Short report

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Research topic: „Enhancement of the freezing method for the ecological construction of complicated basements under the effect of ground water flow "

Lemma: „Enhancement of the freezing method"

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1 Aim of the research project

The ground freezing method is a safe and environmentally compliant remedial method for the construction of building structures in groundwater with complicated basic conditions. Due to its flexibility, its dependable operation and the effective monitoring it has proved itself within tunnelling in the past. Furthermore it has been used in the construction of complicated building pits and underpinnings in groundwater, in particular if other construction methods failed.

The aim of this research project was to identify optimisation possibilities to enhance the ground freezing method also for the construction of basement stories and challenging access building structures, e.g. of underground stations or basement car parks. Because of the significant influence of the ground water flow on the safety, the duration and the costs of freezing applications, the realistic capture of the groundwater flow should be of major concern. Therefore the investigation of the groundwater conditions, which is presently done insufficiently within many projects, as well as the calculative acquisition of the flow considering the growing frost body by using numerical simulations has to be taken into account. As a result of the investigations recommendations for the application of the freezing technique for the construction of rising structures in areas with flowing ground water should be given.

2 Accomplishment of the research project

Within the scope of the research project numerous numerical simulations have been carried out using the program SHEMAT. The program that has been designed originally to describe permafrost problems has been enhanced and adapted to the basic conditions of the artificial ground freezing in collaboration with the Geophysica Beratungsgesellschaft mbH. The verification of the new implemented phase change model based on the unfrozen water content has been achieved by recalculation of model tests with and without ground water flow.

Based on these results a sensitivity analysis has been carried out to investigate the influence of essential input parameters. In conclusion several systems have been investigated concerning the possibility, how to reduce the freezing time by a rearrangement of the present freezing pipes or additional pipes.

Furthermore a real construction work has been recalculated. Therefore an extensive investigation of the ground water conditions has been carried out previously in order to allow a consideration of the ground water flow as close to reality as possible. The investigation contained classic methods like a pumping test, the evaluation of water levels and the numerical simulation with a program for the simulation of the ground water flow as well as the application of the Grundwasser-Fluss-Visualisierungs-Verfahrens (Ground water Flow Visualisation method).

The last mentioned method was applied by the project partner Phrealog. The Method is based on the observation of the drift of floating particles in the groundwater, which can be used to determine the velocity and the direction of the ground water flow.

3 Summary of the results

In the following a summary of the results of the realised work is presented. A detailed description of all investigations and results can be found in the comprehensive final report.

3.1 Sensitivity analysis of a wall affected by ground water flow

To investigate the influence of different parameters and basic conditions a sensitivity analysis has been carried for a frozen wall under the effect of ground water flow. The comparison between the several systems has been done for the point in time of the closure of the frost body. The basic system of the sensitivity analysis is displayed in Figure 1.

