



## **Forecasting of wind generated waves**

# **USERS MANUAL**

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**cgWindWaves**, Version 4/03, User manual

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## General

The wave forecasting methods are both empirical and theoretical. Many factors are involved in wave forecasting, especially in restricted fetch areas. The wave forecasting methods are based on semi-empirical relations (SMB methods, Sverdrup, Munk, and Bretschneider), which link the significant wave height  $H_s$  and significant wave period  $T_s$  to wind speed  $U$ , fetch length  $F$ , and water depth. The wave forecasting procedure is largely graphical, and laborious.

With this program you get an estimate of the waves in restricted fetch water regions. From the water region defined by its map, the mean wind direction and wind velocity, you obtain the significant wave height  $H_s$ , and wave period  $T_s$ , and a wave spectrum  $S(f)$ . The wave prediction is based on the combination of various theories for wave forecasting, for directional effects, and wave spectra, which are implemented in the program. Application of the program is for regions where refraction is negligible.

## Methodology

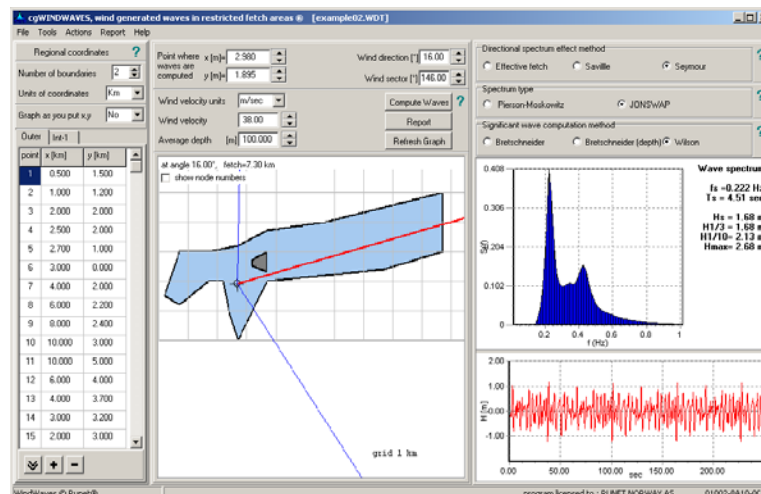
The region of the water, which is defined by its map, is divided in sectors radiating from the point where the wave characteristics are to be determined. These sectors are symmetrically disposed about a centerline which is directed up-wind along the main wind direction.

For each of these sectors the significant wave height ( $H_s$ ) and wave period ( $T_s$ ) are predicted, using one of three known methods. These methods are: two methods by Bretschneider, one without taking into account the water depth and one which takes into account the water depth, and one method by Wilson. In case the water depth is taken into account, an average water depth over the region is considered.

The wave forecasting of the water region is based on a wave spectrum, which is obtained by taking into account the contribution of each of these sectors the water region is divided. Three methods are applied in the program for this contribution.

- The effective fetch method is obtaining an equivalent fetch of the region by an weighted average process of the fetch of each sector. From this fetch the significant wave height and period are predicted, and from them the wave spectrum.
- Saville's method which obtains an equivalent significant wave height and period, by a weighted average process of the predicted significant wave height and period for each sector. From the significant wave height and period the wave spectrum is predicted.
- Seymour's method. According to this the wave spectrum is computed for each sector and the final predicted wave spectrum is obtained by adding up the energy of each sector's spectrum.

For the wave spectra the two known spectra by Pierson-Moskowitz and JONSWAP are used.



