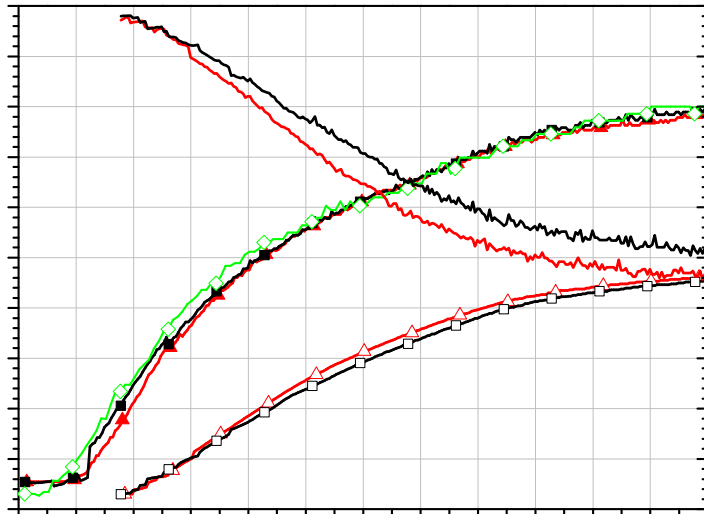


SMARTPICK

V1.50

User Manual

Rev. 1.50, November 2010



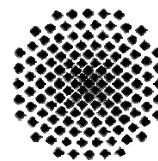
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SMARTMOTE
MONITORING & TESTING

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1 Introduction

The SMARTPICK software is an additional analysis tool for *FreshCon* systems equipped with shear wave sensors. The *FreshCon* system was originally developed at the University of Stuttgart to analyse the setting and hardening of any kind of material (especially fresh cement concrete and fresh mortar) by using an ultrasound analysis. Hereby, a short ultrasonic pulse is send into the specimen and recorded on the opposite side. With known distance between sender and receiver and by determining the travel time of the signal, the velocity of the pulse in the specimen can be calculated. This velocity changes while the material under consideration hardens.

