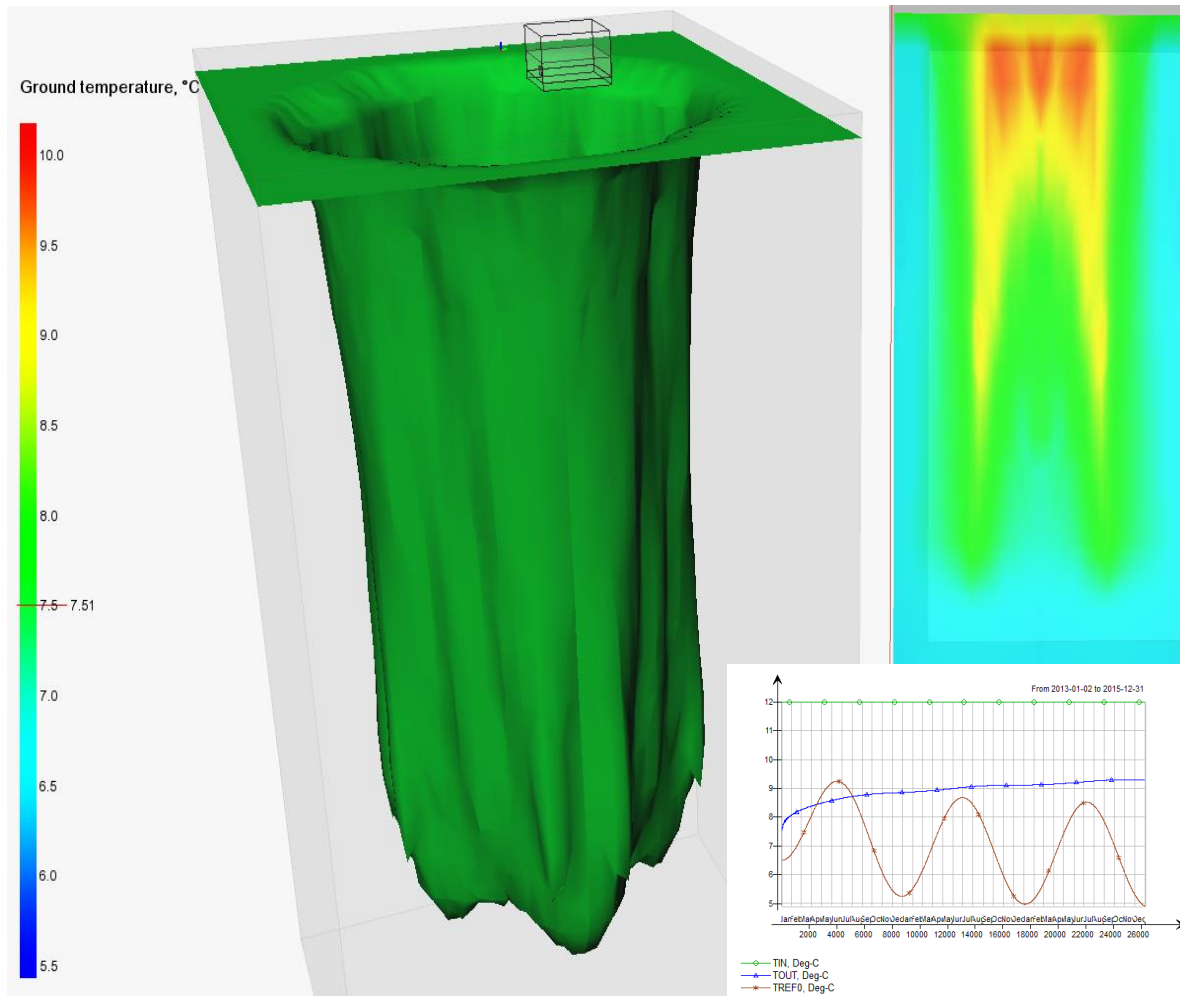


# User Guide: Borehole 1.0



# User Guide: Borehole

## Purpose

The GHX model is a 3D model for an arbitrary combination of boreholes (vertical or leaning) of equal length. The model is based on superposition of cylindrical 2D fields around each borehole and a 1D vertical field for the undisturbed ground temperature including geothermal temperature. It accurately calculates the temperatures, interaction between holes and the pressure drop in the brine liquid circuit. However, there are some restrictions in the model:

- The ground can only have one layer ,
- All holes have the same length,
- Only U-pipes as heat exchanger,
- Constant Borehole Resistance.