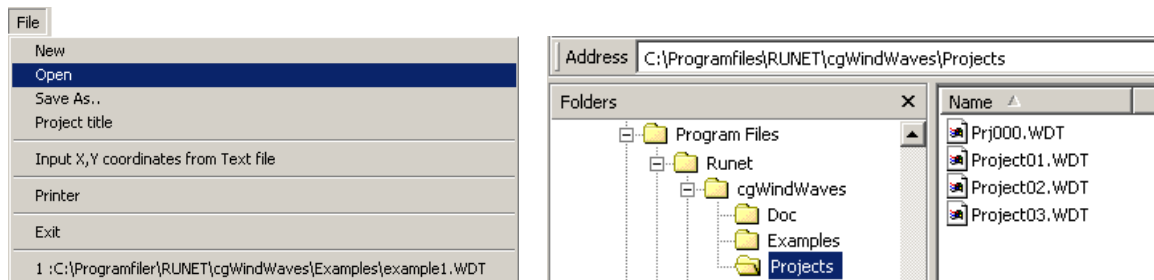
## How to use the Program

1. Open a file. The data are automatically saved in the file.
2. Select the units for coordinates.
3. Specify the number of boundaries (up to 5). Boundary one is the external boundary, and boundaries 2, 3, 4, and 5 are internal boundaries corresponding to islands.
4. Give the Cartesian coordinates of each boundary, or read in the coordinates from a text file.
5. Click at **Refresh Graph** to see the drawing of the region map.
6. Give the coordinates of the point where the waves characteristics are to be determined.
7. Specify the mean wind direction in degrees and the wind sector angle.
8. Select units for the wind velocity, and give the wind velocity.
9. Give the mean water depth of the region
10. Select method for implementing the directional effects
11. Select wave spectrum P-M or JONSWAP
12. Select method for forecasting significant wave height and period from wind velocity, fetch and water depth.
13. Click at **Compute Waves** to obtain the predicted wave heights and period, and the wave spectrum together with a typical wave time record.

By changing the wind parameters, wind direction or wind velocity, or the wave forecasting theories, with a mouse click, the new wave prediction appears at once. In this way you can search very fast for the optimum parameters and wind direction for design wave spectrum.

By clicking at **?** you get help information on the adjacent subject.

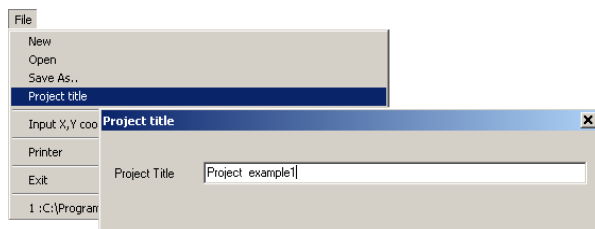
## Files



The project data are automatically saved in a file with ending WDT. All the data for the project is saved in this file. Automatically the project files are created in the folder ..cgWindWaves\Projects. Of course you can place your data files anywhere in your system. With the action [Save as] you make a copy of your project with another name.

## Project Title

Define the title of the projects to show on top of the report pages. The project title can be changed any time.



## Coordinates of water region

You input the basic nodes of the water region outlines.

point	x [km]	y [km]
1	10.000	10.000
2	20.000	8.000
3	25.000	10.000
4	30.000	20.000
5	32.000	22.000
6	36.000	20.500
7	40.200	12.300
8	43.000	10.000

First you choose the number of boundaries. Boundary (outline) one is always the outside region, and 2, 3, 4, 5 are boundaries of inside islands.

You choose the units for the coordinates. (m, km, ft,miles).

You give the coordinates of the outline nodes of each boundary. Give the nodes in sequence as they connected. You may skip nodes between nodes to fill in afterwards. If you select YES for [Make graph as you put x, y] then the same moment you input the coordinates, the graph of the map is drawn. This maybe helpful some times.

Otherwise in order to draw the graph click at.

- By clicking at >> you expand the grid with the input nodal coordinates to make space for more nodes.
- By clicking at + you insert nodes between
- By clicking at – you delete the current selected node.

