INNOVATIVE MONITORING EQUIPMENT FOR PROFESSIONALS

Guideline Signal Matching with DLTWAVE



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In order to work DLTWAVE and to help you in getting started with Signal Matching we have enclosed below Guideline in the steps you should carry out in order to achieve a good Signal Match. Important to mention is that the TNO soil modelling method is being used. Related Theory to Signal Matching is enclosed in the appendix.

Before starting to work with the DLTWAVE software and the related Signal Matching it is important to be aware that you need to have good quality signals (Force and Velocity *x* impedance) as an output of PDA/DLT. Without proper input it is impossible to generate good quality Signal Matches.

A) Exporting a suitable PDA/DLT signal for DLTWave

If you have selected a particular blow which you want to use in the DLTWave you can press below marked button in the toolbar. This action will create a signal matching file with the related extention *.smf. After clicking the button you will be asked where to save the *.smf

Pay attention : below screenshot is in the PDA/DLT acquisition software

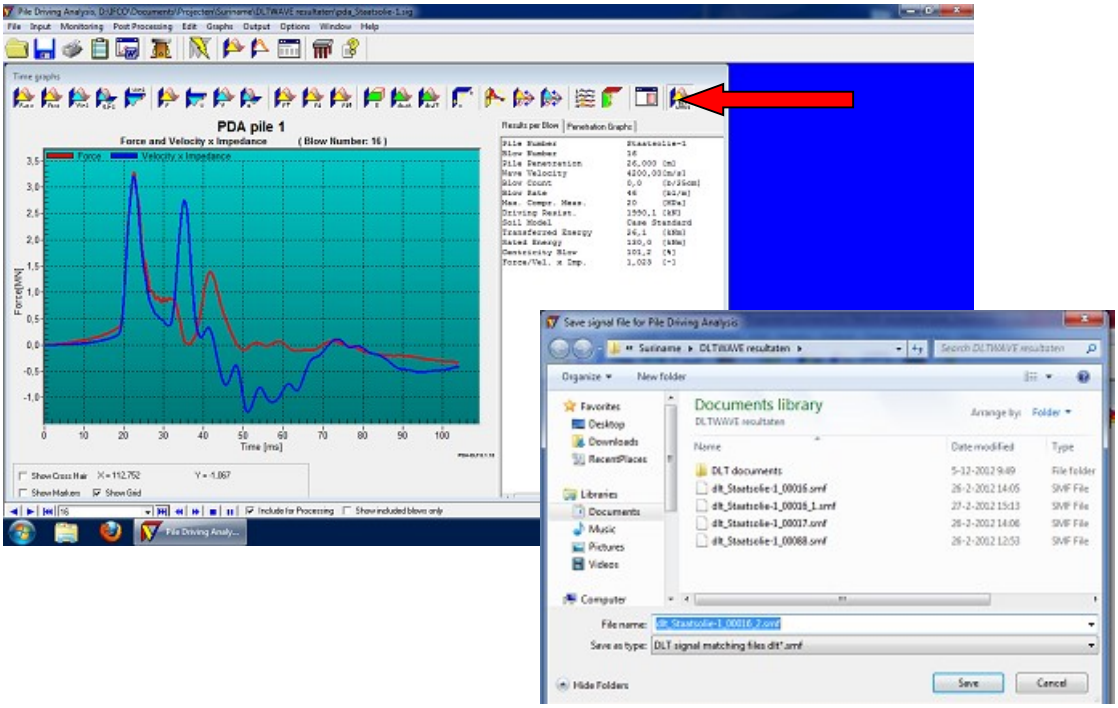


*Fig 0. PDA/DLT screenshot with marked button to create a *.smf file.*

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B) Importing a signal into DLTWave

1. To start with DLTWave you have to import a signal from a PDA/DLT test which you already have carried out. The file you require to import is a *.smf file which is generated in the PDA/DLT software after pressing the button shown on page 1.

2. In the *Drive Setup* menu press the Load button ( ) a choose DLT – signal file (PDA/DLT). A dialog screen will open which allows you to browse on your computer to select the requested *.smf file.

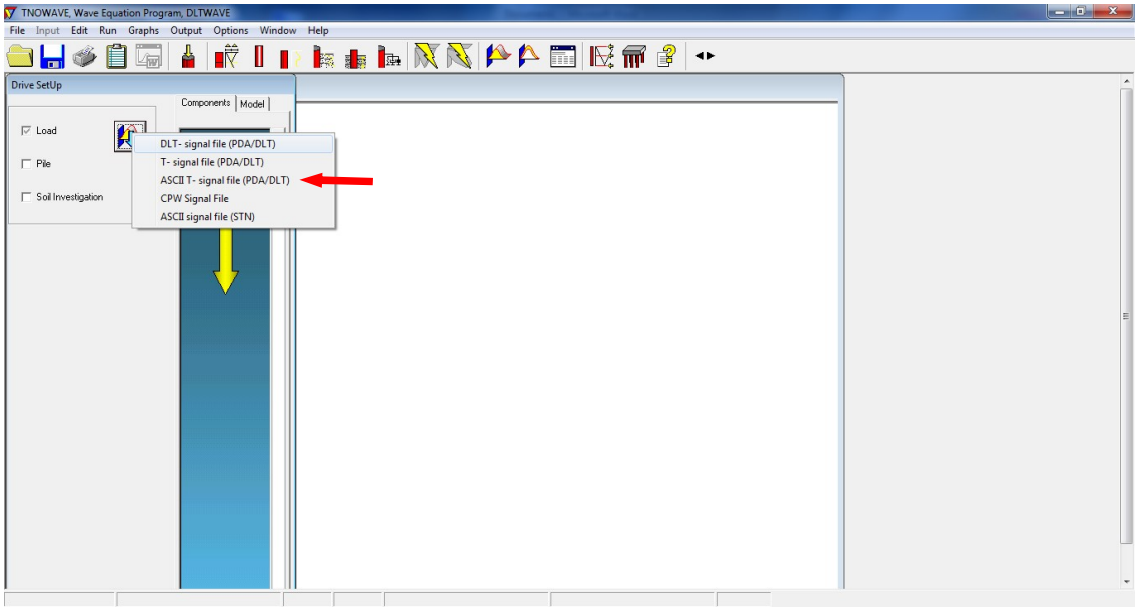
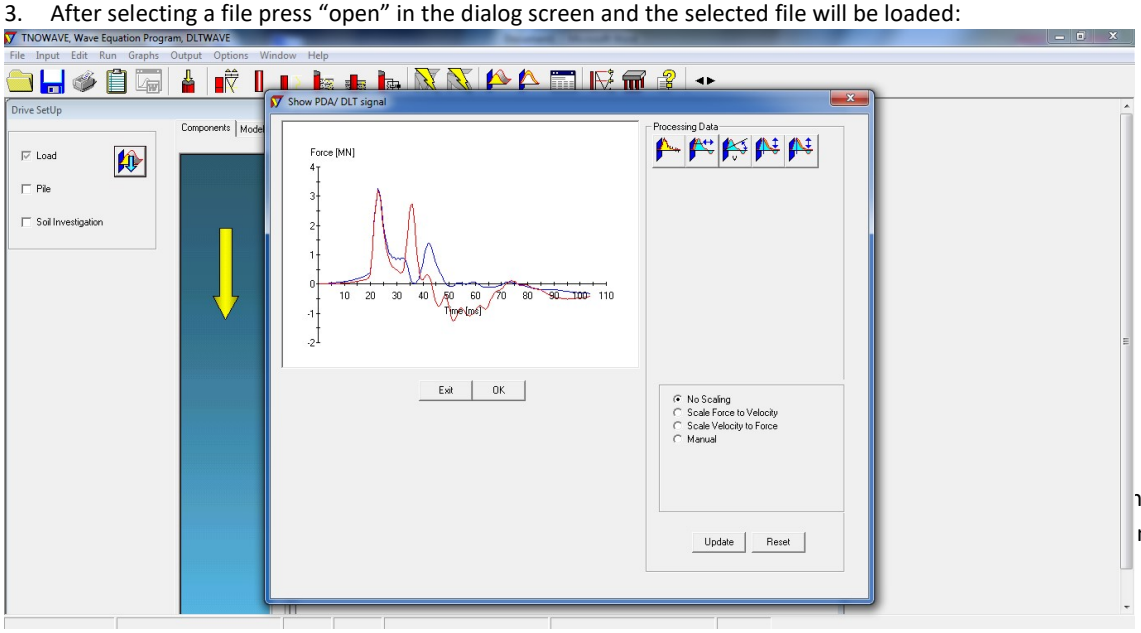


