ministerie van verkeer en waterstaat

rijkswaterstaat

bouwspeurwerk

General Wave Spectrum Model

auteur:
prof drs ir J.K. Vrijling

BSW nr. 90-13

Rijkswaterstaat
Bouwspeurwerk

Postbus 20.000
3502 LA UTRECHT

tel: 030 -859111

september 1990

GENERAL WAVE SPECTRUM MODEL

1.0 General

In many engineering projects a mathematical 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 mathematical description of the wave spectrum.
In the preparation of wave flume tests an accurate description of the spectrum observed locally is of great importance as well.

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 or Sanders 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 other projects such as the calculation of the wave load on the IJmuiden sea lock [8], the design of a harbour in India and the redesign of the Closure dike [9]. Here 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, originally developed in the design of the Eastern Scheldt Barrier to model swell, proved very useful in coastal engineering design projects at various sites in 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:

left flank:

$$S(f) = \alpha\, g^{2}\, (2\,\pi)^{-4}\, f_{p}^{-(m+n)}\, f^{m} \qquad 0 < f < f_{p}$$

right flank:

$$S(f) = \alpha\, g^{2}\, (2\,\pi)^{-4}\, f^{-n} \qquad f_{p} <= f < f_{h}$$

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 α and the moments of the general wave spectrum are easily established.

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

$$\alpha = \frac{H_{s}^{2}\, (n-1)\, (f_{h}\, f_{p})^{(n-1)}}{16\, g^{2}\, (2\,\pi)^{-4}\, \{(n+m)/(m+1)\, f_{h}^{(n-1)} - f_{p}^{(n-1)}\}}$$

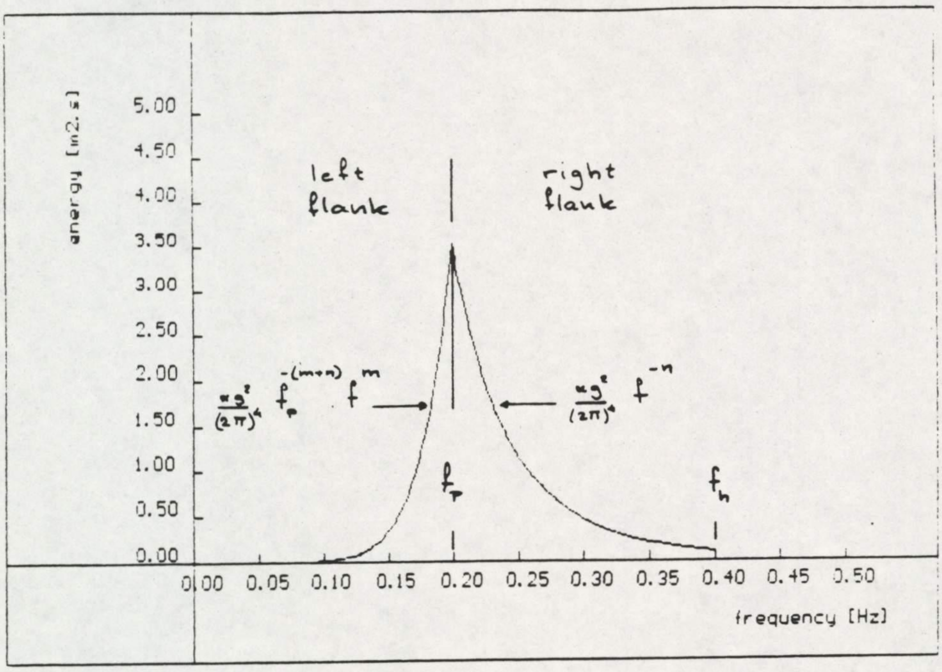

Fig 1 The definition sketch of the general wave spectrum

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

$$m_x = \int_0^{f_h} f^x \, S(f) \, df$$

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

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

On the basis of this result the mean zero-crossing period and the mean period between maxima can be evaluated:

$$T_z = \{ m_0 / m_2 \}^{0.5} \qquad T_m = \{ m_2 / m_4 \}^{0.5}$$

A simple but practical measure of the spectral width is the Tp / Tz ratio, which can also be calculated as a function of the spectral form fixed by m,n and q (see Appendix I)
The Tp/Tz ratio gives a quick impression of the spectral width.

