General wave spectrum model

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1.0 General

In many engineering projects a flexible description of the site specific wave data is necessary. As the spectral approach is gaining ground in the calculation of wave forces, harbour tranquillity, etc. the designer needs a flexible description of the wave spectrum.

Also in the preparation of wave flume tests an accurate description of the spectrum observed locally is of great importance.

The theoretical spectra that are described in the literature such as Pierson-Moskowitch [1], Jonswap [2], Sanders [3] and T.M.A. [4] do not provide the required flexibility to model locally measured wave spectra. Except for their specific range of application, fully grown sea at deep water for the P-M spectrum, developing sea for the Jonswap spectrum and sea in shallow water for the TMA spectrum, the theoretical spectral form is seldom similar to the measured data at a specific site.

In this report the application of the general wave spectrum, that was developed at the design of the storm surge barrier in the Eastern Scheldt [5], is described. This spectrum model has been used in several projects afterwards where its ease of application was proven and experience was gained as to the values of the parameters in specific cases.
2.0 The general wave spectrum model

The general wave spectrum that originally has been used in the design of the Eastern Scheldt Barrier to model swell, proved very useful in coastal engineering design projects all over the world. It is able to describe the spectral form of wind wave spectra, swell spectra and shallow water wave spectra quite accurately.

The general wave spectrum that is one dimensional, is mathematically expressed as follows:

\[
S(f) = \alpha g^2 (2\pi)^{-4} f_p^{m+n} f^m \quad 0 < f < f_p
\]

\[
S(f) = \alpha g^2 (2\pi)^{-4} f_p^n \quad f_p < f < f_h
\]

where

- \( \alpha = f(H_s, f_p, f_h, m, n) \)
- \( f_p \) = peak frequency
- \( f_h \) = cut off frequency = \( q f_p \)
- \( m, n \) = form parameters
- \( g \) = acceleration due to gravity

A definition sketch is given in fig 1.

The expressions for \( \alpha \) and the moments of the general wave spectrum are easily established.

The expression for \( \alpha \) that is needed if the spectral form has to be hindcasted from the significant wave height and the peak frequency, reads:

\[
\alpha = \frac{H_s^2 (n+1) (f_h f_p)^{(n-1)}}{16 g^2 (2\pi)^{-4} \left( \frac{n+m}{m+1} \left( f_h^{n-1} - f_p^{n-1} \right) \right)}
\]
fig 1 The definition sketch of the general wave spectrum

Also the expression for the $x$-th spectral moment is readily derived for the general spectrum. The $x$-th spectral moment is defined as:

$$m_x = \frac{\int f_x S(f) \, df}{f_h}$$

The result of the integral, which can be solved analytically, is:

$$m_x = \frac{\alpha g^2 (2\pi)^4}{n-x-1} \left\{ \frac{n+m}{m+x+1} f_p^{(n-x-1)} - f_h^{(n-x-1)} \right\}$$

where

$$f_h = q f_p$$
On the basis of this result the zero-crossing period and the period between maxima are evaluated easily:

\[
T_z = \left\{ \frac{m_0}{m_2} \right\}^{0.5} \quad T_m = \left\{ \frac{m_2}{m_4} \right\}^{0.5}
\]

A simple but practical measure of the spectral width, the \(T_p/T_z\) ratio can also be calculated as a function of the spectral form fixed by \(m, n\) and \(q\) (see appendix I).

Also the expression for the spectral width \(\epsilon\), that is frequently mentioned in the literature is a function of \(m, n\) and \(q\) according to:

\[
\epsilon = \left\{ 1 - \frac{m_2^2}{m_0 m_4} \right\}^{0.5} = \left\{ 1 - \left( \frac{T_m}{T_z} \right)^2 \right\}^{0.5}
\]

The computer program MOMENT.PAS, that calculates the \(T_p/T_z\) ratio and the spectral width parameter \(\epsilon\) is given in appendix II.
3.0 The estimation of the form parameters of the general wave spectrum

For a specific project the spectral form has to be established after a thorough analysis of the wave climate. The analysis has to provide the evidence that the wave spectrum during a specific season (e.g. South West monsoon) or for a typical type of storm shows similarity for a number of occurrences. If a class of similar spectra is identified on empirical and physical basis, the form can be described by the general wave spectrum model.