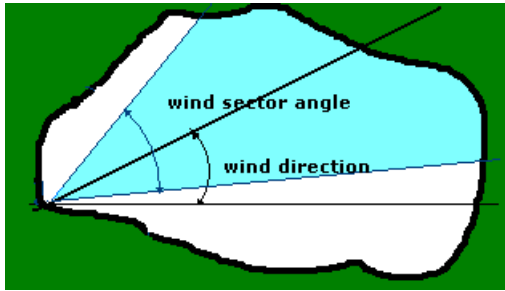
## Input water region coordinates from text file

```

1 10.0 10.0
2 20.0 8.0
3 25.0 10.0
4 30.0 20.0
5 32.0 22.0
6 36.0 20.50
7 40.20 12.30
8 43.0 10.0
.
.
.
33 30.0 55.60
34 12.50 61.30
35 15.30 50.00
36 14.20 40.30
37 10.00 30.00
38 5.30 20.25
R
1 25.0 25.0
2 30.0 32.0
3 31.0 34.0
4 27.0 34.0
5 26 30.0
    
```

You may read the coordinates from the water region from an external text file (\*.txt) made with Notepad or Word. The format of this file is simple. One line for the coordinates of each point with the node number in front and the x and y coordinates following with space separations between. To change outline insert a line with the letter R between.

## Wind Data



Wind direction [°] 39.00

Wind sector [°] 130.00

**Wind direction.** This is the mean wind direction (angle with the horizontal) in degrees.

**Wind sector angle  $\phi$ .** This is the angle inside which we assume the wind effect. The wind sector is assumed half of this angle  $\phi/2$  at each side of the main wind direction. (Maximum value for this angle =  $180^\circ$ ). This wind sector (marked blue in the drawing) is divided in sub sectors radiating from the point where the waves characteristics are to be determined. These sectors are symmetrically disposed about a centerline which is directed up-wind along the main wind direction. The subdivision in the program is in sectors of  $2^\circ$ . When the wind sector angle approaches zero (minimum value in the program =  $4^\circ$ ), the wave prediction approaches the single fetch theory.

Wind velocity units m/sec

Wind velocity 24.00

Average depth [m] 40.000

**Wind velocity** in units you choose (m/sec, km/hr, ft/sec or Miles/sec).

## The Beaufort Scale

Force	Description	knots	m.p.h.	m/s
0	Calm	<1	<1	0.0-0.2
1	Light Air	1-3	1-3	0.3-1.5
2	Light Breeze	4-6	4-7	1.6-3.3
3	Gentle Breeze	7-10	8-12	3.4-5.4
4	Moderate Breeze	11-16	13-18	5.5-7.9
5	Fresh Breeze	17-21	19-24	8.0-10.7
6	Strong Breeze	22-27	25-31	10.8-13.8
7	Near Gale	28-33	32-38	13.9-17.1
8	Gale	34-40	39-46	17.2-20.7
9	Strong Gale	41-47	47-54	20.8-24.4
10	Storm	48-55	55-63	24.5-28.4
11	Violent Storm	56-63	64-75	28.5-32.6
12	Hurricane	$\geq 64$	$> 75$	$\geq 32.7$

### Units

	knot	m/sec	m.p.h.	km/hr	ft/sec
knot	1	0.515	1.152	1.853	1.689
m/sec	1.943	1	2.237	3.600	3.281
m.p.h	0.868	0.477	1	1.609	1.467
km/hr	0.540	0.278	0.621	1	0.911
ft/sec	0.592	0.305	0.682	1.097	1

