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Review of heating of drinking water due to a heat network

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Summary

Deltares and KWR have, together with several drinking water companies, executed a TKI project relating the heating of the pipelines containing drinking water in the subsurface due to heat network pipes or electrical cables which are located in the vicinity of the drinking water pipelines.

TNO has been asked to perform a technical review of the four documents which are the deliverables of the TKI project.

From the review the following conclusions can be drawn.
- The verification of the Plaxis package using Calorics and DgFlow is properly performed.
- The implementation of the coupling of Plaxis with the WANDA package is satisfactory and the obtained results are good.

We recommended to perform further investigations into the following topics:
- The Plaxis computations assume a fixed water temperature, which is not a conservative estimation because this over estimates the cooling of the subsurface due to the drinking water. This could lead to higher drinking water temperatures and therefore an increased risk of bacteria growth in the drinking water.
- The Plaxis computations assume an average drinking water temperature over the diameter of the pipe. However, the actual temperature near the wall could be higher due to the temperature gradient. Especially for larger pipe diameters this could enhance the risk for bacterial growth.

The tasks still left to be done to complete the work described in the project plan are:
- Validation of the WANDA results with field experiments.

Contents

1 Introduction

Deltares and KWR have, together with several drinking water companies, executed a TKI project relating the heating of the pipelines containing drinking water in the subsurface due to heat network pipes or electrical cables which are located in the vicinity of the drinking water pipelines. The project plan is described in [1].

The goal of the project is to develop a workflow to determine the influence of heat network pipelines or electrical cables to the temperature of drinking water pipelines located in the vicinity. For that the software package WANDA will be used. WANDA is the 1-dimensional flow solver developed by Deltares. It's main purpose currently is to calculate water hammer in (drink)water pipelines.
In The Netherlands the drinking water is not allowed to exceed a temperature of 25 ºC to avoid bacteria to develop. Therefore, in the recent years, Deltares has extended the software package to calculate thermal effects along the pipe as well. This to calculate the warming up of the water due to solar influx or other heat sources. As most water pipelines are buried, the heat exchange with and in the subsurface has to modelled as well. If there are heat sources in the vicinity of the drinking water pipes, such as heat network pipes or electrical cables, these have to be taken into account also. For that purpose, WANDA will be coupled with software package Plaxis, a Finite Element model (FEM). Plaxis will calculate the heat transfer in the subsurface including the heat network pipes or electrical cables to the drinking water pipelines. Using these Plaxis results the thermal boundary conditions of WANDA can be specified. Only 2D thermal simulations are performed assuming that the heat pipe/electrical cable and drinking water pipes are in parallel layout. See Figure 1 for a typical layout. No crossings of the two are considered.

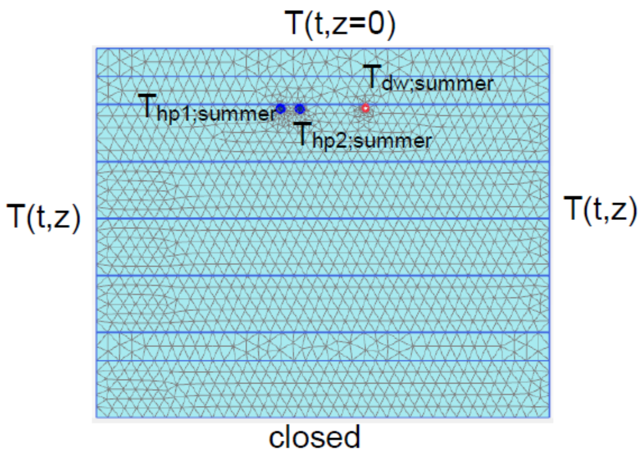

Figure 1 Typical layout of the pipe lines

According to the project plan, in the first part the results of 2D Plaxis will be verified with two other packages Calorics and DgFlow. Then some parameter variation with the 2D Plaxis code and WANDA will be performed. Next, the coupled Plaxis-WANDA simulations will be validated with field experiments.

TNO has been asked to perform a review of the documents which are the deliverables of the TKI project. Four documents have been reviewed, [2], [3], [4] and [5].

Documents [2] and [3] detail on the verification of Plaxis by comparing the results of Plaxis and two other packages, Calorics and DgFlow.

Document [4] describes the summary of the results of 2-dimensional heat transfer analysis. And in document [5] the implementation and results of the Wanda simulations using the boundary conditions are presented.

2 Review

In document [2] the verification of the Plaxis model with Calorics is detailed and in document [3] the verification of the Plaxis model with DgFlow is described.