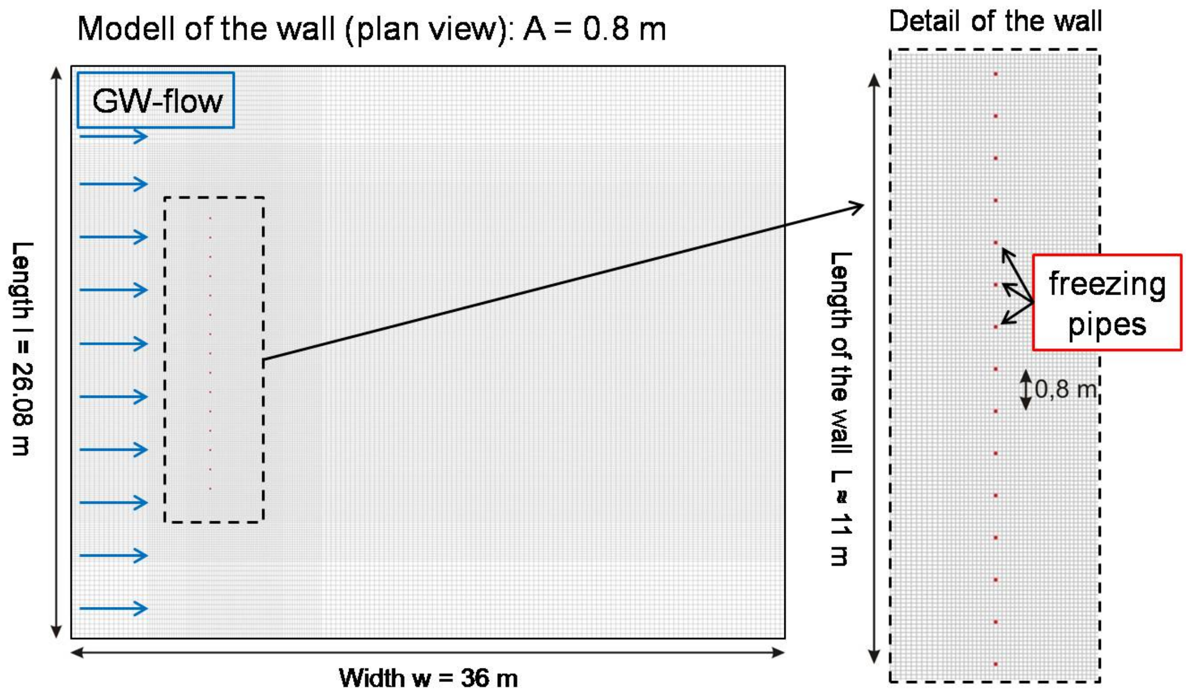

Figure 1: System-sketch of a wall under the effect of ground water flow

The basic system consisted of 15 freezing pipes in a row with a distance of 0.8 m. At the beginning of each simulation the whole system had the same temperature related to the temperature of the groundwater, before those of the freezing pipes were set to -35 °C. In order to keep up the temperature of the ground water flow, which influences negatively the development of the frost body, the temperature in the upstream was kept constant. The ground water flow itself was generated by different potentials on the left and right boundaries of the model.

The ground water flow velocities which are specified in the following are always discharge velocities, which existed prior to the freezing process without any reduction of the sectional area by the frost body.

Out of all investigated parameters and basic conditions the sensitivity analysis has shown that the ground water flow velocity forms the major influencing factor on the freezing process. In the following diagram the freezing times of the basic system are presented for different flow velocities.

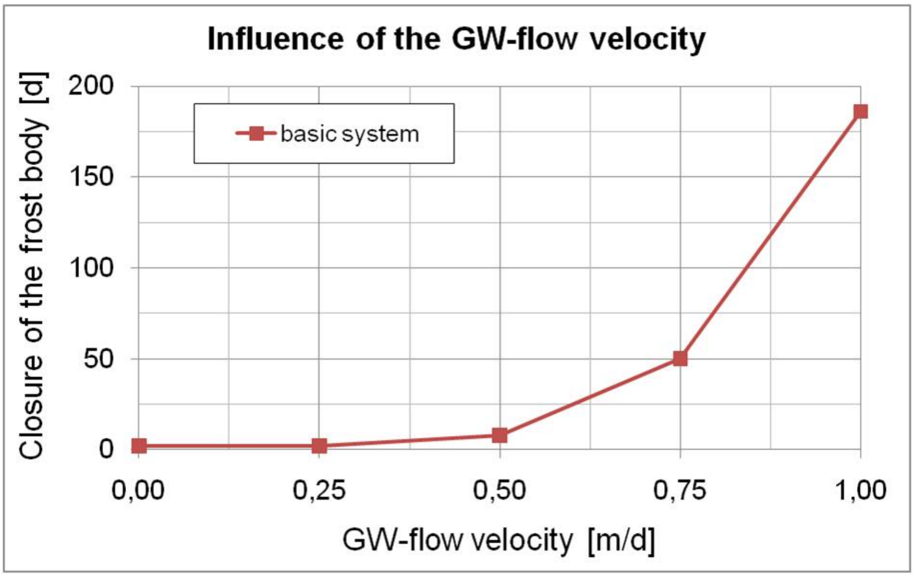

Figure 2: Influence of the ground water flow velocity

It can be seen that the period of time until the frost body is closed is increasing disproportionately with the increase of the flow velocity. Therefore, it is expected that a stationary situation will appear for higher flow velocities and the closure of the frost body cannot be achieved at all.