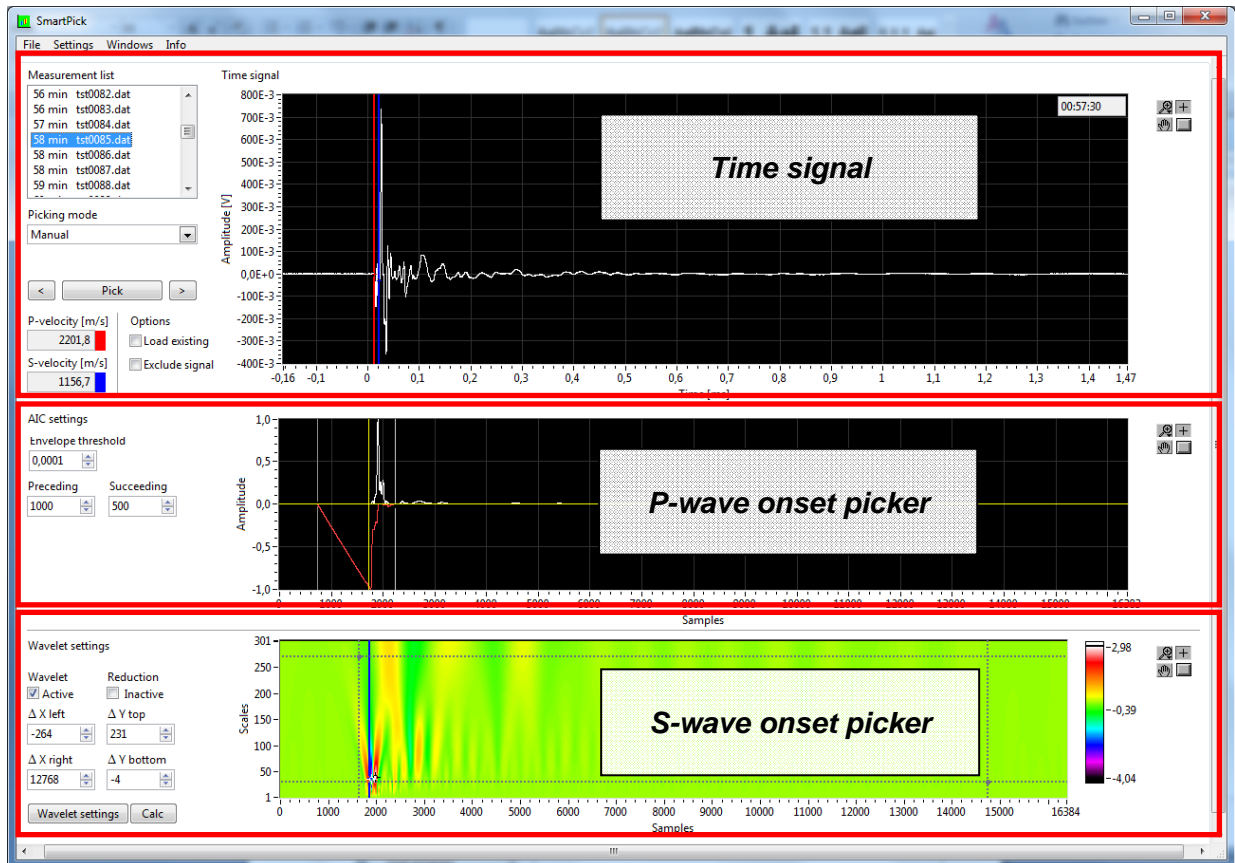


Traditionally, only the speed of the primary wave is determined. This has to be traced back to the fact that shear wave transducers also induce a compression wave into the specimen, which precedes and superimposes the shear wave onset and thus preventing a direct onset determination of the shear wave. With SMARTPICK, a tool is introduced which eludes this problem by extending the analysis space into a combined time-frequency-energy domain. The motivation is that although a primary interacts with the shear wave, its energy is much lower compared to the shear wave when properly introduced into the material. Additionally, their frequency contents differ, allowing discrimination between the two and their specific onset times by these criteria.

Having determined both pulse velocities, the dynamic elastic parameters of the material can be calculated. This gives the user the unique possibility to research the very early age properties of the considered material.

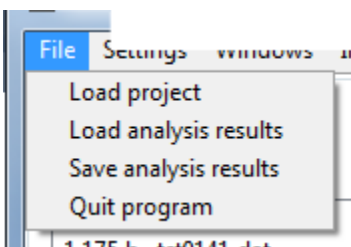
2 The user interface

At the very top, the [main menu](#) is located. It contains the main program controls. The main user interface is composed of three sections. In the top section, the [time signal](#) is located. Here, the signal to be evaluated can be selected, the picking mode is set and the determined pulse velocities are displayed. The centre section shows the [onset picker for the primary wave](#) along with its settings, the bottom window for the [shear wave onset picker](#).



2.1 The main menu

The **File register** contains the standard program controls.



2.1.1 Load project

Select a valid *FreshCon* data folder. To be valid, it has to contain at least the *measurements.txt* and *settings.txt* files along with the measurement data files **.dat*.

2.1.2 Load analysis results

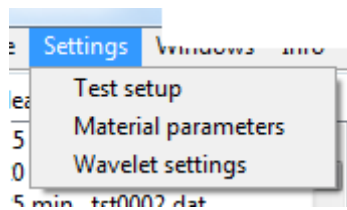
Select analysis results previously obtained with SMARTPICK. The results are located in the project subfolder *Analysis results* and named according to the date and time of their creation.

2.1.3 Save analysis results

Save the current analysis results in an additional file.

2.1.4 Quit program

Exit SMARTPICK.



In the **Settings register**, the [test setup](#), the [material parameters](#) and the [wavelet settings](#) can be changed.

2.1.5 Test setup

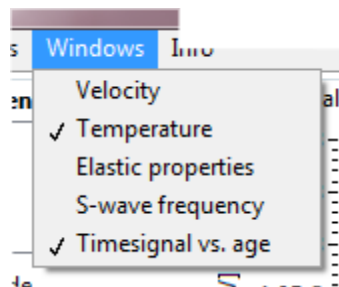
Change the test parameters which were specified during the FreshCon test. The *Experiment name* can be freely chosen. It does not influence the program flow. The *Distance* is needed for the calculation of the pulse velocities. It has to be specified as the distance between the two inner faces of the FreshCon container. The *Delay time* corresponds to the travel time between the sending and receiving transducer when the container faces are directly coupled together. Similarly, the *Reference energy* corresponds to the transmitted energy in the case of direct container face coupling. The *test interval*, *no. of tests* and *signals per test* are fixed values and cannot be changed. The *Zero time* is the time between the preparation of the test specimen and the first ultrasonic measurement. *Pulse width* and *Pulser voltage* are for documentation only.

2.1.6 Material parameters

Specify the material density. This is needed for the calculation of the dynamic elastic properties.

2.1.7 Wavelet settings

Change the wavelet settings. For detailed information, please see [section 2.4](#).



In the **Windows register**, additional windows can be opened and closed.

2.1.8 Velocity

Displays a window with the determined p- and s-wave velocities vs. the measurement time.

2.1.9 Temperature

Shows the temperature data recorded during the test. The data cannot be changed.

