CHAPTER 11

EXPERIMENTAL STUDIES ON THE GENERATION OF WAVES IN SHALLOW WATER

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SYNOPSIS

The seas in front of China coast such as Yellow Sea, East China Sea and Taiwan Straits are all located on continental shelf. In consequence, waves approaching these coasts are generated in shallow water area in comparsion with wave length. The authors has developed tangible calculation procedures for evaluating the wave features in such areas in stationary or moving fetches (1). However, the basical formulas of calculation are derived from experimental data of Bretschneider and Thijsse. In order to investigate the generating process of shallow water wind waves and obtain more detailed informations for correcting calculation criteria, a series of experiments have been performed at a wind tunnel of 75 meters in length. Various investigations on the relationships between waves and wind as well as water depth are to be submitted in this paper.

In addition, the situation of wind wave coexistance with regular wave is studied from experiments, because it resembles the superposition of refracted and local wind waves on the western coast of Taiwan.

SIGNIFICANT WAVE FEATURES

From the experiments, the wave heights and periods increase with wind velocities and fetch lengths, however, they reach fully arisen state more rapidly than deep water waves, only a few minutes in the experiments. After fully arisen, a portion of high waves begin to break and reduce their heights slightly, however, the waves recover their heights after advancing a short distance and then they break partially, such phenomena repeat again and again especially in the cases of the wind being strong. The wave periods remain increasing within the fetch length in these experiments, however, it can be expected that the wave periods and heights may become constant if the fetch length is long enough.

The experimental curves of $gH_{\frac{1}{3}}/U^2$ versus gF/U^2 with parameter gd/U^2 as shown in Fig. 1 have the same tendency with the curves of Bretschneider (2), however, our data are larger than those of Johnson, Huft and Hamada, and even larger than the values predicted from the fetch graph of SMB in the region of gF/U^2 in Fig. 2 are located below breaking limit and Bretschneider's steady state of friction coefficients equal to 0.01. In Fig. 3 the experimental result of the relationship between $gT_{\frac{1}{3}}/U$ versus gF/U^2 is quite agreed with deep water waves.

Statistical characteristics of wave heights and periods have also been calculated. As shown in Fig. 4 and 5 the probability distribution corresponds sufficiently to Gaussian's rather than Rayleigh's. The ratias between various 1/nth wave heights are as follows.

$$H_{1/3}/H_{ave} = 1.38 \qquad (1.60)$$
$$H_{1/10}/H_{1/3} = 1.16 \qquad (1.27)$$
$$H_{max}/H_{1/3} = 1.39 \qquad (1.64)$$

Any of the numbers is smaller than the theoretical value of Longuet-Higgins (in parenthesis). The ratios of 1/nth wave height to root-mean-square wave height Hrms are as follows.

$$H_{ave}/H_{rms} = 0.94$$
$$H_{1/3}/H_{rms} = 1.30$$
$$H_{1/10}/H_{rms} = 1.55$$

They seem to be little concern with spectral width parameter.

On the whole, there is no substantial difference between the statistical properties of wind waves in shallow and deep water.

SPECTRAL ANALYSIS

The power spectra are calculated from experimental records by Blackman-Tukey's method. Sampling time interval Δt is 1/10-1/15 sec., total number of data is N = 800, maximum time lag m equals 40, and folding frequency fm = 5 cps (or 0.375 cps). The degree of freedom calculated by Tukeys formula is 40, is consequence, confidence limit in 10% is 0.73-1.30.

At early stage, the spectra grow continuously as the fetch length becoming longer till saturation state is reached. While the fetch lengths extend, the lower frequency parts of the spectral curves increase their density, as Fig. 6,7,8.

The relationship between wave spectra and wind valocity has the same teńdency of deep water waves. Namely in same fetch length and water depth, the spectra grow with wind velocity being increasing. As Fig. 9 & 11, if the depth is small, the spectral density is smaller than that of deep water waves, as shown in Fig. 12, 13, 14, for same wind velocity. The greater the wind velocity is the earlier the low frequency portion of spectrum developed, and the wider the frequency band becomes. In any case, the high frequency side of equilibrium range decades remarkably and can be represented by f^{-n} .

The oonnection between $T_{1/3}$ and optimum period Top is to be $T_{1/3}$ = 1.23 Top in our experiments, and $T_{1/3}$ = 1.23 Tave = 1.23 Trms, accordingly Trms = Tave = Top.

Phillps pointed out the shape of spectral curves in high frequency side should be:

$$\Phi(f) = \beta g^2 f^{-5}$$

However, Hamada proved that $\Phi(f) = \beta g^2 f^{-n}$, and n will be larger than 5 in deep water wave spectra. Our experiments also reveal n = 7-10 in shallow water waves.

The relationship between H and $E = 2\int \Phi(f)\,df$ is the same as deep water waves, namely $H_{1/3} = 2.83\sqrt{E}$. As shown in Fig. 15.

STUDIES ON THE COPERPOSITION OF REGULAR AND WIND WAVES

According to the special topography of western coast of Taiwan, the beach is very flat and the waves approach from Taiwan Straits are breaking on offshore bars. The distanoe between bars and the main coast or sea dike is still as long as 5 km. Looal wind waves are overlapping on the waves after broken. To investigate such a phenomenon in order to offer design criteria for sea dikes, we generated regular waves by flap type wave generator and blow wind simultaneeusly in the same wind wave channel. The regular wave spectra are shown in Fig. 16 and the spectra of wind wave while regular wave are not to be existing are shown in Fig. 17. Fig. 18 shows the result spectra of overlapping. Apparently there are two kinds of waves existing independently. However, if the regular wave steepness is large such a phenomenon disappears as Fig. 19. The comprison of the energy of resultant wave energy and energy calculated by linear summation is shown in Fig. 20. In case of broken waves superposed by wind waves as the case of western coast of Taiwan. Wave height in front of sea dike can be approximately calculated by $H^2 = Hw^2 + H_R^2$.

CONCLUSION

From experimental data described above following conclusions can be made.

1. The generation procedure of shallow water waves is closed resembling to deep water waves, however, the duration for fully arisen is much shorter.
2. In the range of our experiments wave period seems not to be significantly influented by water depth. The wave height increases with fetch length increasing, however, they are smaller than deep water waves due to the influence of water depth.
3. If wave spectra of shallow wave area are available, the significant wave height can also be calculated by $H_{1/3} = 2.83\sqrt{E}$, $(E = 2\int \Phi(f)\, df)$.
4. In the problem concerning superposition of two series of waves, if the steepness is small, the resultant wave heights can be calculated by linear summation of their energies.

REFERENCE

1. Frederick L. W. Tang: Researches on Calculation of Waves on Long Shoaling Beaches. Jour. of Civil and Hydraulic Engineering, Taiwan Provincial Cheng Kung University. Feb. 1970.

