

## Overview

The software CCGS (Cyclic Crack Growth Software) developed at the Materials Center Leoben allows to estimate fatigue crack growth for different notch and component geometries under variable amplitude loading. Different crack propagation equation (material laws) may be chosen, among them the widely used NASGRO equation and an extended version of the NASGRO equation developed at MCL.

Typical fields of application of this software are in fitness-for-purpose assessment and damage tolerant design. With the help of CCGS, often occurring practical questions can be answered such as:

- How many load cycles can a component withstand until existing cracks reach a critical length?
- Which inspection interval should be prescribed for safety-critical components?
- How do residual stresses influence crack growth?
- How do overloads affect crack propagation?

Table 1 summarizes the capabilities and options available in the demo and the full versions of CCGS.

**Table 1.** Capabilities and options available in the demo and the full versions of CCGS.

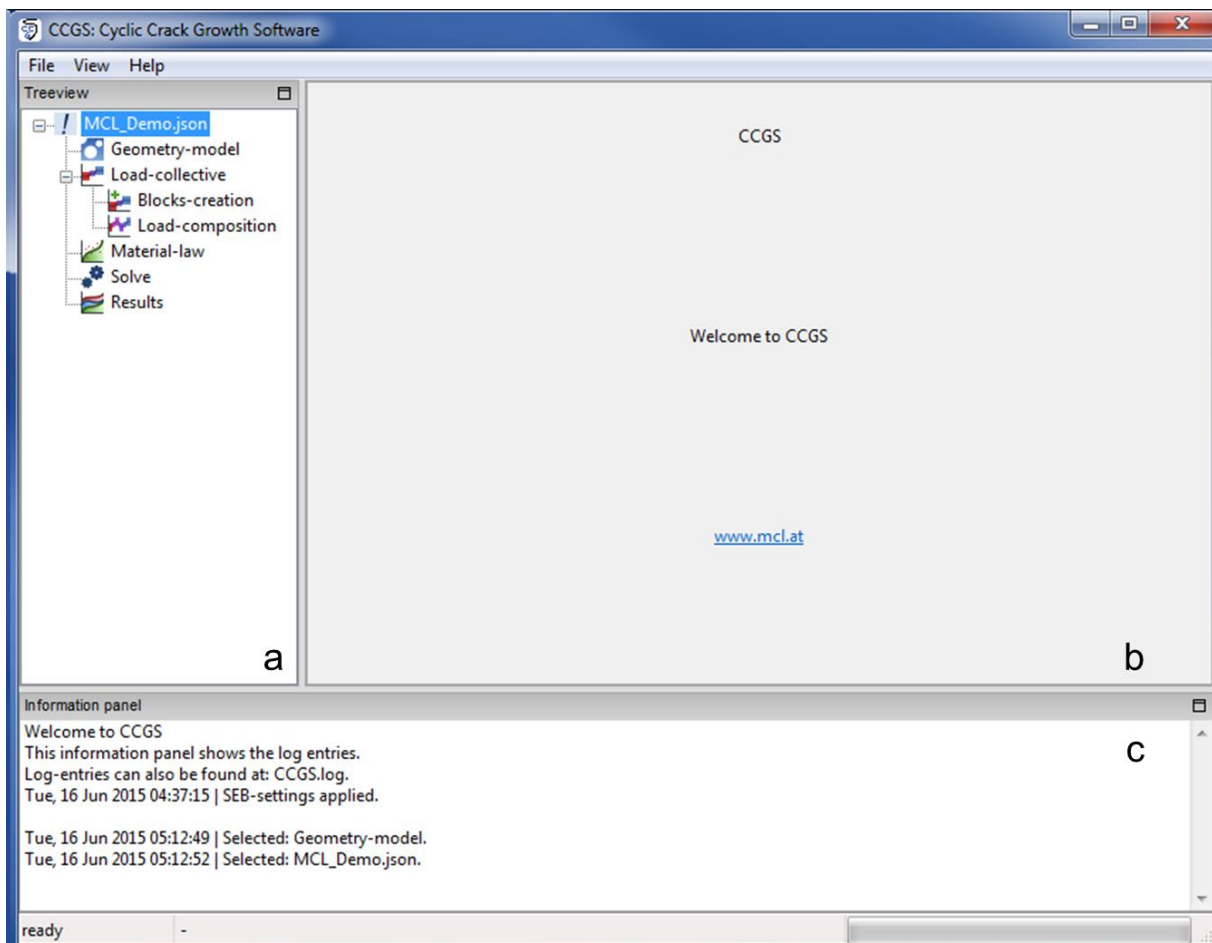
	demo version	full version
Various material laws for calculation of crack propagation	MCL short crack only	✓
Editable notch geometry	✓	✓
Various component/crack geometries	-	✓
Variable amplitude block loads	✓	✓
Residual stress fields	-	✓
Load history (e.g., overload) effects	-	✓
Various integration methods	Runge-Kutta only	✓
Editable integration increment	✓	✓
Generation of different load-time sequences	Sequential load blocks only	✓
Editable abort criterion	-	✓
Tabular illustration of results	-	✓
Automatic report creation	-	✓