2.1.10 Elastic properties

Brings up a window with the dynamic elastic modulus (left scale) and the dynamic Poisson's ratio (right scale) vs. the measurement time. The values are calculated from the determined p- and s-wave pulse velocities and using the material density specified in the [material settings](#). The following formulae are used for the calculation:

$$v_{dyn} = \frac{\frac{1}{2} v_p^2 - v_s^2}{v_p^2 - v_s^2}$$

$$E_{dyn} = v_p^2 \cdot \rho \cdot \frac{(1 + \nu_{dyn})(1 - 2\nu_{dyn})}{1 - \nu_{dyn}}$$

where ν_{dyn}	dynamic Poisson's ratio	[-]
E_{dyn}	dynamic elastic modulus	[N/mm ²]
ρ	material density	[kg/m ³]
v_p	p-wave velocity	[m/s]
v_s	s-wave velocity	[m/s]

2.1.11 S-wave frequency

Displays a window with the development of the s-wave frequency vs. the measurement time. It is calculated from the time difference Δt between the picked minimum and maximum value in the wavelet picker. Δt corresponds to half a wavelength λ of the current signal. The calculation of the s-wave frequency is thus given by

$$f_s = \frac{v_s}{\lambda} = \frac{v_s}{2 \cdot v_s \cdot \Delta t} = \frac{1}{2 \cdot \Delta t}$$

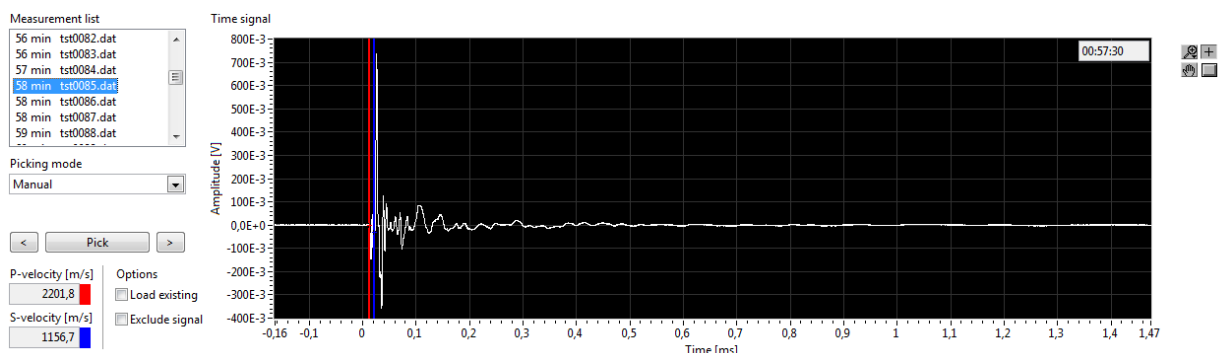
2.1.12 Timesignal vs. age

All recorded time signals are horizontally arranged next to each other, with the time axis pointing in positive y-direction. The time signal's amplitudes are colour coded. The data cannot be changed.

The **Info register** shows the contact and version information for SMARTPICK.

2.2 The time signal

The uppermost section of the user interface shows the options concerning the recorded time signal and the processing control. This includes the selection and display of the time signal, the picking mode and the indication of the determined pulse velocities.



2.2.1 Measurement list

The measurement list shows the available data files for the current project. It is loaded from the *measurements.txt* file, which is located in the project folder. The first part of the file naming is the time of the measurement including the [zero time](#). The second part corresponds to the name of the data file.

2.2.2 Time signal

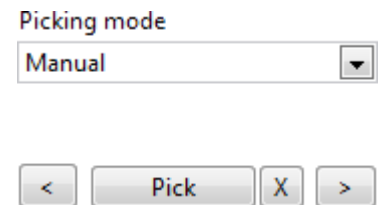
The time signal shows the amplitudes in volts recorded by the transducer over the signal length in milliseconds specified during the experiment. The two cursor positions correspond to the automatically determined onset times of the p- and the s-wave. When manually changing the cursor position, the velocities are adapted according to the cursor drop position. In the top right corner, the measurement time of the current signal is shown in hours, minutes and seconds.



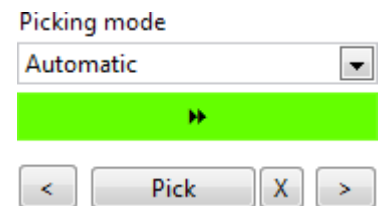
On the right hand side of the time signal, the cursor controls can be found. Clicking the zoom lens symbol gives various possibilities for changing the zoom in the time signal. The cursor changes into a zoom tool. The cross symbol activates the standard cursor tool, which allows changing the set cursor positions. Selecting the hand symbol permits to shift the entire graph position within the given limits and without changing the zoom. The last symbol resets all cursor positions.

