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The effect of climate change on the behaviour of thermo-active diaphragm walls

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Energy geo-structures are becoming more common as a renewable energy solution which utilises shallow geothermal energy to provide heating and cooling to buildings and civil infrastructure projects. There has been an upward trend in the use of thermo-active geo-structures in the United Kingdom, from 150 in 2005 to over 5000 in 2012 [2]. Studies so far have shown that diaphragm walls subjected to combined thermo-mechanical loading show overall increases in lateral displacements, bending moments, shear forces, axial forces, and settlements on the retained side with thermal cycles [6, 7, 8].

This study uses a variation of a validated numerical model [4] to predict the behaviour of thermo-active diaphragm walls in the longer-term including accounting for the influence of climate change. This numerical model also assesses the impact of different modelling assumptions on the model output by comparing a simplified model with a more complex model where atmospheric temperatures affecting ground surface temperatures are included. Research from the IPCC shows increases in ambient temperatures and in maximum extreme temperatures as a result of climate change. Two models are compared in the IPCC report [5], Representative Concentration Pathway (RCP) 2.6 where governments across the world work together to meet the recommendations in the report to reduce overall warming, and RCP8.5 where the current trends of heating continue without any governmental interventions. According to climate model RCP2.6, global mean surface air temperatures will increase by around 1.5°C and extreme daily temperatures (i.e. days where temperatures exceed expected temperatures for the time of year) will increase by around 2°C over the 50-year period chosen for this study, whilst using RCP8.5 global mean surface air temperature increases by approximately 3°C and extreme daily temperatures increase by approximately 5°C.

This study uses the same model geometry as a model validated through centrifuge testing [4] which is a 5m deep cantilever diaphragm wall, like those that would be used in deep excavations for open-topped tunnels in large civil infrastructure projects. The numerical model was developed using the semi-coupled thermo-hydro-mechanical (THM) thermal module available with PLAXIS 2D and uses the HS-Small soil model [3] to allow for variation in shear modulus at small strains (i.e. those associated with retaining walls) to be captured more accurately. Thermal loads were applied by applying heat flows through a plate element with the same mechanical properties of the model diaphragm wall used in centrifuge testing. This model attempts to capture the influence of atmospheric temperatures by applying thermal boundary conditions to the ground surface as well as to the thermo-active diaphragm wall. Studies have demonstrated that a more complex model capturing atmospheric temperatures increases the impact of thermal loading [4], whilst also capturing a more realistic temperature profile throughout the entire depth of the soil body both adjacent to the wall and in the free field condition. In this study, atmospheric temperatures were captured in RCP2.6 by cycling between 30°C and -5°C over the course of the cycle to represent a typical ‘hottest’ and ‘coldest’ day of the year in cycle 1, increasing to 32°C and -5°C in line with the temperature increases described in the IPCC report [5]. Ambient mean temperatures between heating and cooling cycles increased from 20°C to 21.5°C over the 50-year period. In the same model, the temperature within the diaphragm

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wall cycled between 35°C and 10°C in cycle 1, representing the typical operation of a ground source heat pump (GSHP) in heating and cooling. These temperature inputs increased to 37°C and 10°C over the 50-year period. The RCP8.5 atmospheric temperatures cycled between 30°C and -5°C to represent summer and winter in cycle 1 and increase to 35°C and -5°C over the 50-year period. Thermal flows in the diaphragm wall cycled between 35°C and 10°C in cycle 1 and increased to 40°C and 10°C over the 50-year period. The results from this study show increases in lateral displacement, maximum bending moments, positive and negative shear forces and axial forces (compressive (-) and tensile (+)). These results are shown in Figure 1.

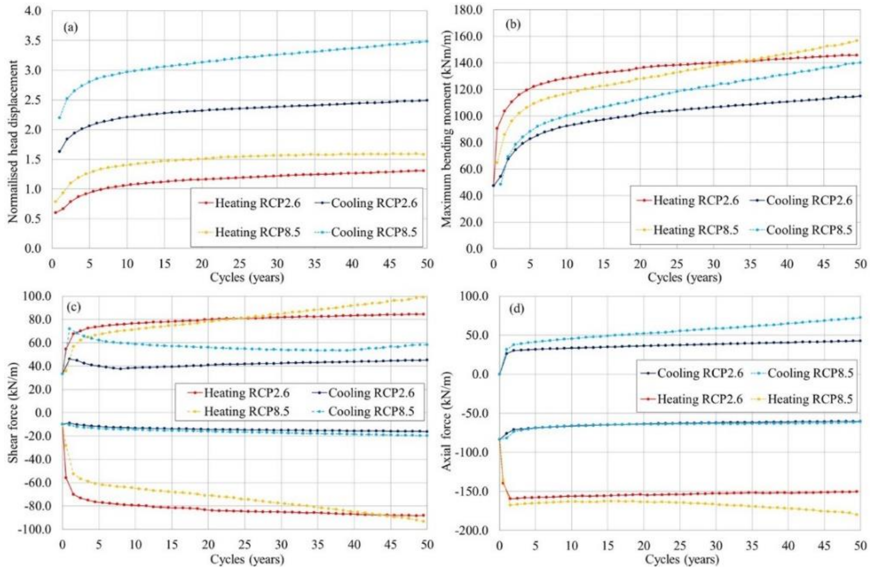

Figure 1: Comparison of (a) lateral displacement; (b) maximum bending moment; (c) shear forces; and (d) axial forces between RCP2.6 and RCP8.5 climate models where atmospheric temperatures are considered in the numerical model.

Significantly, the RCP2.6 model shows that these increases begin to stabilise over the 50-year period, with the increases in the final cycles becoming negligible. With the RCP8.5 model these increases are increasing linearly at the end of the modelling period which can potentially have significant implications not only in terms of serviceability of the structure, but potentially on ultimate limit state as linear increases suggest that design limits will eventually be reached. The findings from this study generally agree with other similar studies, such as a study that analysed the geotechnical performance of energy piles with additional environmental loading as a result of climate change which found that additional compressive and tensile stresses are generated during heating and cooling phases, respectively [1].

Contributor statement

Andrew Minto: conceptualisation, formal analysis, investigation, methodology, writing – original draft.
Anthony K. Leung: funding acquisition, supervision, writing – reviewing and editing.
Jonathan A. Knappett: supervision, writing – reviewing and editing.

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