1 ft=0.3048 m      1 Mile=1610 m      1Nautical Mile=1858 m

### Wave spectra

Spectrum type

Pierson-Moskowitz     
  JONSWAP

Two commonly used wave spectral formulas are implemented in the program

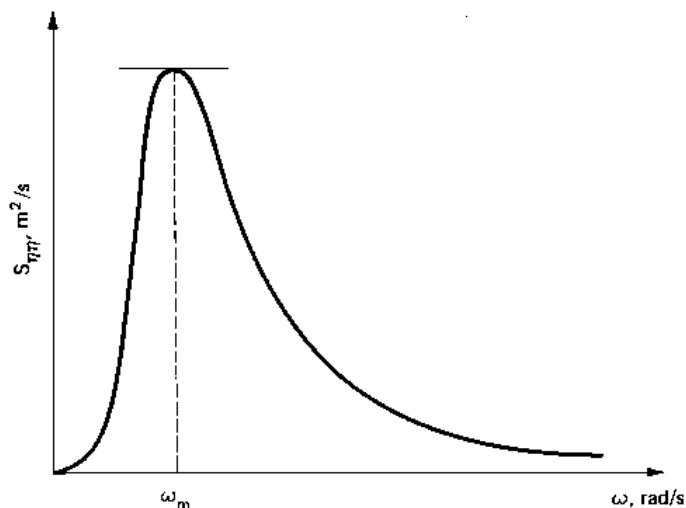
**Pierson-Moskowitz**

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

**JONSWAP**

$$S(f) = \alpha g^2 (2\pi)^{-4} f^{-5} \exp \left\{ -\frac{5}{4} \left( \frac{f}{f_p} \right)^{-4} \right\} \gamma \exp \left\{ \frac{-(f - f_p)^2}{2\sigma^2 f_m^2} \right\}$$

$\sigma_1=0.07$  for  $f \leq f_p$ ,  $\sigma_2=0.09$  for  $f > f_p$



## Significant wave height and period

Significant wave computation method

Bretschneider     Bretschneider (depth)     Wilson's method

The mechanics of wave generation by winds acting over water surface is a complex issue that various semi-empirical methods have been developed. The wave forecasting methods are based on semi-empirical relations (SMB methods Sverdrup, Munk, and Bretschneider), which link the significant wave height  $H_s$  and significant wave period to wind speed, fetch, and water depth.

In the program are implemented three basic and commonly used methods. In this methods  $F$  is the fetch,  $U$  the wind velocity, and  $g$  the acceleration of gravity, and  $D$  is the average depth of the region. The nondimensional terms for significant wave height  $H$  and significant wave period  $T$  are given as:

### **Bretschneider's method**

$$\frac{gH}{U^2} = 0.283 \tanh \left\{ 0.0125 \left[ \frac{gF}{U^2} \right]^{0.42} \right\} \quad \frac{gT}{U} = 7.540 \tanh \left\{ 0.0770 \left[ \frac{gF}{U^2} \right]^{0.25} \right\}$$

[Seymour, R.J. "estimating wave Generation in Restricted fetches", J. ASME WW2, May 1977, pp251-263.]

### **Bretschneider's method with depth effect**

$$\frac{gH}{U^2} = 0.283 \tanh \left\{ 0.530 \left[ \frac{gD}{U^2} \right]^{0.75} \right\} \tanh \left\{ \frac{0.0125 \left[ \frac{gF}{U^2} \right]^{0.42}}{\tanh \left\{ 0.530 \left[ \frac{gD}{U^2} \right]^{0.75} \right\}} \right\}$$

$$\frac{gT}{U} = 7.540 \tanh \left\{ 0.833 \left[ \frac{gD}{U^2} \right]^{0.375} \right\} \tanh \left\{ \frac{0.0770 \left[ \frac{gF}{U^2} \right]^{0.25}}{\tanh \left\{ 0.833 \left[ \frac{gD}{U^2} \right]^{0.375} \right\}} \right\}$$

[Seymour, R.J. "estimating wave Generation in Restricted fetches", J. ASME WW2, May 1977, pp251-263.]

### **Wilson's method**

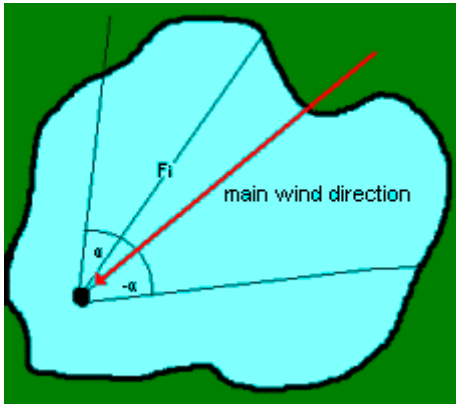
$$\frac{gH}{U^2} = 0.30 \left[ 1 - \left\{ 1 + 0.004 \left[ \frac{gF}{U^2} \right]^{1/2} \right\}^{-2} \right] \quad \frac{gT}{U} = 8.60 \left[ 1 - \left\{ 1 + 0.008 \left[ \frac{gF}{U^2} \right]^{1/3} \right\}^{-5} \right]$$

[Bretschneider, Ch.I.. "Topics in Ocean Engineering, Volume 1", p31-32, Gulf Publishing Company, Houston Texas, 1969.]