2.2.3 Picking mode

For picking the signal onsets, two picking modes are available. In the manual mode, either specific files can be selected via the [measurement list](#), or sequent files by clicking the *Forward* or *Backward* buttons. When a file is loaded, the onset times are automatically picked, using the current picker specifications for the p-wave and s-wave. If the data file has been previously picked, the existing onset times are loaded instead. The *Pick* button can then be used to automatically repick the current signal.





When changing into the automatic mode, a red rectangle appears below the selection, indicating that the automatic processing is currently stopped. To start the automatic picking, either the *Forward* or *Backward* button has to be clicked. Depending on the selection, the picking process starts to analyse the data files in sequential order, either in ascending or descending order, beginning at the currently selected file. The rectangle changes its colour into green and shows an arrow indicating the processing direction. To stop the automatic picking, the green rectangle has to be clicked again.



2.2.4 Velocity indicators

The two velocities shown below the picking mode selector indicate the p- and s-wave velocities corresponding to the currently set cursor positions in the time signal. Clicking on the coloured rectangles to the right of each indicator allows changing the corresponding cursor colours.

P-velocity [m/s]	S-velocity [m/s]
2000.0 	1111.1 

2.2.5 Options

To disregard any previously saved values, the *Load existing* checkbox can be deactivated. Note that this implies that any previously picked values are overwritten.

In case the current signal shall be excluded from the both the manual and the automatic picking, i.e. no onset times shall be saved, the *Exclude signal* checkbox can be activated. The *Exclude signal* checkbox has to be explicitly unchecked to save any result again.

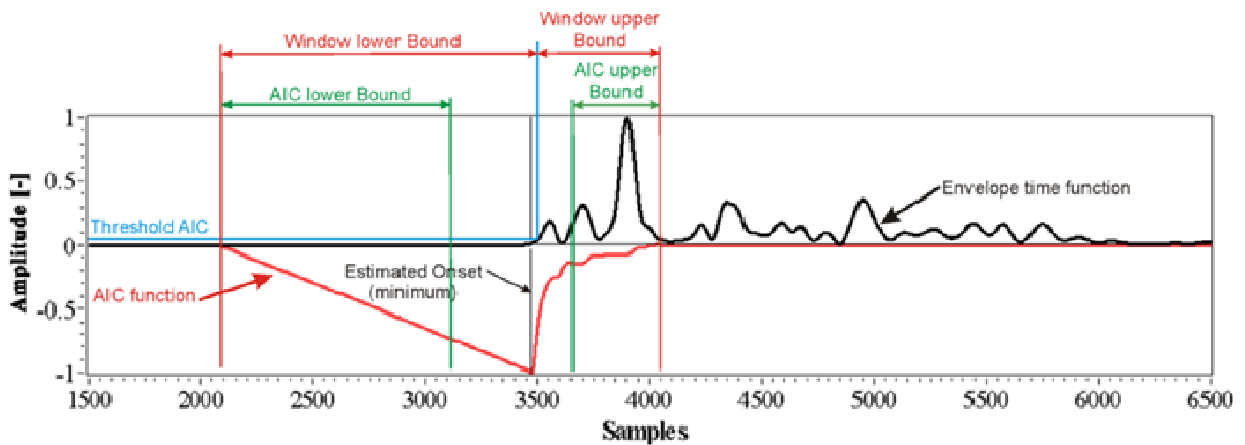
2.3 The p-wave onset picker

The picker for the determination of the p-wave onset is based on the Akaike Information Criterion (AIC)¹. It was adapted to ultrasonic signals by *Kurz, Große and Reinhardt*². The developed autoregressive AIC-picker first creates an envelope time function $E(t)$ via the Hilbert transform $\bar{R}(t)$ from the time signal $R(t)$ as

$$\bar{R}(t) = \frac{1}{\pi} \cdot \int_{u=-\infty}^{\infty} \frac{R(u)}{t-u} du$$

$$E(t) = \sqrt{R(t)^2 + \bar{R}(t)^2}$$

where $\bar{R}(t)$ Hilbert transform
 $R(u)$ time signal
 u current timestep
 $E(t)$ envelope time function



In the envelope time function, a simple threshold level set by the *Envelope threshold* is used to pick an onset window. The size of the window is specified by the parameters *Preceding* and *Succeeding*. These parameters define a number of samples before and after the located amplitude in the envelope time function corresponding to the threshold level.