2. Breschneider: Generation of Wind Waves Over a Shallow Bottom. B. E. B. Tech. Memo No. 51 Oct. 1954.

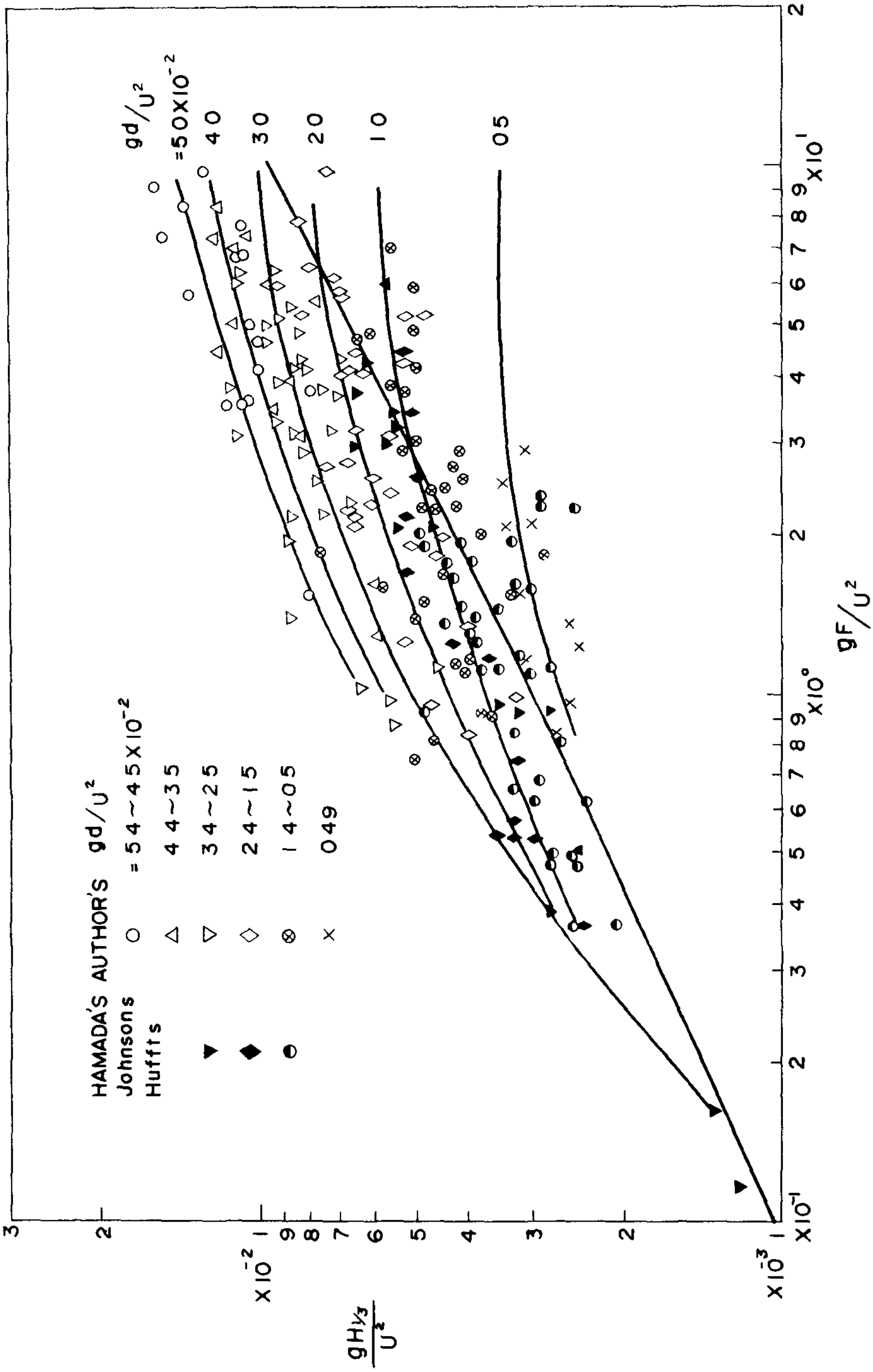

HAMADA'S AUTHOR'S gd/U²
Johnsons
Huffts
=54~45×10⁻²
44~35
34~25
24~15
14~05
049
gd/U²
=50×10⁻²
40
30
20
10
05
gF/U²
gH1/3/U²
×10⁻¹
×10⁰
×10⁻²
×10⁻³

Fig 1

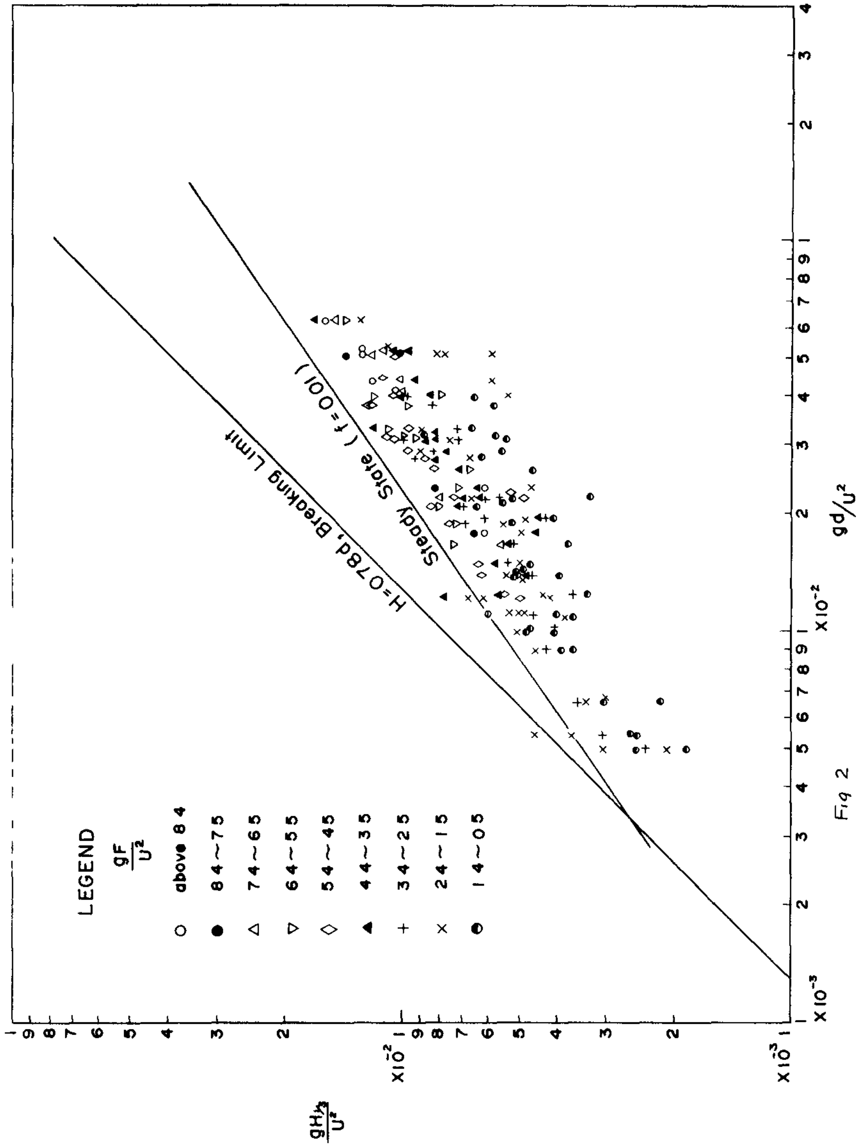

LEGEND
gF/U²
○ above 8.4
● 8.4 ~ 7.5
△ 7.4 ~ 6.5
▷ 6.4 ~ 5.5
◇ 5.4 ~ 4.5
▲ 4.4 ~ 3.5
+ 3.4 ~ 2.5
× 2.4 ~ 1.5
◐ 1.4 ~ 0.5
Steady State (f = 0.01)
H = 0.78d, Breaking Limit
gd/U²
gH⅓/U²
X10⁻²
X10⁻³

