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Rijkswaterstaat, RIKZ

Analysis of Low Frequency Waves at Petten

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ABSTRACT:

In this report a software algorithm written in Matlab 5.3 is presented with which low frequency waves at the Petten Sea Defense can be analyzed and decomposed into incident free, incident bound and reflected free waves. The outline of the algorithm is presented and a user manual, which is also available online, is appended. The software itself is included on a CD ROM.
The underlying theory is presented in this document. The algorithm is validated against a number of synthetic cases which show the correct implementation of the theory into the algorithm. Furthermore, an analysis is made of low frequency wave data measured during the storm of December 6, 1999 at Petten in the Netherlands. The algorithm has been designed such that other (storm) days may be analyzed easily under the assumption that the data structure of those records are identical to the data of December 6th. The program can be used to answer questions about the fraction of incoming low frequency wave energy as part of the total energy, the relative portion of the bound wave energy, their cross-shore variation, and the presence of standing waves.

This report and manual corresponds to the M-RAT software version 1.1

REFERENCES:

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1 Introduction

1.1 General

In order to predict wave run-up on shores and seadikes, it is important to know the wave climate in the nearshore region. Besides energy in the wind wave band (with typical frequencies of 0.06-0.15 Hz), there is also considerable energy in the infragravity or low frequency band (0.01 - 0.06 Hz). These low frequency waves are generated under groups of wind waves at deeper water and propagate with the groups themselves as so-called bound waves. As the groups approach the shore, the wind waves refract, shoal and eventually break. In this process energy is dissipated in the form of turbulence and heat, but is also transferred to the lower frequencies, thus increasing the amplitude of the infragravity waves and releasing them from the group. The released long waves do not break but are reflected off the shore and propagate seaward. The so-called leaky waves propagate out to the deep sea whereas some of these waves may become refractively trapped along the coast, which means they cannot escape to deeper water anymore. If certain conditions are met these trapped waves may resonate and grow considerably in amplitude. These waves are called edge waves and have been suggested to be important in bar formation and rip current spacing. Together with the incoming low frequency waves, the reflected waves form a standing wave pattern.

Analysis of measurements has shown that the low frequency band contains a large portion of the total energy (up to 70%), especially in shallower water (Wright et al., 1979; Huntley et al., 1981; Holman, 1981; Guza & Thornton, 1982, 1985; Oltman-Shay & Guza, 1987; Howd et al., 1991). The low frequency waves can thus be of considerable importance and are likely to influence the run up of the shorter waves themselves. Laboratory measurements have shown that near a structure (Janssen et al, 2000) the correlation between the low frequency waves and the wave groups can be such that the highest short waves “ride” on top of a crest of a low frequency wave (a positive correlation). This means that the high waves, which will cause the largest run up to begin with, will penetrate further up the slope of the dike because of the presence of the long waves. For the purpose of coastal defense, this combination of wave effects is likely to be normative.

For the specific case of the Petten site this work is a continuation of the analysis performed by De Haas et al. (1998).

1.2 Objectives

The objective of this study is to design a software algorithm with which measured data from pressure recorders can be used to separate the low frequency wave field into incoming and reflected, and free and bound components. The result is a flexible tool with which data can be read and analyzed.
The program can be used to answer the following questions:

1. What is the fraction of incoming low frequency wave energy as part of the total energy?
2. What is the relative portion of the bound wave energy?
3. How do these fractions vary as function of the cross-shore coordinate?
4. Are standing long waves present?
5. How will the addition of measuring devices increase the reliability of the analysis results?

### 1.3 Layout of this report

The report consists of the following elements: In Chapter 2 a brief literature review is given of the wave theory used in the algorithm.

In Chapter 3, a software algorithm named M-RAT (Matlab Reflection Analysis Tool) is presented which analyzes the incident (bound and free) and reflected infragravity wave from measurements using pressure recorders at the Petten coast. The algorithm separates the incoming from the outgoing low frequency waves in the time domain, using a method described below. After this separation a bispectral analysis is performed on the remaining time signal of the incoming waves. With this method an estimate can be made of the percentage of bound low frequency waves in the incoming wave train. The output consists of plots of the time series of the observed wave train, and the analyzed incoming and reflected wave trains, the spectral representation of these wave trains and the reflection coefficients. In tabular form the Hm0 wave heights of the wind wave signal, the incoming and outgoing and the low frequency signal are given in absolute numbers and as a percentage of the total. Also, the percentage bound wave energy is given. For details of the output we refer to the GUI Manual which accompanies this report.

In Chapter 4, the algorithm is validated against a number of synthetic cases which will show the correct implementation of the theory into the algorithm.

In Chapter 5 an analysis is made of low frequency wave data measured during the storm of December 6, 1999 at Petten in the Netherlands. The algorithm has been designed such that other (storm) days may be analyzed easily under the assumption that the data structure of those records are identical to the data of December 6th. Finally, conclusions and recommendations are made.
2 Literature Review

2.1 Separation of incident and reflected waves

A number of methods have been derived in order to separate incident from reflected waves.

Miche (1951) was the first to introduce a method to estimate the reflection coefficient on a sloping beach for regular waves. Cast into Battjes (1974) surf similarity parameter the expression for the reflection coefficient becomes

\[ R = 0.1 \frac{\beta^2}{\tan \beta} \]

where

\[ \frac{\beta^2}{\tan \beta} = \frac{\tan \beta}{\sqrt{H / L_0}} \]

where \( \beta \) is the beach slope, H is the wave height and \( L_0 \) is the deepwater wavelength. This method is only valid for monochromatic waves since the reflection pattern due to irregular waves is much more complex.

The best-known methods for irregular waves have been derived for laboratory (flume) environments which are closely controlled. The first methods were advanced by Thornton and Calhoun (1972), Goda and Suzuki (1976) and Morden et al. (1976) who all simultaneously measured the wave records in two surface piercing wave probes to separate the signal into two free waves (one in each direction of the flume). This method has a number of disadvantages:

- if the spacing between the probes is too large, there is a loss of coherence between the signals.
- if the spacing is too small, there is a loss of contrast.
- due to the fixed spacing of the wave probes, waves which wave lengths fit exactly an integer number of times in a length of twice the spacing cannot be resolved.
- high sensitivity to errors.

A method which overcomes most of these limitations was derived by Mansard & Funke (1980) who used a three-gauge array instead. The extra information from the third gauge is used to minimize the error through a least-squares analysis. This method transforms the wave signal into the frequency domain. For every frequency a matrix is solved for the amplitude of the incoming wave, the amplitude of the reflected wave, and noise. The method was shown to be accurate in a number of laboratory studies and is the one which is used in the algorithm.