## Program structure

In addition to the title, menu and status bars, the CCGS main window is divided into three areas (Fig. 1 a-c):

- a. Navigation panel: Here, all steps necessary for crack propagation calculations are arranged chronologically from top to bottom.
- b. Typing and drawing area: In this area all the inputs to the current step take place. Furthermore, the calculation results are displayed in this area.
- c. Information panel: Here, all work steps of the user are logged. Also the current crack length and the corresponding load cycle number are written out here repeatedly during a calculation.

In order to carry out crack growth calculations as mentioned above, the various steps in the Navigation panel have to be edited. In what follows, the individual steps are explained in more detail.



**Figure 1.** Different areas of the CCGS main window: **a** Navigation panel, **b** Typing and drawing area, **c** Information panel.



## Step 1: Geometry model

The cracked component available in the CCGS demo version is a Single Edge Bending (SEB) specimen, i.e., a flat bar with height  $W$  and thickness  $B$  containing an initial crack of length  $a_0$  loaded in bending (see Fig. 2). The dimensions of the flat bar as well as the initial crack length can be arbitrarily changed. By clicking on the green check mark, the preview is updated.

In addition it is possible to change the load type between three-point, four-point and eight-point (reversed four-point) bending.

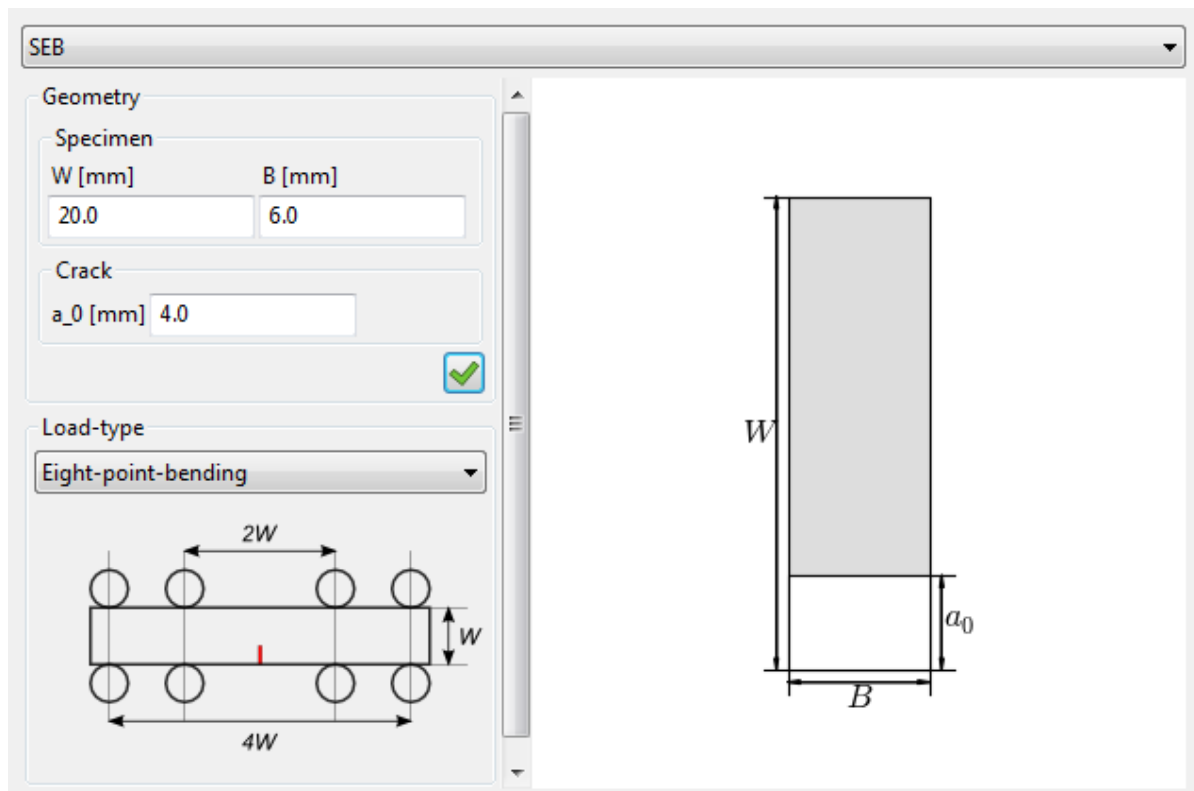
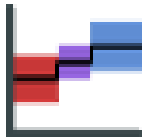


Figure 2. Typing and drawing area; Step 1: Geometry model.