## Background

To get as reliable result as possible is it necessary to have a good knowledge of the properties of the ground where the boreholes are to be located. For the case of Sweden such properties can be found at e.g. SGI: <http://www.swedgeo.se/upload/Publikationer/Varia/pdf/SGI-V511.pdf>.

## Basic Settings

The basic settings are of three types, geometrical parameters, physical properties and additional parameters.

The screenshot shows the 'GHX\_MIR: a mathematical model in BoreholeTest1' window. The 'General' tab is active, displaying the 'Object name' as 'GHX\_MIR' and 'Object type' as 'GHX\_MIR'. A descriptive text states: '3D model for an arbitrary combination of boreholes (vertical or leaning) of equal length. The model is based on superposition of cylindrical 2D fields around each borehole and a 1D vertical field for the undisturbed ground temperature including geothermal temperature'. A 3D diagram illustrates a borehole in a coordinate system with axes x, y, and z, showing the borehole's orientation defined by 'Phi Yaw' and 'Theta Pitch'. Below the diagram, a cross-sectional view of the borehole shows the 'Ground', 'Hole', 'Grout', 'Pipe', and 'Liquid' layers. The 'Geometrical Parameters' section includes input fields for 'Hole' (ZHOLE: 120 m, RHOLE: 0.0575 m, LCASING: 1 m) and 'Pipe' (NPIPE: 1 items, RPIPE: 0.016 m, THICKPIPE: 0.0026 m). The 'Borehole Pattern' section includes 'NHOLE: 1 items', 'X-coord', 'Y-coord', 'Phi (Yaw)', and 'Theta (Pitch)'. The 'Physical Properties' section includes 'Ground and Surface Layer' (Ground, Grout), 'Pipe' (Pipe), and 'Liquid' (Liquid). The 'Additional Parameters' section includes 'Borehole Resistances' (Response Test, Heat Resistances) and 'Numerics and Visualization' (Computational Parameters).

Figure 1: Basic Form for GHX\_MIR .

## Geometrical Parameters

The geometrical properties are more or less self-explaining, see figure 1. The user supplies the radius  $R_{HOLE}$ , active length,  $Z_{HOLE}$ , the length of the casing through the surface layer,  $LCASING$ , for the hole(s) and the radius,  $R_{PIPE}$ , for the U-pipe. The parameter  $N_{PIPE}$  is the number of U-pipe in the hole, that is the  $N_{PIPE} = 1$  gives one down and one up pipe.  $THICKPIPE$  is the thickness of the pipe wall.

The holes are all straight but can have different inclination. The borehole pattern can be arbitrary with the exception that the holes are not allowed to overlap or intersect. The pattern is given as x- and y-coordinates and as angels for each hole. The Phi (Yaw) angel is the angel between the hole and the x-axis on the ground surface, the Theta (Pitch) angel is the angel between the borehole and the vertical z-axis.

## Physical Properties

The user must supply physical properties of the ground and surface layer, the filling material (grout), the pipes and the brine liquid, see figure 2.