An innovation over the Mansard and Funke method was presented by Zelt and Skjelbreia (1992) who allowed for more than three wave gauges. The gauges closest to the point of
interest were weighed more heavily through a non uniform weighting coefficient. This method is especially advantageous in the case of a large number of gauges in a limited area. This is not the situation at Petten but our algorithm is made flexible enough to allow for an unlimited number of gauges.

A method which has been used successfully in the field was presented by Guza et al. (1984). They used information from a co-located pressure sensor and a velocity meter and shallow water theory to separate shoreward and seaward propagating long waves. This method as such is not valid for waves in intermediate depth and cannot be applied in the present case because there are no velocity meters installed yet.

Based on this short review of the reflection analysis methods, the method by Mansard and Funke (1980) is selected for its accuracy and robustness. By default, the method works with three wave gauges. If two gauges are selected the method reduces to the deterministic method by Goda and Suzuki (1976). On the other hand, it is allowed to insert an unlimited number of gauges which is advantageous if the signals are very coherent.

### 2.2 Determination of phase-locked waves

The separation of incident from reflected waves gives no information about the nature of the incoming low frequency waves. These waves may either be free or phase-locked (bound) to the higher frequency (wind) waves.

The fraction of phase-locked higher or lower harmonics in a measured wave signal can be estimated using bispectral analysis (Hasselmann et al., 1962). For a detailed derivation we refer to Kim and Powers (1979). This theory was applied to study measured surface gravity waves by Herbers et al. (1994) and Dutch field data by Ruessink (1998).

The bispectrum is defined as the two-dimensional Fourier transform of the third-order autocorrelation and can be expressed in terms of Fourier coefficients as

$$B_{j,k} = E[F_j F_k F^*_j + k]$$

(1.3)

for the lower harmonic analysis of differences. In this $E[ ]$ denotes the expected value. It is convenient to normalize the bispectrum such that the squared bicoherence is obtained as

$$b_{j,k}^2 = \frac{|B_{j,k}|^2}{E[F_j F_k]^2 E[F_{j+k}]^2}$$

(1.4)

which ensures that the bicoherence of a completely phase locked signal goes to unity. This means that the bound portion of the total wave spectrum can be given as

$$S_b(f_j) = b_{j}^2 S(f_j)$$

(1.5)
With this theory it is possible to retrieve the fraction of bound low frequency energy in the total signal, given any measured time series. This theory has been incorporated in the algorithm described below.
3 Description of Algorithm

The theory presented above has been cast into a Matlab (version 5.3 or higher) software algorithm named M-RAT. M-RAT has been equipped with a Graphical User Interface. The User Manual is presented in Appendix A and as an online document included in the software.

In this Chapter we will present the basic flow chart which describes the sequence of operations performed to analyze the recorded data. Essentially, the processing of the measurements to the desired output parameters consists of the following four parts:

1. Data input.
2. Separation of incoming and reflected components.
3. Separation of bound and free incoming signals.
4. Output of spectra and parameters.

This partition is used consistently in the structure of the algorithm. The modules corresponding to the above four points are named:

1. Dat_In
2. Sep_Free
3. Sep_QPC
4. Post_Out

The flowchart which describes the interaction of these components is given schematically in Table 1.

The Dat_In function transforms the data files with the measurement data to a binary Matlab file, in which the observations are ordered in columns by location. This file includes information of the location of the measuring devices and the local bathymetry. The algorithm ensures that the data is (made) synchronous. The filename can be chosen by the user, the extension is given as "*.ani".

Using the information stored in the *.ANI file, the surface elevation time series is separated into incoming and outgoing waves (in "Sep_Free") using a least-squares method. This results in a time series of the incident and reflected waves.

The method assumes linear theory and longcrested waves with a propagation direction along the cross shore array of sensors. This assumption excludes the analysis of obliquely incident waves, directionally-spread waves, and edge waves.

On the incoming wave signal a bispectral analysis is performed which (in "Sep_QPC") which will give an estimate of the percentage of bound low frequency energy in the total incoming low frequency energy. Spectra of the three wave components (incoming free, incoming bound and outgoing free low frequency waves) and time series of incident and reflected wave motion are written to a file in the "Post_Out" function. This output is used
in the graphics. In addition some integral parameters of the low frequency significant wave heights are stored (see for details below).

The manual for the Matlab program which is based on this flowchart is presented as a separate (online) document and in Appendix A.

Table 1 Schematic overview of the program structure for the analysis of low frequency waves at Petten.
4 Verification of Matlab Algorithm

4.1 Introduction

In order to check the algorithm in the Matlab routines a number of tests were performed on the algorithms using synthetic wave fields. The routines that generate these synthetic wave fields were designed to simulate laboratory conditions. Although the wave trains are at laboratory scale the techniques apply equally well on any other scale. If the algorithms are found to work correctly for these laboratory cases we may assume them to work on the field scale under the assumptions made above.

The parameters used in the verification are as follows:

- Sample rate: 20Hz
- Bottom slope: 1:50
- Spectral definition: JONSWAP (free waves)
- Record length: 8192 points, 409.6 [sec]
- Water depth: .5 m
- Peak frequency short wave field: 1Hz

The M-RAT program consists of a number of algorithms. The basis of the separation in incident and reflected wave motion is a generic algorithm based on linear wave theory. We will refer to this algorithm as the Linear Wave Separator (LWS). The LWS allows for a number of probes between 2 and N as input. Where 2 is a fixed minimum that reduces the solver to the Goda and Suzuki (1976) two point method. For a surplus of probes (N>2) the solution is sought through least squares. The algorithm is adapted to include shoaling effects over an uneven bottom (Van Dongeren and Janssen, 2000). Bispectral analysis is applied to detect quadratic phase coupling of subharmonics (forced waves).

4.2 Validation of separation method

The first step in the verification is to check the performance of the Linear Wave Separator (LWS). To verify this we generate a wavefield that is a superposition of incident and reflected wave components without the addition of noise. In the four panels of Figure 1 the time series and spectra as obtained from the analysis are superposed by the synthetic wave motion.

The synthetic wave motion was generated on a 1:50 uniform slope and linear wave theory was assumed valid. In this analysis we used the minimum number of wave gauges (2) to show that the algorithm in the absence of noise reduces to a two point method. The synthesized and re-analyzed wave motion of both the reflected and incident wave trains are identical. This shows that the method is implemented correctly.
Figure 1. Algorithm check for two point without noise. a) Left upper panel: Time signal incident wave motion (synthesized and reanalyzed), b) Right upper panel: Energy density spectrum incident wave motion. c) Left lower panel: Time signal reflected wave signal (synthesized and reanalyzed). d) Right lower panel: Energy density spectrum reflected wave motion.