The AIC function $AIC(t_W)$ is then calculated for the selected window as

$$AIC(t_W) = t_W \cdot \log\left(\text{var}(R_W(t_W, 1))\right) + (T_W - t_W - 1) \cdot \log\left(\text{var}(R_W(1 + t_W, T_W))\right)$$

where $AIC(t_W)$ AIC function within the selected window
 t_W time within the selected window
 R_W time signal within the selected window
 T_W maximum time of the selected window

AIC settings

Envelope threshold

0.0005

Preceding

1000

Succeeding

500

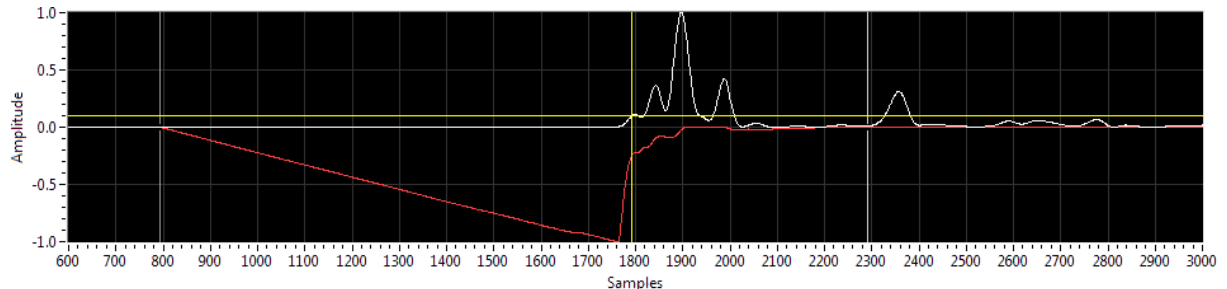
¹ AKAIKE, H.: *A new look at the statistical model identification*. IEEE transactions on automatic control, vol. AC-19, no. 6, 1974.

² KURZ, J.H.; GROÙE, C.U.; REINHARDT, H.W.: Strategies for reliable automatic onset time picking of acoustic emissions and of ultrasound signals in concrete. Ultrasonics, vol. 43, pp. 538 - 546, 2005.

$\text{var}(R_W(t_W, 1))$ the variance of R_W from the current value of t_W

$\text{var}(R_W(1 + t_W, T_W))$ the variance of R_W between $1 + t_W$ and the T_W

The point of the global minimum in AIC function then equals the onset time of the time signal.



In SMARTPICK, the p-wave onset picker shows the envelope time function (white) and its corresponding AIC function (red). The *yellow cursor* indicates the point where the specified threshold level is exceeded. The two *gray cursors* are related to the preceding and succeeding samples. To change the AIC parameters, either the values in the input boxes can be changed, or the cursors in the AIC graph can simply be shifted to the desired values.

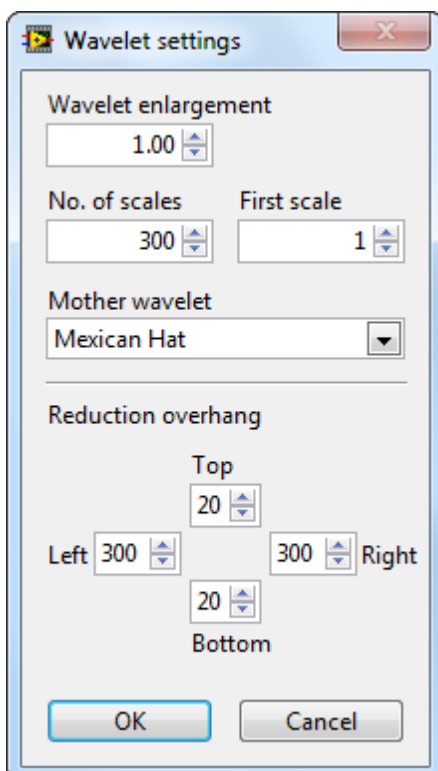
To the right of the graph, [cursor controls](#) like described for the time signal can be found.

The five parameters of the AIC picking algorithm are to be set individually for different concrete mixes. However, there are some general suggestions that should be taken into account:

- *AIC threshold*: The *AIC threshold* should be chosen as low as possible. Values down to 0.001 are feasible.
- *Window lower bound*: This value should not exceed the amount of pretrigger samples. A good value to start is to set the *Window lower bound* to the value of the pretrigger samples.
- *Window upper bound*: This value should be less than the *Window lower bound*. Preferably *Window upper bound* should be half of the chosen *Window lower bound*.

- *AIC lower bound*: *AIC lower bound* should be less than *Window lower bound* for almost all situations. Only in case of very early stage at which the electromagnetic noise dominates the signal and velocity of the tested material is quite low *AIC lower bound* has temporarily to be set to a value that is 50 to 100 samples larger than *Window lower bound*.

- *AIC upper bound*: *AIC upper bound* must be less than *Window upper bound*.