fig. 1. Starting screen DLTWave showing the Drive Setup menu.

3. After selecting a file press “open” in the dialog screen and the selected file will be loaded:



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C) Modelling the Pile

After importing the *.smf file has been completed the pile can be modelled.

5. Press the pile modelling button ( the Drive Setup screen. This will open the pile and allows you to define the pile on which you are going to apply the signal match on.

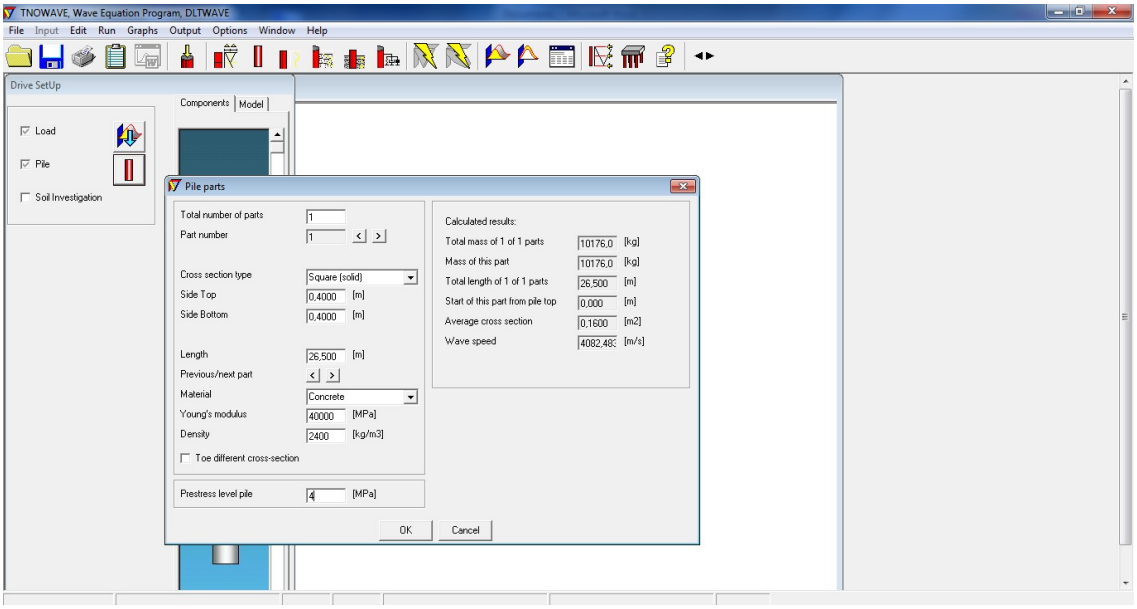


fig. 3. Pile modelling screen

6. Fill in the pile properties like:
    a. number of parts
    b. type of cross section
    c. Side at the top (and if applicable a different Side length at the bottom)
    d. The length of the pile
    e. Pile material
    f. Young's Modulus
    g. Density
    h. Pre stress level in the pile (when applicable)

Remark : When the pile consists of multiple parts, above input is required for all individual pile parts.

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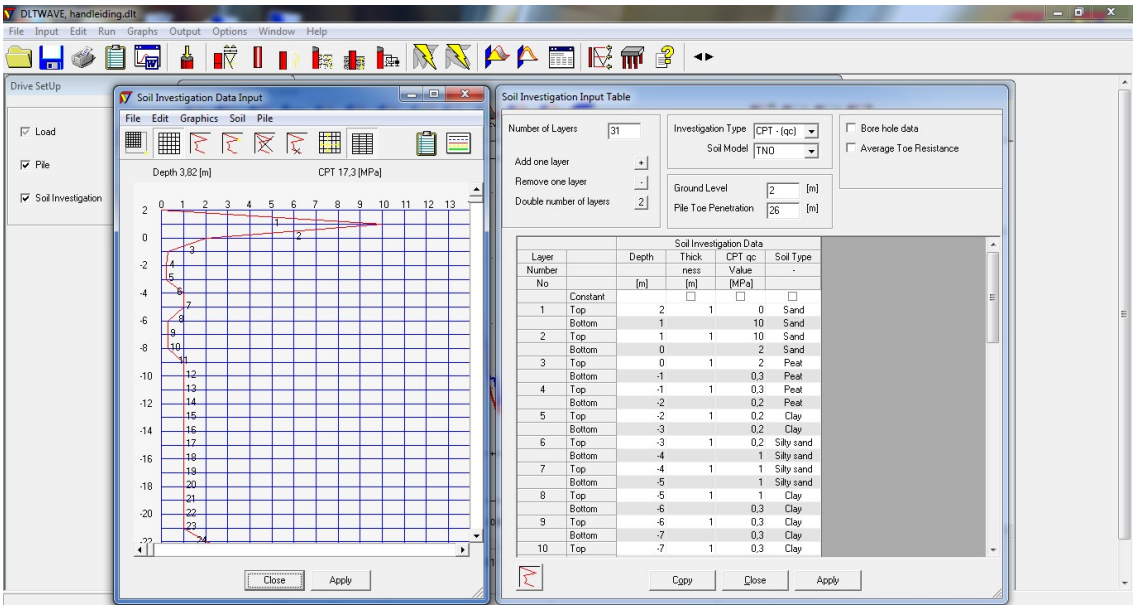
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D) Soil Investigation

Once all the pile properties have been entered the following step is to enter the soil investigation data into the program.