If only two wave gauges are used in the analysis noise in the signal will not be reduced and the algorithm will try to interpret the noise as part of the wave signal. The effect of synthetically adding 15% noise in the signal and using only two wave gauges in the analysis is shown in Fig. 2.

If we use the same signal but now repeat the analysis using four wave gauges we find the results as shown in Figure 3. (Please note that the time domain signal is not identical to the previous case due to the random phase generator in the wave synthesis). The noise in the signal is suppresses so that the synthesized and reanalyzed wave motions for both the incoming and the outgoing signal are nearly identical. From these results we may conclude that the N-point method will effectively improve the estimates of incident and reflected wave motion in the presence of noise. Although theoretically further addition of wave gauges will improve the reduction of noise in the signal in practice there is a trade off between an increase in the number of signals and the coherence between more distant probes.
Figure 2. Two point method in the presence of 10% noise. Time signal reflected wave motion (true and analysed).

Figure 3. Algorithm check for N-point (4-point) method in the presence of 10% noise. a) Left upper panel: Time signal incident wave motion. b) Right upper panel: Energy density spectrum incident wave motion and noise. c) Left lower panel: Time signal reflected wave signal. d) Right lower panel: Energy density spectrum reflected wave motion and noise.
4.3 Verification of bispectral analysis method

The previous verifications were all performed with free incoming and reflected waves. Next the implementation of the bound wave analysis algorithm through bispectral analysis is shown.

The first verification of the bispectral algorithm consists of the test described by Kim and Powers (1979). A bichromatic signal with frequency components at 1.3 and 1.8 Hz is generated. In the first test a bound (or phase-coupled) sub-harmonic component at the difference frequency 0.5 Hz is also generated while in a second test the sub harmonic component at the same frequency is free or uncoupled.

These two test cases are analyzed using bispectral theory which is capable of detecting phase locking between components. The result of this test are shown in Figure 4. Figure 4a shows that in the case of the first test the algorithm correctly interprets all the energy at the sub harmonic frequency (at 0.5 Hz) as bound or phase-coupled energy which Fig. 4b shows that in the second case the algorithm correctly detects no coupled subharmonic energy.

This test shows how the bispectral analysis is an effective tool to detect phase coupling in a wave field and verifies the correct implementation of the bispectral algorithm in the M-RAT code.

![Figure 4](image)

Figure 4. a) Left panel: bispectral analysis of coupled components. b) Right panel: similar wave field (identical energy densities) but uncoupled

Next the algorithm is applied to an irregular wave field which contains subharmonics at a large number of frequencies instead of at just one. To generate the synthetic case we apply the steady state solution for forced subharmonics as derived by Longuet-Higgins and Stewart (1962). The first synthetic case only consists of a short wave field and forced low frequency motion. No outgoing long wave motion or free incident wave motion is present. This to test the effectiveness of the algorithm for an irregular wavefield. The incident short waves are defined using a random phase and JONSWAP target spectrum.
Figure 5 Verification of phase coupling algorithm for irregular waves.

The short waves will not be involved in the analysis other than the driving force and coupling source for the forced low frequency waves. In Figure 5 the comparison between the synthetic coupled (bound) long wave energy density and the energy density obtained from the analysis is shown. Small deviations are caused due to limited record length and the related statistical uncertainty in the bispectral estimate.

4.4 Verification of synthetic “field” case

In the practical situation as encountered in Petten we may expect the presence of incident and reflected free low frequency motions as well as phase-coupled (bound) low frequency motion.

In the next test a signal is synthesized which contains incident short waves, and free incoming, free reflected and bound incoming low frequency waves. This case in effect simulates a field case as may be encountered at the Petten site.

The total signal is generated for multiple measurement locations and is analyzed using M-RAT. In the algorithm the reflected low frequency motion is computed using the LWS algorithm. The incident wave motion is then obtained by subtracting the reflected wave motion from the total signal. Rather than obtaining the incoming wave motion directly from the separation computation, this last step is applied because the method assumes linear waves. The reflected low frequency waves satisfy this assumption better than the incoming wave motion (which contains nonlinear bound waves).

Figure 6 shows the synthesized and re-analyzed incoming low-frequency wave motion. The corresponding spectral densities are shown in the right panels of that figure. The signals are nearly co-incident except for some energy loss at the lowest frequencies. The bottom panels show the synthesized and re-analyzed reflected low-frequency wave trains. The spectra
show a close match as well. From Figure 6 we can conclude that we can indeed make an estimate of the total incident and reflected wave motion using the method described here.

Figure 6  Verification analysis result with synthetic wave field including forced wave motion. a) Top left: Time series incident wave field. b) Top right: Energy density incident wave field. c) Bottom left: Time series reflected wave field. D) Bottom right: Energy density reflected wave field.

The bispectral estimate of the forced wave motion in the signal is obtained by determining the bispectrum over the complete wavefield (including all low frequency components and the short wave field). The result of that analysis is shown in Figure 7.

Again we find confirmation that the bispectral analysis of finite length record can give a reliable estimate of the amount of phase coupled energy present in a signal because the synthesized coupled low frequency wave spectrum matched the reanalyzed coupled low frequency wave spectrum. With this result we can conclude that the approach as described here can indeed be successfully applied to determine the ratio of incident and reflected energy. By including bispectral analysis on the signal also an estimate of the amount of phase coupling is given.
4.5 Analysis interpretation

Since in the analysis an alternative definition is used for 'incident' long wave motion we will support this definition by a series of graphs. Prior to interpreting the results obtained with M-RAT the user should be familiar with these definitions. The 'incident' low frequency wave motion is defined as the total low frequency wave motion minus the reflected wave motion. This definition was stated to circumvent the effects of non-linear wave motion in the incident wave field (forced waves).

A wave field was simulated and all components and their superposition are shown in Figure 8. We see from this figure that we consider three components in the analysis, incident and reflected free wave motion and incident non-linear (forced) low frequency motion. Also we assume that the total surface elevation is a superposition of these components.

An argument for the alternative definition of 'incident' wave motion is shown in Figure 9. In the top panel of this figure we show the result of the LWS (Linear Wave Separator) for the incident wave motion superposed by the actual incident wave motion. Although there is a fairly good resemblance this is seen not to be very exact. In the second panel of that figure (moving from top to bottom) we see the result of the LWS analysis for the reflected wave motion compared to the synthetic reflected wave motion. This shows that the reflected wave motion is retrieved much better from the analysis as was the case for the incident wave motion. This is explained by the presence of non-linear components in the incident wave field and the incapability of the LWS analysis to deal with them. In the third panel of Figure 9 we see a comparison of the synthetic incident wave field and the total...
surface elevation from which the reflected waves (as found in the analysis) were subtracted. It can be seen from this panel that resemblance is much better than the LWS analysis result for the incident wave motion and the actual wave motion. It is for this reason that it was decided to use the alternative definition of incident wave motion.