Fig 2

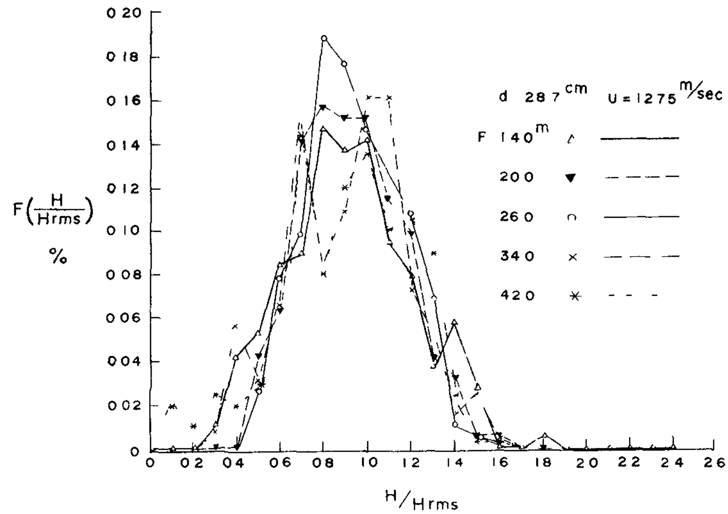
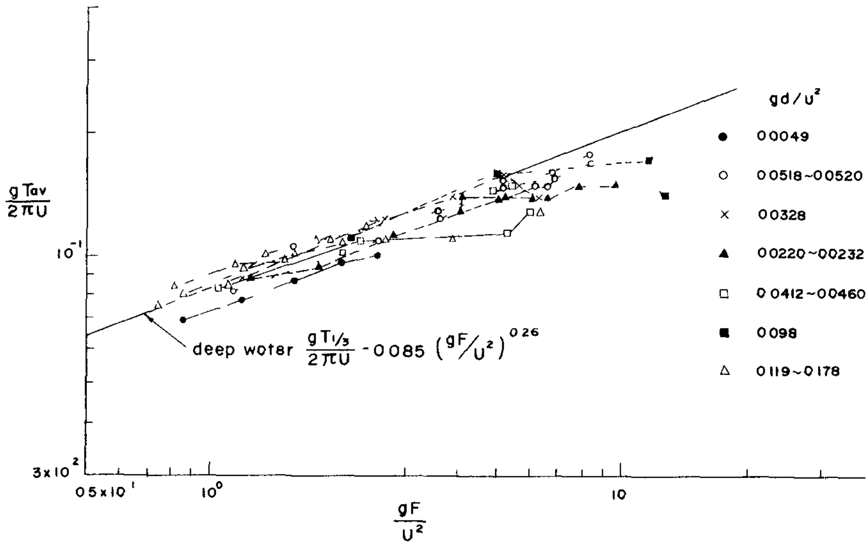
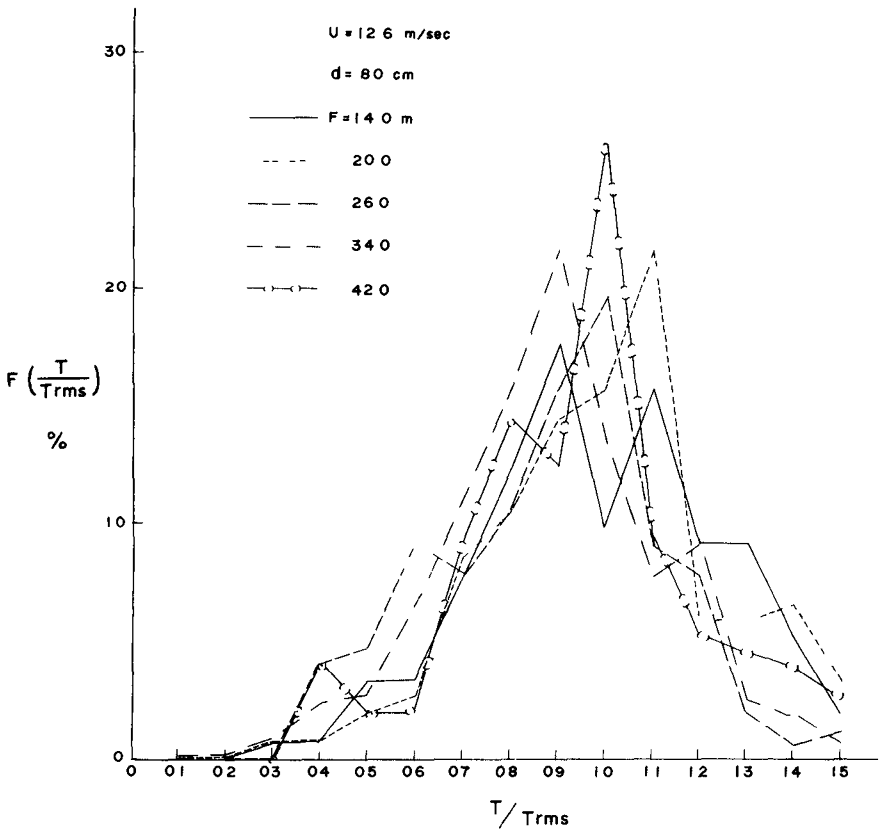

d 287 cm U = 1275 m/sec
F 140 m
200
260
340
420
F(H/Hrms) %
H/Hrms

Fig 4


gd/U²
00049
00518~00520
00328
00220~00232
0 0412~00460
0098
0119~0178
g Tav / 2πU
deep water gT1/3 / 2πU - 0085 (gF/U²) 026
gF/U²



U = 12 6 m/sec
d = 80 cm
F = 14 0 m
20 0
26 0
34 0
42 0
30
20
10
0
F (T/Trms)
%
0
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
T/Trms

Fig 5

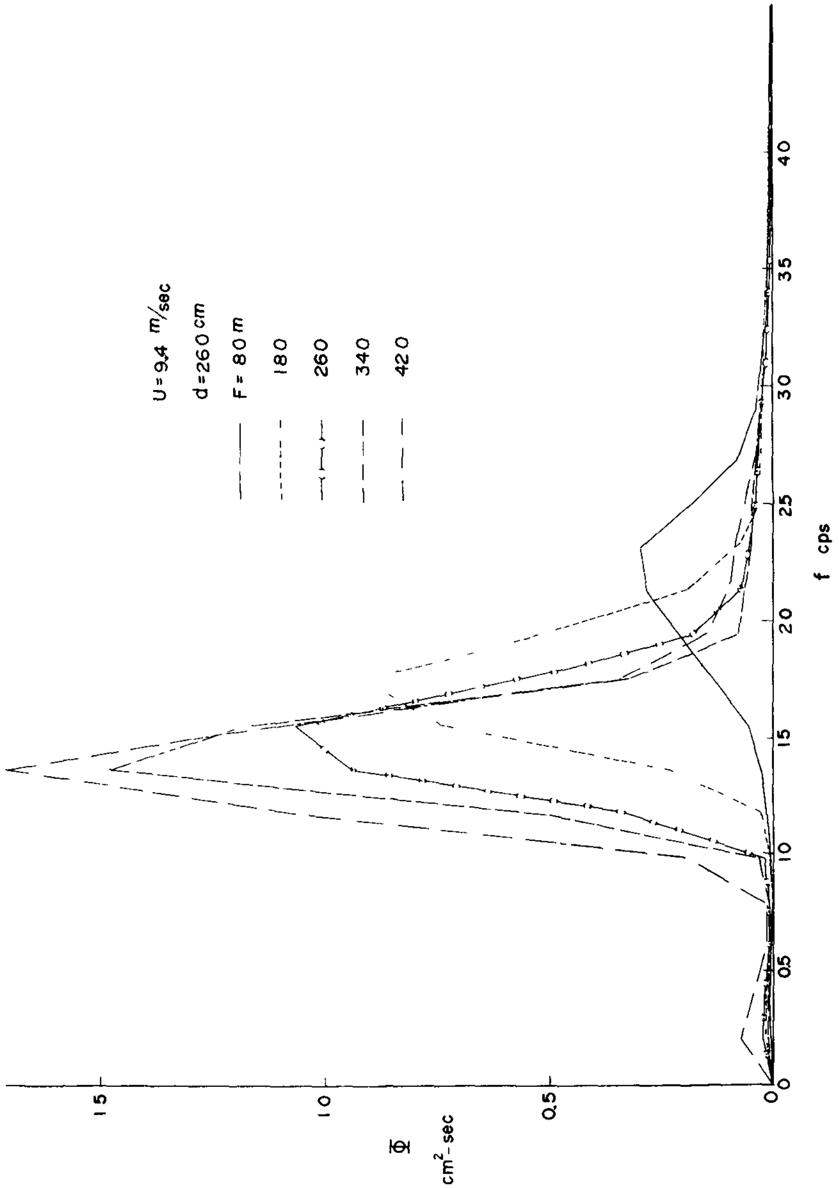

U = 9.4 m/sec
d = 260 cm
F = 80 m
180
260
340
420
f cps
Φ
cm²-sec
0
0.5
1.0
1.5
5
10
15
20
25
30
35
40