The formal expression for the spectral width ϵ, that is frequently mentioned in the litterature is a function of m,n and q, viz.:

$$\epsilon = \{ 1 - \frac{m_2^2}{m_0 m_4} \}^{0.5} = \{ 1 - (\frac{T_m}{T_z})^2 \}^{0.5}$$

The computer program MOMENT.PAS, that calculates the practical measure of spectral width Tp/Tz and the formal spectral width parameter ϵ as a function of m,n and q 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 $S(f_p)$:

If the left flank is defined as:

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

The normalised left flank reads:

$$\frac{S(f)}{S(f_p)} = \{ \frac{f}{f_p} \}^m$$

If the right flank is given by:

$$S(f) = \alpha g^2 (2\pi)^{-4} f^{-n} \qquad f_p <= f < f_h$$

The normalised right flank reads:

$$\frac{S(f)}{S(f_p)} = \{ \frac{f}{f_p} \}^{-n}$$

The simple result is that spectral values { f , S(f) } can be normalised by 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 equal to 1.0 while the exponent b is chosen to minimise the residual standard deviation around the regression equation:

$$y = a\,x^{b} \qquad \text{where } a = 1.0$$

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 S.W. monsoon

Analysis of 28 datapoints

The fitted function is :

Y := 0.963 * X^ 7.000

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

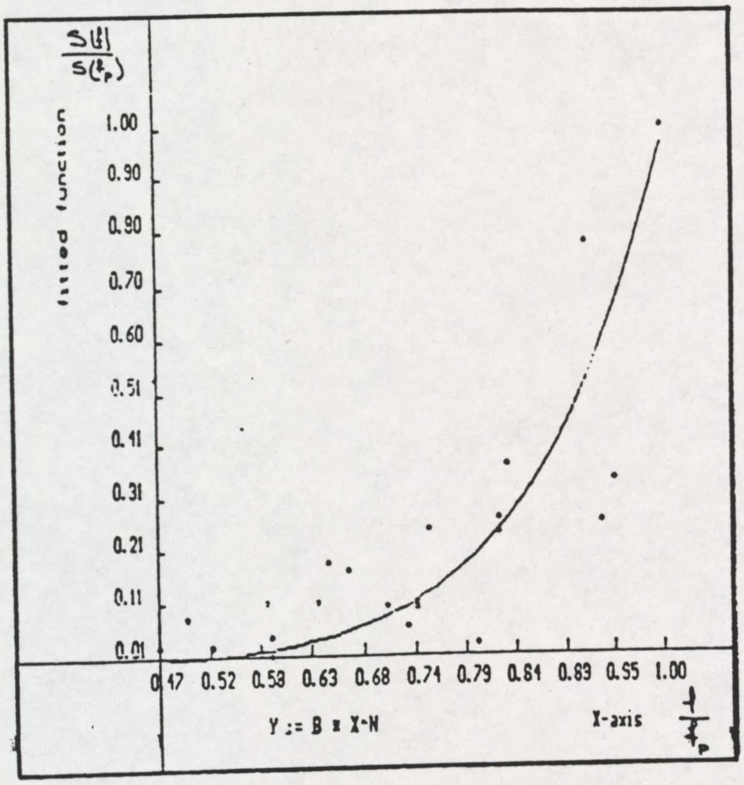

fig 2. FITTING THE LEFT FLANK OF THE MONSOON SPECTRUM

REGRESSION ANALYSIS right flank SW-monsoon

Analysis of 50 datapoints

The fitted function is :