**Incident wave motion (alternative definition)**

Total observed surface elevation minus the surface elevation obtained for the reflected wave motion from the LWS algorithm.

The new definition may be slightly confusing in the interpretation of the M-RAT results. The observed time series is converted to a number of components. These components are

- Observed signal = $S_m$
- Incident signal LWS = $S_{ai}$
- Reflected signal LWS = $S_{au}$
- Incident signal = $S_{di}$
- Total signal LWS = $S_i$

These signals are related through their definitions as in

$$S_{di} = S_m - S_{au}$$  \hspace{1cm} (3.1)

which leads to

$$S_i = S_{ai} + S_{au} \neq S_{di} + S_{au} = S_m$$  \hspace{1cm} (3.2)

This is shown graphically in Figure 10. In the top panel of this figure we see the comparison of $S_i$ and $S_m$. It is obvious from equation (3.2) that these cannot not be equal unless

$$S_{ai} = S_{ai}$$  \hspace{1cm} (3.3)

which is not the case in this numerical example. Note that the alternative definition for incident wave motion implicitly assumes the noise in the incident signal to be of a smaller order than the non-linear long wave motion in this signal. In the bottom panel of Figure 10 we see the comparison between $S_{ai} + S_{au}$ and $S_m$. From the definition of $S_{ai}$ ($S_{ai} = S_m - S_{au}$) it is obvious that they should match perfectly. This is confirmed in the bottom panel of this figure.
Figure 8  Time series of simulation to illustrate definition of 'incident' wave motion. From top to bottom: incident free wave motion, reflected free wave motion, incident non-linear wave motion, superposition of all components.
Figure 9  Analysis results for numerical example. Panels from top to bottom: 1. Analysed and synthetic incident wave motion superposed 2. analysed and synthetic reflected wave motion superposed 3. total surface elevation minus reflected wave motion and incident wave motion superposed.
Figure 10 Visualisation of alternative definition incident wave motion. Top panel: superposition of incident and reflected wave motion obtained from the LWS motion superposed by the summation of the incident wave motion (alternative definition) and reflected wave signal obtained from the LWS analysis. Bottom panel: Total signal prior to analysis superposed by super posed by the summation of the incident wave motion (alternative definition) and reflected wave signal obtained from the LWS analysis.
5 Analysis of Stormday November 6, 1999

5.1 Introduction

The M-RAT program is used to analyse the stormday of November 6th, 1999 which occurred at the Petten measurement site. The significant wave heights during the peak of the storm measured over 4 meters at an offshore location (35 kilometers from the site) with peak period of close to 10 seconds. The mean water level at the peak of the storm coincided with high tide at +1.8 meters NAP (Dutch reference level; comparable to MSL). The wind speeds measured 20 m/s from a direction due West (270 degrees). For details we refer to De Kruif (2000).

5.2 Parameter input

In our analysis the data records from a number of pressure sensors are used. The parameters which are used in the User Interface are given below. Unless otherwise noted, the values are taken from De Kruif (2000).

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<td>392</td>
<td>493</td>
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Table 1: Input values for the measurement positions used. The asterisks denote * = values are calculated as 0.70 meters above the bed level (email F. Wolf); ** = values are measured from the bathymetric Fig. 3.8; *** = values are received by email from F. Wolf.

The position of the measuring stations and the transect of the bathymetry is shown in Figure 11. It should be noted that the uncertainty in the instrument parameters such as the recorder depth and the total depth, is likely to affect the results. Certainly, the local depth will have changed after storms, and especially a transverse movement of the bar will have an effect on the local depth at the measuring positions. Also, the recorder depth was not known exactly anymore. The most important parameter, however, is the choice of the cut-off frequency.

As an example, the following table gives the computed Hm0 of the surface elevation after transformation of the raw pressure data. These results are before analysis using M-RAT.
The parameters which are varied are the cut-off frequency and the recorder depth for the data taken at MP17.1.

![Bathymetry and measuring stations used.](image)

<table>
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<th>recorder depth/ cut off frequency</th>
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<th>-5.3(m)</th>
<th>-6 (m)</th>
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</thead>
<tbody>
<tr>
<td>0.3 (Hz)</td>
<td>1.57</td>
<td>1.59</td>
<td>1.60</td>
</tr>
<tr>
<td>0.33 (Hz)</td>
<td>1.74</td>
<td>1.76</td>
<td>1.79</td>
</tr>
<tr>
<td>0.4 (Hz)</td>
<td>2.75</td>
<td>2.90</td>
<td>3.07</td>
</tr>
</tbody>
</table>

Table 2: Computed Hm0 values using data from MP17.1 for a range of cut-off frequencies and recorder depths.

On the basis of a criterion given by Ruessink for the Mast-Coast 3-D project we choose the cut-off frequency such that the pressure response factor is ten at its maximum. This corresponds to a $f_{cut} = 0.33 \text{ Hz}$, which we will use in the remainder. The choice of the cut-off frequency will affect the computed Hm0 values for the short wave range but not the low frequency values in which we are interested in this analysis.

A more serious limitation is the sparseness of the measurement locations. The large distance between subsequent probes reduces the reliability of the analysis. This fact was acknowledged in the request by RIKZ. Also, as stated above, the assumption of shore-normal propagating waves may be violated in the field by the presence of edge waves, directionally-spread waves and obliquely-incident waves. For this reason, the results from the analysis should therefore be interpreted with care.

These values of Table 1 are input to the GUI. After applying the transformation and synchronisation buttons all data is synchronised at 14:05:01 (for this case) and converted to surface elevations.
The data set is stored as an *.ani file. The data is then analyzed in order to separate incident from reflected waves and the bispectral analysis is performed. The results are written to a user-selected *.ano file. This file can be loaded for plotting of data.

5.3 Output

The results for every location in the table above are analyzed using an array of the three nearest pressure sensors. The algorithm produces tabular output of:

- the observed total significant (spectrally determined) wave height Hm0,s1 (m) (short and long waves)
- the observed significant wave height for the short waves
- the total low frequency wave height Hm0,lo (m)
- the incoming bound low frequency wave height Hm0,lobo (m)
- the incoming low frequency wave height Hm0,loin (m)
- the reflected low frequency wave height Hm0,lore (m)
- the ratio of low frequency energy and total energy
- the ratio of bound wave height and the total low frequency wave height.
- the ratio of bound wave height and the incoming low frequency wave height
- the ratio of the reflected and incident low frequency wave height (“the reflection coefficient”).
- the ratio of bound wave height and the total incident low frequency wave height.