Besides the influence of the ground water flow velocity the influences of the pore content n, the content of quartz q, the temperature of the ground water T and the distance of the pipes A have been investigated. In Figure 3 the results of these investigations are summarised.

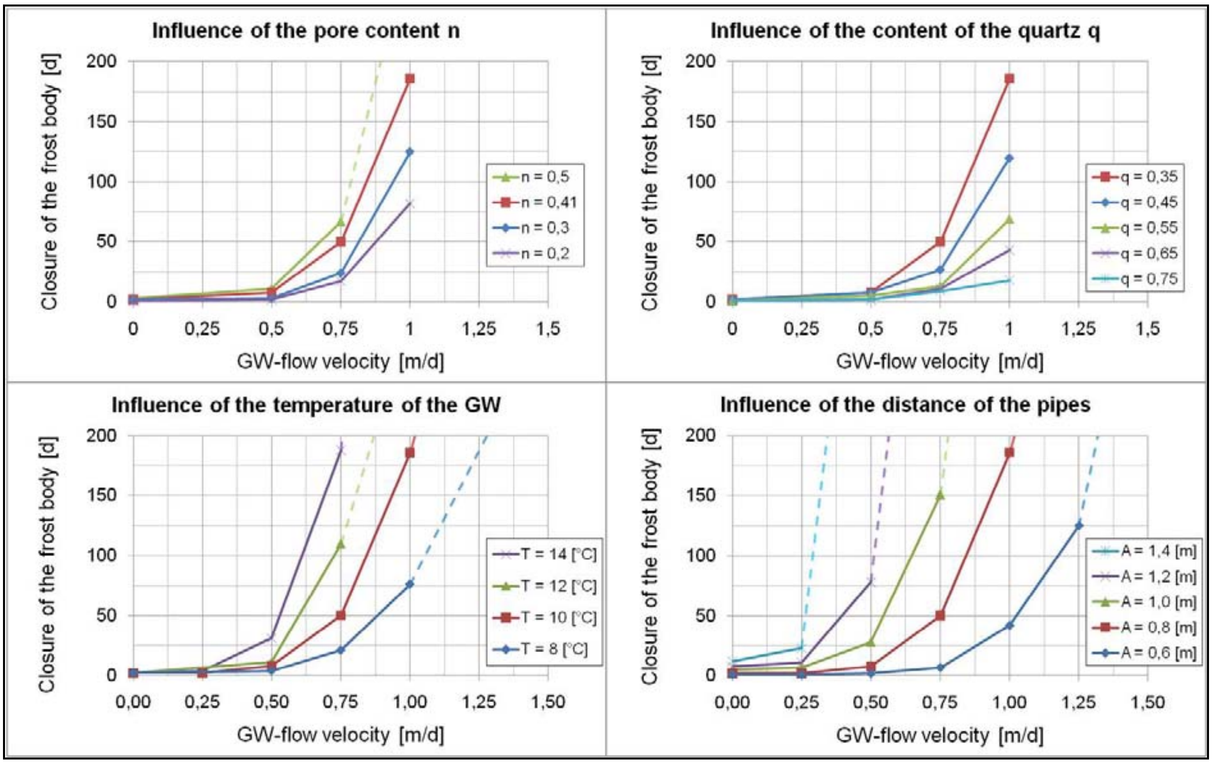

Figure 3: **Influence of the investigated parameters subjected to the flow velocity**

In each diagram the red curve describes the course of the freezing time against the flow velocity of the basic system, whereas the other curves describe the courses with varied parameters.