Fig 6

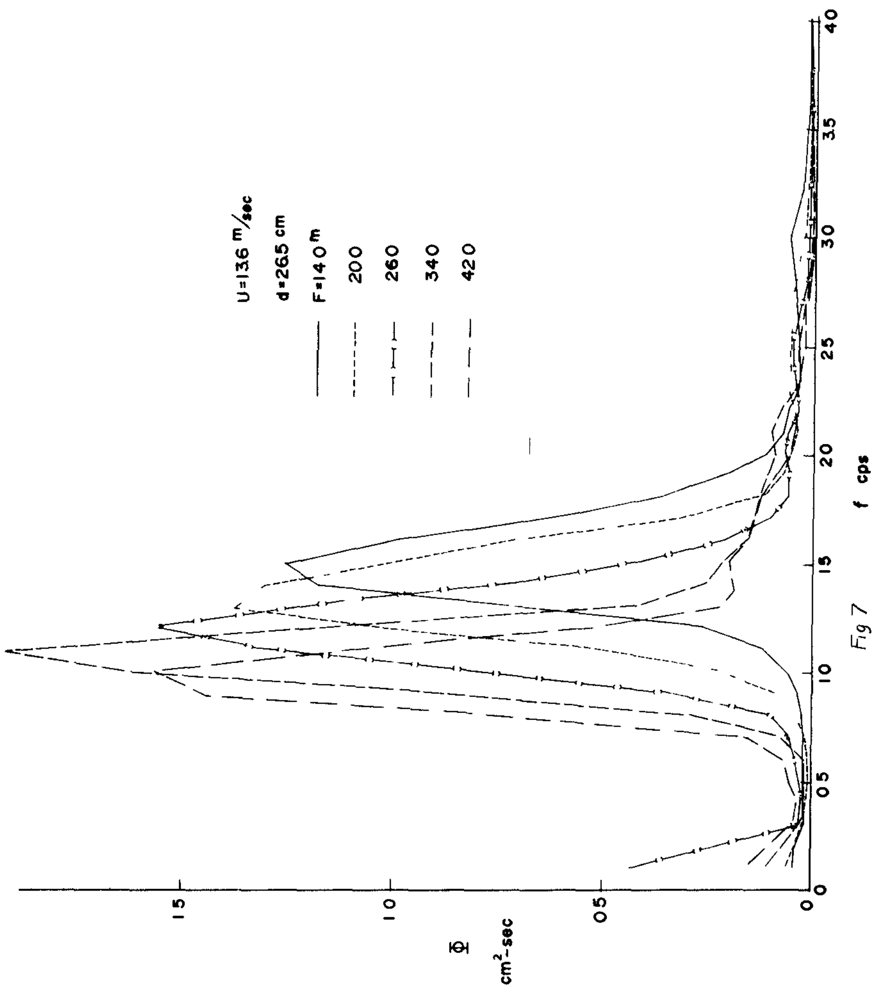

U=13.6 m/sec
d=26.5 cm
F=140 m
200
260
340
420
Φ
cm²-sec
f cps
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Fig 7

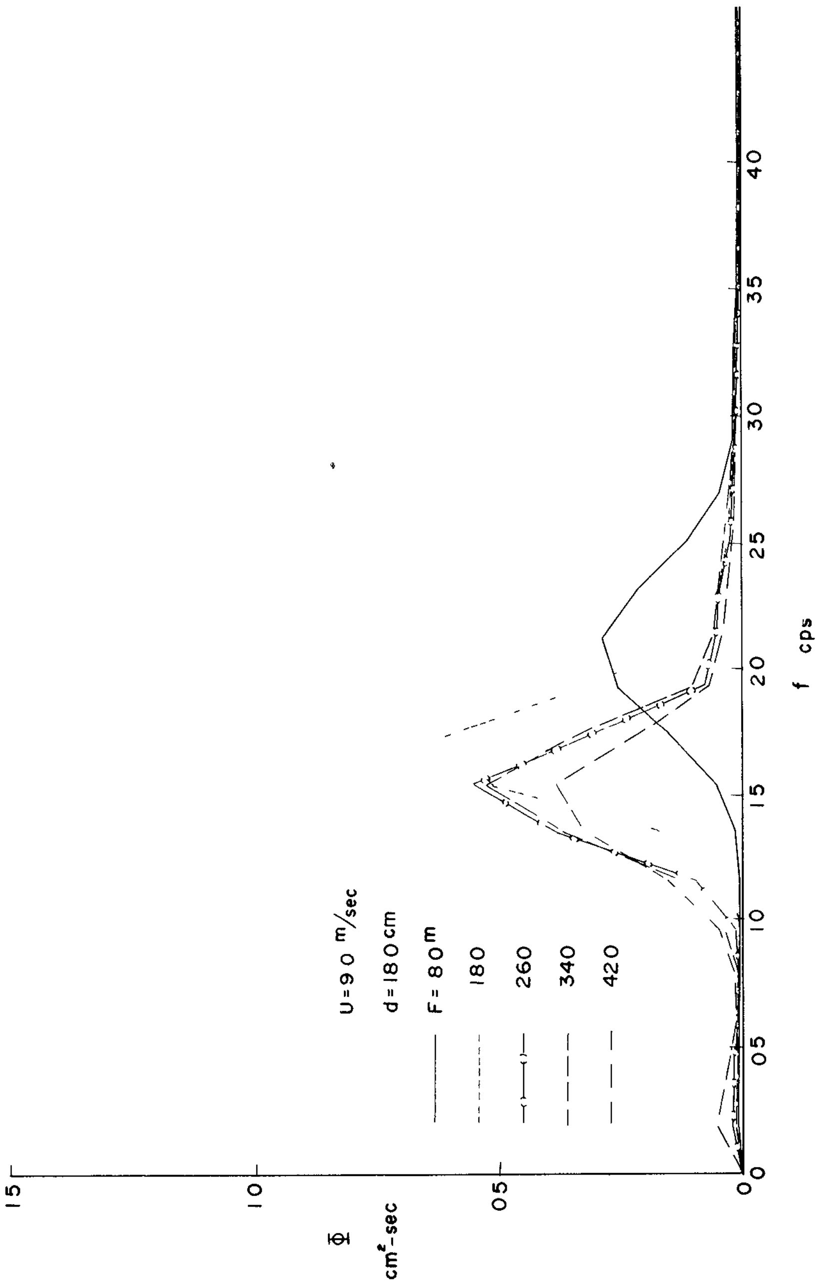

U = 9 0 m/sec
d = 18 0 cm
F = 8 0 m
18 0
26 0
34 0
42 0
Φ
cm²-sec
0
0 5
1 0
1 5
0
5
10
15
20
25
30
35
40
f cps

Fig 8

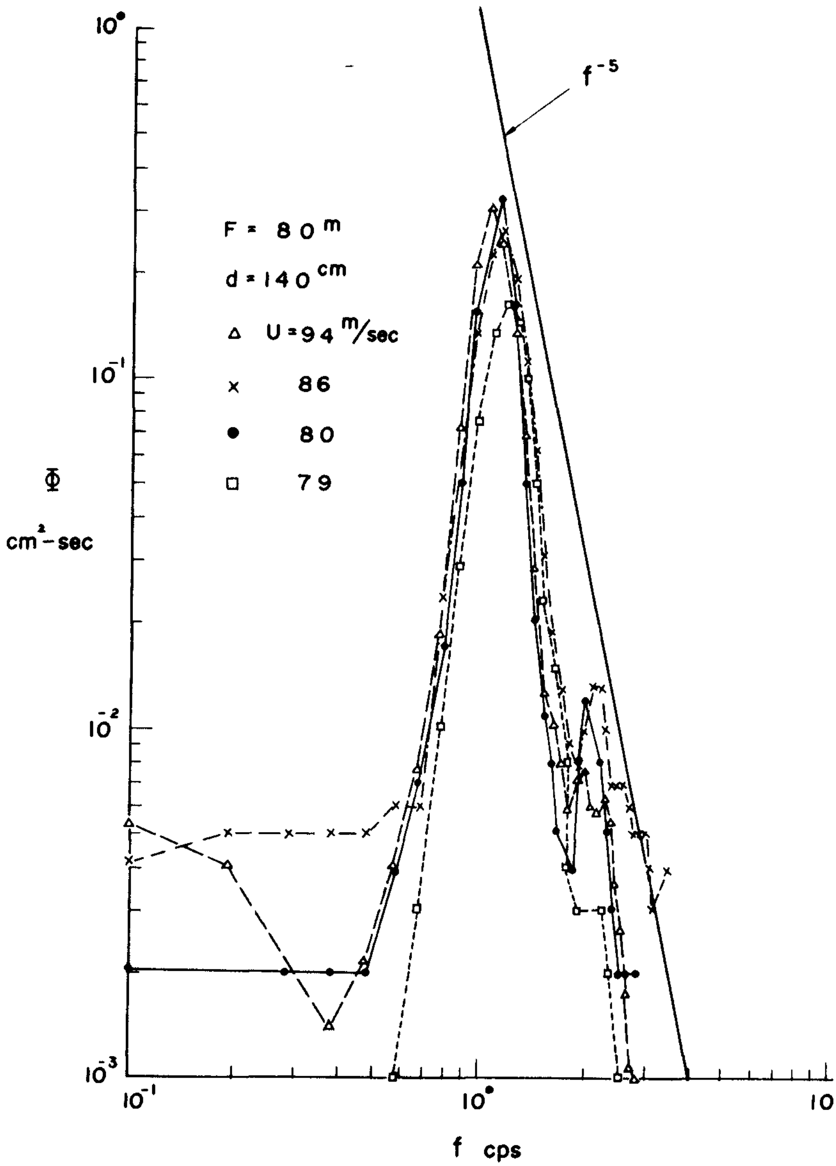

f^-5
F = 80^m
d = 140^cm
U = 94 m/sec
86
80
79
Φ
cm²-sec
10°
10⁻¹
10⁻²
10⁻³
10⁻¹
10°
10¹
f cps