2.4 The s-wave onset picker

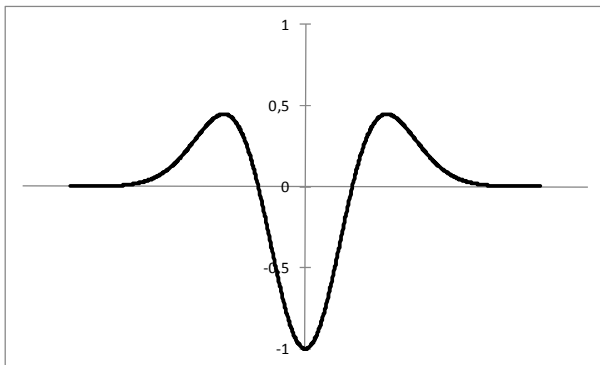
To determine the onset time of the shear wave, the time signal is transformed into a time-frequency domain by means of a continuous wavelet transform. Hereby a scalable *mother wavelet* is moved along the time axis and the correlation between the signal and the mother wavelet is calculated. This corresponds to a multiplication of the signal's Fourier transform with the scaled wavelet.

In the *Wavelet settings*, different scaling parameters can be chosen. The *Wavelet enlargement* sets the width change of the mother wavelet for successive scales. I.e. the higher the enlargement value, the more importance is given to the

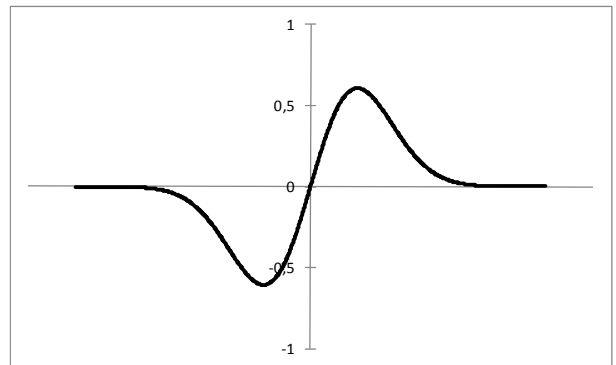
analysis of lower frequencies and vice versa. The value for *No. of scales* determines the frequency resolution of the wavelet graph. Hereby, low scales correspond to high frequencies and high scales to low frequencies. Changing the no. of scales visually corresponds to changing the maximum value of the y-axis. Similarly, the *First scale* sets the starting point for the frequency analysis, visually like changing the minimum value of the wavelet graph.

Finally, the *Mother wavelet* can be selected. Four different options are available: Mexican Hat, Antisymmetric, Shannon and Haar. They are of the form

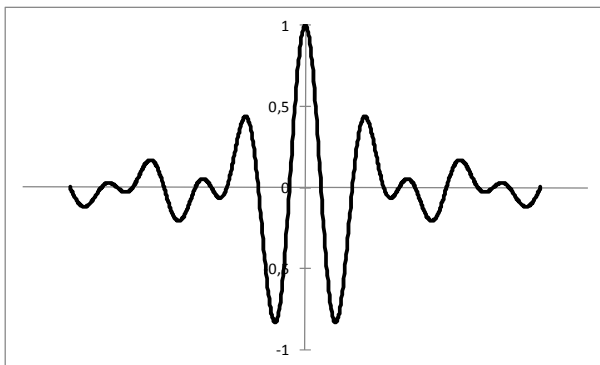
Mexican Hat	$\psi(x) = (x^2 - 1) \cdot e^{-\frac{x^2}{2}}$
Antisymmetric	$\psi(x) = x \cdot e^{-\frac{x^2}{2}}$
Shannon	$\psi(x) = \frac{\sin(\xi)}{\xi} \cdot \cos\left(\frac{3\pi x}{2}\right)$ with $\xi = \frac{2\pi x}{4}$
Haar	$\psi(x) = \begin{cases} 1 & \text{for } x \in [0; \frac{\alpha}{2}] \\ -1 & \text{for } x \in [\frac{\alpha}{2}; \alpha] \\ 0 & \text{for } x \notin [0; \alpha] \end{cases}$