It becomes clear that the pore content, the quartz content and the temperature of the ground water have a significant influence on the freezing process if ground water flow is present. However without any ground water flow the influence is marginal. The influence of the distance of the freezing pipes is the most considerable. For distances of A > 1.0 m and even for small velocities the closure of the frost body does not occur within the considered period of time.

3.2 Optimisation possibilities in order to reduce the freezing time

The sensitivity analysis has shown that the most considerable influence on the freezing process results from the ground water flow velocity itself and that the freezing method is limited by increased velocities. For this reason investigations have been carried out, how the freezing time can be reduced by an arrangement of the freezing pipes adapted to the specific ground water flow situation. Some of the investigated cases are displayed in Figure 4.

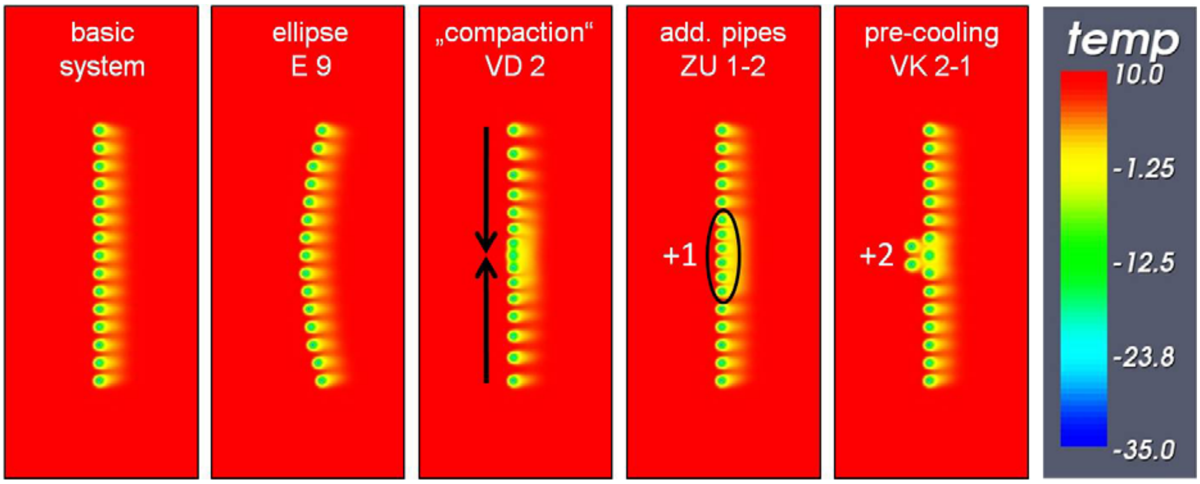

Figure 4: **Subset investigated systems in order to optimise the freezing time of a frozen wall under the effect of ground water flow**

The investigations comprised systems with changed outlines of the wall (e.g. ellipse) and systems with smaller distances of the pipes in the middle of the wall (“compaction”) keeping the total number of pipes the same. Furthermore systems with additional pipes in the middle of the wall or which have been installed in front of the wall in order to achieve a pre-cooling effect have been tested.

The investigations have shown that the freezing time of the system “wall” cannot be reduced significantly only by changing the outline. However the further investigated possibilities have turned out to be effective. In the following chart some of the investigated systems are compared among each other for a flow velocity of v = 1.0 m/d.

