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The creation of expanded diameter gravel wells in unconsolidated formations for High-Temperature Aquifer Thermal Energy Storage Systems: Theoretical and numerical evaluation of borehole stability

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High-Temperature Aquifer Thermal Energy Storage (HT-ATES) systems have the potential to cost-effectively store large volumes of thermal energy, bridging the supply-demand gap for variable renewable heat sources, such as solar thermal or power-2-heat conversion [3, 4]. These systems involve the injection and extraction of heated and cooled groundwater in aquifers via tube wells [11]. A HT-ATES system will be showcased at TU Delft, which involves the use of an Expanded Diameter Gravel Well (EDGW) to increase well capacity and reduce mechanical clogging compared to conventional wells [9]. This has the potential to reduce the number of wells needed and lower the costs of the HT-ATES system.

An EDGW has previously been constructed at depth in unconsolidated formations using a jetting technique for borehole expansion [8]. This well (expanded 2.6 fold from 600 mm to 1570 mm diameter) was taken into routine operation for drinking water production. A second expanded borehole (expanded 4.1 fold from 600 to 2460 mm diameter) collapsed upon testing the enhanced removal of the filter cake before it could be completed as EDGW. The missing explanation for the collapse of the second well highlights a knowledge gap regarding the stability of an expanded diameter borehole in unconsolidated formations. To prevent collapse of future expanded boreholes and to better manage the drilling process, this study aims to investigate the effects of an enlarged diameter on well stability through a theoretical analysis.

The stability of the EDGW borehole is evaluated in two ways, see Figure 1 for a schematic of the workflow. Firstly, the effects of an enlarged diameter on the stability of the well are evaluated analytically using a poroelastic framework [1, 2, 7]. Different conditions are taken into account regarding the stress state, mud pressure, and hydraulic conductivity of the aquifer. Secondly, field test conditions for the anticipated EDGW in the HT-ATES system are simulated numerically using the two and three-dimensional finite element software. The EDGW to be built in Delft, will be constructed within the Maassluis formation. The target aquifer is located at a depth of 120 – 182 m and is mainly composed of sandy units [5]. The simulation is divided into an initial, drilling, and open borehole (seepage) stage [6, 10]:

1. During the initial stage, in-situ stresses and pore pressures are applied.
2. The well bore volume will be removed during the drilling stage, resulting in a stress state that is no longer in equilibrium, and a mud pressure is applied to the borehole wall.
3. For the open borehole prior to backfilling stage, the effect of time-dependent fluid flow due to mud losses is evaluated on well stability.

During the open borehole stage, both situations with and without the presence of a filter cake (varying in thickness and hydraulic permeability) will be evaluated. Furthermore, the effect of the presence of thin clay/silt layers on the stability problem will also be taken into account, where special attention is paid to the roof of the well.

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The final results of this study are presented in the form of critical conditions regarding stress state, required mud pressure, and hydraulic conductivity for enlarged diameter boreholes in unconsolidated formations. Additionally, a design for the EDGW field test as part of the HT-ATES system in Delft is proposed, taking into account uncertainties such as the in-situ stress state and strength parameters of the formation.

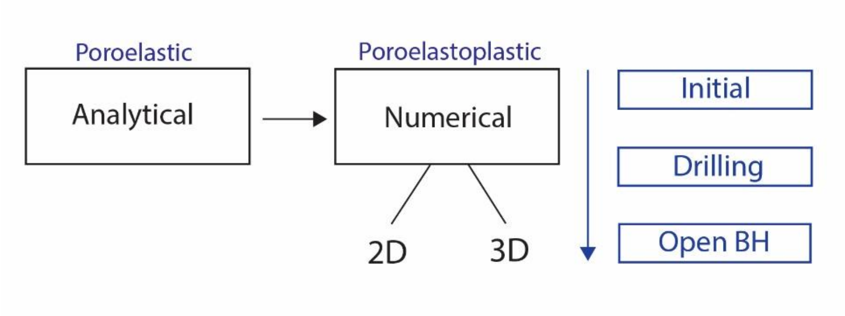

Figure 1: Workflow of the stability analysis.

Data Availability Statement

Data supporting the research can be found in the PUSH-IT community on Zenodo.

Contributor statement

Conceptualization: All authors; Writing-original draft: Tessel Grubben; Writing-review & editing: other authors.

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