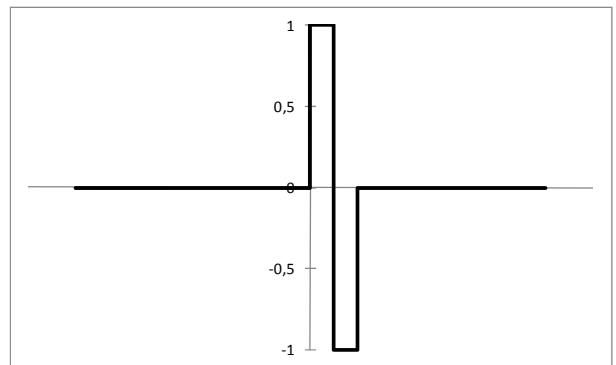
Mexican Hat wavelet



Antisymmetric wavelet



Shannon wavelet



Haar wavelet

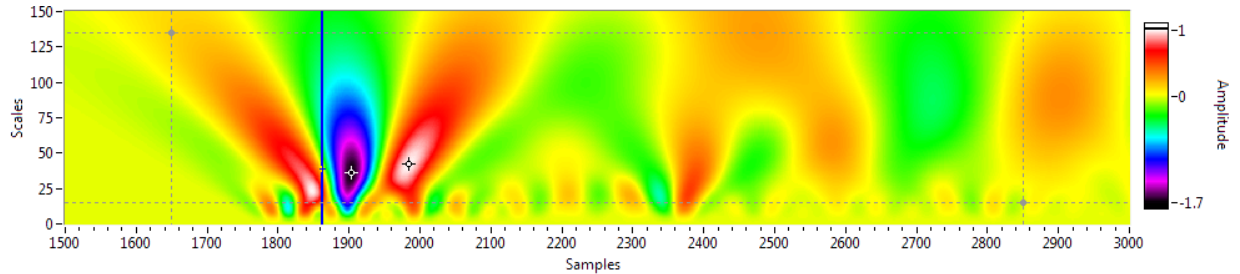
Analytically, the change of the mother wavelet $\psi(x)$ as governed by the chosen parameters produces a daughter wavelet

$$\psi^*(t) = \psi\left(\frac{t - \tau}{s}\right)$$

where τ is a parameter for shift of the wavelet along the time axis and s a scaling parameter. The former is automatically chosen in SMARTPICK according to the size (number of samples) of the time signal. The latter is set by the user in the wavelet settings as

$$s = j \cdot (\text{Wavelet width}) + (\text{First scale}) \quad \text{where } j = 0 \dots (\text{No. of scales}).$$

In the wavelet graph in the right half of the screen, the calculated transform of the time signal in the time-frequency domain is displayed. To the right of the wavelet graph, [cursor controls](#) as described for the time signal are located.

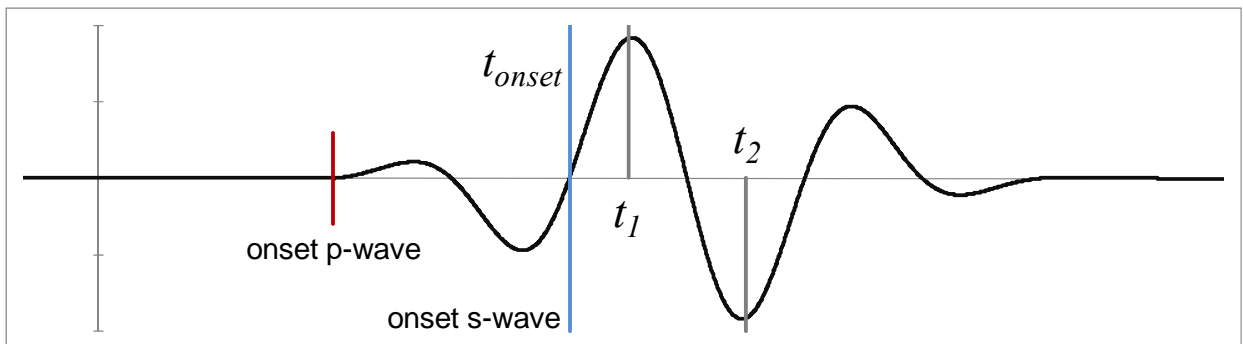


The calculation of the s-wave onset time takes the two conditions as a basis. First, it is presumed that when using shear wave transducers, the predominant part of the impulse energy is transmitted with the shear wave and not the accompanying primary wave. Furthermore, the frequency contents of the shear and primary waves most likely differ from each other. Meeting these two conditions allows an identification of the maximum and minimum value in a certain window in the wavelet graph as the extreme values of the induced shear wave. The distance on the time axis Δt between the first extreme value t_1 and the second extreme value t_2 corresponds to half the oscillation period T of the shear wave.

$$\frac{T}{2} = \Delta t = t_2 - t_1 \quad \text{for } t_2 > t_1$$

Subtracting a quarter of an oscillation period from the time of the maximum value yields the onset time of the signal.

$$t_{onset} = t_1 - \frac{T}{4} = t_1 - \frac{\Delta t}{2} = \frac{3}{2}t_1 - \frac{1}{2}t_2$$