7. Start entering soil investigation data by pressing the soil investigation button () in the Drive Setup screen.

8. There are several options to define soil properties in DLTWAVE. The easiest method is to insert CPT data from the soil (when available) into the program. This can be done by entering all values by hand or by using the mouse pointer to draw a copy of the CPT. *Be aware that the more layers you add to the soil model the longer the signal matching will take.*



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9. The soil model can be improved if you add the soil classification the each layer. This can be done on the numerical input screen (last column in fig 4.) When the CPT contains a wide spread of tip resistance values (q_c) in the layers around the pile toe the program can calculate the average tip resistance. Using this option will improve the signal matching results.

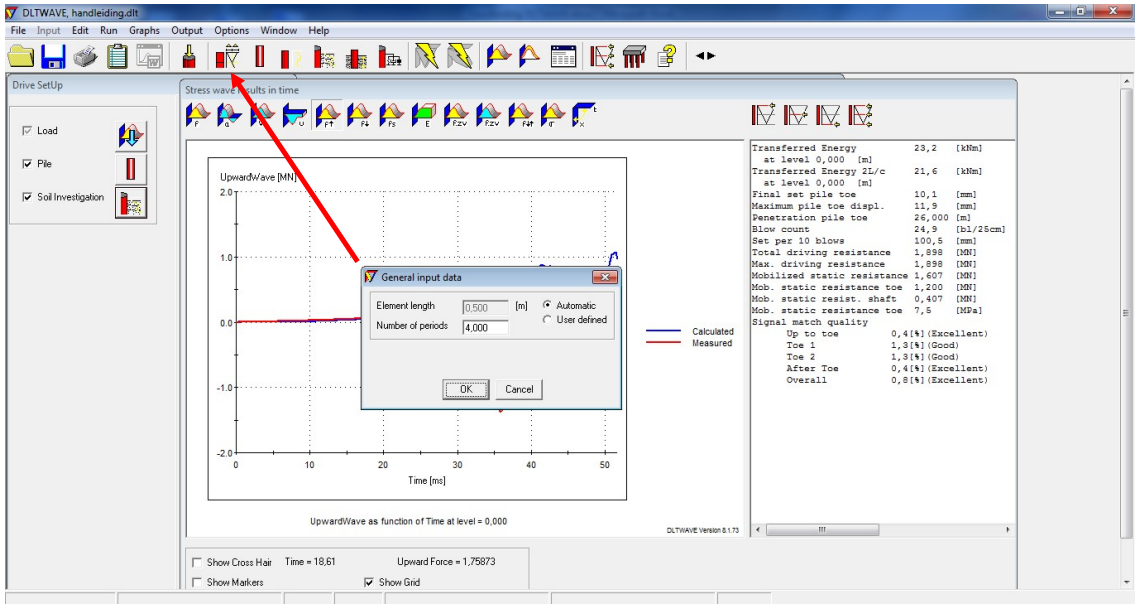


fig. 5. Soil modelling screen with left the option to draw your CPT and on the right side the numerical input screen.

10. After entering soil data make sure that the *element length* is being defined. The longest defined element length needs to be smaller then the thinnest entered soil layer in the program to obtain good results. The element length is default on *automatic*, but using the *user defined* option makes you more aware about what you are doing.

11. Now the number of periods need to be entered. The number of periods is related to the times L/c over which the signal matching has to be performed. Theoretical only 2L/c is right, because the sensors during testing have been mounted a distance around 2 times the pile diameter below the pile head. For a good quality match number of 4 to 6 periods needs to be entered.

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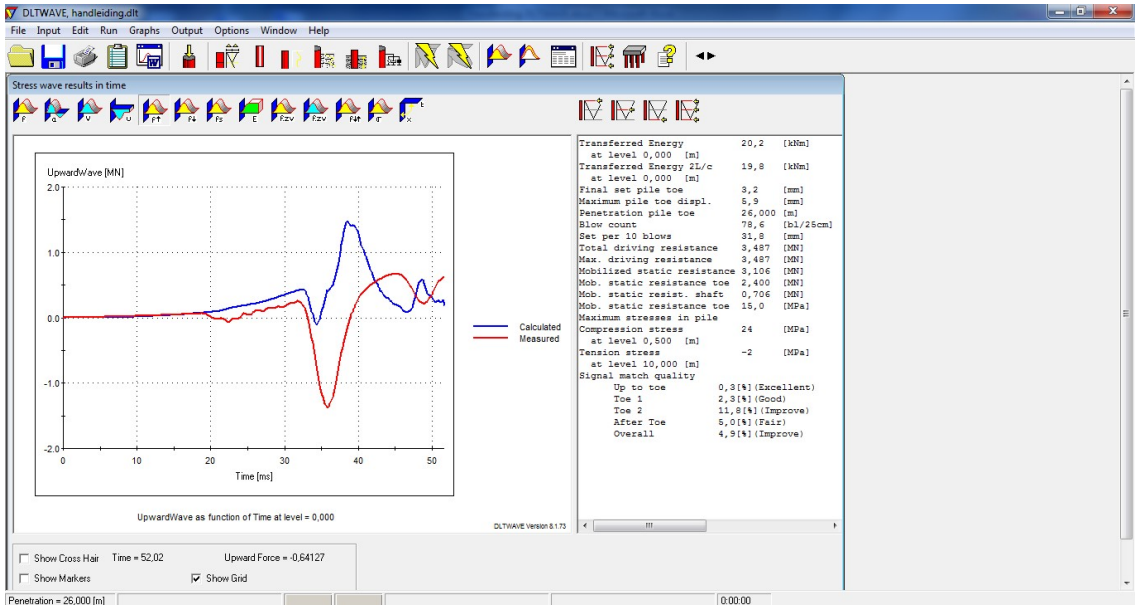


fig. 6. Initial run with DLTWAVE showing calculated signal and measured signal. The signal match needs to be improved

D) The first Signal Match

12. Now a first run can be done. The analysis corrects itself on to 2L/c (up to the toe reflex). In figure 6 it is clearly visible that the calculated signal is in the first part above the measured signal. This indicates that the friction is overestimated. Also the toe reflex is higher. This value is also above the measured value. Based on these results the signal match needs to be improved.