## Directional spectrum effects

Directional spectrum effect

Effective fetch
  Saville's method
  Seymour's method



In narrow fetch areas there is a dominant fetch for the wave prediction. In restricted fetch areas, there is not one dominant fetch to predict the waves. In this case three methods have been implemented in the program

### 1. Effective fetch method

$$F_{\text{eff}} = \frac{\int_{-\alpha}^{+\alpha} F \cos(\phi) d\phi}{\int_{-\alpha}^{+\alpha} \cos(\phi) d\phi}$$

An effective fetch ( $F_{\text{eff}}$ ) obtained as a fetch weighted average, is used for the prediction of significant wave height and significant wave period.  $F$  is the fetch along a ray radiating from the point at which the waves are to be determined, and making an angle  $\phi$  with the main wind direction. The integral is over a wind sector area (usually from  $-\pi/2$  to  $\pi/2$ )

### 2. Saville's Modified method

$$H_s = \frac{1}{2\alpha} \sqrt{\int_{-\alpha}^{+\alpha} [H(\phi) \cos(\phi)]^2 d\phi}$$

$$T_s = \frac{\int_{-\alpha}^{+\alpha} T(\phi) [H(\phi) \cos(\phi)]^2 d\phi}{\int_{-\alpha}^{+\alpha} [H(\phi) \cos(\phi)]^2 d\phi}$$

The significant wave height  $H_s$  obtained as weighted average, and the significant wave period as the energy weighted average.  $H(\phi)$  and  $T(\phi)$  are the wave height and wave period of waves generated along a ray radiating from the at which the waves is to be determined, and making an angle  $\phi$  with the main wind direction. The integral is over a wind sector area (usually from  $-\pi/2$  to  $\pi/2$ ).

[Bretschneider, Ch.I.. "Topics in Ocean Engineering, Volume 1", p32-34, Gulf Publishing Company, Houston Texas, 1969.]

### 3. Seymour's method

The water region is separated in small sectors at angles  $\phi$  around the main wind direction up to a boundary angle (usually from  $-\pi/2$  to  $\pi/2$ ). For each sector the significant wave height and significant wave period are computed, and from them a wave spectrum. The final wave spectrum is obtained from energy-average of all these spectrums, and from this spectrum the significant wave height and significant wave period are computed.

Seymour's method seems to give more realistic results for restricted fetch areas, because the wave spectrum is predicted at each wind sector. The wave frequencies are better represented in the final forecasted wave spectrum. With this method double peak spectra will be predicted in some regions as many in field measurements have shown.

[Seymour, R.J. "estimating wave Generation in Restricted fetches", J. ASME WW2, May 1977, pp251-263.]

## References

- 1) Bretschneider, C. I. "*Topics in Ocean Engineering, Volume 1*", Gulf Publishing Company, Houston Texas, 1969.
- 2) Hallam M.G., Heaf N.J, Wootton, L.R., "*Dynamics of Marine Structures*", Ciria Underwater Engineering Group, London 1977.
- 3) Kinsman B., "*Wind Waves*." Prentice Hall, Inc., Englewood Cliffs, New Jersey 1965.
- 4) Muga B., J., and Wilson J. F. , "*Dynamic Analysis of Ocean Structures*." Plenum Press, New York, 1970
- 5) Newman, J., N. "*Marine Hydrodynamics*", MIT Press, Cambridge, Massachusetts, 1977.
- 6) Seymour, R.J. "*Estimating Wave Generation in Restricted fetches*", J. ASME WW2, May 1977, pp251-263.
- 7) World Meteorological Organization, "*Handbook on Wave Analysis and Forecasting*", WMO No 446, Geneva Switzerland 1976

## Example

A water region as shown in the map, with the largest fetch about 200 km. The wind velocity is taken 60 km/hr. The waves are computed at a point in a protected area. For the directional effects the Seymour's method is selected. This method seems to give more realistic results for restricted fetch areas, because the wave spectrum is predicted at each wind sector. The wave frequencies are better represented in the final forecasted wave spectrum. With this method double peak spectra will be predicted in some regions as many in field measurements have shown.