The oscillation period T is the reciprocal of the shear wave frequency f_{shear}

$$f_{shear} = \frac{1}{T}$$

and thus the shear wave frequency can be calculated to

$$f_{shear} = \frac{1}{2 \cdot \Delta t}$$

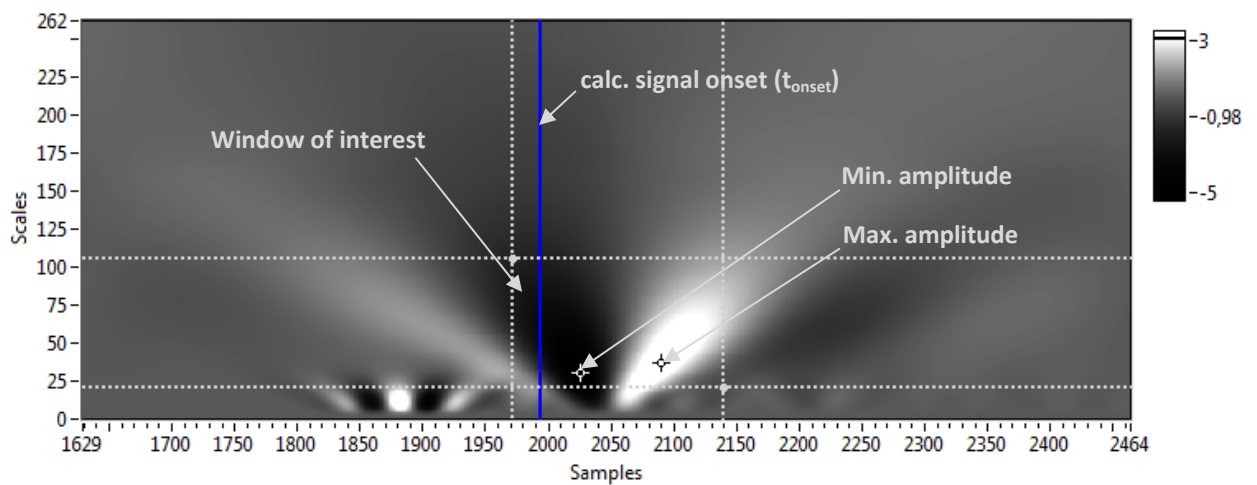
The window in which the extreme values are picked can be set by dragging the dashed gray cursors into the desired positions. It can then be fine-tuned with the parameters ΔX left,

ΔX right, ΔY top and ΔY bottom. These parameters set the distances between the extreme values and the borders of the picking window. To repick the extreme values in the new window, the *Pick* button has to be clicked. This also updates the picking window.

To increase the speed of the wavelet calculation, the checkbox *Reduction* can be activated. When active, the wavelet is only calculated in a window corresponding to the cursor positions, plus an overhang on each side as specified in the [Wavelet settings](#) in the section *Reduction overhang*. The settings for *First scale* and *No. of Scales* are ignored in this case. To completely deactivate the wavelet calculation, the *Wavelet* checkbox can be selected. Note that no elastic properties can then be derived. A recalculation of the wavelet can be executed by clicking the *Calc* button.

Wavelet settings

Wavelet	Reduction
<input checked="" type="checkbox"/> Active	<input type="checkbox"/> Inactive
ΔX left	ΔY top
-550	45
ΔX right	ΔY bottom
684	-18
<input type="button" value="Wavelet settings"/>	<input type="button" value="Calc"/>



3 Program flow

3.1 First steps

Once a project has been [loaded](#) via the [main menu](#), the [measurement list](#) with the available data files updates. An existing [analysis results file](#) can then optionally be loaded. Clicking on one of the data files loads the selected [time signal](#). The [p-wave onset](#) can be picked by clicking the *Pick* button, where the identified onset is dependent on the [AIC settings](#). If the wavelet calculation is [activated](#) and a [material density](#) is specified, also the [s-wave onset](#) is calculated. The results for the velocity are shown in the [indicators](#), as well as in the [velocity window](#), which can be brought up via the [main menu](#). Also the [elastic properties](#), the [shear wave frequency](#) and the [measured temperature](#) can be displayed.

3.2 Manual picking mode

To continue with another file in the manual [picking mode](#), either the [Forward](#) or [Backward](#) button can be clicked, or a measurement can be selected from the [measurement list](#). The last position of the [p-wave onset and s-wave onset cursors](#) in the time signal graph are saved in the [analysis results file](#), unless the [Exclude](#) button is activated. Upon loading a new time signal, the onset times are automatically picked. To change the picked position, either the picking options for the [p-wave picker](#) and the [s-wave picker](#) can be adjusted, or the [cursors](#) indicating the picked onset in the time signal can be shifted. In the wavelet graph, the [picking window](#) size is adjusted to meet the [selected values](#), i.e. the distance between the extreme values and the window borders is kept constant after the new minimum and maximum has been identified, resulting in a change of the window size.

3.3 Automatic picking mode

When the automatic [picking mode](#) is chosen and a [direction](#) for the picking is selected, SMART-PICK works off the files with the set parameters until [terminated](#) or when the last or first file in the measurement list is reached. The procedure is analogue to manual picking.