In a practical case the powers m and n are estimated by a regression analysis of the normalised left and the normalised right flank of a number of measured spectra from the same class.

The theoretical spectrum is normalised by a division by the spectral peak value:

The left flank:

\[ S(f) = \alpha \cdot g^2 \cdot (2\pi)^{-4} \cdot f_p^{-m-n} \cdot f^n \quad 0<f<f_p \]

The normalised left flank:

\[ \frac{S(f)}{S(f_p)} = \left\{ \frac{f}{f_p} \right\}^m \]

The right flank:

\[ S(f) = \alpha \cdot g^2 \cdot (2\pi)^{-4} \cdot f_p^{-n} \quad f_p<f<f_h \]

The normalised right flank:

\[ \frac{S(f)}{S(f_p)} = \left\{ \frac{f}{f_p} \right\}^{-n} \]

The simple result is that spectral values \( \{f, S(f)\} \) can be normalised dividing the frequency by the peak frequency and the spectral value by the spectral peak value.

The normalised values of several measured spectra are split in a left and a right flank and consequently collected per flank.
The values of m and n are established by a regression analysis on the normalised left flank and the normalised right flank data set respectively.

A form of forced regression is preferred however as the coefficient a has to be approximately 1.0 while the exponent b is chosen to minimise the residual standard deviation around the regression equation:

$$y = a x^b$$

An example of the fitting procedure performed with the computer program LINFIT.PAS is given in the figures 2 and 3.
Regression Analysis  left flank, southwest monsoon

Analysis of 28 data points

The fitted function is:

\[ Y = 0.963 \times X^{7.000} \]

St. deviation of estimate = 0.123
Max. Deviation of estimate = 0.333

![Graph showing fitted function](image)

fig. 2. Fitting the left flank of the southwest monsoon spectrum
REGRESSION ANALYSIS left flank, southwest monsoon

Analysis of 50 data points

The fitted function is:

\[ Y = 0.994 \times X^{-3.500} \]

St. deviation of estimate = 0.085
Max. Deviation of estimate = 0.239

fig. 3. Fitting the right flank of the southwest monsoon spectrum
4.0 A comparison of the general wave spectrum with the P-M spectrum, the Sanders spectrum and the Jonswap spectrum

One of the first expressions for the wave spectrum was given by Pierson-Moskowitz:

\[
S_{PM}(f) = \alpha g^2 (2\pi)^4 f^{-5} \exp\left\{ -\frac{5}{4} \left( \frac{f}{f_p} \right)^4 \right\}
\]

This spectral form was observed for fully grown ocean waves.

During the Jonswap experiments it was found that this expression did not fit the spectra observed during ideal generation conditions. For these conditions a better fit was reached if a peak enhancement factor was added to the P-M expression:

\[
S_j(f) = S_{PM}(f) \cdot \exp\left\{ -\frac{(f-f_p)^2}{2\sigma_f^2} \right\}
\]

It should be noted that the typical position of the P-M spectrum and the J-spectrum along the frequency axis differs considerably for equal significant wave height. The steepness \(H_s / L_p\) for the P-M spectrum is equal to 2.55\% while this value is 4 to 5\% depending on the fetch length for the J-spectrum.

From a graphical comparison of the general spectrum model and the P-M-spectrum it appears that the best fit is found for \(m = 7\) and \(n = 4\) (see fig 4). The form of the J-spectrum is best approximated if \(m\) and \(m\) are chosen 8 and 5 respectively (see fig 5).