Y := 0.994 * X^ -3.500

St. deviation of estimate = 0.085
Max.deviation of estimate = 0.293

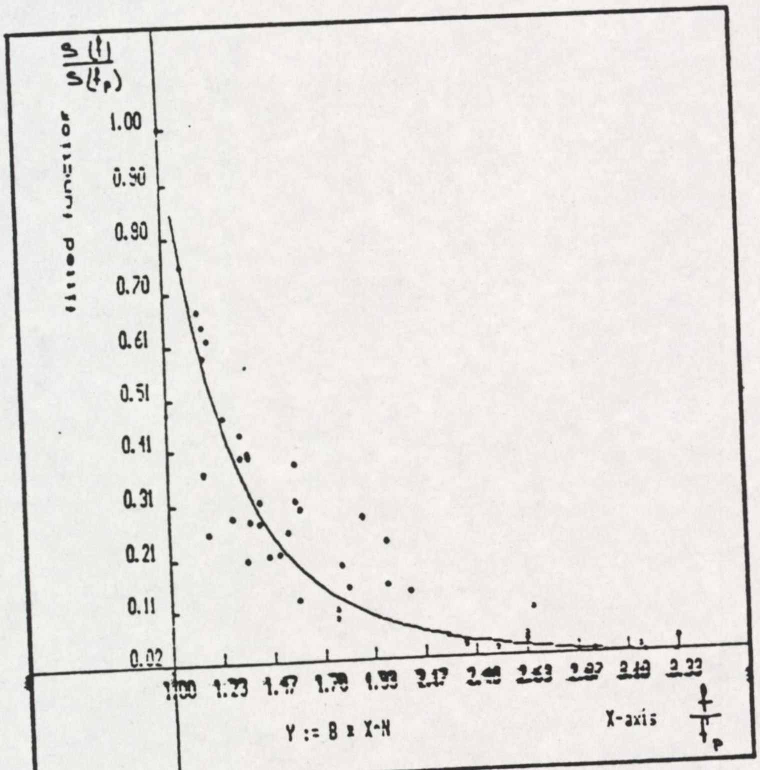

fig 3. FITTING THE RIGHT FLANK OF THE MONSOON SPECTRUM

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 a wave spectrum was given by Pierson and Moskowitz [1]:

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

This spectral form was observed on the North Atlantic ocean for fully grown ocean waves.

During the Jonswap experiments carried out at the North Sea, 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:

$$S_J(f) = S_{PM}(f)\, \tau^{\exp\left\{ -\frac{(f - f_p)^2}{2 \sigma f_p} \right\}}$$

where τ, σ = form parameters

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 Hs / Lp 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 visual 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 n 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).

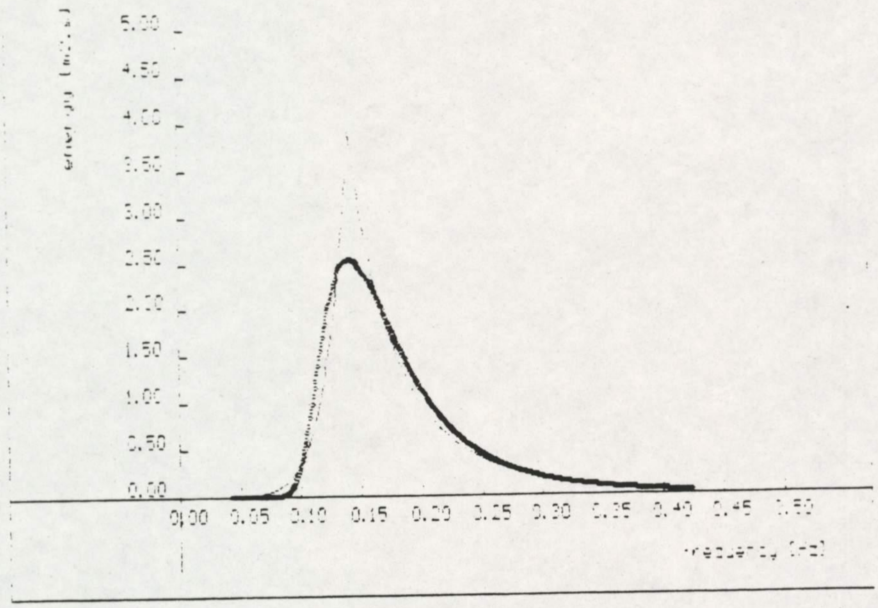

Fig. 4 The comparison between the P-M spectrum and the general spectrum with m = 7 and n = 4; The wave steepness defined on deep water Hs/Lp = 2.55%