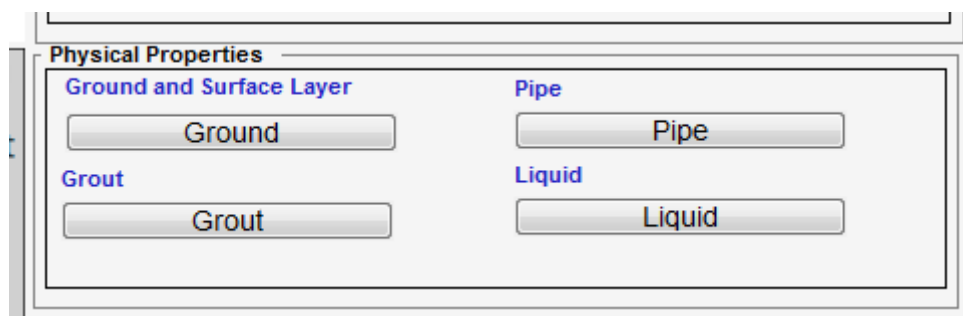
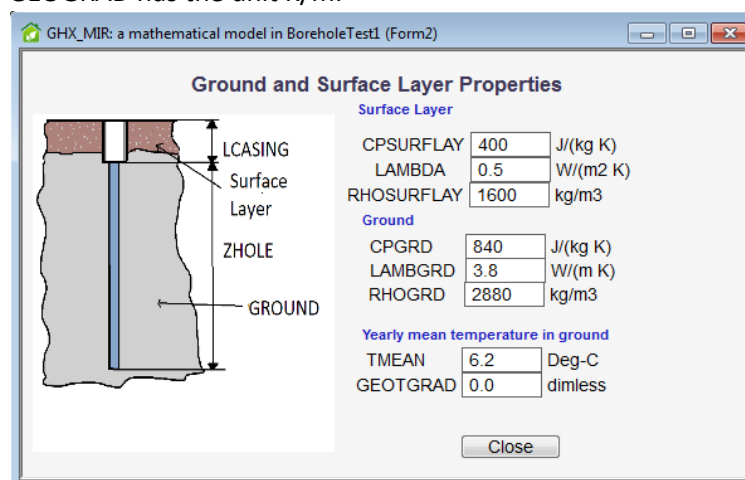


Figure 2: Physical properties.

For the ground and the surface layer there are three basic parameters to supply, the heat capacity  $c_p$ , the heat conductivity  $\lambda$  and the density  $\rho$ . For the ground the user also must give the annual mean temperature in the ground,  $T_{MEAN}$ . This should be known for the location or it can be taken as the annual mean temperature in the climate file used. It is also possible to add a gradient to the ground temperature, there  $GEOGRAD$  has the unit K/m.



Ground and Surface Layer Properties		
<b>Surface Layer</b>		
CPSURFLAY	400	J/(kg K)
LAMBDA	0.5	W/(m2 K)
RHOSURFLAY	1600	kg/m3
<b>Ground</b>		
CPGRD	840	J/(kg K)
LAMBGRD	3.8	W/(m K)
RHOGRD	2880	kg/m3
<b>Yearly mean temperature in ground</b>		
TMEAN	6.2	Deg-C
GEOTGRAD	0.0	dimless

Figure 3: Input form for ground and surface layer

For the pipe the user must give the heat capacity  $c_p$ , the heat conductivity  $\lambda$  and the roughness of the pipe wall, EPSILON, which is used for the pressure loss calculation in the pipe(s)

For the grout the user must specify the heat capacity  $c_p$ , the heat conductivity  $\lambda$  and the density  $\rho$ .

For the liquid the user chooses between a predefined set of brines including non-mixed water. The parameter TFREEZE is the freezing point of the brine, given by the user. This defines the mixture of the brine. The user must also give the heat conductivity, LAMBLIQ, for the brine, all other properties for the liquid are calculated as temperature dependent properties.

The figure shows three separate input windows from the EQUA software. The first window, titled 'Pipe properties', contains input fields for CPPPIPE (2200 J/(kg K)), LAMBPIPE (0.42 W/(m K)), and EPSILON (5.0E-6 m). The second window, titled 'Grout Properties', contains input fields for CPGROUT (4180 J/(kg K)), LAMBGROUT (0.6 W/(m K)), and RHOGROUT (1000.0 kg/m3). The third window, titled 'Brine Liquid properties', contains a dropdown menu for LIQTYPE (Potassium Carbonate), a text field for TFREEZE (0.0 Deg-C), and a text field for LAMBLIQ (0.42 W/(m K)). Each window has a 'Close' button at the bottom.

Figure 4: Input forms for pipe, grout and liquid.

## Borehole Resistances

The Borehole resistances can be supplied as data from a Response Test or as detailed resistances. For the Response Test the user must supply the measured mass flow for one hole, MRB, and the measured temperatures in and out from the borehole, TINRB and TOUTRB, see figure 3 below. The borehole resistance from the Response Test, RB, must also be supplied. The detailed resistances, figure 5, are calculated from these data.