The significant wave heights for the low frequency waves are determined from a spectral analysis where

\[
H_{m0,lo} = 4 \sqrt{ \int_{0}^{0.05} E(f) df }
\]

(4.1)

The wave height for the short waves is computed as

\[
H_{m0,s} = 4 \sqrt{ \int_{0.05}^{0.33} E(f) df }
\]

(4.2)

The upper limit in the integral has been chosen at about half the peak frequency of the incident wind waves, which sets the limit at 0.05 Hz.

Besides tabular output, the spectral density plots of the total low frequency energy density, the incoming and reflected, and the bound low frequency energy density are shown.

5.4 Results and Analysis

The resulting parameters from the analysis of the storm day are shown in Table 3.
The Hm0 wave heights for the short and long waves (row 3) and the short waves only (row 4) are computed directly from the transformed pressure data. As noted above the results are affected by the cut off frequency, the total depth and the recorder depth. The value at MP7 is only possible if this position is outside the breaker zone. The numerical simulations of storms in 1995 by De Haas et al. (1998) indicate that this may be the case. Moreover, at both positions a variation of the cut-off frequency did not change the results much. In any case the value of the Hm0 for the short and long waves does not affect the computation of the low-frequency reflection which is the scope of this report.

<table>
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<tr>
<th></th>
<th>mp7.2</th>
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<th>mp18</th>
<th>mp17.1</th>
<th>mp16</th>
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<td>2.45</td>
<td>1.33</td>
<td>1.60</td>
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<td>Hm0 (m) of low frequency waves</td>
<td>0.67</td>
<td>0.66</td>
<td>0.37</td>
<td>0.34</td>
</tr>
<tr>
<td>6</td>
<td>Hm0 (m) of bound low frequency waves</td>
<td>0.14</td>
<td>0.14</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>Hm0 (m) of total (bound and free) incident low frequency waves</td>
<td>0.53</td>
<td>0.54</td>
<td>0.37</td>
<td>0.31</td>
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<td>8</td>
<td>Hm0 (m) of reflected low frequency waves</td>
<td>0.38</td>
<td>0.32</td>
<td>0.29</td>
<td>0.20</td>
</tr>
<tr>
<td>9</td>
<td>ratio total low frequency and total (short and long wave) energy</td>
<td>0.29</td>
<td>0.26</td>
<td>0.27</td>
<td>0.21</td>
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<td>10</td>
<td>ratio bound wave and total low frequency waves</td>
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<td>0.22</td>
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<td>0.23</td>
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<tr>
<td>11</td>
<td>ratio bound wave and incident low frequency waves</td>
<td>0.26</td>
<td>0.26</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>12</td>
<td>ratio incident low frequency and total (short and long wave) energy</td>
<td>0.23</td>
<td>0.21</td>
<td>0.27</td>
<td>0.19</td>
</tr>
<tr>
<td>13</td>
<td>ratio reflected and incident low frequency waves</td>
<td>0.63</td>
<td>0.58</td>
<td>0.79</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 3: Overview resulting parameters analysis storm day.

The Hm0 value of the total low frequency motion (row 5) shows an decrease of wave height from mp16 to mp18 which is due to the trough in the bathymetry and can be explained using Green’s Law of energy conservation, see below. On the foreshore the wave height shows an increase to 0.67 m at the most shoreward station. As can be seen from the ratio of the total low frequency wave height and the Hm0 of the long and short waves (row 9), the fraction of low frequency energy increases shoreward to a value of 0.29 with a slight reduction over the trough.

The wave height of the bound waves (row 6) is more or less constant at 0.09 over the deeper portion of the bathymetry and increases to 0.14 in shallower water. This is due to the fact that with decreasing water depth the response to the radiation stress forcing increases. This mechanism was first derived by Longuet-Higgins and Stewart (1962). Instead of a shoaling factor which corresponds to Green’s Law \( h^{14} \) we find a sharper increase with depth. The fraction of bound wave height and the total low frequency wave is more or less
constant at 0.23 (row 10), while the fraction of bound wave height in the incoming low frequency wave (row 11) also has a value of about 0.25.

This rapid shoaling (i.e. more rapid than Green’s Law predicts) is also seen in the wave height of the total (bound and free) incident low frequency wave, see row 7. This means that energy from the short waves must be transferred to the low frequency waves as the short waves shoal and decay. In this process the bound wave increases and free low frequency waves are released. The ratio of incident low frequency wave height over the total wave height (row 12) varies between 0.19 and 0.27.

The reflected low frequency wave (row 8) does (inversely) shoal with depth according to Green’s Law. This indicates that this wave is a free wave which does not gain energy in the process but propagates seaward rather unaffected.

The Hm0 wave heights of the total low frequency signals, the incident total (bound and free) low frequency, the bound low frequency and the reflected low frequency signals are shown in Figure 12.

![Figure 12](image)

Figure 12 Hm0 wave heights vs. distance offshore, see legend

Note that the wave heights of the incident and reflected waves do not necessarily add to the wave height of the total. In fact, the apparent discrepancy between the sum of the incident and reflected waves and the total is a measure of the presence of standing waves. This will be discussed below in more detail.

The reflection coefficient of the reflected over the incident low frequency waves varies along the bathymetry from 58 to 79%, see row 13. Surprisingly, the reflection coefficient is only 0.63 at the most shoreward position. While inside the inner surfzone one would expect reflection coefficients of one, this need not be the case just outside the breaking region. According to Symonds et al. (1982) infragravity waves are generated by a moving breakpoint which acts as a wave maker. It may therefore be possible that the incident low frequency waves experience a destructive interference with the breakpoint generated wave. The incoming wave may therefore be reduced in height as it propagates through the
breakpoint and the surfzone. This wave reflects off the beach and propagates back out to sea. The reflected wave is reduced in wave height only through inverse shoaling. In this way the reflected wave is smaller than the incident waves just outside breaking, which explains the low reflection coefficient. However, this explanation is rather speculative with the limited available data but warrants more investigation in the future.

In addition to the integral parameters spectral density plots of the low frequency range are shown in Figure 13.

The most interesting aspect of these figures is that at every location they give an impression of the presence of standing or propagating waves per frequency, and of the occurrence of a node or anti-node at that frequency.