With these values for \(m\) and \(n\) the Sanders spectrum is also well represented (see fig. 6).
fig. 4. The comparison between the P-M spectrum and the general spectrum with \( m = 7 \) and \( n = 4 \); The wave steepness defined on deep water \( H_s/L_p = 2.55\% \).

fig. 5. The comparison between the Jonswap spectrum and the general spectrum with \( m = 8 \) and \( n=5 \); The wave steepness defined on deep water \( H_s/L_p = 5.0\% \).
fig. 6. The comparison between the Sanders spectrum and the general spectrum with $m = 8$ and $n = 5$; The wave steepness defined on deep water $H_s/L_p = 5.0\%$

fig. 7. The fictitious double peaked spectrum found by adding the general spectrum with $f_p = 0.1$, $m = 7$ and $n = 3.5$ for swell and the general spectrum with $f_p = 0.2$, $m = 7$ and $n = 3.5$ for wind waves
5.0 Practical experience

In a number of projects experience has been acquired with the application of the general wave spectrum.
The table gives values for m and n for a number of special conditions from previous projects. These values could provide some guidance in future projects, but should not be accepted as a law.
Also typical values found in these previous projects for the spectral width and the wave steepness, defined on deep water, are given.

<table>
<thead>
<tr>
<th>type</th>
<th>m</th>
<th>n</th>
<th>Tp/Tz</th>
<th>ε</th>
<th>Hs/Lp</th>
</tr>
</thead>
<tbody>
<tr>
<td>developing sea</td>
<td>8.0</td>
<td>5.0</td>
<td>1.26</td>
<td>0.68</td>
<td>0.05</td>
</tr>
<tr>
<td>fully grown sea</td>
<td>8.0</td>
<td>4.0</td>
<td>1.40</td>
<td>0.75</td>
<td>0.026</td>
</tr>
<tr>
<td>shallow water swell</td>
<td>4.0</td>
<td>2.5</td>
<td>1.80</td>
<td>0.79</td>
<td>0.03</td>
</tr>
<tr>
<td>deep water swell</td>
<td>5.0</td>
<td>6.5</td>
<td>1.08</td>
<td>0.79</td>
<td>0.002</td>
</tr>
<tr>
<td>monsoon</td>
<td>7.0</td>
<td>3.5</td>
<td>1.56</td>
<td>0.77</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Uptill now only single peaked spectra have been considered. In some cases double peaked spectra are found. This is mostly seen where new wind waves grow on top of a swell.

The swell may be represented by a field of waves broken due to limited depth (shallow water swell) or by wave energy that originates from distant wave fields and that reaches the site after considerable dispersion.

In both cases new waves with a shorter peak period may grow on top of the swell under the influence of local wind.

Two examples are the wave spectra observed in the Eastern Scheldt and the wave spectra that are measured in the Indian coast during the NE-monsoon. It should be noted that in the second example the direction of swell and wind waves may be totally different.

These double peaked spectra are easily modelled by adding two general wave spectra with different peak periods and other parameters.

\[ S(f) = S_s(f)S_p(f) + S_w(f)S_p(f) \]
A plot of a fictitious double peaked spectrum, that depicts a young sea \((m = 8, n = 5)\) developing on top of a monsoon wave field \((m = 7, n = 3.5)\), is presented in fig. 7.

The existence of a wave spectrum in a mathematically tractable form as described above facilitates the application of the spectral approach for linear phenomena as diffraction or wave forces on structures.
The principle of the spectral approach is given in fig. 8.

fig. 8. The principle of the spectral approach for diffraction.
Literature


ANALYSIS OF STATISTICAL MOMENTS  hurricane data $H_s$ Karwar

Analysis of 25 datapoints
MEAN = 3.075
ABS.DEVIATION = 0.797
ST.DEVIATION = 1.042
SKEWNESS = 0.880
KURTOSIS = 3.072

$X_{\text{max}}$ = 5.770
$X_{\text{min}}$ = 1.530

ANALYSIS OF STATISTICAL MOMENTS  hurricane data $T_p$ Karwar

Analysis of 25 datapoints
MEAN = 8.323
ABS.DEVIATION = 0.881
ST.DEVIATION = 1.136
SKEWNESS = 0.508
KURTOSIS = 2.374

$X_{\text{max}}$ = 10.610
$X_{\text{min}}$ = 6.780

ANALYSIS OF STATISTICAL MOMENTS  hurricane data $S_p$ Karwar

Analysis of 25 datapoints
MEAN = 2.820
ABS.DEVIATION = 0.517
ST.DEVIATION = 0.644
SKEWNESS = 0.475
KURTOSIS = 2.974