The figure shows a single input window titled 'Borehole: a mathematical model in RBtest.GHXHP25-Rb1.Plant (Form2)'. It is divided into two sections. The first section, 'Measured data in response test', contains input fields for Massflow MRB (0.86 kg/s), Temp into ghx TINRB (18 Deg-C), and Temp out of ghx TOUTRB (15 Deg-C). The second section, 'Calculated data in response test', contains an input field for Calculated borehole resistance RB (0.042 (m2 K)/W). Below this field is a note: 'Set RB to zero if Heat Resistances are given'. A 'Close' button is located at the bottom of the window.

Figure 5: Input form for data from Response Test.

If the user wants to give detailed resistances, RB must be set to zero.

### Detailed Heat Resistances

The user also has the possibility to supply detailed heat resistances. These are the resistances actually used in the calculation.

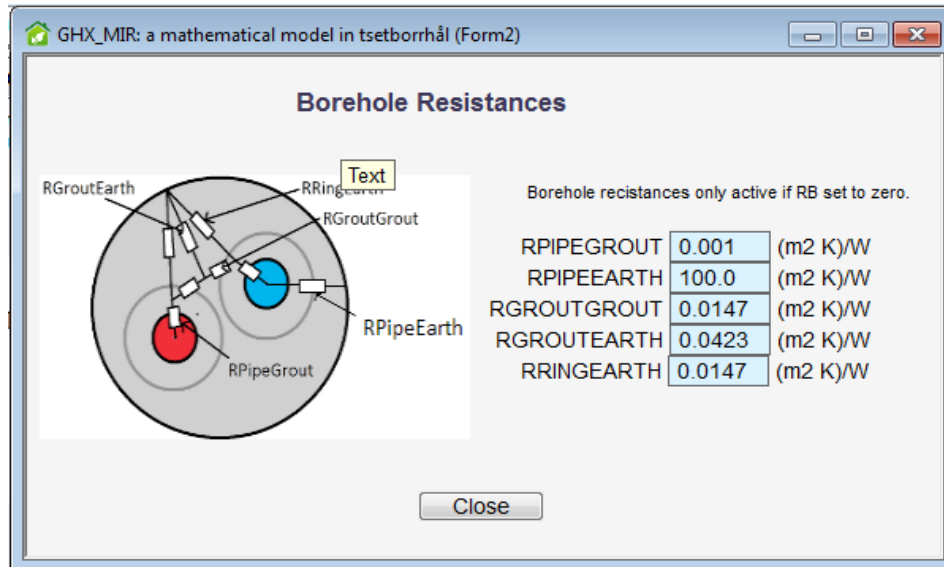


Figure 6: Detailed heat resistances.

### Computational Parameters

When using large number of holes the model may be too slow to be of practical use. There are ways to overcome this and make the model run faster. By mirror the borehole pattern it is possible to make the computations in a small part of the whole domain. This is controlled with the MIR parameter.

MIR = 0 means no mirrors, i.e. all holes are computed.

MIR = 1 means a reflection in one symmetry axis (the x-axis) thus at most halving the computation work.

MIR = 2 means reflections in two symmetry axis (the x- and y-axis), the computational work is at most reduced by a factor 4.

MIR = 3 means reflections in three symmetry axis (x-, y- and 45°-axis), the computation work is at most reduced by a factor 8.

Holes with coordinates on the symmetry axis are reflected on one less symmetry axis, thus it is important to carefully place the holes in order to get the most reduction of the computational work see more in the last section.

Using mirror holes does not influence the accuracy of the computed result.

The parameters for the computational grid, figure 5, can also be adjusted, but *changing these may influence the accuracy of the computed result. It is important that the user runs some tests with different values of these parameters to get reliable results.*

For a more detailed description consult the technical documentation.  
RMAX is the maximal radius of the Computational domain. It is important so set the radius large enough to cover the influence of the borehole, but at the same time it is desirable to have as small value due to speed and accuracy.  
NRING is the number of layers in radial direction.  
NLAYT is the total number layers in the z-direction in the ground. NLAYT must be greater than NZHOLE+2.

Figure 7: Computational and visualization form.