Calorics is a 1-dimensional soil temperature model developed by KWR and has been tested and validated (up to 1.5 m below the soil surface). Next to the comparison study, some sensitivity studies on 1-dimensional heat transfer calculations of Plaxis were conducted. Figure 2 shows a typical result of the comparison and some (small) differences between the results of Plaxis and Calorics are observed.

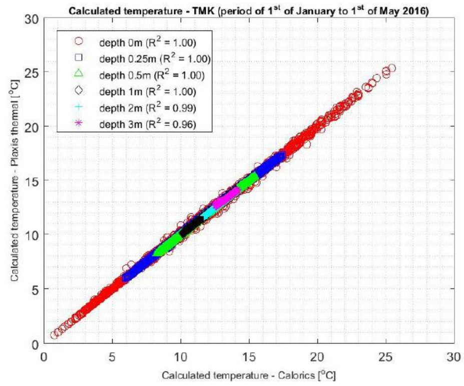

Figure 4.4 Comparison of calculated temperatures from 1st of January 2016 until 1st of May 2016 between Plaxis thermal and Calorics at depth of 0 to 3 m (TMK case)

Figure 2 Typical result of the comparison of Plaxis and Calorics.

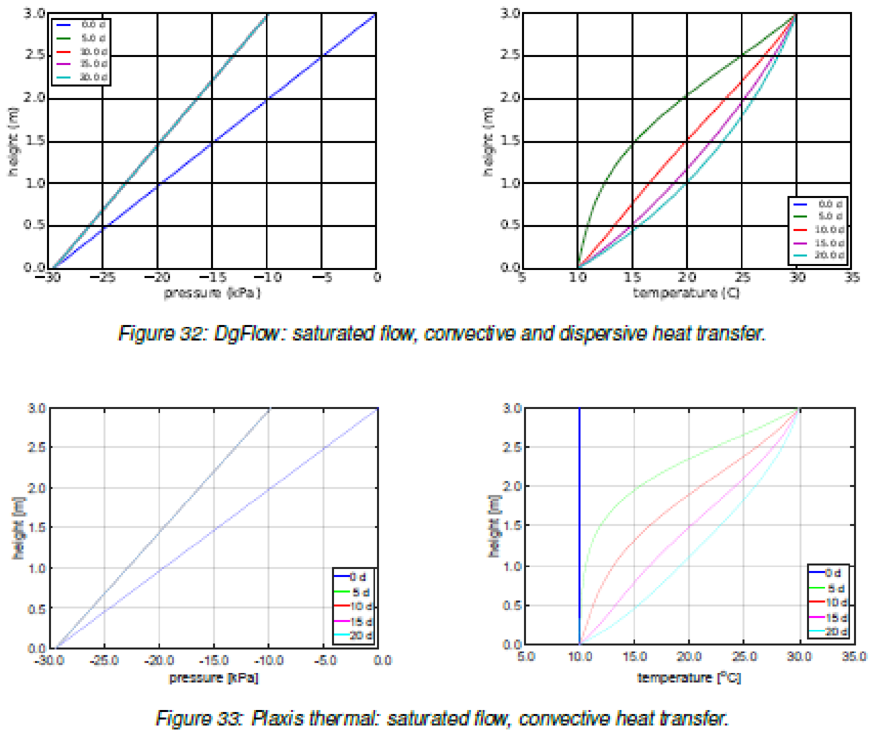

Figure 3 Result of the comparison of Plaxis and DgFlow for a model with groundwater flow. A maximal difference of 0.5 °C is observed.

DgFlow is a finite element program that solves ground water flow and heat transfer problems and has been verified theoretically. Looking at the results in [3] we see that there are some differences between Plaxis and DgFlow, but they can be explained by for instance inclusion of groundwater. See for instance Figure 3. However, in practice the effect of the ground water flow can be neglected because the velocities are in general far too low to have a significate effect on the temperature of the subsurface.

Also, in document [3] the mesh dependency is analysed, and mesh size independent results are obtained. Furthermore, the influence of the placement of boundary conditions is investigated. From this investigation the minimal distances from the area of interest is determined.

Looking at all the results, the verification with both Calorics and DgFlow is satisfactory.

Document [4] consists of a summary of a list of 2D simulations using Plaxis to investigate the effect of several parameters of the computation. Here the drinking water pipe itself is not modelled but a heat transfer coefficient to the wall, assuming a constant water temperature, is applied. This assumption is an overestimation of the cooling effect of the drinking water on the subsurface If the drinking is not kept constant, this might lead to higher drinking water temperatures and thus an increased risk of bacteria growth in the drinking water. An estimation of the effect of this assumption is not given. This would be a valuable addition to the sensitivity study.