$X_{\text{max}}$ = 4.536
$X_{\text{min}}$ = 1.753
General Wave Spectrum

\[ S(f) = \alpha g^2 (2\pi)^{-4} f_p^{-(m+1)n} f_n^{-(n-1)} \quad 0 < f_p \leq f_p \]

\[ S(f) = \alpha g^2 (2\pi)^{-4} f_n^{n-1} \quad f_p < f_n \leq f_n \]

\[ m_0 = \alpha g^2 (2\pi)^{-4} \left\{ \frac{n + m}{(m+1)(n-1)} f_p^{-(n-1)} - \frac{1}{n-1} f_n^{-(n-1)} \right\} \]

\[ \alpha = \frac{H_s^2}{16g^2(2\pi)^{-4}} \frac{(n-1)(f_n f_p)^{n-1}}{n + m \frac{f_n^{n-1} - f_p^{n-1}}{m+1}} \]

Eastern Scheldt swell spectrum:  \( m = 4.0 \quad n = 2.5 \)
Monsoon spectra:  \( m = 7.0 \quad n = 3.5 \)
P.Monsoon swell:  \( m = 5.0 \quad n = 6.5 \)
young sea:  \( m = 8.0 \quad n = 5.0 \)
hurricane:  \( m = 3.0 \quad n = 5.0 \)

\[ m_x = \alpha g^2 (2\pi)^{-4} \left\{ \frac{n + m}{(m+x+1)(n-x-1)} f_p^{-(n-x-1)} - \frac{1}{n-x-1} f_n^{-(n-x-1)} \right\} \]

\[ T_z^2 = \frac{m_0}{m_x} = \frac{n + m}{(m+1)(n-1)} f_p^{-(n-1)} - \frac{1}{n-1} f_n^{-(n-1)} = \frac{n + m}{(m+3)(n-3)} f_p^{-(n-3)} - \frac{1}{n-3} f_n^{-(n-3)} \]

if \( f_n = q f_p \):

\[ T_z^2 = \frac{m_0}{m_2} = f_p^{-2} \frac{n + m}{(m+1)(n-1)} - \frac{q^{-(n-1)}}{n-1} = \frac{n + m}{(m+3)(n-3)} - \frac{q^{-(n-1)}}{n-3} \]

\[ \frac{T_p}{T_z} = \sqrt{\frac{n + m}{(m+3)(n-3)} - \frac{q^{-(n-3)}}{n-3} \frac{n + m}{(m+1)(n-1)} - \frac{q^{-(n-1)}}{n-1}} \]

\[ q \approx 5.0 \]

\[ q = \infty \quad q = 5.0 \]

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<table>
<thead>
<tr>
<th>Type</th>
<th>m</th>
<th>n</th>
<th>$\frac{T_p}{T_z}$</th>
<th>$\frac{T_p}{T_z}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Scheldt</td>
<td>4.0</td>
<td>2.5</td>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>P. Monsoon swell</td>
<td>5.0</td>
<td>6.5</td>
<td>1.09</td>
<td>1.08</td>
</tr>
<tr>
<td>Monsoon</td>
<td>7.0</td>
<td>3.5</td>
<td>2.0</td>
<td>1.56</td>
</tr>
<tr>
<td>young sea</td>
<td>8.0</td>
<td>5.0</td>
<td>1.28</td>
<td>1.26</td>
</tr>
<tr>
<td>hurricane</td>
<td>3.0</td>
<td>5.0</td>
<td>1.16</td>
<td>1.14</td>
</tr>
</tbody>
</table>

if $q = \infty$:

$$
\frac{T_p}{T_z} = \sqrt{\frac{(m+1)(n-1)}{(m+3)(n-3)}}
$$
PROGRAM SPECTRAL_MOMENT_CALCULATION(INPUT,OUTPUT);

USES Crt,MathLib;

CONST
G = 9.81;

VAR
x : INTEGER;
alfa, f_p, f_h, q, m, n, M_0, M_2, M_4,
T_z, T_m, T_p, T_p_T_z_ratio, epsilon : REAL;