## Visualization of the Ground temperature field

By giving non-zero parameters to the visualization grid is it possible to save a time series of the temperature field in the ground. The parameters N1, N2 and N3 is the number of grid points in the x-, y- and z-axis. These parameters does not have any influences on the computed result. The visualization grid is only an observation grid. The parameter TOUTPUT gives the interval between visualization samples times in hour. This is not coupled to the IDA simulation parameter “Time step for output” and can be set independent of the output intervals for the prn-files.

To see the result after the simulation you go to the 3D-tab and mark the variable “Ground temperature”, see Figure 8.

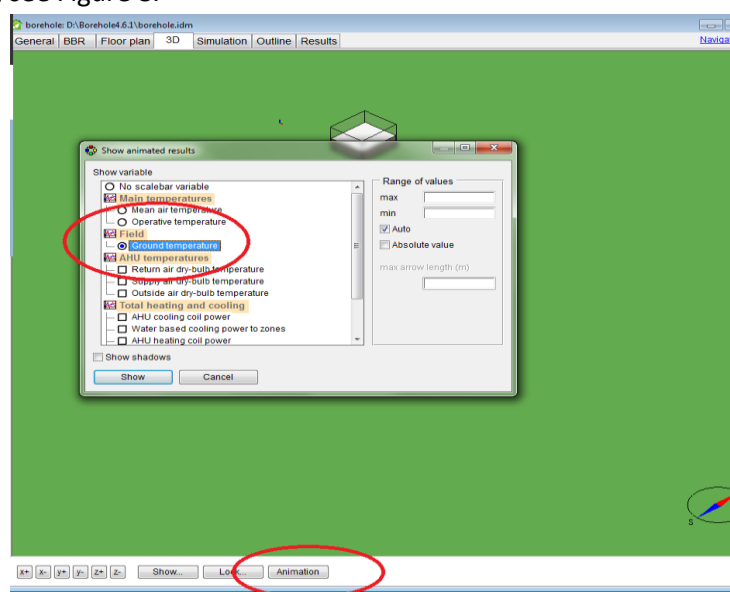


Figure 8: The Variable “Ground temperature”

Now the time dependent temperature field in ground will be visible as in Figure 9.

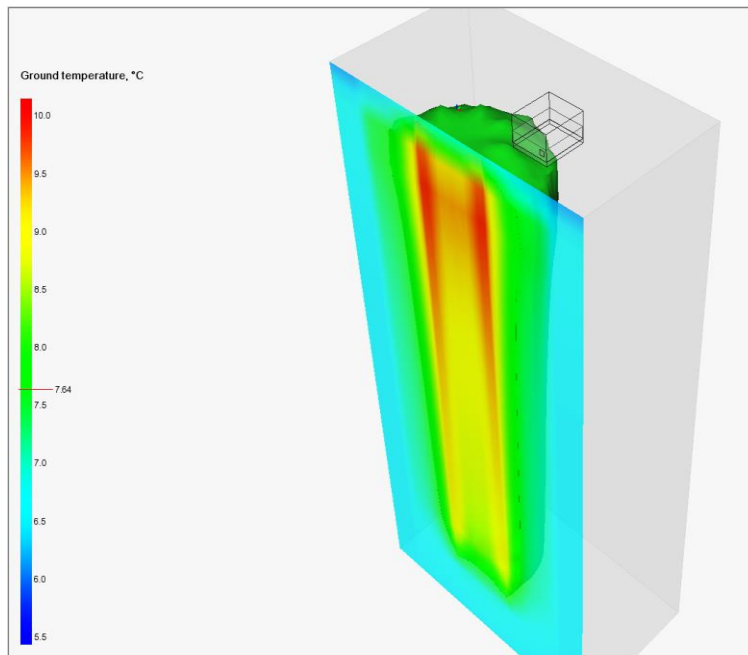


Figure 9: An example of the ground temperature field at a given time.