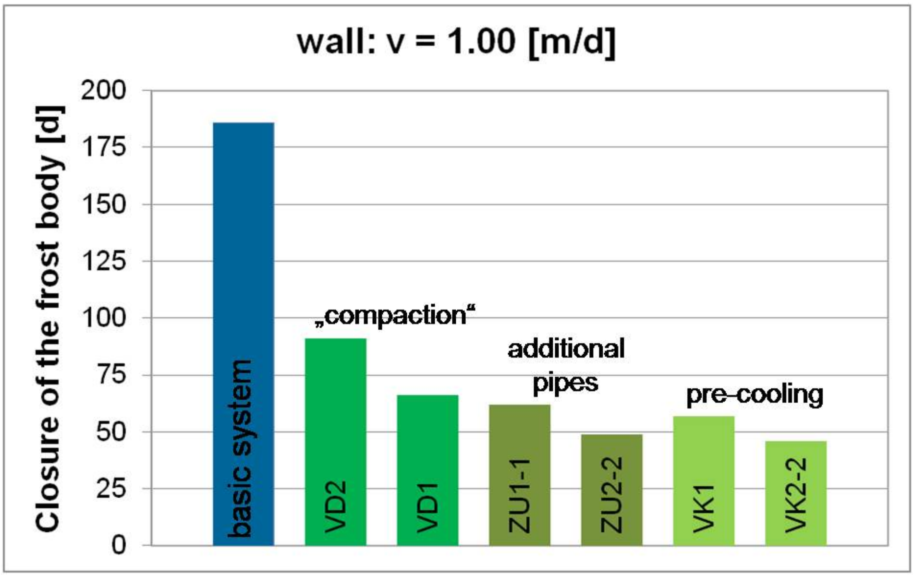

Figure 5: **Comparison of the freezing time of different systems**

It can be seen that the freezing time of the investigated wall can be reduced significantly by simply adding one or two pipes in the middle of the wall (ZU) or even without additional pipes only by reducing the distance of the pipes in the middle of the wall (VD). However the pre-cooling (VK) has turned out to be the most effective way.

Subsequent to the system "wall" several closed systems with different profiles have been investigated, how they can appear for example in the construction of building pits. Several systems with square (Figure 6), rectangular and elliptic shapes have been investigated. In order to reduce the computing time the symmetry was used and only half systems were modelled in each case.

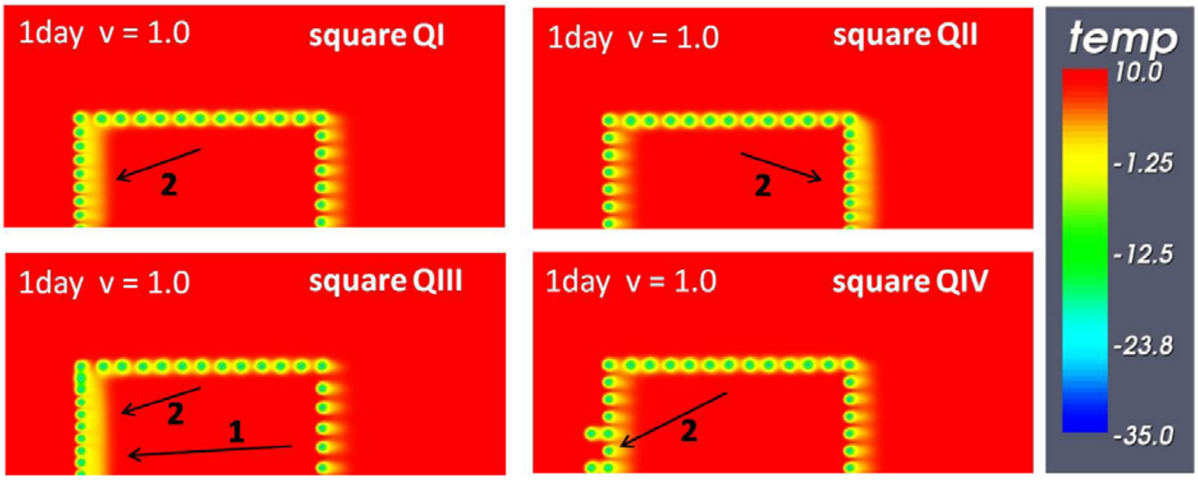

Figure 6: Square systems

For the optimisation freezing pipes have been removed from the side parallel to the ground water flow direction and have been placed elsewhere. Furthermore a system QIII was investigated where additionally one pipe was disarranged from the downstream into the upstream.