Project ....

### Wave Forecasting

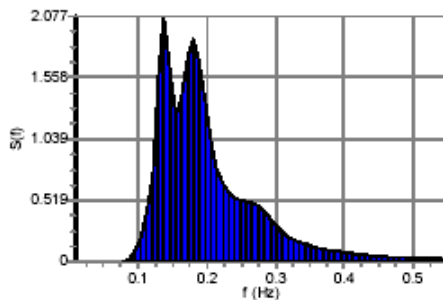
Water region



Mean wind direction	30.000°
Wind sector	180.000°
Wind velocity	60.000 Km/hr
Average water depth	100.000 m

Wave spectrum type	JONSWAP
Significant wave computation method	Wilson's method
Method implementing directional effects	Seymour's method

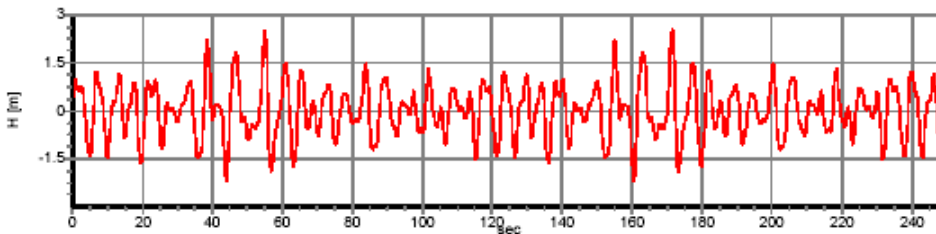
Wave spectrum



### Predicted Waves

Significant wave frequency	$f_s = 0.137$ Hz
Significant wave period	$T_s = 7.28$ sec
Significant wave Height	$H_s = 3.27$ m
	$H_{1/3} = 3.27$ m
Mean of heighest 1/10 waves	$H_{1/10} = 4.16$ m
Maximum wave height	$H_{max} = 5.23$ m

Wavetime series



Project ....

**Spectral values**

f [HZ]	T [sec]	S [f]	f [HZ]	T [sec]	S [f]	f [HZ]	T [sec]	S [f]	f [HZ]	T [sec]	S [f]
0.009116	50	0.000	0.146	6.85	1.584	0.283	3.53	0.423	0.421	2.38	0.059
0.017	58.25	0.000	0.155	6.47	1.236	0.292	3.43	0.361	0.429	2.33	0.054
0.026	38.83	0.000	0.163	6.13	1.376	0.300	3.33	0.300	0.438	2.28	0.049
0.034	29.13	0.000	0.172	5.83	1.743	0.309	3.24	0.250	0.446	2.24	0.045
0.043	23.30	0.000	0.180	5.55	1.878	0.318	3.15	0.212	0.455	2.20	0.041
0.052	19.42	0.000	0.189	5.30	1.694	0.326	3.07	0.184	0.464	2.16	0.038
0.060	16.64	0.000	0.197	5.07	1.336	0.335	2.99	0.162	0.472	2.12	0.035
0.069	14.56	0.000	0.206	4.85	1.007	0.343	2.91	0.144	0.481	2.08	0.032
0.077	12.94	0.000	0.215	4.66	0.786	0.352	2.84	0.129	0.489	2.04	0.029
0.086	11.65	0.009	0.223	4.48	0.657	0.361	2.77	0.117	0.498	2.01	0.027
0.094	10.59	0.064	0.232	4.31	0.583	0.369	2.71	0.105	0.506	1.97	0.025
0.103	9.71	0.195	0.240	4.16	0.537	0.378	2.65	0.095	0.515	1.94	0.023
0.112	8.96	0.386	0.249	4.02	0.512	0.386	2.59	0.087	0.524	1.91	0.021
0.120	8.32	0.728	0.258	3.88	0.502	0.395	2.53	0.079	0.532	1.88	0.020
0.129	7.77	1.551	0.266	3.76	0.494	0.403	2.48	0.071	0.541	1.85	0.018
0.137	7.28	2.077	0.275	3.64	0.471	0.412	2.43	0.065	0.549	1.82	0.017