13. To improve the signal match we need to adjust parameters in the *Soil Model Input Table*

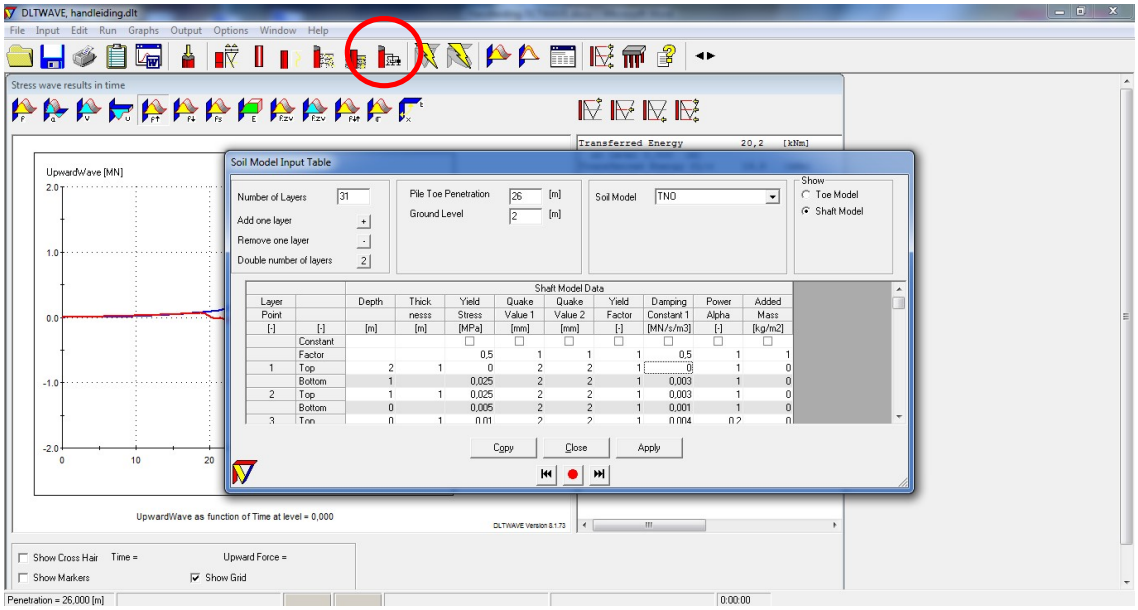


fig. 7. Overview of the "Soil Model Input Table"

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14. After modifying the *Yield Factor* and *Damping Constant* related to the shaft model in an equal proportion in the "Soil Model Input Table" For example changing the values from 1.0 to 0.9 in this case. This will result in less shaft friction and a better match. Make sure that after you changed a value in the "Soil Model Input Table" that you confirm your changes by pressing "Apply" followed by "Close". Only pressing close will not save your settings.
15. Be aware parameters related to the pile properties, ground level and pile penetration are not being changed, because these are fixed.

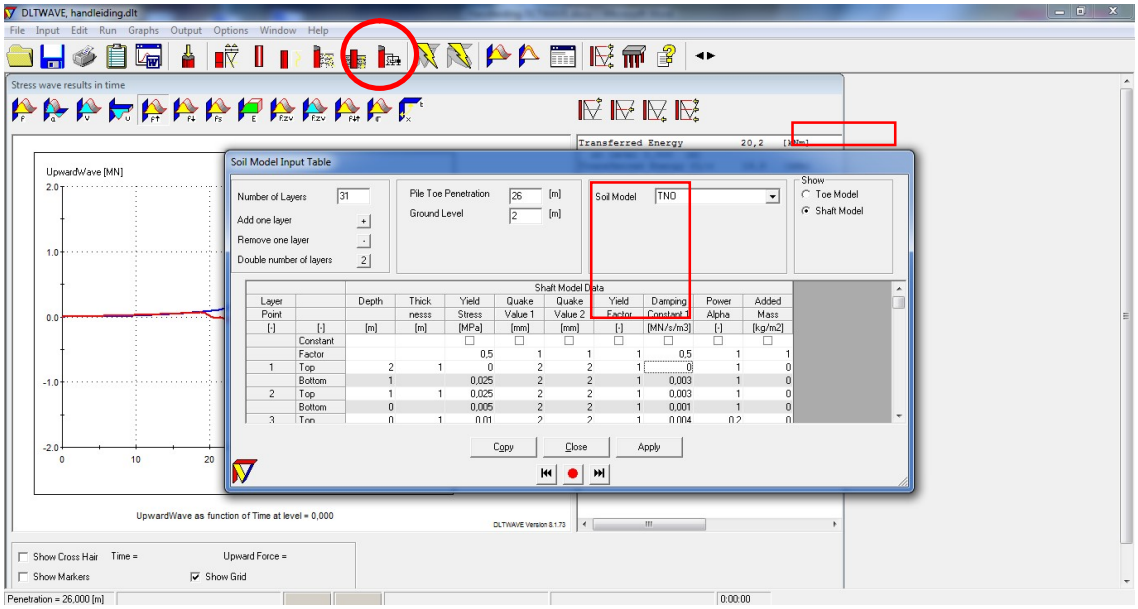
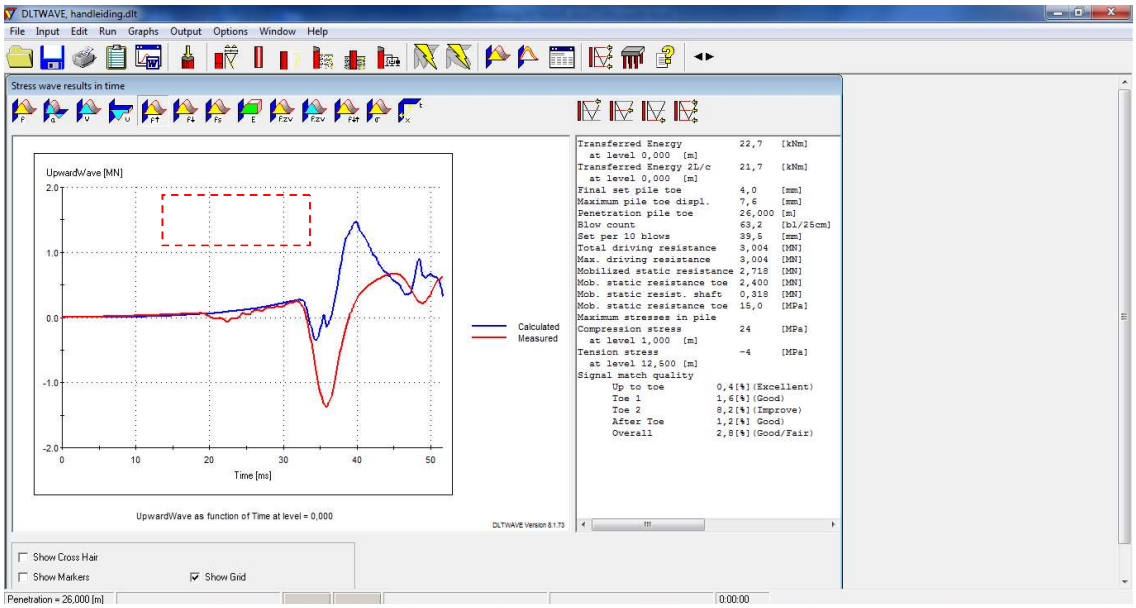