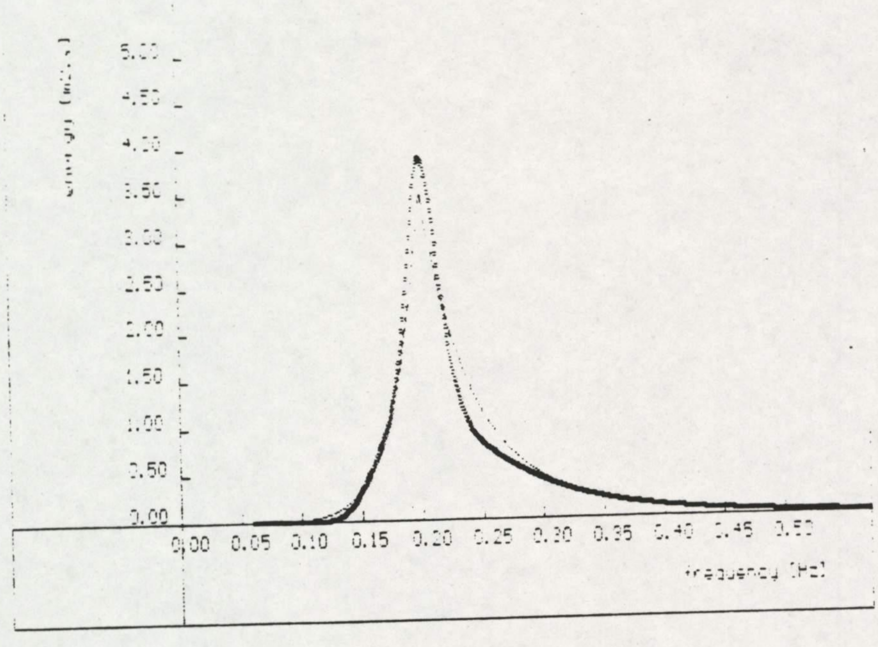

Fig. 5 The comparison between the Jonswap spectrum and the general spectrum with m = 8 and n = 5; The wave steepness defined on deep water Hs/Lp = 5.0%

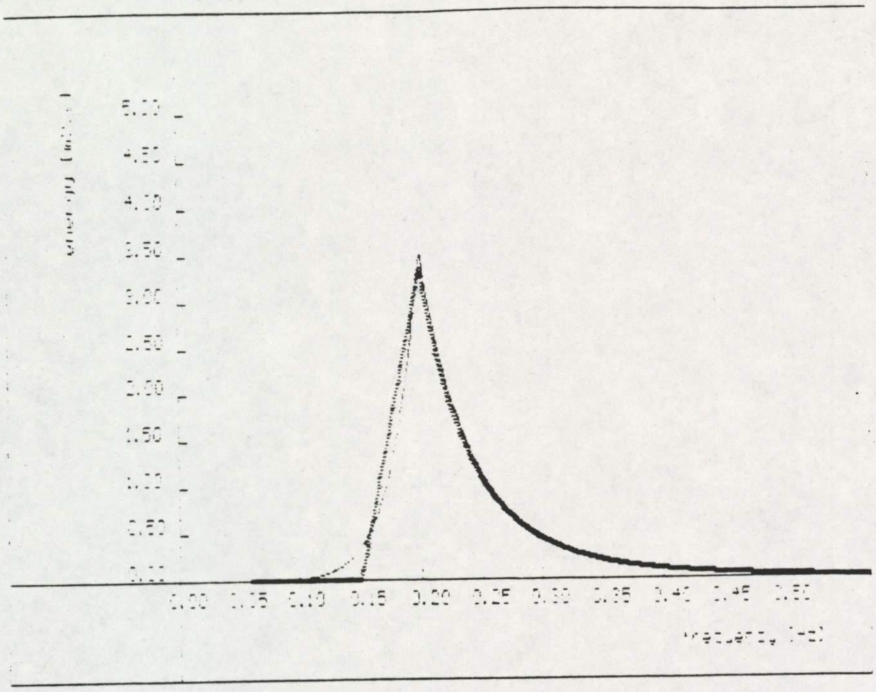

fig. 6 The comparison between the Sanders spectrum and the general spectrum with m = 8 and n = 5; The wave steepness defined on deep water Hs/Lp = 5.0%