If for a particular frequency, the energy in the reflected wave is equal to the energy in the incident wave, a “pure” standing wave occurs. If the energies are not equal, then there is a standing wave present with a propagating wave in the direction of the larger component: a partial standing wave. Furthermore, a comparison between the energies in the incident and reflected waves and the total signal yields information about the phase of the standing wave. For example, if the measuring location is at a local node of the standing wave at a particular frequency, the energy in the total signal would be zero, and in the case of a node the energy would be

$$E_{\text{tot}} = \left( \sqrt{E_{\text{in}}} + \sqrt{E_{\text{re}}} \right)^2$$  \hspace{1cm} (4.3)

where $E_{\text{tot}}$ is the energy in the total signal, $E_{\text{in}}$ the incident wave, and $E_{\text{re}}$ the reflected wave. This analysis is illustrated with some examples from the figure.

At location MP7 (top left figure), the incident energy is larger than the reflected energy which implies a partial standing wave with a shoreward propagating component. The amplitudes of the waves are the square root of the energies, so in this case the amplitude of the propagating wave is about as large as the amplitude in the standing wave components.

At location MP18 (middle lefthand figure), at $f=0.023$ Hz, the incident and reflected energies are the same which implies the presence of a standing wave. The total energy is approximately the square of the sum of the wave heights according to the relation above, which means that there is a local node at this frequency. The same is true at the peaks of the analyzed total spectrum at $f = 0.012$ and $0.021$ Hz at MP17 (middle righthand figure).

In most other locations and frequencies there is no pure standing but we see a partial standing wave pattern with a larger shoreward propagating component.
Figure 13: Spectral density vs. frequency for five measurement locations. From top left: MP7, MP6, MP18, MP17 and MP16. See legends for explanations.
6 Conclusions and Recommendations

6.1 Conclusions

In this report an algorithm called M-RAT (Matlab Reflection Analysis Tool) is presented with which measured signals from pressure recorders at the field site at Petten can be used to separate the low-frequency wave field into incoming free, incoming bound and reflected free low frequency waves.

The algorithm is based on theory by Mansard and Funke (1980) for the separation of incident from reflected waves and on theory by Hasselmann (1962) for the computation of the bound waves in the incoming low frequency signal. The algorithm has been programmed in Matlab (v. 5.3) code and has been equipped with a Graphical User Interface which allows for the inclusion of a user-selected number of pressure sensors into an input file. M-RAT has been verified against a number of synthetic wave cases which show the correct implementation of the wave separation module and the bound wave computation module.

The analysis tool is applied to the storm of December 6\textsuperscript{th} 1999. Due to the limited number of pressure sensors and their large spatial separation it is difficult to draw firm conclusions. However, the questions posed in the introduction can be answered at least partially:

The percentage of total low frequency wave height in the total wave height (long and short waves) is about 25\% with a maximum of 29\% at the most shoreward position. The percentage of the incoming low frequency wave height in the total wave height is of the same order at about 25\%.

The percentage of bound waves is about 20 to 25\% of the total low frequency in terms of wave height.

The incoming low frequency waves can be seen to shoal more rapid than what would be expected using Green’s Law of energy flux conservation. This means energy must be transferred to the low frequencies from the wind wave frequencies in the shoaling and breaking process. The reflected wave does inversely shoal with Green’s Law as it propagates out. This means it is a free wave which experiences little interaction with the incident short wave groups.

The reflection coefficient (the ratio of the reflected over the incoming wave height) has a value of about 0.65 in the transect. The variation in the coefficient for every position is due to the different nature in the shoaling of the incident low frequency waves and the reflected waves.

From the spectral density plots at the lowest frequencies it can be seen that (partial) standing waves are present. The plots give an indication about the relative size of the standing wave to the propagating wave at every frequency. Also, it can be determined
whether a local node or anti-node occurs. For particular positions and frequencies nodes of a standing wave can be seen, but for most other frequencies a mix of standing and propagating modes (i.e. a partial standing wave) is seen.

6.2 Recommendations

The uncertainty in the analysis increases with increasing distance between the measuring positions. In order to improve accuracy it is recommended to increase the density of the pressure pads, especially in the nearshore zone. In this way the behavior of the reflection coefficient in the outer breaker zone and just outside of breaking can be analyzed more accurately.

It is also recommended that pressure pads be co-located with velocity meters, as has been done for one measuring position recently. Colocation improves the correlation between the signals and will yield a better estimate of the incident and reflected wave fields. It is possible to adapt the current software to include this type of device.

It is advisable to study the influence of obliquely incident waves and directionally-spread waves on the results with a numerical model. With the same model the presence of edge waves for the bathymetry and wave conditions at Petten can be studied. This analysis can be performed with the two-dimensional (2DH) version of the SURFBEAT model used by De Haas et al. (1998).
References


A User Manual
User Manual

M-RAT

The Matlab-Reflection Analysis Tool

Manual for
M-RAT version 1.1

WL | Delft Hydraulics
Marine and Coastal Infrastructure
P.O. Box 177
2600 MH Delft
The Netherlands
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Introduction

The Matlab-Reflection Analysis Tool (M-RAT) is a Matlab based program designed to facilitate the separation of incident and reflected wave motion as observed at the Petten field site. The program is UI-based which means that user input is given through the User Interface provided with the program. The set-up of the program is completely modular and is easily extendable to different sets of data, data formats, new analysis techniques and extended post-processing.

In the first section a general overview of the program structure with its components and their interaction is given. Then we will go into more detail and describe the use of the screens the user will come across. The structure of this manual is strongly related to the structure of M-RAT. In the manual the complete description of the M-RAT windows is given. With each screen a paragraph titled ‘Buttons & Boxes’ is added that provides information on the buttons and edit boxes the user will find on the M-RAT screens. Although M-RAT is UI based also a description of the input and output files is given. These files hold all the information needed for the analysis and post-processing. The inclusion of a description on these files enables the user to add new modules for data-input or post-processing.

This user manual is an online help-tool that will hopefully provide the information needed to use the M-RAT analysis tool.
Installation

The M-RAT installation is very straightforward: the installation consists of straightforward copying. The installation steps are described in the following.

- Unpack the MRAT.EXE file directly from the CD to any position on your PC.
- Add the MRAT directory to your MATLAB path permanently.
- Type 'MRAT' at the Command Window prompt.