Fig. 8. Overview of the "Soil Model Input Table" Damping constant and Yield Factor



. *Fig. 9. Result of a better signal match along the shaft after changing Damping constant and Yield Factor*

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In figure 9 The improved signal match is shown after carrying out a single run. Also note that (in this case) The driving resistance has been reduced to 3.0 MN.

16. The *Yield Factor* from the pile toe and the *Damping* Constant at the toe are reduced in the same proportion. This will result a better match involving the toe reflex. . Also here be sure that after you changed a value in the "Soil Model Input Table" that you confirm your changes by pressing "Apply" followed by the red button to perform a single run.

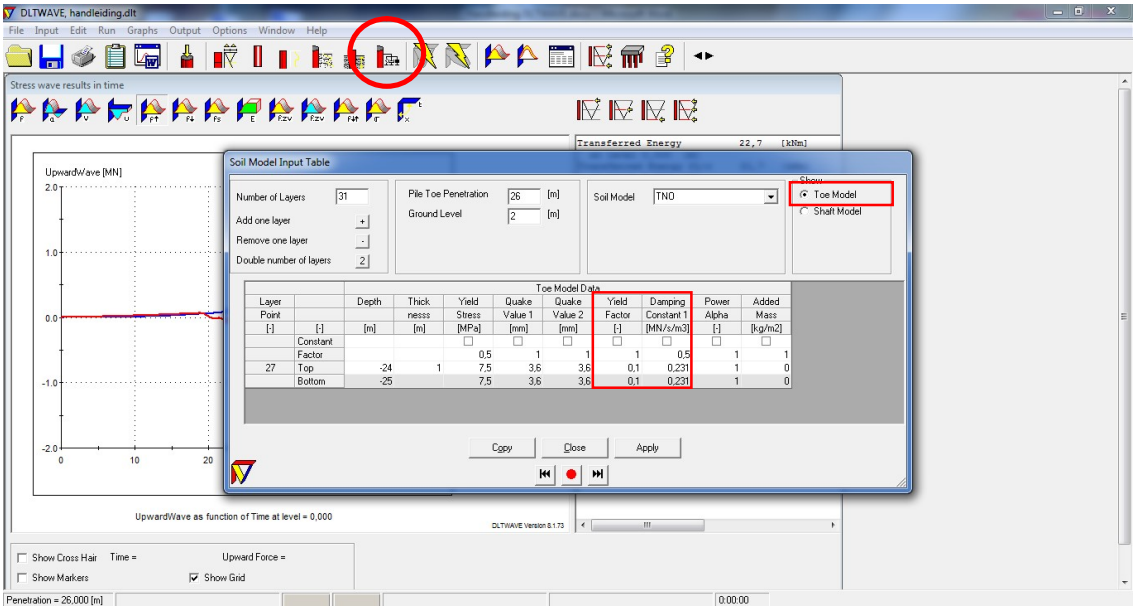


Fig. 10. Overview of the "Soil Model Input Table" Damping constant and Yield Factor for the Toe model

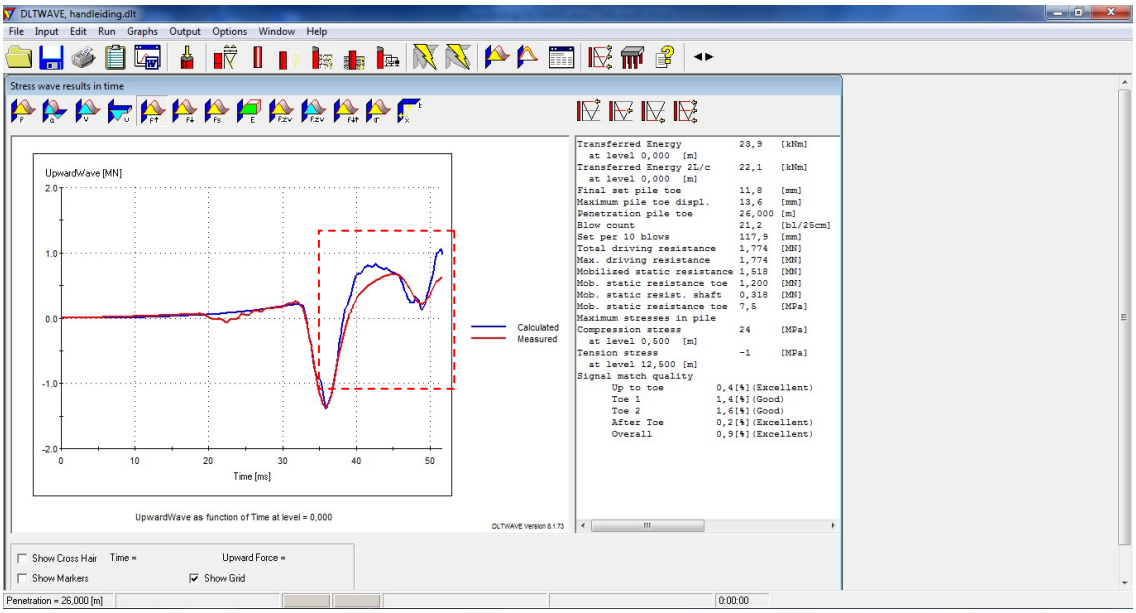


Fig. 11 Result of the signal match after changing the Yield Factor for the Toe model

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The result of changing the *Yield factor* and *Damping Constant* gives overall a better match. The Total driving resistance has been reduced (in this specific situation) and now the software is ready to optimize the results by starting the automatic matching.

17. Go to the toolbar and select the Run DLTWave button ( )  r pressing the button pop-up menu appears and in this menu choose “Automatic Matching” followed by the option “Soil Parameters. Make an initial run first to see if the matching is running properly and if so start the continuous matching procedure.