Fig 9

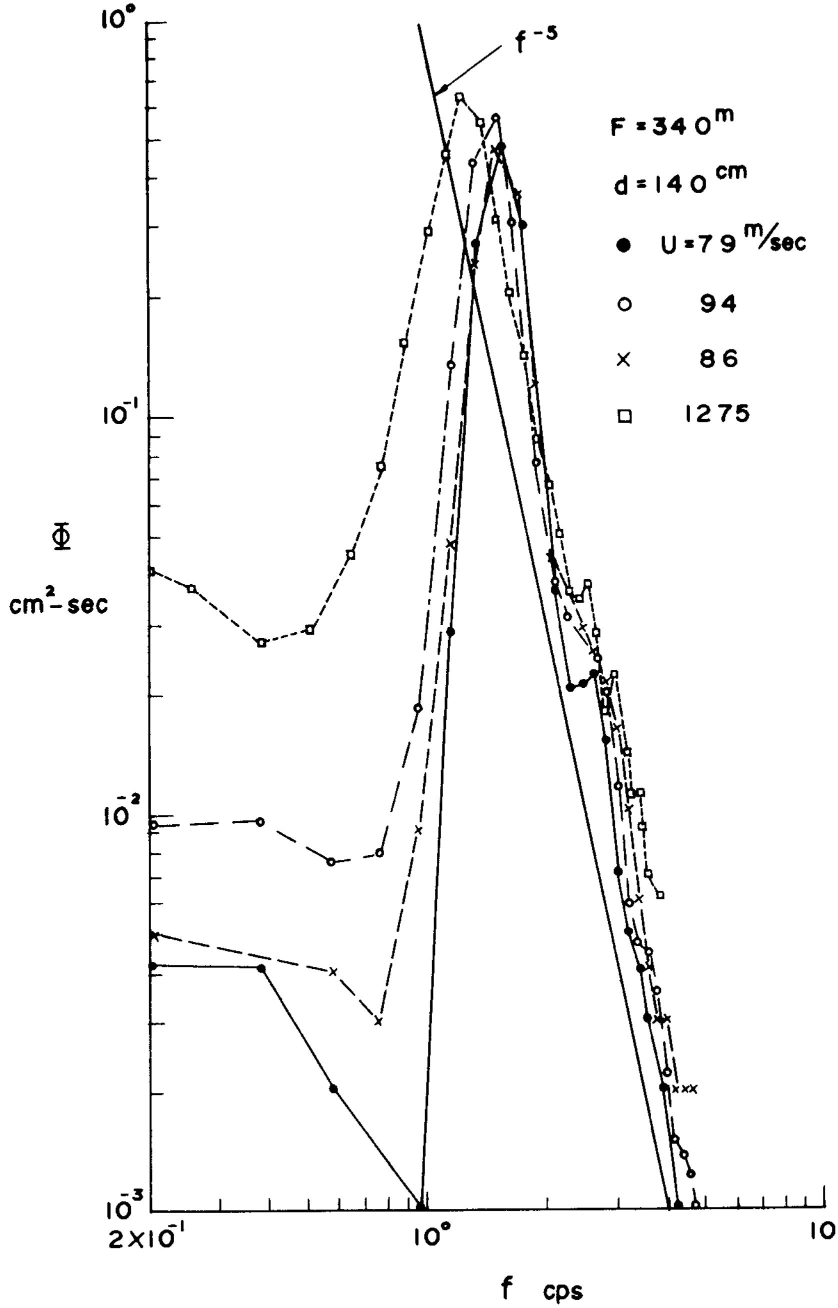

f⁻⁵
F = 340 m
d = 140 cm
U = 79 m/sec
94
86
1275
Φ
cm²-sec
10⁰
10⁻¹
10⁻²
10⁻³
2×10⁻¹
10⁰
10¹
f cps

Fig 10

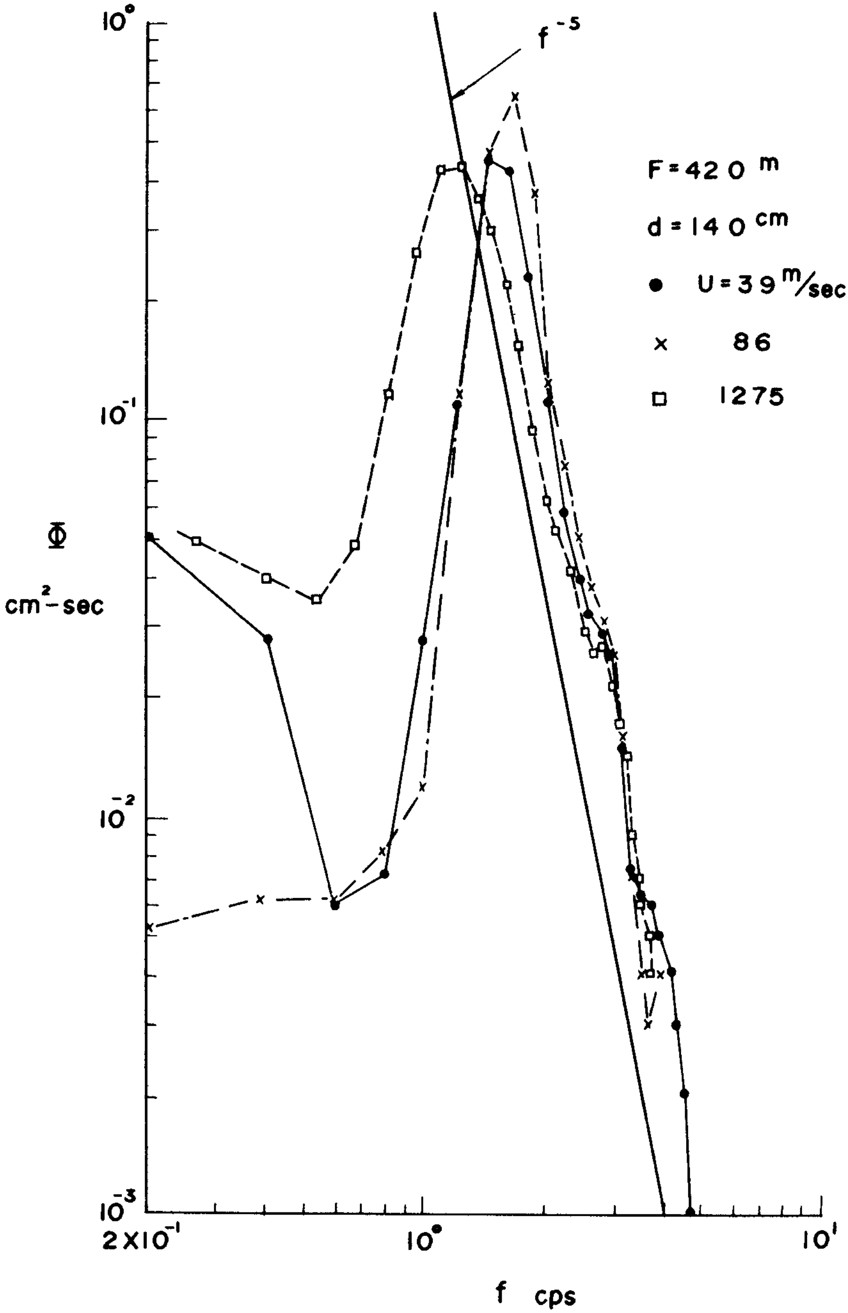
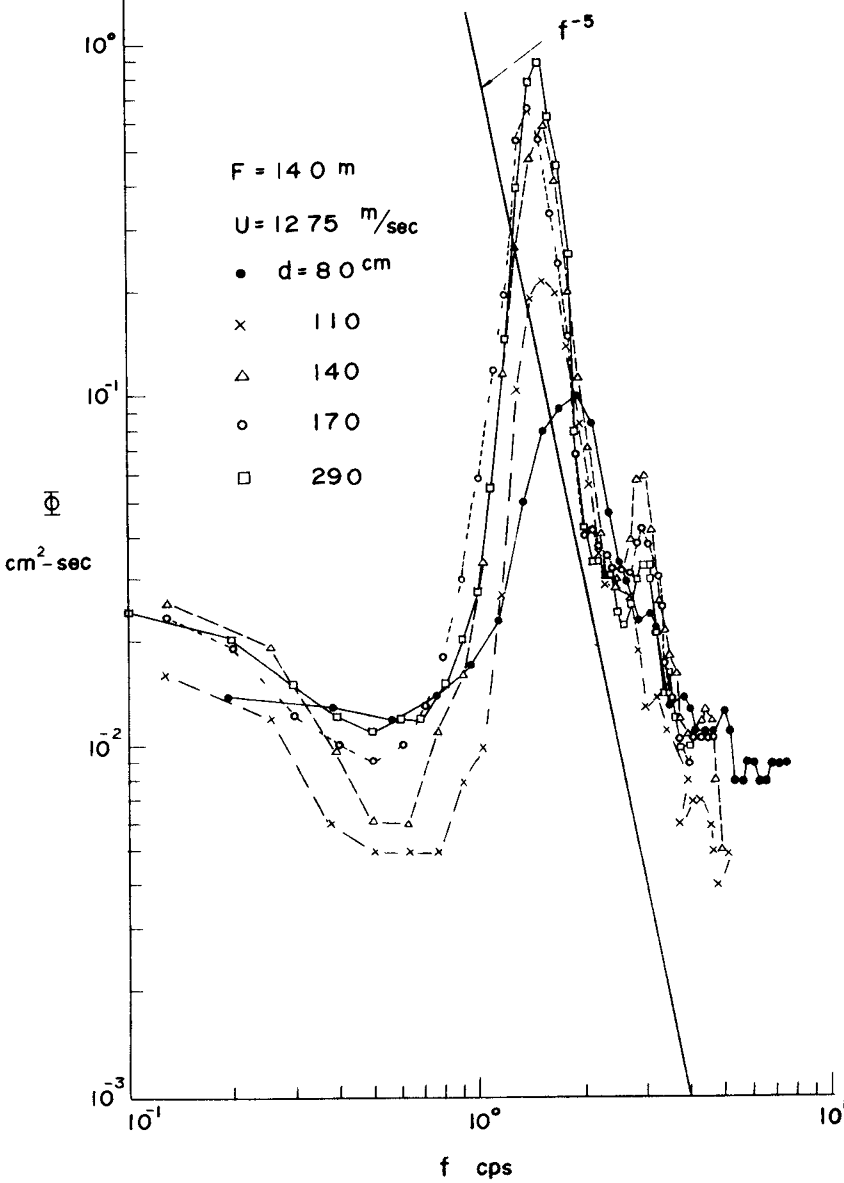