## Step 2: Load collective

In this step, the loading of the component is defined. This is done by first creating different load blocks (*Block creation*) and then arranging these blocks to the load-time sequence used for the subsequent crack growth calculation (*Load composition*).

### **Block creation**

With a double click on ‚*Block creation*‘ in the Navigation panel a new load block is created.

The individual block loads are then defined by their number of load cycles  $N$  (or the cumulative load cycle number  $\Sigma N$ ), the load ratio  $R$  and the stress amplitude  $\sigma_a$  (Fig. 3). Via a button bar blocks can be added, deleted, copied or pasted. It is also possible to save created blocks in files. By clicking on the green check mark, the current block load sequence is shown graphically in the Preview panel (see Fig. 4). A block load sequence can be deleted right-clicking on the corresponding block load sequence and selecting *Delete*.

	<i>name</i>	$N[-]$	$\Sigma N[-]$	$R_{\sigma}[-]$	$\sigma_a [MPa]$
1	Section: 1.	20	20.0	-0.5	50
2	Section: 2.	30	50.0	-1	100
3	Section: 3.	50	100.0	0.1	20

**Figure 3.** Creation of load blocks.

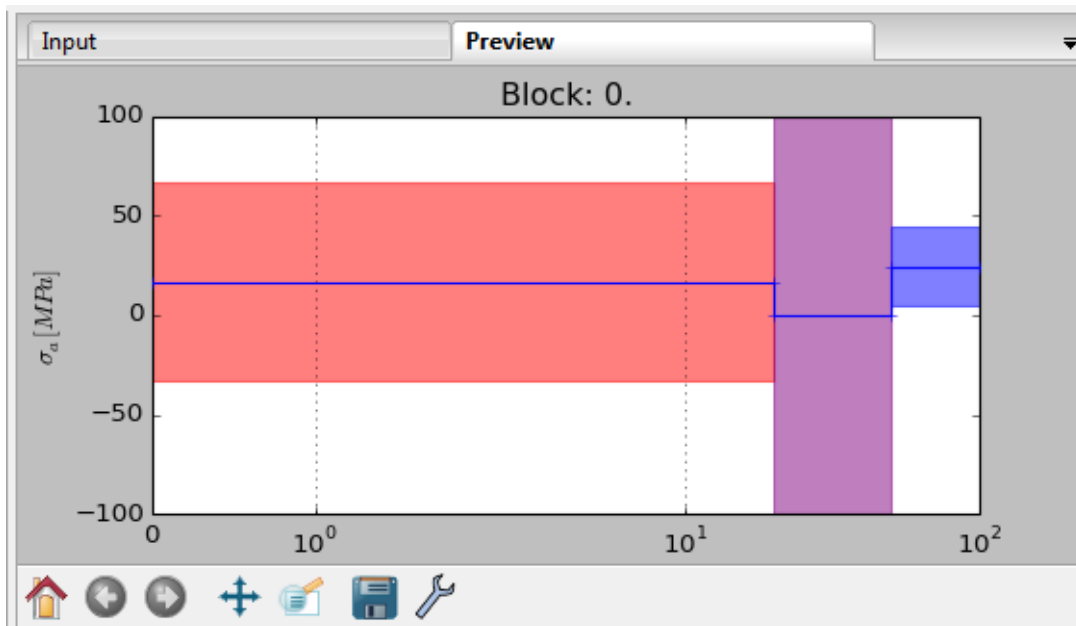


Figure 4. Graphical representation of the load block.

### Load composition

Now, after one or more load blocks have been defined, they have to be arranged to the sequence used in the subsequent crack growth calculation (*Load composition*). On the left side of the load composition window, all previously defined load blocks are shown. They can be marked and manoeuvred into the right window by clicking on the right arrow button. All load blocks in the right window are considered sequentially from top to bottom in the crack propagation calculation. The order of the block load sequences can be changed by using the arrow-up and/or arrow-down buttons (see Fig. 5).