FUNCTION Spectral_Moment(x: INTEGER; alfa, m, n, f_p, f_h: REAL):REAL;
VAR
Constant,|Iulp|,|Iulp2| : REAL;
BEGIN
Constant := alfa * SQR(G/SQR(2*pi));
Hulp1 := n-x-1;
Hulp2 := (n+m)/((m+x+1)*(Hulp1));
Spectral_Moment := Constant*( Hulp2* Power(f_p,-Hulp1) - Power(f_h,-Hulp1)/Hulp1);
END;

BEGIN
alfa := 0.06194;
q := 5.0;
f_p := 0.1;
f_h := q*f_p;
ClrScr;
WRITELN('M , N ?');READLN(n);
IF ABS(n - 5.0) < 0.01 THEN n := 4.99; { to prevent division by 0 in M_4 }
M_0 := Spectral_Moment(0, alfa, m, n, f_p, f_h);
M_2 := Spectral_Moment(2, alfa, m, n, f_p, f_h);
M_4 := Spectral_Moment(4, alfa, m, n, f_p, f_h);
T_z := SQRT(M_0/M_2);
T_m := SQRT(M_2/M_4);
T_p_T_z_ratio := 1/(f_p*T_z);
epsilon := SQRT(1 - M_2*M_2/M_0/M_4);
WRITELN('T_p/T_z = ',T_p_T_z_ratio:10:3);
WRITELN('e = ',epsilon:10:3);
READLN;
END.

PROGRAM Spectra(input,output);
USES Printer,Crt,Graph,MathLib,PlotLib;

CONST
MAX = 20;

TYPE
ARY = ARRAY[1..MAX] OF REAL;

VAR
Answer   : CHAR;
NAAM,JobName : STRING[30];
I,N,typ    : INTEGER;
f,f,p,f_p1,f_p2,Sp_max,Sp_min,Hs,Hs_1,Hs_2,
M_spectrum_1,N_spectrum_1,M_spectrum_2,
N_spectrum_2,M0,M2,step,Alfa_PM,Alfa_J,
Alfa_S,Alfa_M,Alfa_G_1,Alfa_G_2,hulp,hulp1,
hulp2      :REAL;
Frequency,Sp : ARY;

PROCEDURE GET_DATA(VAR N : INTEGER ; VAR X,Y : ARY ; VAR Y_max,Y_min : REAL);

PROCEDURE MaxMin_V(V : REAL ;VAR V_max,V_min :REAL);
BEGIN
IF V > V_max THEN V_max := V;
IF V < V_min THEN V_min := V;
END;

BEGIN
Y_max := -Q ; Y_min := Q;
ClrScr;
WRITE('NAME OF INPUT FILE ? ');
READLN(NAAM);
N:=0;
ASSIGN(BESTAND,NAAM);
RESET(BESTAND);
READLN(BESTAND,JobName);
READLN(BESTAND,Hs);
READLN(BESTAND,Fp);
READLN(BESTAND,N);
FOR I:= 1 TO N DO
BEGIN
  READLN(BESTAND,X[I],Y[I]);
  GotoXY(30,4);WRITE(I:3,Y[I]:10:3);
  MaxMin_V(Y[I],Y_max,Y_min);
END;

PROCEDURE PARAMETER_Pierson_M(Hs,FP:REAL;VAR Alfa:REAL);
CONST
  CST= 0.0616215; { g^2/ 2pi^-4 }
  N = 5;
VAR
  H1,H2 :REAL;
BEGIN
  HI :=N*Power(FP,(N-1));
  Alfa:= SQR(Hs)/(16*CST) *H1;
END; {PARAMETER}

PROCEDURE PARAMETER_Jonswap(Hs,FP:REAL;VAR Alfa:REAL);
CONST
  CST= 0.0616215; { g^2/ 2pi^-4 }
  gamma = 3.3;
  N  = 5;
VAR
  H1,H2 :REAL;
BEGIN
  H1 := Power( FP , (N-1));
  Alfa:= SQR(Hs)/(16*CST) *H1/(H2);
END; {PARAMETER}