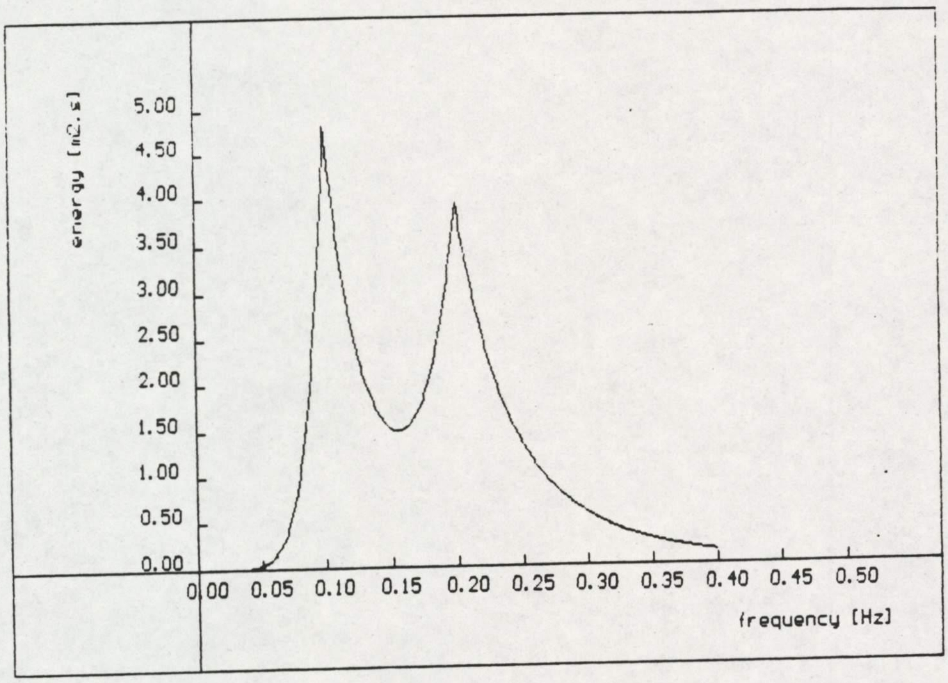

fig. 7 The fictitious double peaked spectrum found by adding the general spectrum with fp = 0.1, m = 7 and n = 3.5 for monsoon waves and the general spectrum with fp = 0.2, m = 7 and n = 3.5 for wind waves

5.0 Practical experience

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

type	m	n	Tp/Tz	ε	Hs/Lp
developing sea	8.0	5.0	1.26	0.68	0.05
fully grown sea	8.0	4.0	1.40	0.75	0.026
shallow water swell	4.0	2.5	1.80	0.79	0.03
deep water swell	5.0	6.5	1.08	0.57	0.002
monsoon	7.0	3.5	1.56	0.77	0.01

Untill 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 along 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.

$$S(f) = S_s(f, f_{p1}) + S_w(f, f_{p2})$$

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.