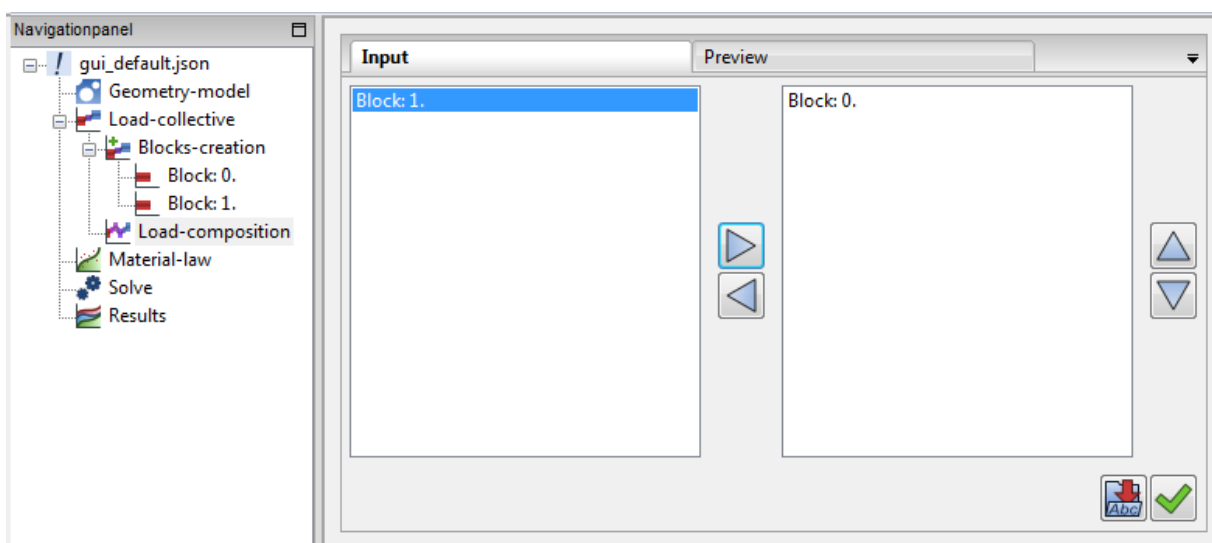
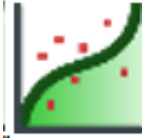


Figure 5. Definition of load block sequences used for calculation.



### Step 3: Material law

In the demo version of CCFG, the only material law (fatigue crack propagation equation) available is *MCL short crack*. This model is an extension of the NASGRO equation and described in detail in the publication [„Modified NASGRO equation for physically short cracks‘](#). It is able to describe the “anomalous” behaviour of short cracks very well based on an extended description of the cyclic crack growth resistance curve (R-curve).

The editing is done – similar to Step 2 – again via a button bar. In Fig. 6 a dataset for the quenched and tempered steel 25CrMo4 is shown. The exact meaning of the individual parameters is described in the publication cited above.

use	$R$ [-]	$a_k$ [mm]	$C$ [mm/MPa $\sqrt{m}$ ]	$\alpha$ [-]	$\sigma_{max}/\sigma_F$ [-]	$m$ [-]	$v_1$ [-]	$v_2$ [-]	$l_1$ [mm]	$l_2$ [mm]	$\Delta K_{th,eff}$ [MPa $\sqrt{m}$ ]	$\Delta K_0$ [MPa $\sqrt{m}$ ]	$C_{th}$ [-]	$K_{IC}$ [MPa $\sqrt{m}$ ]
<input checked="" type="radio"/>	-1.0	0.0	7.6e-07	3.0	0.3	1.42	0.45	0.55	0.08	1.55	2.5	8.5	0.115	90.0

**Figure 6.** Material law *MCL short crack*; data for the QT steel 25CrMo4.



## Step 4: Solve

In step 4 an abort criterion has to be selected which will stop the crack growth calculation (Fig. 7); in the demo version only the maximum number of cycles can be chosen.

To optimize the calculations, both the number of decimal places as well as the increment of the integration intervals can be varied. The Runge-Kutta method is used for numerical integration.

The crack growth calculation is started by clicking the green check mark (*start solver*). A running calculation can be terminated at any time by clicking the red X button (*stop solver*). The calculation results can then be displayed in the *Results* step of the Navigation panel.

The screenshot shows a software interface for defining calculation parameters. It is divided into two main sections: 'Abort-criterion' and 'Settings'.  
In the 'Abort-criterion' section, there are two radio buttons. The first is selected and is labeled  $N_{max}$  with a text input field containing '1000.0' and a unit indicator '[-]'. The second is unselected and is labeled  $a_{max}$  with a text input field containing '1.0' and a unit indicator '[mm]'.  
In the 'Settings' section, there is a text input field for  $\Delta N$  containing '10.0' and a unit indicator '[-]'. Below it is a spin box for  $R_{digits}$  with the value '4' and up/down arrow buttons.  
At the bottom right of the dialog, there are two buttons: a red 'X' button and a green checkmark button.