Document [5] details on the implementation on the thermal boundary condition in WANDA. Also, the coupling procedure with Plaxis is described. The subsurface around the drinking water pipe can be subdivided in sections for which the heat transfer and storage are calculated based on the soil properties. After some investigation it turned out that when the subsurface around the pipe is divided into 4 sections this is sufficient. See Figure 4, which is taken from [5]. The procedure is now that the outer temperature values (T ambient, in Figure 1) are taken from the 2D Plaxis simulation. For each of the 4 sections the average value from Plaxis is applied to account for the thermal behaviour of the subsurface including the heat sources.

As WANDA is a 1-D code only the cross sectional average of the water temperature is calculated. With larger diameter pipes there could be a temperature gradient in the water and the actual temperature of the fluid at the wall could be lower or higher than the average, which could be a risk for bacterial growth.

The 2D Plaxis results with the inclusion of the heat sources show that the temperature in the subsoil depends upon the drinking water temperature in a linear fashion. Therefore, it does not matter at which distance from drinking water pipe the models are coupled.

Several parameters are varied, such as pipe material, pipe diameter and soil type.

For steady state simulation the length of the pipe and velocity are coupled, and the heating/cooling of the drinking water is only a function of residence time.

Also, transient simulations with a varying flow rate, mimicking daily operation, are performed. The heating of the drinking water in the transient simulation is lower compared to the steady state simulations.

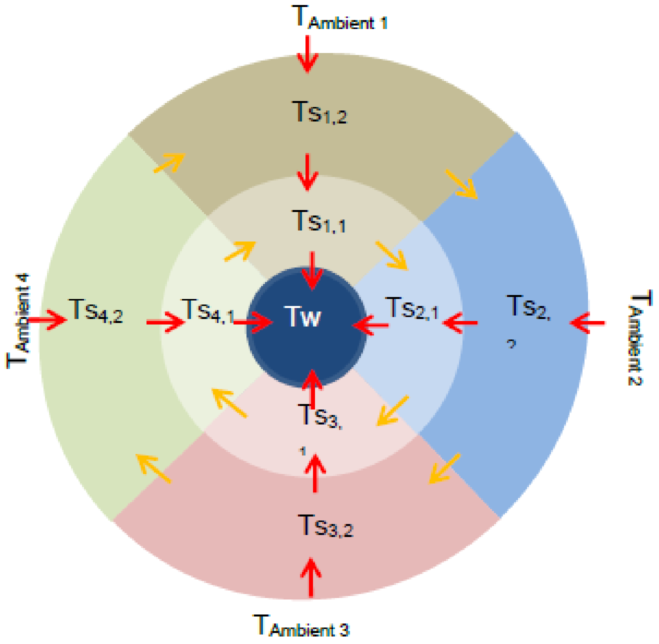

Figure 4 Overview of the division in sections and layers of the subsoil around the pipe. Ts are soil temperatures, Tambient are soil temperatures at the boundary of the domain used in Wanda. T w is the temperature of the water. This is the cross section of one element in the Wanda pipe. (From [5])

3 Conclusions and recommendations

From the review the following conclusions can be drawn.
- The verification of the Plaxis package using Calorics and a DgFlow is properly performed and Plaxis can be used to calculate the heat transfer in the subsurface.
- The implementation of the coupling of Plaxis with the WANDA package is satisfactory and the obtained results are good.

The tasks still left to be done to complete the work described in the project plan are:
- Validation of the WANDA results with field experiments.

We recommended to perform further investigations into the following topics:
- The Plaxis computations assume a fixed water temperature, which is not a conservative estimation because this over estimates the cooling of the subsurface due to the drinking water. This could lead to higher drinking water temperatures and therefore an increased risk of bacteria growth in the drinking water.
- The Plaxis computations assume an average drinking water temperature over the diameter of the pipe. However, the actual temperature near the wall could be higher due to the temperature gradient. Especially for larger pipe diameters this could enhance the risk for bacterial growth.

Furthermore, in the current TKI project the heating of drinking water in pipes which are in the vicinity of heat network pipes/electrical cables in a parallel configuration have been analysed. A logical next step would be to look at crossings of drinking water pipes and heat network pipes/electrical cables.

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4 Signature

Delft, November 2019

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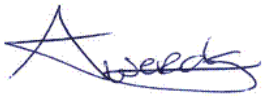

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