To get started, type one of these: helpwin, helpdesk, or demo.
For product information, visit www.mathworks.com.

```mrat```

Now you should see the M-RAT main screen. If this is not the case evaluate the error message. Make sure the path is updated correctly and the MATLAB version is at least 5.3.
Program structure

The program basically consists of three parts:

- Data input screen
- Data analysis
- Post-processing

To improve usability a Start-Screen has been added where the user is given a number of options. The structure of the program is shown in Figure 1.

Figure 1 Schematic representation of M-RAT
Main screen

After typing MRAT at the prompt the screen as shown in Figure 2. It offers four options.

1. Generate input file
2. Perform analysis
3. Plot results
4. Quit

1) Will open the ‘Input screen’ to create an ANalysis Input (ANI) file. The ANI file holds all the information concerning: file locations, time series, depth etc..
2) The analysis screen prompts you to select an ANI file created previously and will ask you for a location to write the ANalysis Output (ANO) file to. Then you can perform an analysis for this case with personalised settings.
3) Here you can finetune the postprocessing of the analysis result. You need a valid ANO to do any postprocessing. So in the total analysis this would typically be the last step.
4) Leave the MRAT program

![Main screen MRAT program](image)

Figure 2 Main screen MRAT program

Buttons & Boxes

B Generate input file
Closes main screen and opens Input screen.
B  **Perform analysis**
Pressing this button will close the Main screen and open the Analysis screen.

B  **Plot results**
Main screen will be closed and Postprocessing screen is opened.

B  **Quit**
End M-RAT operation.
Input screen

The basic overview of the Input screen is shown in Figure 3. On the screen a number of buttons are shown. The left side of the screen is enabled at startup while the left side remains disabled. The left side is what we can call the ‘ANI Control’ while on the right side of the screen we have ‘Station Control’. These controls will be enabled when we add a station or view its properties.

We will treat them separately and give a short description on their respective function. For each edit screen we will briefly describe the desired input.

![Input Screen](image)

Figure 3 The appearance of the Input screen at startup

Buttons & Boxes

B Add
Switches to ‘Station Control’ and allows the user to select a Station and set its properties.

B Remove
Removes selected station from list permanently.

B Properties
Views the station properties by switching to ‘Station Control’. This option allows for checking or editing of the Station settings. (see Figure 4)
B Synchronise

This option becomes available after adding a new station. It synchronises the new station to the existing set. If multiple stations are to be added this operation can be performed on all Stations simultaneously. So first the complete set of Stations can be defined and the synchronising can be performed before saving the input file.

B Transform

Before we can do any analysis the observations have to be transformed to surface elevations from their original format (usually MV). As for the synchronising this operation can be performed after the complete set of Stations has been defined. M-RAT will only transform those series that were not transformed to surface elevations previously.

B Save

After finishing with your Input session you can save the input file as an *.ANI file. Although other extensions are allowed .ANI is recommended. The ‘Save’ button is disabled if the files are not transformed to surface elevations and synchronised.

B Load

Previously created *.ANI files can be re-loaded. The contents of the input files can be viewed, changed and updated. Note that no automatic save is applied. In order to save the *.ANI file with new settings the file should be saved!

![Image of Input Screen](image)

Figure 4 The input screen after property selection

B New

The present settings are discarded and a new *.ANI file is created. You lose all unsaved work! Handle with caution.
B Preview

This option offers the user a fast preview at the transformed time series. Serious errors in the transformation are sometimes easily detected by visual inspection of the time series or the energy density spectrum (see Figure 5).

![Figure 5 The input screen after property selection](Image)

B Help

This option will open the indexed digital help file.

B Main

Return to main screen of the M-RAT program.

E Name station

Enter a name for the station so it makes sense to you or any other users of the M-RAT program.

E No files in seq.

Enter the number of files you want to taper behind the file you selected. This option is included to offer the possibility of elongating the time series. Longer time series offer better spectral resolution. The maximum number of files is 6. The names of the file should be sequential.

E Select column

Select the column in the file that corresponds to the station.

E Sample Rate

Enter the sample rate of the station in Hz.
E Range Recorder mV
Enter the range of the recorder in mV. This is the maximum value minus the offset. For example, 2500 – 500 = 2000.

E Offset recorder
Enter the offset of the recorder in mV.

E Range Recorder in Bar
Enter the corresponding range of the recorder in Bar.

E Type of recorder
Select the type of recorder for this station.

E Depth Recorder
Enter the depth the recorder relative to NAP in m. (only for pressure recorder). This is a negative number if the position of the recorder is below NAP.

E Cut-off
Enter the desired cut-off frequency for the pressure-to-surface transformation. The transfer function is very sensitive for high-frequency noise in the recording. Here a sensible choice should be made between including all relevant information into the analysis and adding redundant noise.

E Local depth
The bottom level with reference to NAP in m. This is a negative number if the bottom is below NAP.

E Water level
The mean water level due to tides or storm set-up with reference to NAP in m. This is a negative number if the water level is below NAP.

E Distance to reference point
The reflection analysis is based on phase differences. It will indicate wave propagating towards your reference point as incident waves. Waves propagating in opposite direction will be identified as reflected waves. For straightforward interpretation of the results it is advisable to choose a point of reference shoreward of the wave gauge closest to shore.
Analysis screen

This screen is where the actual analysis of the data takes place. The layout of the screen is shown in Figure 6. Here the user is to select an input file to analyse. As an option he can select an output file. If no output file is selected the analysis results are not saved.

![Analysis screen](image)

**Figure 6** Overview analysis screen M-RAT

**Buttons & Boxes**

**B Browse Input**
Select *ANL* input file for reflection analysis.

**B Browse Output**
Select location and *ANO* file to store analysis results.

**B Perform analysis**
After pressing this button the user is prompted to give the number of blocks used in the ensemble averaging in the spectral output as in the bispectral analysis. The default is set at 8. Also he is prompted to enter the cut-off for the reflection analysis. The reflection analysis uses linear theory and is not applicable for regions with breaking waves etc.. The default is set at .05 Hz but can be changed by the user.

**B Plot results**
This option is enabled after the completion of the analysis. It will close the analysis screen (and wipe out its present settings) and open the Postprocessing screen.
B Main
This button will close the analysis screen and will return to main screen.

E Select position
Here the user selects the location where the analysis is performed and output is generated. The user selects the position with reference to which the wave motion is described in the reflection analysis.

Figure 7 Overview analysis screen M-RAT with selected *.ANI file
Postprocessing screen

The Postprocessing screen was designed to view the analysis results. Also it offers the possibility to output graphs to file and analysis results to a summary table. The overview is shown in Figure 8.

![Postprocessing screen](image)

Figure 8 Overview Postprocessing screen M-RAT

The top menu of the figure is not shown in Figure 8 but has the options ‘File’ and ‘Help’. The ‘File’ menu choice is important since this is where the .ANO file has to be selected for viewing. First an Output (*.ANO) file has to be selected. This is done through the File option in the figure menu (top of the screen).