## Interface of the Model

There are three connections to the model, see figure below:

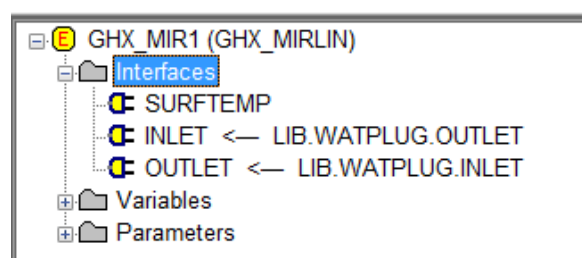


Figure 10: Interfaces.

The SURFTEMP is a scalar temperature connection for the surface temperature. It can be connected to the ambient air temperature in a climate model or similar. The INLET and the OUTLET are of PMT-type for the in- and outgoing brine liquid.

## Using the borehole model in the ESBO plant

To use the borehole model in the ESBO plant the user must perform some steps, see Figure 11:

1. In the ESBO template, drag in a “Brine to water heat pump” or a “Brine to water chiller” and the “Ground source borehole loop”.
2. Press “Build plant model”

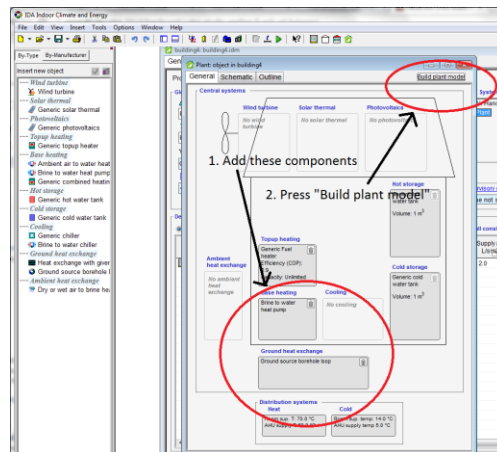


Figure 11: The ESBO template.

3. Open the "Schematics" view. The borehole component and circuits is located to the left.
4. Right click on the Borehole components and choose "replace" and press ok.
5. In the "Insert object" list mark "GHX\_MIR" and press ok. The schematic should now look like Figure 12.

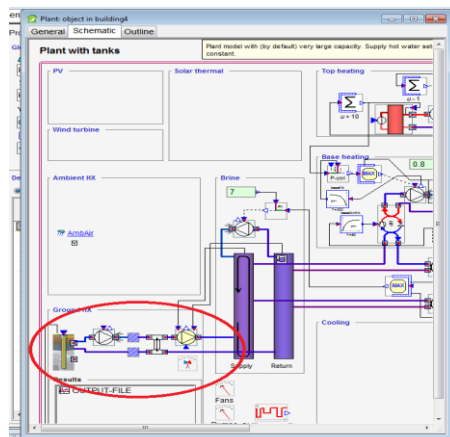


Figure 12: The schematic with replaced borehole component.

6. If you want you can now replace the pumps and the decoupler with other components, but for many applications is it possible to keep the circuit as it is.
7. If you keep the pump, you must change some parameters in that component, Figure 13.

Name	Value	Start	Unit	Connected to
ETAPUMP	0.8		di...	
TFREEZE	-25		De...	
LIQTYPE	Ethylene...			
TAUT	60.0		di...	
TAUM	50.0		di...	
PHEAD	100		Pa	
DPO	0.1		Pa	
MFNOM	1.0		kg/s	
MMIN	1.0		kg/s	
TMASIDE	2.0			
Energy meter	[Default] ...			

Figure 13: Parameters to change in the bhPump.

Set PHEAD = 30000 (default) or similar value. MFNOM should be set to give a massflow approximately 1 kg/s/hole.

## Finding and using symmetry in the borehole pattern

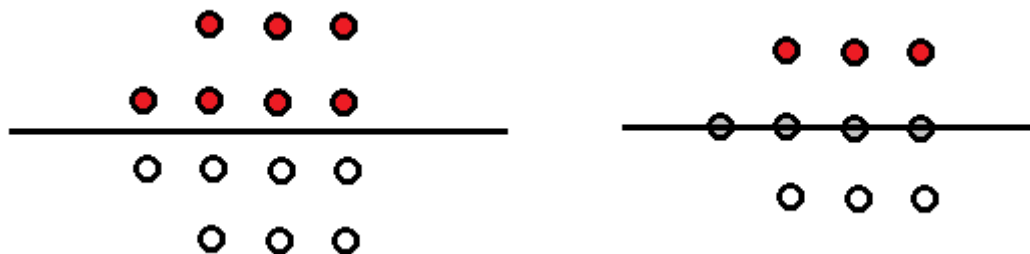
The most effective way to speed up the simulation when having a large borehole storage is to use symmetry in the borehole pattern. By using symmetry we can calculate the temperatures in a small section of the storage and mirror the result to the whole domain. This mirroring technique calculates the full field using superposition; there is no numerical approximation involved.