f^-5
F = 420 m
d = 140 cm
U = 39 m/sec
86
1275
Φ
cm²-sec
10°
10⁻¹
10⁻²
10⁻³
2X10⁻¹
10°
10¹
f cps

Fig 11



f^-5
F = 140 m
U = 12.75 m/sec
d = 80 cm
110
140
170
290
Φ
cm²-sec
10°
10⁻¹
10⁻²
10⁻³
10⁻¹
10°
10¹
f cps

Fig 12

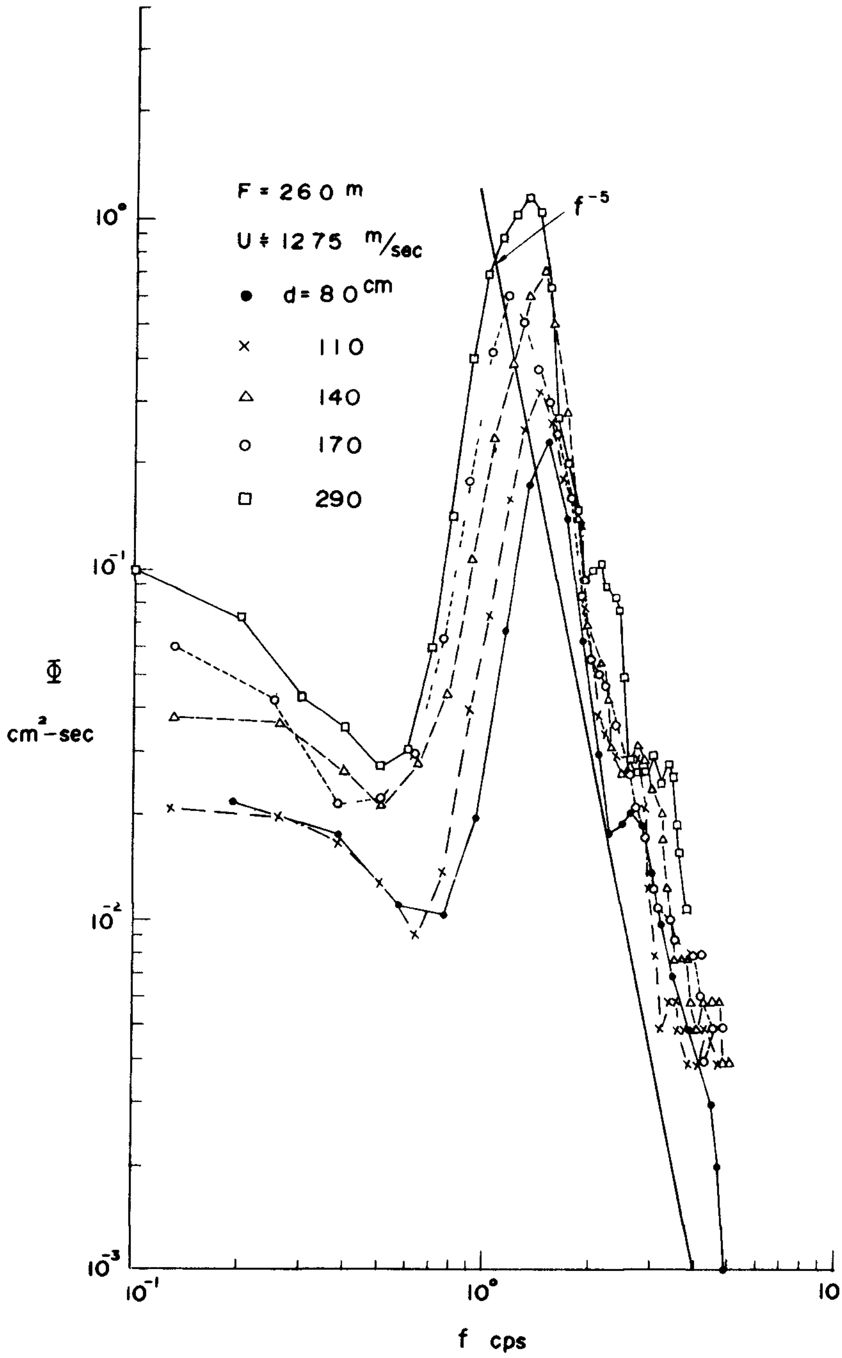

F = 260 m
U ≑ 12.75 m/sec
d = 80 cm
110
140
170
290
f⁻⁵
Φ
cm²-sec
10⁰
10⁻¹
10⁻²
10⁻³
10⁻¹
10⁰
10¹
f cps