E) Continuous Signal Matching

The continuous matching procedure may take some time, this depends strongly on the amount of entered soil layers and pile elements.

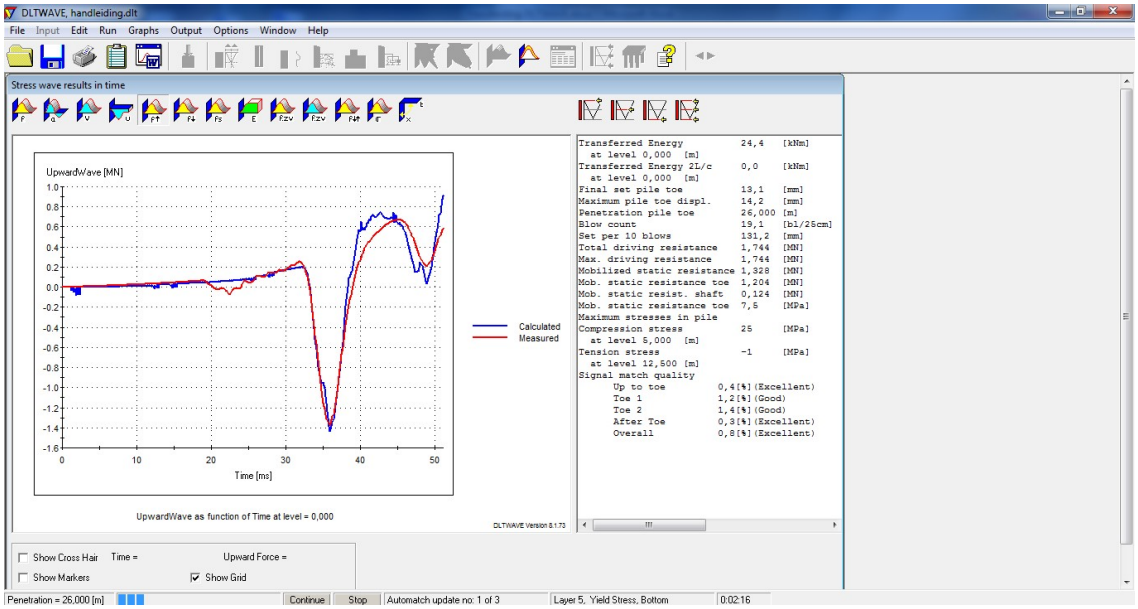


Fig. 12 Result of the signal match after the automatic run.

For an additional match with similar soil setup only a new *.smf has to be imported to create a signal match for a second pile on the same project. This means that after carefully determining the first match and evaluating the results additional signal matches can be performed quite efficiently.

After finishing the signal match the load settlement diagram can be calculated.

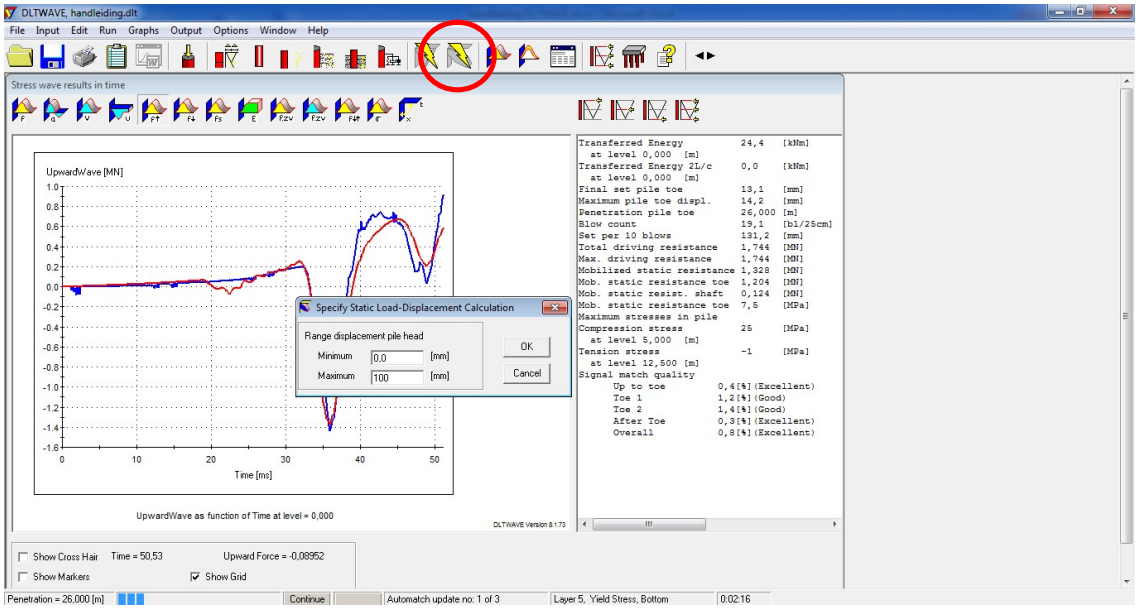
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F) Results

18. To calculate the load settlement diagram press the button “Get Static Load Displacement Diagrams”. This button is right next to the “Run DLTWave with similar lay-out ( ) . 



19. Enter the range of the pile head displacement. The maximum displacement is normally 100 mm, a pile is commonly rejected after exceeding a displacement of more than 100 mm.

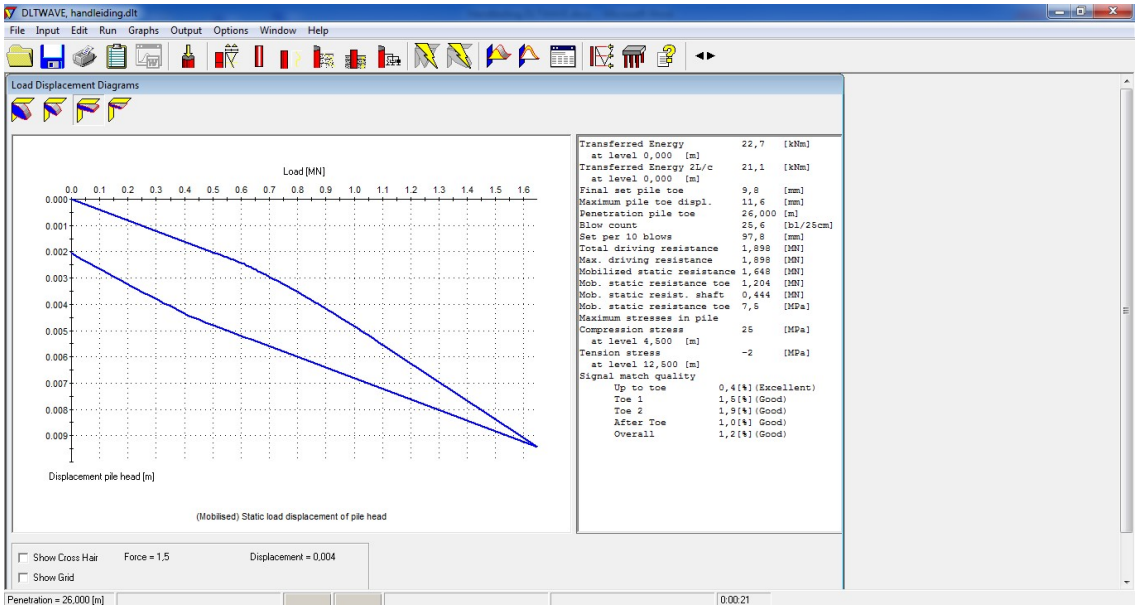


Fig. 14 The calculated Load displacement diagram of the pile head.