After opening the *.ANO file the analysis results are shown and the user can make a selection of what should be viewed. The user can switch between time series, energy density spectra and reflection coefficient. The Postprocessing after opening an *.ANO file is shown in Figure 9. Here a time series plot is shown after the analysis. Superposition of multiple data series can be obtained by holding down the <SHIFT> or <CTRL> button on the keyboard and select another series from the selector.

It should be noted that incident wave motion is defined as the total wave motion minus the outgoing wave motion. As a check one can visually sum the reflected and the incident wave motion to find the ‘Observed surface elevation’. This can be seen from the definition made in the analysis

\[ S_{di} = S_o - S_{ar} \]  \hspace{1cm} (1)

where \( S_{di} \) is incident wave motion, \( S_o \) is the observed signal and \( S_{ar} \) is the reflected wave motion obtained from the analysis. From this we can see immediately that the following relation holds
\[ S_o = S_{di} + S_{ar}. \]  
(2)

Due to the alternative definition of incident wave motion we must also note that
\[ S_{ar} \neq S_{di} + S_{ar}. \]  
(3)

where \( S_{di} \) is the total wave motion found in the least squares analysis. This is actually the sum of incident and reflected wave motion found in the least squares analysis. the reason why this relation is violated is that \( S_{di} \) is not the same as the incident wave motion as found in the analysis.

This definition may be confusing at first instance but was found to be a useful one to circumvent the presence of non-linear wave motion in the incident wavefield (see Van Dongeren and Janssen, 2001\(^1\)). Also for a more thorough definition and visualisation of the effect of such a definition on the interpretation of results we refer to this report.

After completing the selection and setting the x- and y limits to the desired values the plot can be saved by pressing the ‘SAVE’ button on the screen or selecting ‘SAVE’ in the figure menu. M-RAT will prompt for file location and the file will be saved in the format that was selected with the selector on the screen.

![Figure 9 Overview Postprocessing screen M-RAT after opening .ANO file. Time series plot is shown.](image)

Figure 10 Overview Postprocessing screen M-RAT after opening *.ANO file. Frequency spectra plot is shown.

Buttons & Boxes

File

Plots
Here the user can select an *.ANO file for the Postprocessing

Main
Close Postprocessing and return to Main screen

Analysis
Close Postprocessing and go to Analysis screen

Exit
Leave M_RAT

Help

Subject Index
Opens digital help file

About MRAT
No action
B  Save Plot
M-RAT will prompt for a file location and save the file in the format that was
selected with the File Type Selector on the Post Processing Screen. Only the data
plot is saved (not the UI as a whole).

B  Table Output
A Table with analysis results will be plotted to the command window.

E  Select Output Graphs
A selector box that switches between time series and energy density plots. Also
cohere and reflection coefficient can be selected. The coherence is between the
first and second station in the set of stations. The reflection coefficient is determined
for the wave gauge location that was selected in the analysis.

E  Select graphic file format
A selector box that offers the possibility to change the output format of the graphic
file. Available are: jpeg, tiff, bitmap and PostScript.

E  X- and Y limit edit boxes
Here the user can set the limits for the x- and y axis. Settings are also used for the file
output.

E  Grid Switch
On/off switch for the active figure. Settings are also used for the file output.
ANI File Structure

The input file is a Matlab Cell array of Structures. The User Interface can read this Cell array but it can also be read directly. This can be useful as a check of the input file. Also it enables the user to apply an alternative analysis on the data available in the ANI files. In order to be able to read the file the structure of this file is explained in this chapter.

As mentioned before the ANI file is a Cell array of Structures\(^2\). The structure of the file is explained in Matlab language since this is the only program that may successfully read the files. In Table 1 an overview is given of the structure. The

<table>
<thead>
<tr>
<th>User Command</th>
<th>Who</th>
<th>InMat{1}</th>
<th>InMat{1}.String</th>
</tr>
</thead>
<tbody>
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<td>Matlab</td>
<td>ans</td>
<td>ans</td>
<td>NamShow: 'mp62'</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
<td>FileShow:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>'D:\Projects\RIKZ\Observario\nsPetten\MP6,7,8,18\T-140501.asc'</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>FileCount: '6'</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>StartTime: '140501'</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DLoc: '2.0'</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>Dist: '122.7'</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>ColSel: '3'</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>MV: '2500'</td>
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<tr>
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<td></td>
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<td></td>
<td>SWL: '1.8'</td>
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<td>DRec: '-0.69'</td>
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<td>TypeSelect: [2x1 cell]</td>
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<td></td>
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<td>DoneButton: 'Done'</td>
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<tr>
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<td>CanButt: 'Cancel'</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>trans: 'done'</td>
</tr>
</tbody>
</table>

Table 1 Overview of structure of ANI files

The first row of Table 1 shows the Matlab commands (these should be typed at the Command Window prompt after an ANI file was loaded with the ‘load’ command). InMat is the name of the cell array that will be a variable in your workspace after loading an ANI file. If cell ii is entered by typing InMat{ii} a list of Matlab Structures is given. These hold all the information entered in the Input screen and can be read, altered or removed. Note that if essential information is removed from the ANI file it will no longer be available for editing in the M-RAT User Interface.

\(^2\) Cell Arrays and Structures are standard Matlab data storage formats.
ANO File Structure

As for the input file the structure of the ANO file is given here. The ANO file is a Matlab Structure. After loading an ANO file in the command window it can be edited directly. A variable ‘Out’ will be added to your workspace. ‘Out’ is the Matlab structure that holds all analysis data. In Table 2 an example is shown of the structure of the ANO files generated by M-RAT.

<table>
<thead>
<tr>
<th>User Command</th>
<th>Who</th>
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<th>Out:FileIn</th>
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<td></td>
</tr>
<tr>
<td></td>
<td>Your variables are:</td>
<td>Out =</td>
<td>ans =</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td></td>
<td></td>
</tr>
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<td>Matlab</td>
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<td>S: [2999x5 double]</td>
<td>path: 'D:\Projects\RIKZ\Input'</td>
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<td>name: 'final3b.ANI'</td>
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<td></td>
<td>t: [1x5999 double]</td>
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<tr>
<td></td>
<td></td>
<td>M: [5999x4 double]</td>
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<td></td>
<td>BiPass: [5999x1 double]</td>
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<td></td>
<td></td>
<td>RData: [5999x1 double]</td>
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<td>Zwav: [5999x4 double]</td>
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<td>Snorm: [171x1 double]</td>
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<tr>
<td></td>
<td>FileOut: [1x1 struct]</td>
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<td></td>
</tr>
</tbody>
</table>

Table 2 Overview of structure of ANO files

The ANO file can be loaded with the Matlab ‘load’ command. All entries into this structure can be viewed, edited and/or removed. Again note that editing the ANO files outside the User Interface may cause them to be no longer readable by the User Interface.
The RAT file

After the complete analysis is performed the results can be summarised in a table. This table will be sent to the command window. Also this table output is saved in the *.RAT file. This file has the same name as the corresponding *.ANO file and is saved in the same directory. The file is a low-level text file that holds the same information as the table plotted to the Command Window and has a similar layout.