**Figure 7.** Definition of the abort criterion and specification of the numerical accuracy.

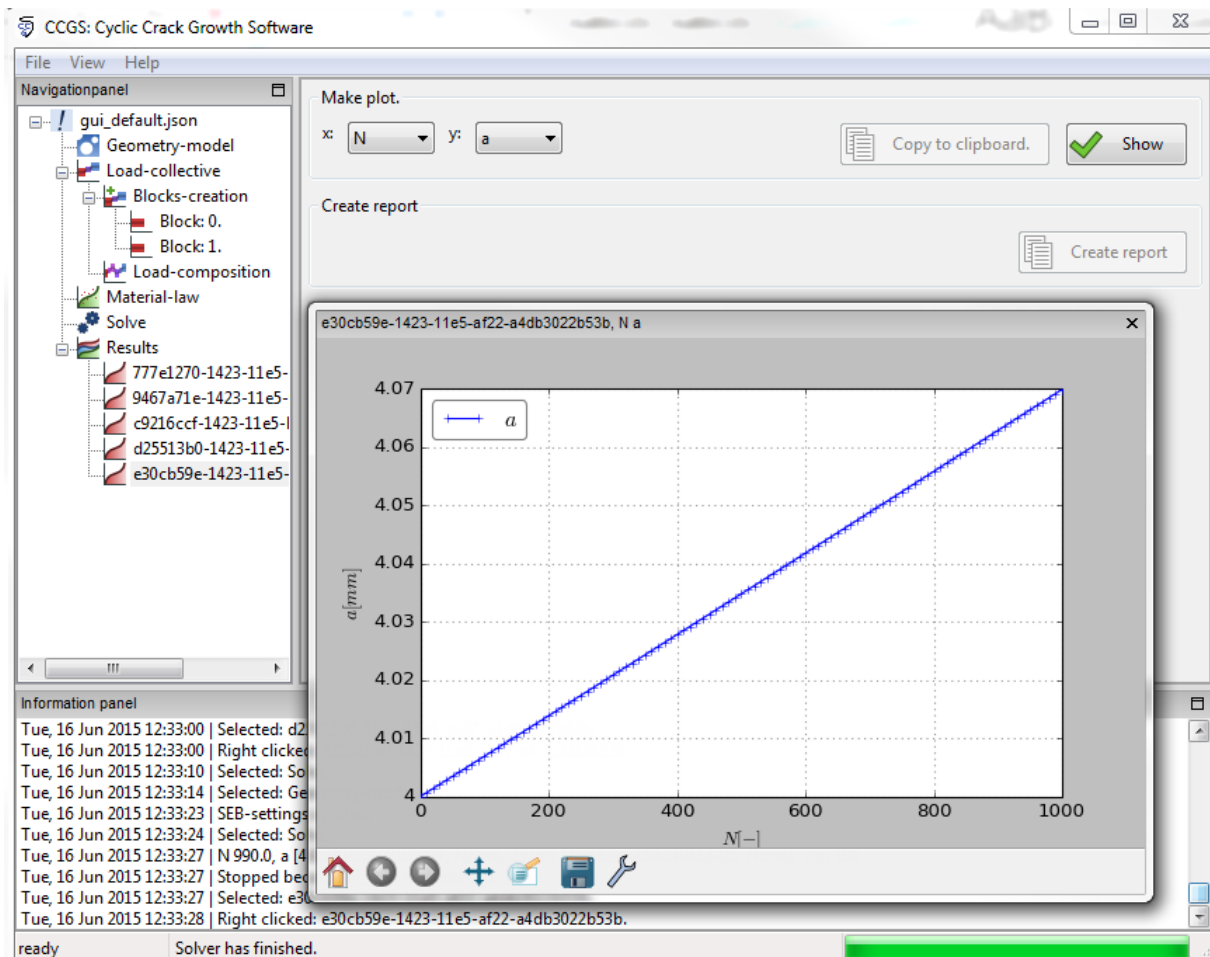


## Results

Here, the results of the calculations are listed and written into a results file. The results file may be renamed or deleted by right-clicking on the file name.

After a results file has been selected, the results of the crack propagation calculation can be displayed graphically by selecting one of the following choices for the x and y axes, respectively (Fig. 8):

a	crack length [mm]
dadN	crack propagation rate [mm/cycle]
deltaK	stress intensity factor range [MPa√m]
N	load cycle number [-]
R_K	load ratio [-]



**Figure 8.** Result window with graphical illustration of crack length vs. number of load cycles.