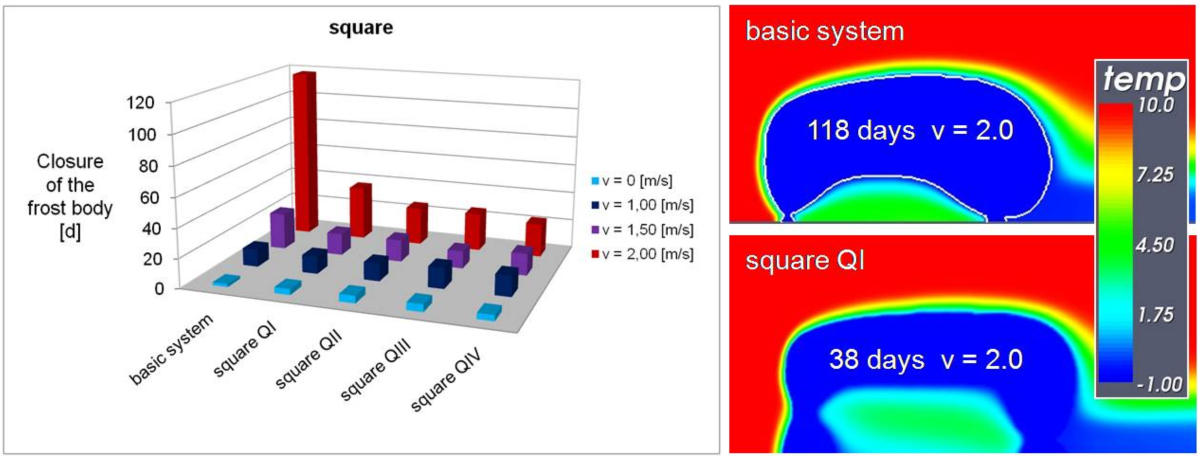

Figure 7: Freezing time and temperature plot for different square systems

The comparison of the freezing times in Figure 7 shows that the investigated rearrangements have significant positive effects if a high flow velocity occurs. As displayed by the temperature plots for the time of the closure of the frost body the inward-looking growth of the frost body is reduced. Thereby the excavation is not hindered by an excessively developed frost body.

The results shown for example for the square are also valid for the investigated rectangular and elliptic systems. Generally disarranging pipes from the side parallel to the flow to the side normal to the flow as well as pre-cooling reduces the freezing time and the inward-looking growth of the frost body.

Furthermore it has been investigated how to reduce the freezing time also for freezing applications under the effect of nozzles as a result of surrounding building development. In this context it was noticed that the freezing time can be reduced only for some variations and only marginally because of the high flow velocity within the nozzles. Therefore the freezing time of freezing applications under the effect of nozzles can be reduced almost only by some additional pipes. Hence possible optimisations should be verified in order to avoid negative effects by pretended optimisations.

3.3 Recalculation of a real construction work

On the basis of the results shown previously one can realise that ground water flow has a significant influence on freezing applications. However this influence is often underestimated and due to an insufficient investigation in many cases only inadequately considered. Therefore within this research project an extensive investigation of the ground water situation of a real construction work has been carried out. In the surrounding field of the project several levels plus a well for the execution of a pumping test were installed. Via the permeability derived from the pumping test and daily measurements of the levels numerical flow calculations have been carried out and the ground water flow velocity was calculated against the time in the area of the freezing application. Furthermore measurements of the ground water flow velocity and direction have been run by means of the GFV-method as described previously. These measurements mostly showed plausible results and resulted in an average flow velocity of $v \approx 0.2$ m/d. However in a level, which is located only 6 m from the well a ground water flow was measured during the pumping test with a direction away from the well. Due to this physical contradiction the direct transfer of the measured values without the connection on conventional measurements is cast into doubt.