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Another result of the Signal Matching is the maximum Static bearing capacity of the pile. This parameter is very interesting to know in order to determine whether the required load which the pile needs to resist can be applied or not.

In order to get results as a function of depth several graphs can be viewed by selecting *Graphs* followed by the option *"Graphs as a function of depth"*.

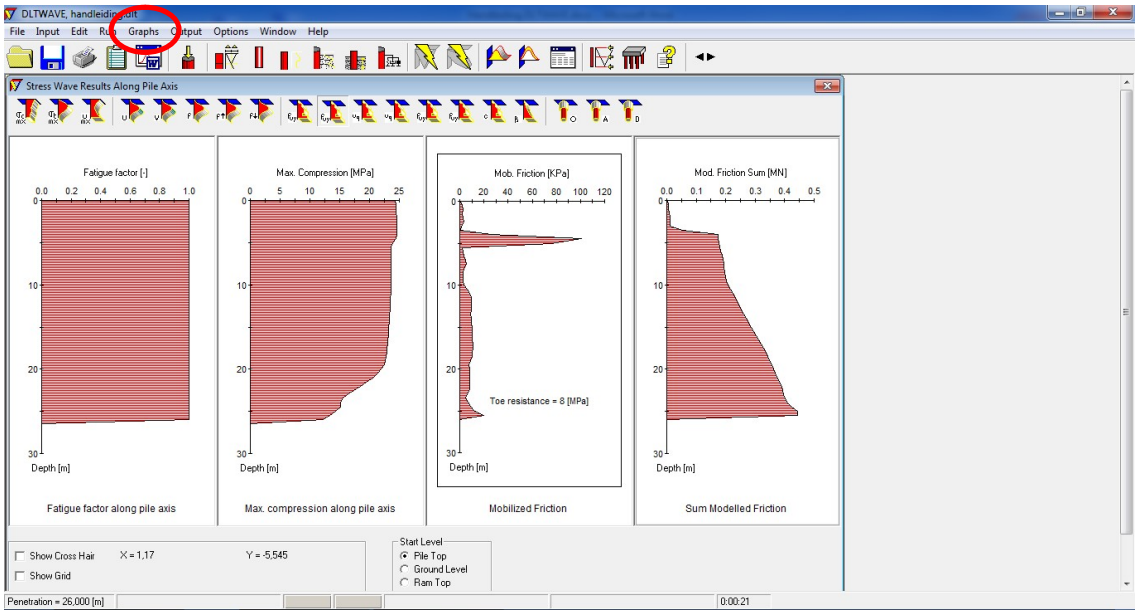


Fig 15 . "Graphs as a function of depth"

On the right there is an impression is shown about how the overall friction is divided along the shaft of the pile The beta-factor shown on the left graph shows if there is any damage onto the pile shaft.

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Theory related to Signal Matching

A) Case Method

The first direct method of determining pile capacity was developed at the Case Institute of Technology by Rausche (1970). As described above, the total driving resistance is calculated from an input/output relation. (tmax is the time of maximum downward force wave.)

$$R_{tot} = F^{\downarrow}(t_{max}) + F^{\uparrow}(t_{max} + \frac{2L}{c})$$ Eq. 40

-or-

$$R_{tot} = F_{t1}^{\downarrow} + Ft_{t2}^{\uparrow}$$ Eq. 41

where,

$$F_{t1}^{\downarrow} = F^{\downarrow}(t_{max}), F_{t2}^{\uparrow} = F^{\uparrow}(t_{max} + \frac{2L}{c})$$ Eq. 42

As well, the total driving resistance consists of a static and dynamic part.

$$R_{tot} = R_{sta} + R_{dyn}$$ Eq. 43

$$R_{sta} = R_{tot} - R_{dyn}$$ Eq. 44

In the Case method, driving resistance is assumed to be entirely at the toe and the dynamic driving resistance is assumed to be proportional to the pile toe velocity which is calculated from the measured pile head force and velocity. The Case damping constant Jc is determined by correlation with a static load test or from signal matching.

$$R_{dyn} = J_c Z.v_{toe}$$ Eq. 45

-or-

$$v_{toe} = \frac{(F_{t1}^{\downarrow} - F_{t2}^{\uparrow})}{Z}$$ Eq. 46

Thus,

$$R_{sta} = F_{t1}^{\downarrow} + F_{t2}^{\uparrow} - J_c(F_{t1}^{\downarrow} - F_{t2}^{\uparrow})$$ Eq. 47

-or-

$$R_{sta} = F_{t1}^{\downarrow}(1 - J_c) + F_{t2}^{\uparrow}(1 + J_c)$$ Eq. 48

In terms of the measured values, F1, v1, F2, and v2 and from Eq 26 and Eq 27,

$$R_{sta} = (1 - J_c)\frac{(F_1 + Zv_1)}{2} + (1 + J_c)\frac{(F_2 - Zv_2)}{2}$$ Eq. 49

Some typical values for the Case damping constant Jc are:

Sand	0.00–0.15
Sandy silt	0.15–0.25
Silty clay	0.45–0.70
Clay	0.90–1.20

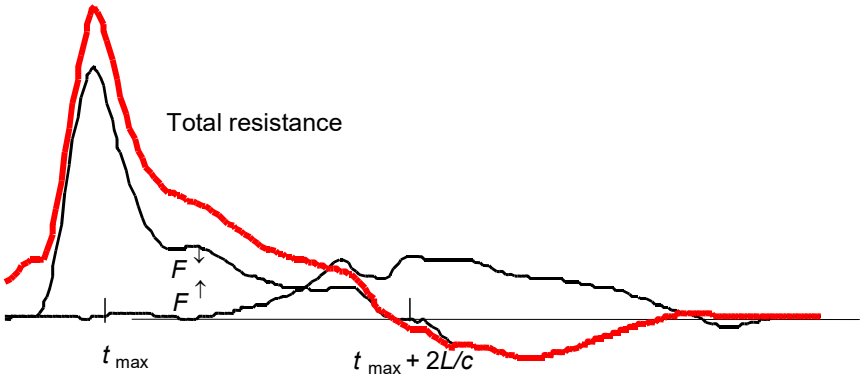
The Case method is recommended for end bearing piles with some shaft friction.