Fig 13

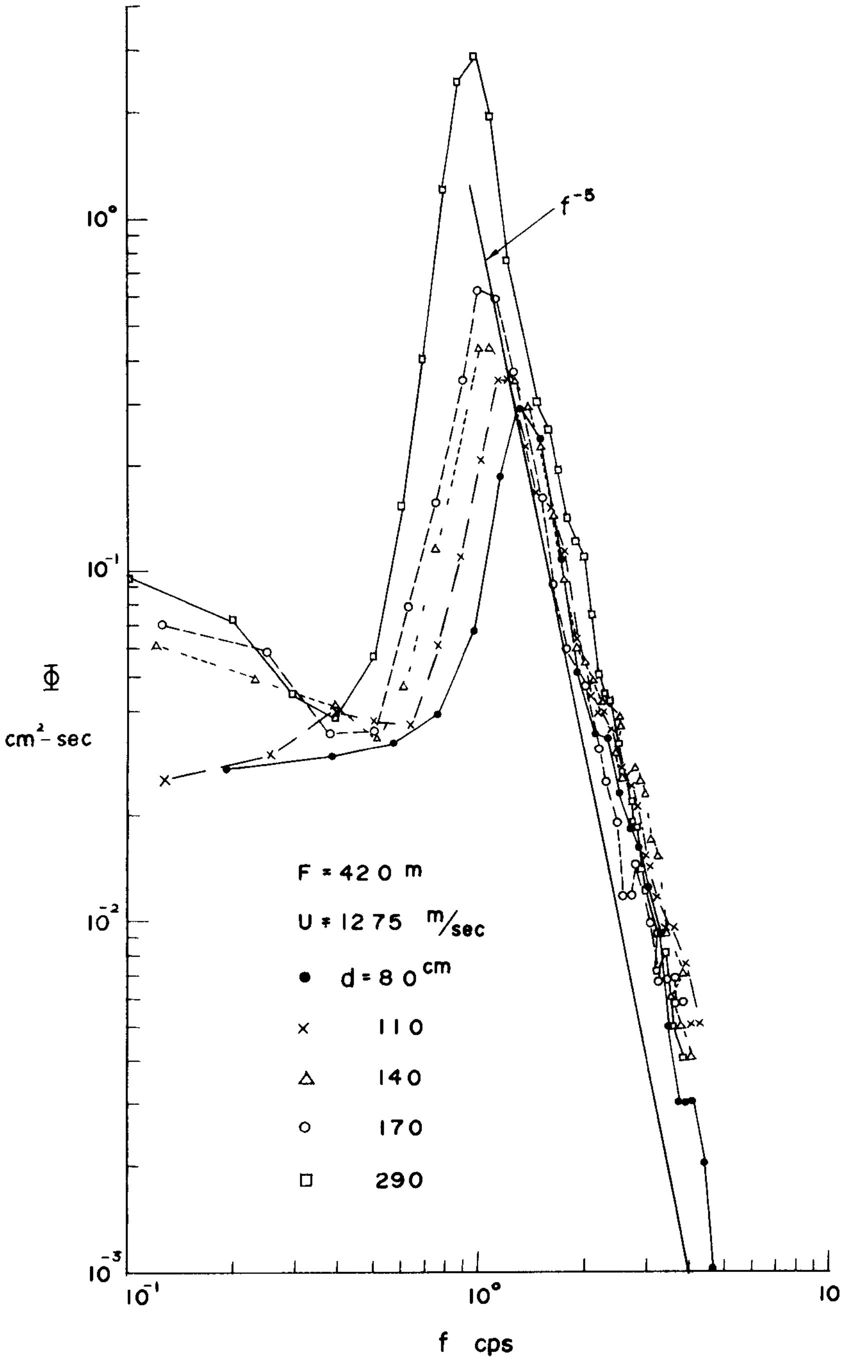

f^{-5}
10^{0}
10^{-1}
10^{-2}
10^{-3}
Φ
cm² - sec
F = 420 m
U = 12 75 m/sec
d = 8 0 cm
110
140
170
290
10^{-1}
10^{0}
10^{1}
f cps