Assumptions made in the superposition calculation are: 1, the holes are equally spaced around the symmetry axis and 2, the coordinates are centered round the origin. To be able to use the mirroring technique you might need to adjust the coordinates for some holes to get the equal spacing. You might also need to do some easy translation and rotations of the pattern to get it centered round origin and symmetry axis.

In the figures below we have calculated the speedup as

$$Speedup = \frac{\text{Number of holes in the borehole storage}}{\text{Number of simulated holes}}.$$

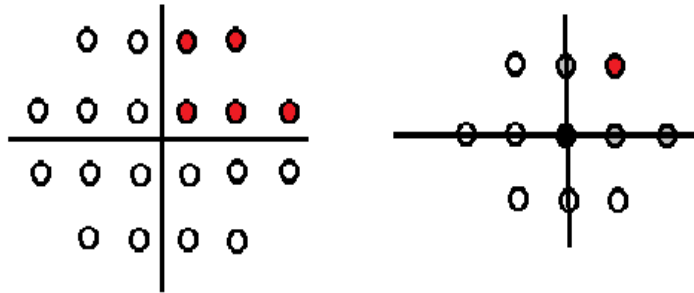
The speedup depends on how the holes can be mirrored. In the figures below you can see some possible configurations of the boreholes pattern giving different speedups. Holes marked with an empty circle is the mirror holes and holes with colors (red, gray and black) are the calculated holes. Thus, you give only the coordinates for the colored holes and the number of simulated holes, NHOLE = number of colored holes.



Left: All holes above symmetry line are mirrored once (marked red), speedup 2, give NHOLE = 7.

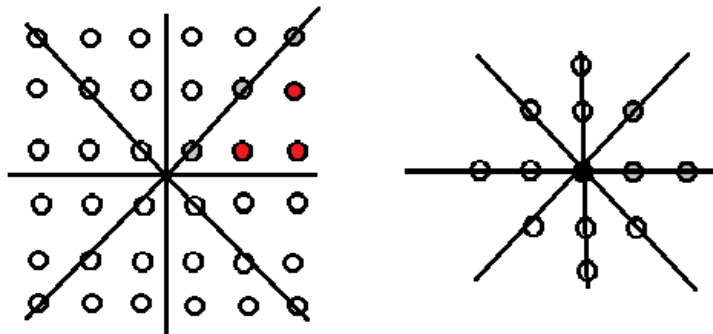
Right: the holes above the symmetry line are mirrored once and the one on the symmetry line are not mirrored giving a speed up as  $10/7 = 1.43$ , NHOLE = 7.

### Two symmetries (MIR = 2, symmetries around the x- and y-axis)

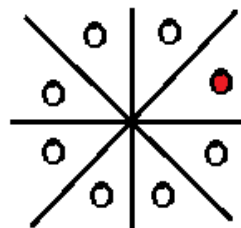


Left: The holes in the first quadrant are mirrored in two axes, giving speedup 4, NHOLE = 5. Right: The hole in the first quadrant is mirrored twice, the holes on the axis once and the one in the origin none, giving speedup as  $11/5 = 2.2$ , NHOLE = 5.

### Three symmetries (MIR = 3, symmetries around the x-, y- and 45° -axis)



Left: The holes in the lower first quadrant are mirrored eight times and the holes on the 45-degree symmetry axis is mirrored four times giving a speedup  $36/6=6$ , NHOLE = 6. Right: The holes on the axis is mirrored four times and the one in the origin none giving a speedup  $13/4=3.25$ , NHOLE = 4.



Best possible speedup is achieved with a configuration as above; the hole in the lower part of the first quadrant is mirrored eight times, speedup = 8, NHOLE = 1.