PROCEDURE PARAMETER_Monsoon(Hs,FP:REAL;VAR Alfa:REAL);
CONST
  CST= 0.0616215; { g^2/ 2pi^-4 }
  FM = 0.5;
  M = 7.0; N = 3.5;
VAR
  H1,H2 :REAL;
BEGIN
  H1 := (N-1)* Power( FM*FP ,(N-1));
  H2 := (N+M)/(M+l)*Power(FM,(N-l)) - Power(FP,(N-l));
  Alfa:= SQR(Hs)/(16*CST) *H1/(H2);
END; {PARAMETER}
PROCEDURE PARAMETER_Sanders(Hs,FP:REAL;VAR Alfa:REAL);
CONST
CST = 0.0616215; \{ g^2/ 2pi^-4 \} 
gamma = 0.75; 
N = 5;
VAR
H1,H2 :REAL;
BEGIN
H1 := (N-1)* Power( FP,(N-1));
H2 := 3 - 2*gamma;
Alfa := SQR(Hs)/(16*CST) *H1/(H2);
END; {PARAMETER}

PROCEDURE PARAMETER_General(M,N,Hs,FP:REAL;VAR Alfa:REAL);
CONST
CST = 0.0616215; \{ g^2/ 2pi^-4 \} 
FM = 0.5;
VAR
H1,H2 :REAL;
BEGIN
H1 := (N-1)* Power( FM*FP,(N-1));
H2 := (N+M)/(M+1)*Power(FM,(N-1)) - Power(FP,(N-1));
Alfa := SQR(Hs)/(16*CST) *H1/(H2);
END; {PARAMETER}

FUNCTION Pierson_M_Spectrum(f,fp,alfa :REAL):REAL;
CONST
\{ alfa =0.0081; original value \}
CST = 0.0616215; \{ g^2/ 2pi^-4 \} 
g = 9.81;
sa = 0.07;
sb = 0.09;
gamma = 3.3;
BEGIN
Pierson_M_Spectrum := alfa* CST *power(f,-5)*exp(-5/4*power((f/Q)),=4))
END;

FUNCTION Jonswap_Spectrum(f,fp,alfa :REAL):REAL;
CONST
sa = 0.07;
sb = 0.09;
gamma = 3.3;
VAR
s: REAL;
BEGIN
IF f<=fp THEN s:=sa ELSE s:=sb;
SPECTRA.PAS  Blz. 4.

Jonswap_Spectrum:= Pierson_M_Spectrum(f,fp,alfa) * Power(gamma,exp((-sqr(f-fp)) /
        (2*sqr(s)*sqr(fp))))

END;

FUNCTION Monsoon_Spectrum( f,fp,Alfa:REAL):REAL;
CONST
  CST= 0.0616215; { g^2 / 2piM }
  N = 3.5;
  M = 7.0;
  FM = 0.5;
  K = M+N;
BEGIN
  IF f>=fp THEN
    Monsoon_Spectrum := Alfa * CST * Power(f,-N)
  ELSE
    Monsoon_Spectrum := Alfa * CST * Power(fp,(-(M+N)) * Power(f,M);
END; {Monsoon_Spectrum}

FUNCTION Sanders_spectrum(f,fp,alfa :REAL):REAL;
CONST
  c =0.06175;
  gamma = 0.75;
VAR
  fm : REAL;
BEGIN
  fm := gamma * fp;
  IF f < fm THEN Sanders_spectrum := 0.0
  ELSE BEGIN
    IF f >= fp THEN Sanders_spectrum := alfa * c * Power(f,-5)
    ELSE Sanders_spectrum := (f- fm)* alfa * c * Power(fp,-5)/(fp-fm)
  END;
END;

FUNCTION General_Spectrum(M,N,f,fp,Alfa:REAL):REAL;
CONST
  CST= 0.0616215; { g^2 / 2piM }
  FM = 0.5;
BEGIN
  IF f >= fp THEN General_Spectrum:= Alfa * CST * Power(f,-N)
  ELSE General_Spectrum := Alfa * CST * Power(fp,-(M+N)) * Power(f,M);
END; {Monsoon_Spectrum}

