Compressed air energy storage in sand, principles and field test

Author(s)
J.K. Haasnoot
CRUX Engineering BV, Pedro de Medinalaan 3c, 1086 XK Amsterdam, The Netherlands, Haasnoot@cruxbv.nl
Co-authors: F. Mouwen (Park-id), O. Detert (Huesker gmbh)

Introduction

The present public demand to use more renewable energy sources, from an environmental perspective and/or in order to become independent of (foreign) energy suppliers, brings challenges to the present electricity grid. The electricity output of the renewable sources fluctuates, depending on the sunshine and wind. At present this already leads to problems in balancing the electricity grid. With a more increasing use of renewable sources, the need for large scale electricity storage also increases. Compressed Air Energy Storage (CAES) is considered one of the most promising techniques for the storage of electricity to balance the fluctuating output of the renewable sources. A few CAES installations are at the moment in operation. However, their location depends on specific geological circumstances, such as hard rock caverns or rock salt solution cavities.

The research discussed in the article explores the feasibility of storing compressed air in soft cohesionless soils, e.g. sand and gravels. In the Netherlands, and other deltaic and coastal regions, soil is present up to great depths, more than 500 m, before reaching bedrock. The objective would be to mobilize the surrounding soil mass to counterbalance the internal (high) pressure in the underground storage container. A feasibility study is performed using both analytical and finite element techniques to establish the pressure limits depending on the soil properties and depth below surface level.

Principle and Conditions

The principle is to mobilize the surrounding soil mass to counterbalance the high internal forces. In order to mobilize the soil mass, the lining should be flexible and thereby being capable to transfer the load. The main advantage is that the forces in the lining of the air container are minimized and that the lining can be constructed as light as possible. In this research the lining itself is not schematized, but is regarded as an infinitely flexible airtight membrane, by which an upper boundary is established for the occurring strains and displacements at the wall of the container. The general outline of the air container is based on the assumption that its construction should be possible with present state-of-the-art techniques.

Analytical Analysis

In order to have an analytical solution which describes the relationship between soil parameters, depth, pressure and strain at the air containers wall, relationships are used that are common in the directional drilling industry. This relationship gives the opportunity to explore the relationship between the strain at the borehole wall, which can be expressed as an expansion of the borehole or displacement at the borehole wall, and the internal pressure, in dependence of the effective stresses or depth, and the (stress dependent) soil stiffness and strength. This is illustrated by Fig 1. in which the relationship between the strain and pressure is graphically given for three different soil stiffness values.

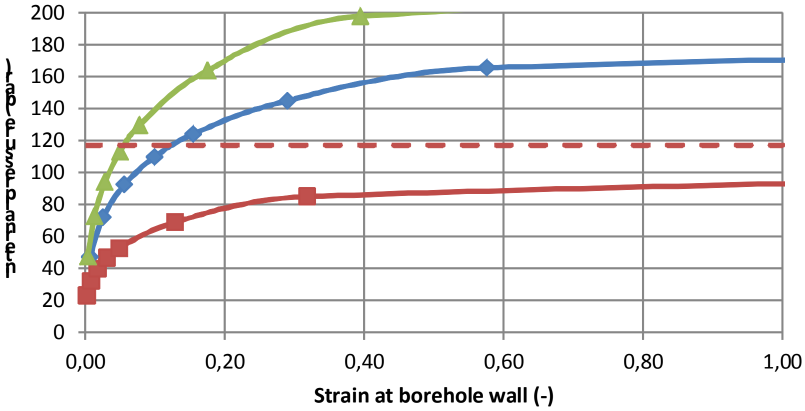

Figure 1. The relation between strain at the borehole wall and the internal pressure.

Finite Element Analysis

The analytical results are checked with an axi-symmetrical finite element model for the different relevant parameters. An illustrative example of the displacement field in the model is given in Figure 2. The displacement field shows a gradual decrease of expansion with depth, with the maximum total displacement at some distance below the top of the container. The analytical and FEM results are compared and discussed.

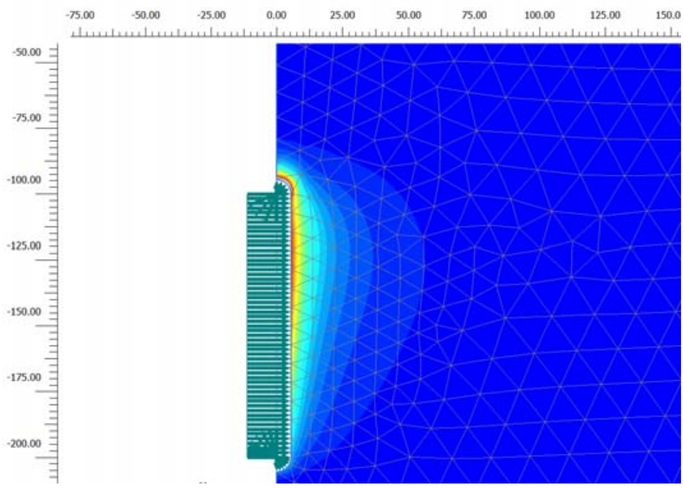

Figure 2. Illustrative example of the displacement field around the air container in the finite element model.

Fieldtest Set-up

A fieldtest set-up is developed to test the principle of mobilising the soil pressure to counterbalance the high internal pressures. This field test is funded by a grant of the Dutch government. The test set-up is described in the paper.

Conclusions

The research discussed in this paper explores the feasibility of storing compressed air in soft cohesionless soils, e.g. sand and gravels. The principle is to mobilize the surrounding soil mass to counterbalance the high internal forces. In order to mobilize the soil mass, the lining should be flexible and thereby being capable to transfer the load. The research shows, using both analytical and finite element calculations, that high pressures can be stored, with limited strain at the wall of the storage container.