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B) Maximum Case Method



Derivation of driving resistance from measurements

The Maximum Case method is recommended in cases where the full toe resistance is not mobilized before the downward travelling wave reaches the toe (e.g. displacement piles with large end bearing). To determine the maximum resistance, the Maximum Case method does not assume that maximum driving resistance occurs at *t*max. Instead, the maximum is found over the entire sampling range. The value 2*L*/*c* is kept constant.
Some typical values for the Maximum Case damping constant *Jc* (derived from the standard Case damping constants) are:

Sand	0.00 – 0.35
Sandy silt	0.35 – 0.45
Silty clay	0.65 – 0.90
Clay	1.10 – 1.40

The Maximum Case method is recommended for displacement piles with large end bearing.

C) TNO Method

The TNO method uses soil investigation results directly to estimate soil damping. The total driving resistance consists of a static and dynamic part. In the TNO method, driving resistance is divided into shaft resistance driving resistance and toe resistance driving resitance(both static and dynamic).

$$R_{tot} = S_{dr} + T_{dr} \qquad \text{Eq. 56}$$

The shaft resistance is equal to the maximum *extrapolated* upward travelling wave between *t*max and *t*max + 2*L*/*c*.

$$S_{dr} = S_{sta} + S_{dyn} = 2F^{\uparrow}_{max_{ext}} \qquad \text{Eq. 57}$$

The dynamic shaft resistance is proportional to an average shaft velocity *v*shaft and a shaft damping constant, c_{shaft}. (*O* is the pile perimeter, *P* the penetration, and *b* the blow length.)

$$S_{dyn} = v_{shaft} C_{shaft} O.P \qquad \text{Eq. 58}$$

$$v_{shaft} = \frac{1}{b}\int_0^b \frac{F^{\downarrow}}{Z}dt - \frac{c}{2P}\int_{\frac{2(L-P)}{c}}^{\frac{2L}{c}} \frac{F^{\uparrow}}{Z}dt \qquad \text{Eq. 59}$$

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$$S_{sta} = S_{dr} - S_{dyn}$$ Eq. 60

The driving toe resistance is calculated as follows:

$$T_{dr} = R_{tot} - S_{dr}$$ Eq. 61

The dynamic toe resistance is proportional to the toe velocity *v*toe and a toe damping constant, Ctoe. (*A* is the cross sectional area of the pile.)

$$T_{dyn} = v_{toe} C_{toe} A_{toe}$$ Eq. 62

$$v_{toe} = \frac{1}{b}\int_0^b \frac{F^{\downarrow}}{Z} dt - \frac{1}{b}\int_{\frac{2L}{c}}^{\frac{2L}{c}+b} \frac{F_{\uparrow}}{Z} dt$$ Eq. 63

$$T_{sta} = T_{dr} - T_{dyn}$$ Eq. 64

For the pile toe damping there is a relation between the Case damping factor and damping constants

$$J_c = A_{toe}.C_{toe} / Z$$

Some typical values for the damping constant are:

	Shaft MNs/m^3	Toe MNs/m^3
Sand	0.02 – 0.10	0.4 – 2.0
Sandy silt	0.05 – 0.15	1.0 – 3.0
Silt	0.10 – 0.25	2.0 – 5.0
Silty clay	0.20 – 0.40	4.0 – 8.0
Clay	0.25 – 0.50	5.0 – 10.0

For short blows, the pile velocity is not directed downward for the whole pile, influencing the shaft friction reflections measured at the pile top. For longer blows, all reflections appear at the pile top. The figures below show this effect on the calculated upward travelling wave at the pile top. Both figures represent a pile with the same shaft friction model but different blow duration. The short impact force has a blow duration of 0.2 *L/c*, while the long impact force has a blow duration of 2 *L/c*. The maximum applied force is 5 MN.

The upward travelling force maximum over the period of 2 *L/c* is 0.3 MN for the short impact and 1.8 MN for the long impact. From the soil model, the static shaft resistance of the pile is 2.5 MN and, thus, half of the static resistance is reflected (i.e. 1.25 MN of the measured upward travelling force is due to shaft friction. The other half is due to shaft damping.)
The shaft resistance for the Impedance and **TNO** methods show large differences (Equations 51 and 57). The upward travelling wave for the short blow is much lower. To obtain a more realistic maximum upward travelling wave value, the upward travelling wave is extrapolated to point *C* which has led to good results.

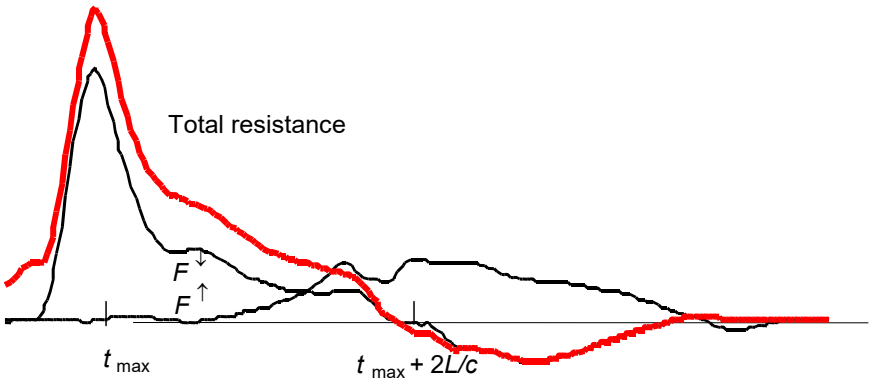
As in the **Maximum Case method** to determine the maximum resistance, the **Maximum TNO method** does not assume that maximum driving resistance occurs at *t*max. Instead, the maximum is found over the entire sampling range.

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D) Maximum TNO Method



Derivation of driving resistance from measurements

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Some typical values for the Maximum TNO damping constants are:

	Shaft MNs/m^3	Toe MNs/m^3
Sand	0.05 – 0.25	1.0 – 5.0
Sandy silt	0.12 – 0.40	2.5 – 7.0
Silt	0.15 – 0.45	3.0 – 7.5
Silty clay	0.30 – 0.60	6.0 – 10.0
Clay	0.35 – 0.75	7.5 – 15.0

The Maximum TNO method is recommended for displacement piles with large end bearing.

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