After all a recalculation of the freezing application with the program SHEMAT was carried out taking the investigated ground water situation into account. In the following diagram calculated courses of the temperature are compared with those measured.

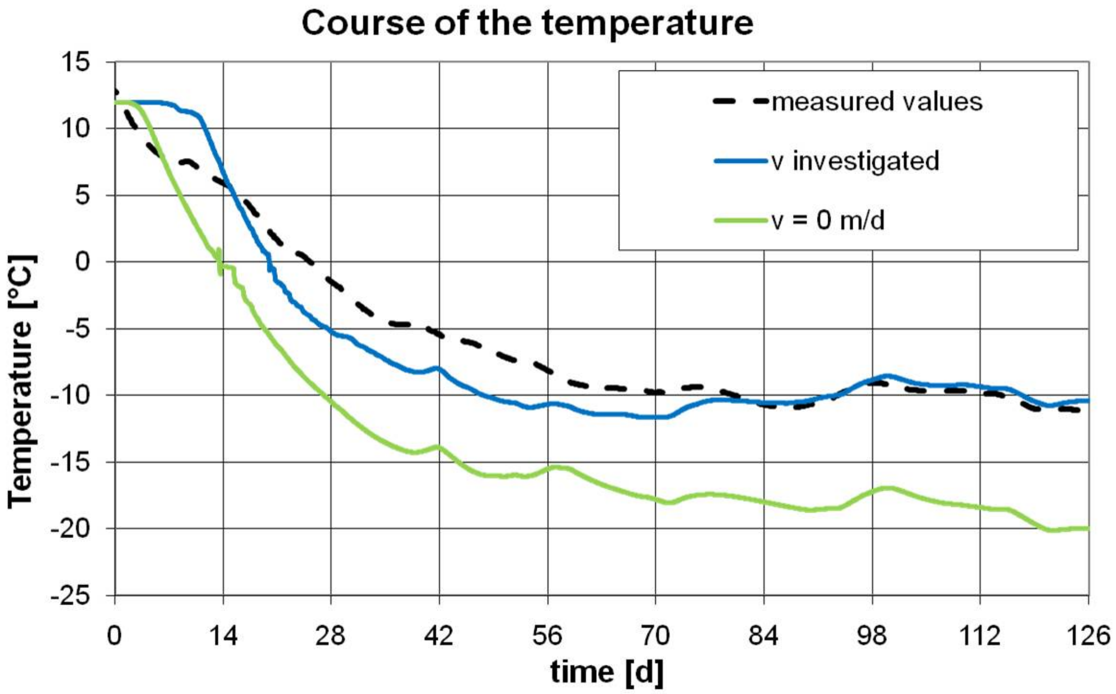

Figure 8: **Measured and calculated courses of the temperature in a section through the construction work**

It becomes apparent that a good accordance between measured and calculated temperatures can be achieved considering the flow velocities obtained by the measurements of the levels and the numerical simulation. On the contrary a disregard of the ground water flow is resulting in an underestimation of the temperature inside the frost body.

4 Conclusion

The sensitivity analysis carried out within the research project has shown that many factors affect the freezing behaviour of soil. However the most considerable influence results from the velocity of the ground water flow. For higher velocities the application reaches its limits. In this case the growth of the frost body might stop before the required frost body is developed. However an arrangement of the freezing pipes adapted to the ground water flow or some additional pipes can achieve significant advantages regarding the freezing time as well as the undesirable inward-looking growth of the frost body. However for this purpose the knowledge of the present ground water situation and the soil parameters is necessary in order to carry out realistic preliminary investigations. Finally it has been shown that it is possible to describe real construction works realistically via the enhanced program SHEMAT. Consequently a useful tool for the optimisation of the freezing application in advance of construction works has been developed.