FUNCTION Spectrum( Tpe : INTEGER; f, FP_1, FP_2: REAL):REAL;
BEGIN
    CASE Tpe OF
    1: Spectrum := Pierson_M_Spectrum(F,Fp_1,Alfa_PM);
    2: Spectrum := Jonswap_Spectrum(F,Fp_1,Alfa_J);
    3: Spectrum := Sanders_Spectrum(F,FP_1,Alfa_S);
    4: Spectrum := Monsoon_Spectrum(F,FP_1,Alfa_M);
    5: Spectrum := General_Spectrum(M_spectrum_1,N_spectrum_1,F,FP_1,Alfa_G_1) +
       General_Spectrum(M_spectrum_2,N_spectrum_2,F,FP_2,Alfa_G_2);
    END
END;

PROCEDURE Grafiek_en_Print;
BEGIN
    f := 0.2*fp_1; step := 0.0001; M0 := 0; M2 := 0;
    Hulp1 := spectrum(typ,fp_1,fp_1,fp_2);
    IF INT(Hulp1)<1.0 THEN Hulp2 := 1.0
    ELSE Hulp2 := 2.5;
    IF Hulp1 > 2.5 THEN Hulp2 := 5.0 * INT(Hulp1/5.0+0.5);
    GraphPaper(0.0,0.0,0.5,Hulp2,'frequency [Hz]','energy [m2.s]');
    FOR I := 1 TO N DO DrawCircle(Frequency[I],Sp[I]);
    while f<0.5 do
    begin
        hulp := spectrum(typ,f,fp_1,fp_2);
        Tekenen_grafiek(f,hulp);
        hulp := hulp * step;
        M0 := M0 + hulp; { calculate M0 }
        M2 := M2 + SQR(f) * hulp; { calculate M2 }
        f:=f+step
    end;
{ f:=0.2*fp;
    while f<0.4 do
    begin
        hulp := spectrum(1,f,fp);
        DrawCircle(f,hulp);
        f:=f+0.001
    end; }
OutTextXY(400,50,'Hardcopy (Y/N) ? '); Answer := ReadKey;
IF UpCase(Answer) IN ['Y','Y'] THEN
BEGIN
    SetColor(0);
    OutTextXY(400,50,'Hardcopy (Y/N) ? '); SetColor(15);
    Hardcopy(false,0);
    WRITELN(LST,JobName);
    WRITELN(LST,CHR(12));
END;}
BEGIN

{ M_spectrum N_spectrum
Eastern Scheldt 4.0 2.5
Monsoon spectrum 7.0 3.5
P.Monsoon spectrum 5.0 6.5
Hurricane spectrum 12.0 4.0
Developing sea 8.0 5.0 }

M_spectrum_1 := 8.0; N_spectrum_1 := 6.5;
M_spectrum_2 := 8.0; N_spectrum_2 := 4.0;
typ := 5;
WRITE('Piekfrequentie 1 ='); READLN(fp_1);
WRITE('H sign 1 = '); READLN(Hs_1);
WRITE('Piekfrequentie 2 = '); READLN(fp_2);
WRITE('H sign 2 = '); READLN(Hs_2);
{ GET_DATA( N,Frequency,Sp, Sp_max,Sp_min ); } PARAMETERS_Pierson_M(Hs_1,fp_1, Alfa_PM);
PARAMETER_Jonswap(Hs_1,fp_1, Alfa_J);
PARAMETER_Sanders(Hs_1,fp_1, Alfa_S);
PARAMETER_Monsoon(Hs_1,fp_1, Alfa_M);
PARAMETER_General(M_spectrum_1,N_spectrum_1,Hs_1,fp_1, Alfa_G_1);
PARAMETER_General(M_spectrum_2,N_spectrum_2,Hs_2,fp_2, Alfa_G_2);
Grafiek_en_Print;
WRITELN('Alfa = ',Alfa_G_1:10:4,Alfa_G_2:10:4);
WRITELN('Mo = ',M0:10:4,'  M2 = ',M2:10:4);
WRITELN('Hs = ',4* SQRT(M0):10:4,'  Tz = ', SQRT(M0/M2):10:2);
READLN;
END.