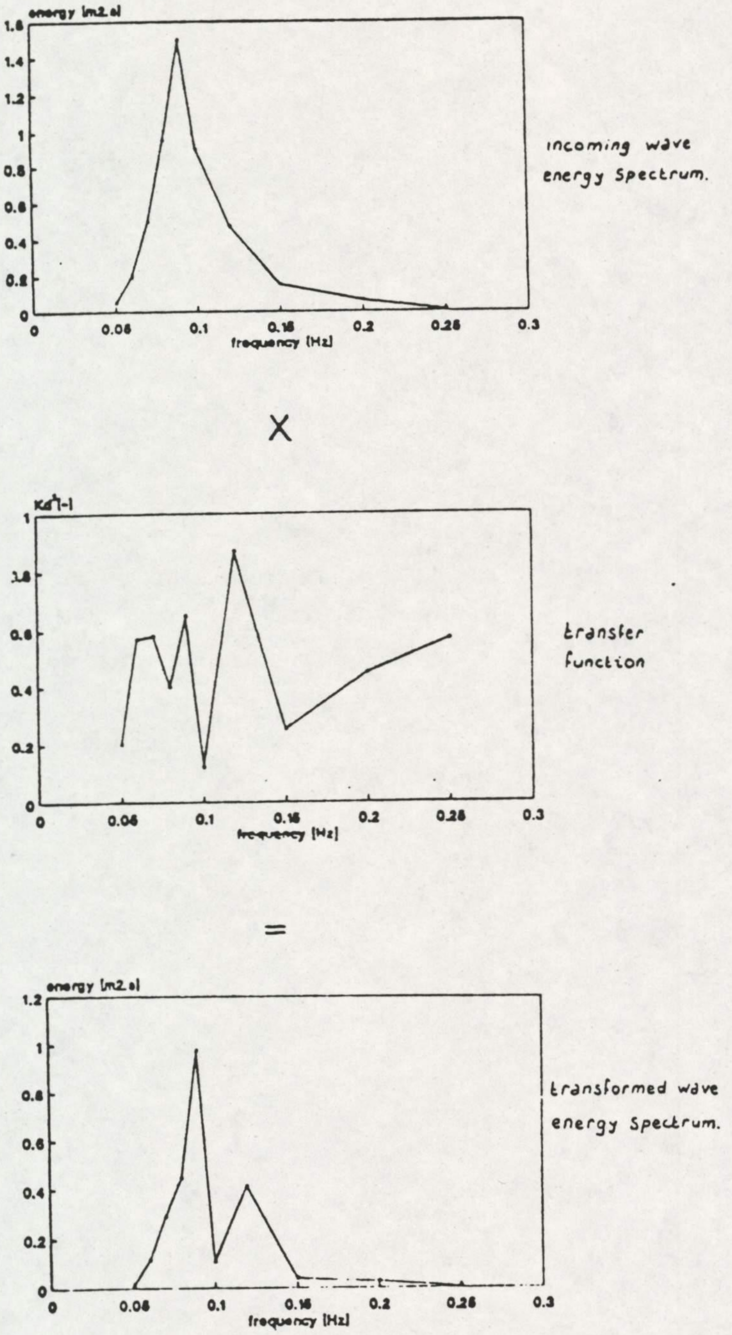

Fig. 8. The principle of the spectral approach for diffraction.

Literature

[1] Pierson,W.J.and Moskowitz,L. A proposed spectral form for fully developed wind seas based on the similarity theory of S.A.Kitaigorodskii,J.geophys. Res. 69, 5181-5191, 1964

[2] Hasselman,K. et alt.Measurements of wind-wave growth and swell decay during the joint North Sea Wave Project (Jonswap), Deutsche Hydrogr. Zeitschrift, A8, No 12, 1973

[3] Sanders,J.W., A Growth-stage scaling model for the wind driven sea, Deutschen Hydrografischen Zeit-schrift, Band 29,1976

[4] Bouws,E.et alt.,Similarity of the wind wave spectrum in finite depth water, Journ. of Geoph. Res.,Vol 90, January 1985

[5] Vrijling,J.K.,Bruinsma,J.,Hydraulic boundary con-ditions, Symp. on Hydraulic aspects of coastal structures, Rotterdam, 1980

[6] Gadre,M.R.,Kanetkar,G.N, Variation in Wave Energy distribution along the coast of India, CWPRS

[7] Dattatri,J.,Waves off Mangalore harbor-West coast of India, Journal of ASCE,February,1973

[8] WBS, De belastingen op de deuren van de zeesluis te IJmuiden, Utrecht, 1980

[9] WBS, Rapportage aanpassing Afsluitdijk; De hydrau-lische randvoorwaarden , Utrecht, 1988

GENERAL WAVE SPECTRUM

$$S(f) = \alpha\, g^2 (2\pi)^{-4} \cdot f_p^{-(m+n)} \cdot f^{m} \qquad 0 < f < f_p$$

$$S(f) = \alpha\, g^2 (2\pi)^{-4} \, f^{-n} \qquad f_p < f < f_h$$

via integration of $S(f)$:

$$m_0 = \alpha\, g^2 (2\pi)^{-4} \left\{ \frac{n+m}{(m+1)(n-1)} \cdot f_p^{-(n-1)} - \frac{1}{n-1} f_h^{-(n-1)} \right\}$$

If H_s and f_p are known α reads:

$$\alpha = \frac{H_s^2}{16\, g^2 (2\pi)^{-4}} \; \frac{(n-1)\left(f_h \cdot f_p\right)^{n-1}}{\frac{n+m}{m+1} f_h^{(n-1)} - f_p^{(n-1)}}$$

Eastern Scheldt swell spectrum : $m = 4.0 \quad n = 2,5$

Monsoon spectra : $m = 7.0 \quad n = 3,5$

PeMonsoon swell : $m = 5.0 \quad n = 6.5$

young sea : $m = 8.0 \quad n = 5.0$

hurricane : $m = 3.0 \quad n = 5.0$

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

The general expression for the x-th spectral moment

$$T_z^2 = \frac{m_0}{m_2} = \frac{\frac{n+m}{(m+1)(n-1)} f_p^{-(n-1)} - \frac{1}{(n-1)} \cdot f_h^{-(n-1)}}{\frac{n+m}{(m+3)(n-3)} f_p^{-(n-3)} - \frac{1}{(n-3)} f_h^{-(n-3)}}$$

if $f_h = q \cdot f_p$ the result is:

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

A simple measure of spectral width:

$$\frac{T_p}{T_z} = \left\{ \frac{\frac{n+m}{(m+3)(n-3)} - \frac{q^{-(n-3)}}{(n-3)}}{\frac{n+m}{(m+1)(n-1)} - \frac{q^{-(n-1)}}{(n-1)}} \right\}^{\frac{1}{2}}$$

A value of $q \sim 5.0$ is a reasonable estimate

Type	m	n	$q=\infty$ T_p/T_z	$q=5$ T_p/T_z
Easten Scheldt swell	4.0	2.5		1.80
Pre Monsoon swell	5.0	6.5	1.09	1.08
Monsoon	7.0	3.5	2.0	1.56
young sea	8.0	5.0	1.28	1.26
hurricane	3.0	5.0	1.16	1.14

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,Hulp1,Hulp2 : 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;

   WRITELN(' M , N  ? ');READLN(m,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(' ε        = ',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          : INTEGER;
  f,fp,
  Sp_max,Sp_min,
  Hs,
  M_spectrum,N_spectrum,
  Alfa_PM,Alfa_J,Alfa_S,Alfa_M,Alfa_G,
  hulp,hulp1,hulp2:REAL;
  Frequency,Sp        : ARY;



PROCEDURE GET_DATA( VAR N : INTEGER ; VAR X,Y : ARY ;
                    VAR Y_max,Y_min : REAL);
CONST
  Q = 10e5;

VAR

  I       : INTEGER;
  Dummy1,
  Dummy2,Dummy3  : REAL;

  BESTAND : TEXT;


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;
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
               H1  := 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));
               H2  := 0.065 * Power(gamma,0.803) + 0.135;
               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+1)*Power(FM,(N-1)) - Power(FP,(N-1));
               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/fp),-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;
   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
       CS1= 0.0616215;  { g^2/ 2pi^-4 }
       N  =  3.5;
       M  =  7.0;
       FM =  0.5;
       K  =  M+N;


    BEGIN
         IF  f >= fp  THEN
                      Monsoon_Spectrum := Alfa * CS1 * Power(f,-N)
                      ELSE
                      Monsoon_Spectrum := Alfa * CS1 * 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/ 2pi^-4 }
  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 : REAL):REAL;
  BEGIN
    CASE  Tpe  OF
        1: Spectrum :=  Pierson_M_Spectrum(F,Fp,Alfa_PM);
        2: Spectrum :=  Jonswap_Spectrum(F,Fp,Alfa_J);
        3: Spectrum :=  Sanders_Spectrum(F,FP,Alfa_S);
        4: Spectrum :=  Monsoon_Spectrum(F,FP,Alfa_M);
        5: Spectrum :=  General_Spectrum(M_spectrum,N_spectrum,F,FP,Alfa_G);
    END
  END;

PROCEDURE Grafiek_en_Print;

BEGIN
    f :=  0.3*fp;

    Hulp1 := spectrum(5,fp,fp);

    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 < 3*fp do
          begin
            hulp := spectrum(5,f,fp);
            Teken_grafiek(f,hulp);
            f:=f+0.001
          end;
    f := 0.3*fp;

    while f < 3*fp 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','J'] THEN
                             BEGIN
                               SetColor(0);
                               OutTextXY(400,50,'Hardcopy (Y/N) ? ');
                               SetColor(15);
                               Hardcopy(false,6);    { 6 groot }
                             {  WRITELN(LST,JobName); }
                               WRITELN(LST,CHR(12));
                             END;
  CloseGraph;Textmode(2);
END;


BEGIN
  M_spectrum := 7.0;
  N_spectrum := 3.5;

   {                         M_spectrum    N_spertrum
    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      }

  WRITE('Piekfrequentie = '); READLN(fp);
  WRITE('H sign         = '); READLN(Hs);
{  GET_DATA( N ,Frequency,Sp, Sp_max,Sp_min );}

  PARAMETER_Pierson_M(Hs,FP, Alfa_PM);
  PARAMETER_Jonswap(Hs,FP, Alfa_J);
  PARAMETER_Sanders(Hs,FP, Alfa_S);
  PARAMETER_Monsoon(Hs,FP, Alfa_M);
  PARAMETER_General(M_spectrum,N_spectrum,Hs,FP, Alfa_G);



  Grafiek_en_Print;
  WRITELN('Alfa = ',Alfa_G:10:4);
 READLN;
END.
```