## Theoretical summary of example

### Wave spectra

#### Pierson-Moskowitz

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

#### JONSWAP

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

### Significant wave height and period

#### 1. Bretschneider's method

$$\frac{gH}{U^2} = 0.283 \tanh \left\{ 0.0125 \left[ \frac{gF}{U^2} \right]^{0.42} \right\} \quad \frac{gT}{U} = 7.540 \tanh \left\{ 0.0770 \left[ \frac{gF}{U^2} \right]^{0.25} \right\}$$

#### 2. Bretschneider's method with depth effect

$$\frac{gH}{U^2} = 0.283 \tanh \left\{ 0.530 \left[ \frac{gD}{U^2} \right]^{0.75} \right\} \tanh \left\{ \frac{0.0125 \left[ \frac{gF}{U^2} \right]^{0.42}}{\tanh \left\{ 0.530 \left[ \frac{gD}{U^2} \right]^{0.75} \right\}} \right\}$$

$$\frac{gT}{U} = 7.540 \tanh \left\{ 0.833 \left[ \frac{gD}{U^2} \right]^{0.375} \right\} \tanh \left\{ \frac{0.0770 \left[ \frac{gF}{U^2} \right]^{0.25}}{\tanh \left\{ 0.833 \left[ \frac{gD}{U^2} \right]^{0.375} \right\}} \right\}$$

#### 3. Wilson's method

$$\frac{gH}{U^2} = 0.30 \left[ 1 - \left\{ 1 + 0.004 \left[ \frac{gF}{U^2} \right]^{1.2} \right\}^{-2} \right] \quad \frac{gT}{U} = 8.60 \left[ 1 - \left\{ 1 + 0.008 \left[ \frac{gF}{U^2} \right]^{1/3} \right\}^{-5} \right]$$

### Directional spectrum effects

#### 1. Effective fetch method

$$F_{\text{eff}} = \frac{\int_{-\alpha}^{+\alpha} F \cos(\phi) d\phi}{\int_{-\alpha}^{+\alpha} \cos(\phi) d\phi}$$

An effective fetch (F<sub>eff</sub>) obtained as fetch weighted average, is used for the prediction of significant wave height and significant wave period. F is the fetch along a ray radiating from the point at which the waves is to be determined, at an angle (phi) with the main wind direction. The integral is over the wind sector area.

#### 2. Saville's Modified method

$$H_s = \frac{1}{2\alpha} \sqrt{\int_{-\alpha}^{+\alpha} [H(\phi) \cos(\phi)]^2 d\phi}$$

$$T_s = \frac{\int_{-\alpha}^{+\alpha} T(\phi) [H(\phi) \cos(\phi)]^2 d\phi}{\int_{-\alpha}^{+\alpha} [H(\phi) \cos(\phi)]^2 d\phi}$$

The significant wave height H<sub>s</sub> obtained as weighted average, and the significant wave period as the energy weighted average. H( ) and T( ) are the wave height and wave period of waves generated along a ray radiating from the point at which the waves is to be determined, and making an angle (phi) with the main wind direction. The integral is over the wind sector area.

#### 3. Seymour's method

The water region is separated in small sectors at angles phi around the main wind direction up to a boundary angle. For each sector the significant wave height and significant wave period are computed, and from them a wave spectrum. The final wave spectrum is obtained from energy-average of all these spectrums, and from the final spectrum the significant wave height and significant wave period are computed.

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