure can be achieved by locating a cavern at a sufficient depth or by installing a "water curtain" around the cavern [2,3]. The latter requires performing a comprehensive hydraulic analysis for gas containment of the storage terminal. By contrast to the unlined rock cavern, the concept of the lined rock cavern, LRC, is an UGS of gas at high pressure, supported by the surrounding rock [4–7]. The main idea of the LRC is to prevent the gas leakage from the cavern by a thin steel lining. In normal conditions, the LRC is completely impermeable and no extra hydraulic analysis for gas containment is needed.

The UGS, considered in this paper, is planned to be constructed with one or more LRCs. The structure of the LRC is simple: its reservoir wall is designed from a concrete wall and a steel lining. Although the concrete wall is reinforced, it just transports the gas pressure from the cavern onto the surrounding rock. The same holds for the steel lining, which only enables impermeability (sealing). The LRC load capacity is thus provided by the surrounding rock only.

To improve the economic effectiveness of the UGS designed with LRCs, this paper introduces a cost optimization of the UGS structure. Since a recent attempt [8] was based on the optimization of a single gas cavern only, this research handles the optimization of the entire UGS with any selected number of caverns. The optimization is performed by the non-linear programming (NLP) approach. For this purpose, the NLP optimization model is developed. Since the optimization is proposed to be performed for the phase of the preliminary design, only some basic conditions are defined in the optimization model in order to assure sufficient strength safety of the rock mass and impermeability of the cavern wall and steel lining. The latter is achieved by the limitation of the steel lining and concrete wall stains. The primary objectives of the proposed optimization are:

- Minimization of the investment costs of the UGS system,
- Storing the highest possible quantity of gas under high pressure,

* Corresponding author. Tel.: +386 2 2294 300; fax: +386 2 2524 179.
E-mail address: stojan.kravanja@uni-mb.si (S. Kravanja).

0141-0296/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2011.05.001