Fig 14

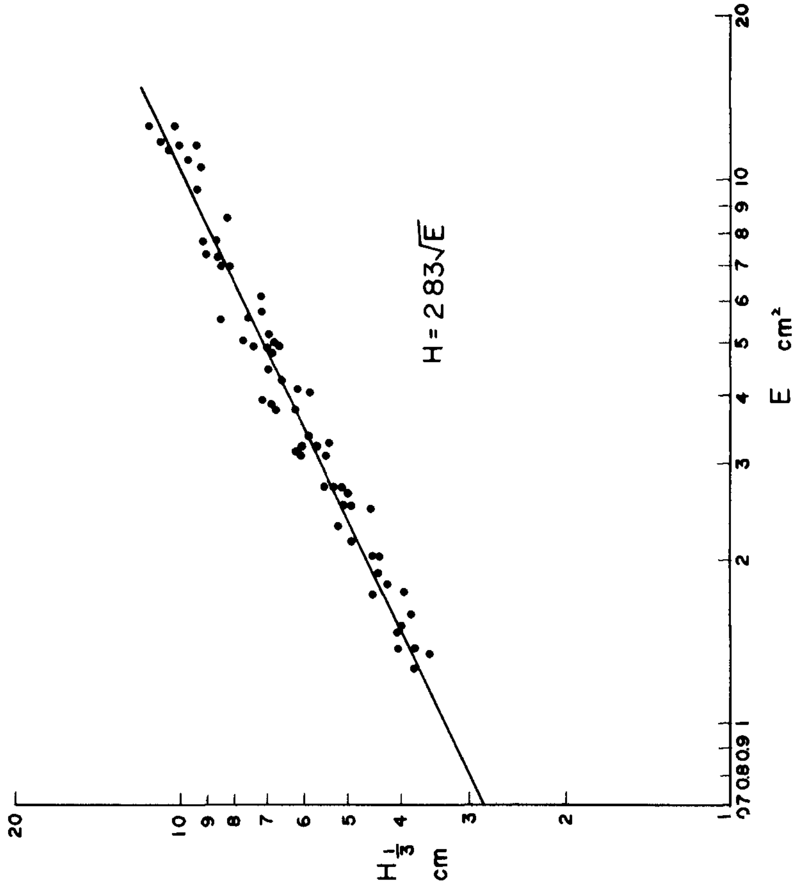


Fig 15

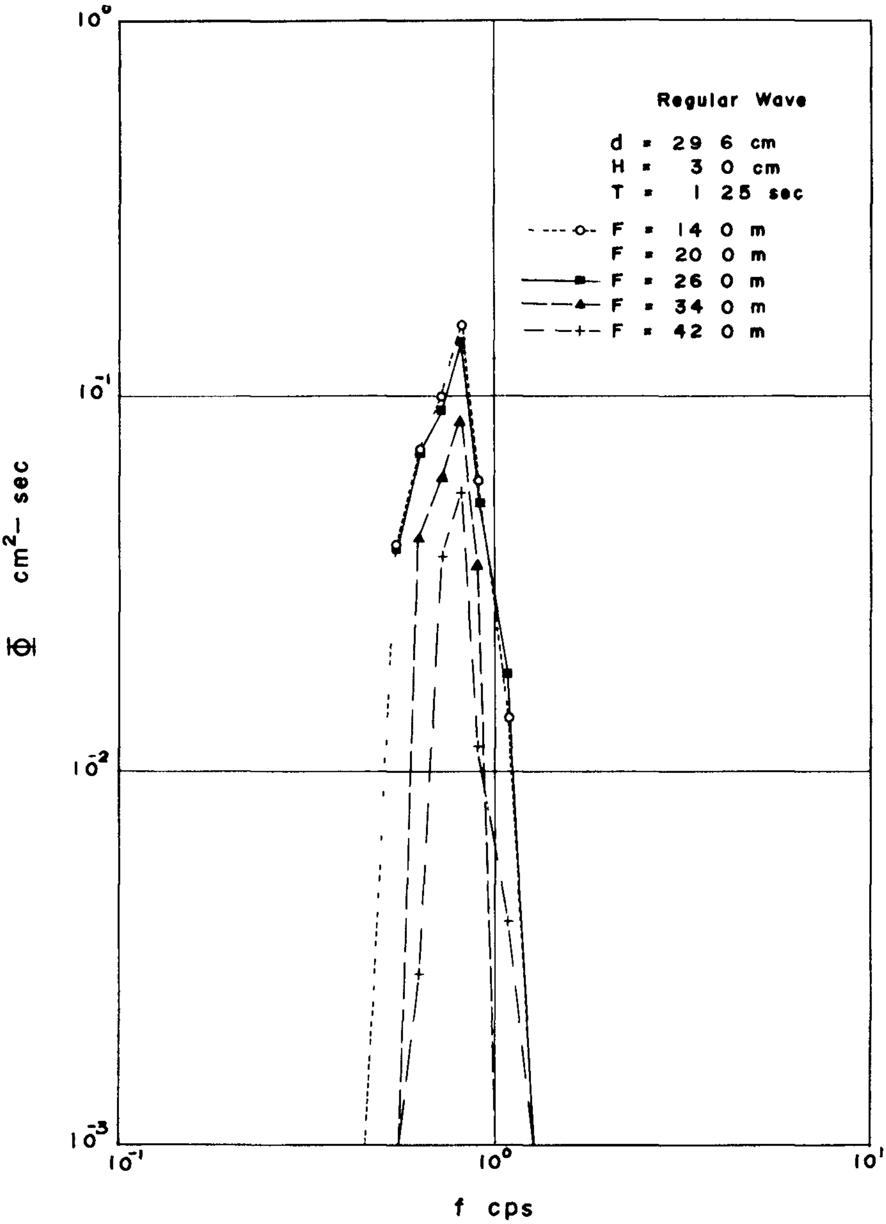
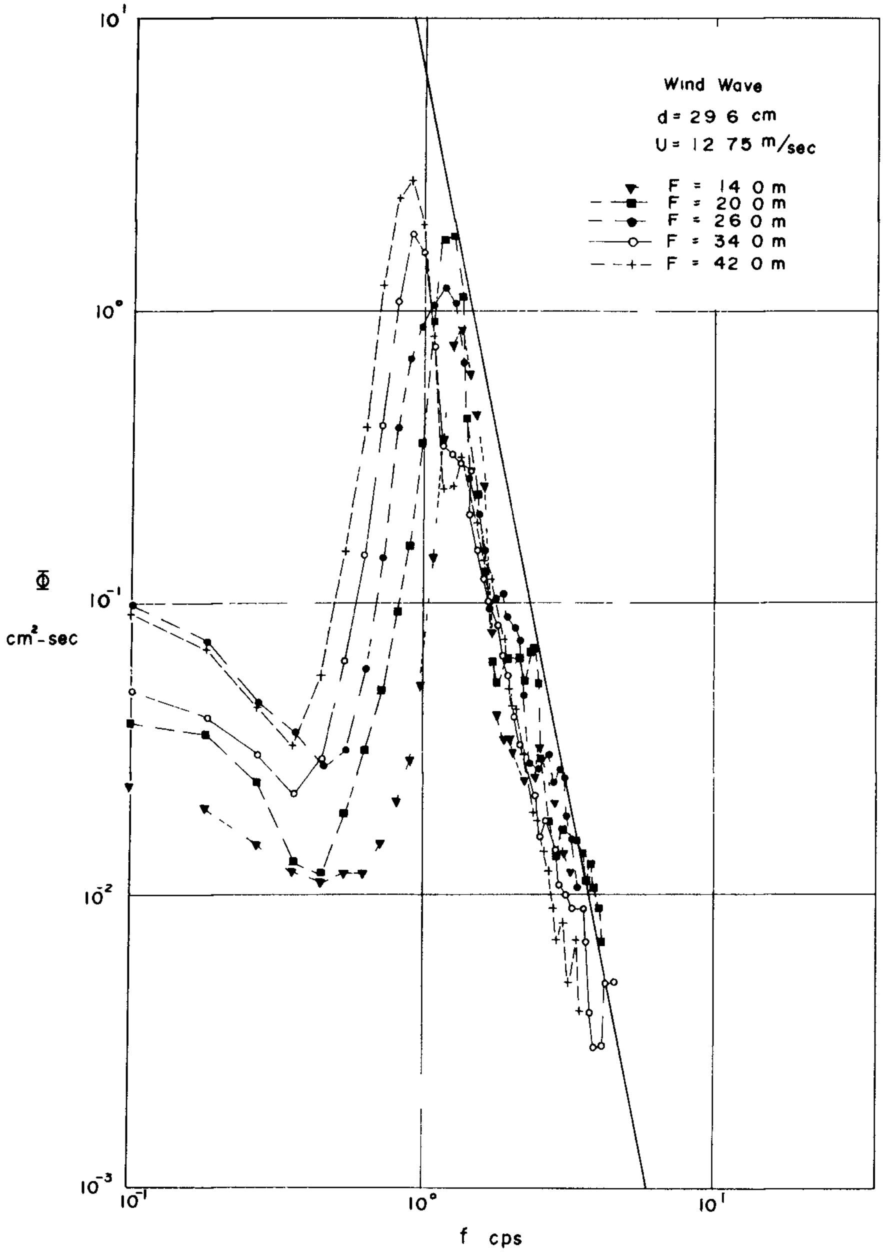

Regular Wave
d = 29 6 cm
H = 3 0 cm
T = 1 25 sec
F = 14 0 m
F = 20 0 m
F = 26 0 m
F = 34 0 m
F = 42 0 m
Φ cm²- sec
f cps

Fig 16


Wind Wave
d = 29 6 cm
U = 12 75 m/sec
F = 14 0 m
F = 20 0 m
F = 26 0 m
F = 34 0 m
F = 42 0 m
Φ
cm²-sec
10¹
10⁰
10⁻¹
10⁻²
10⁻³
f cps

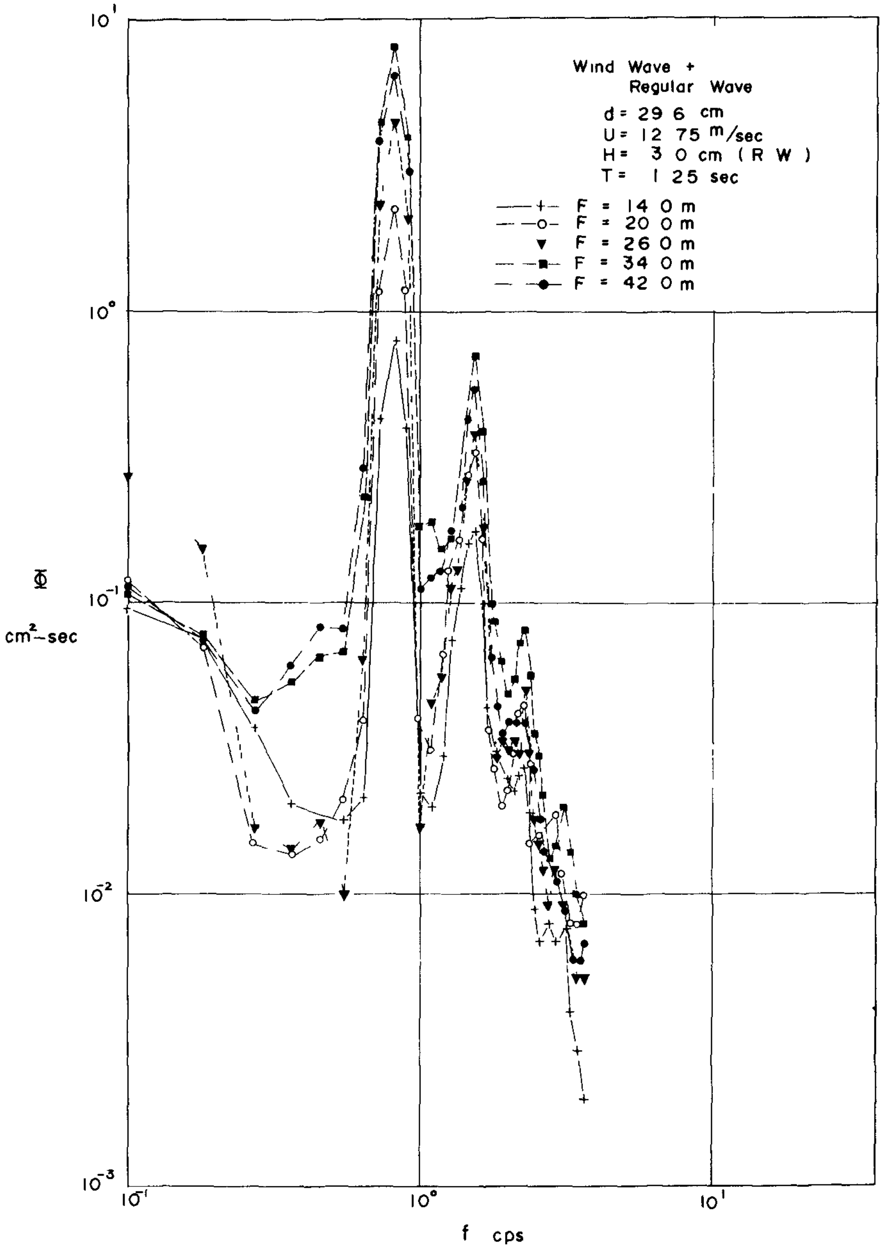

Wind Wave + Regular Wave
d = 29 6 cm
U = 12 75 m/sec
H = 3 0 cm (R W)
T = 1 25 sec
F = 14 0 m
F = 20 0 m
F = 26 0 m
F = 34 0 m
F = 42 0 m
Φ cm²-sec
f cps

Fig 18

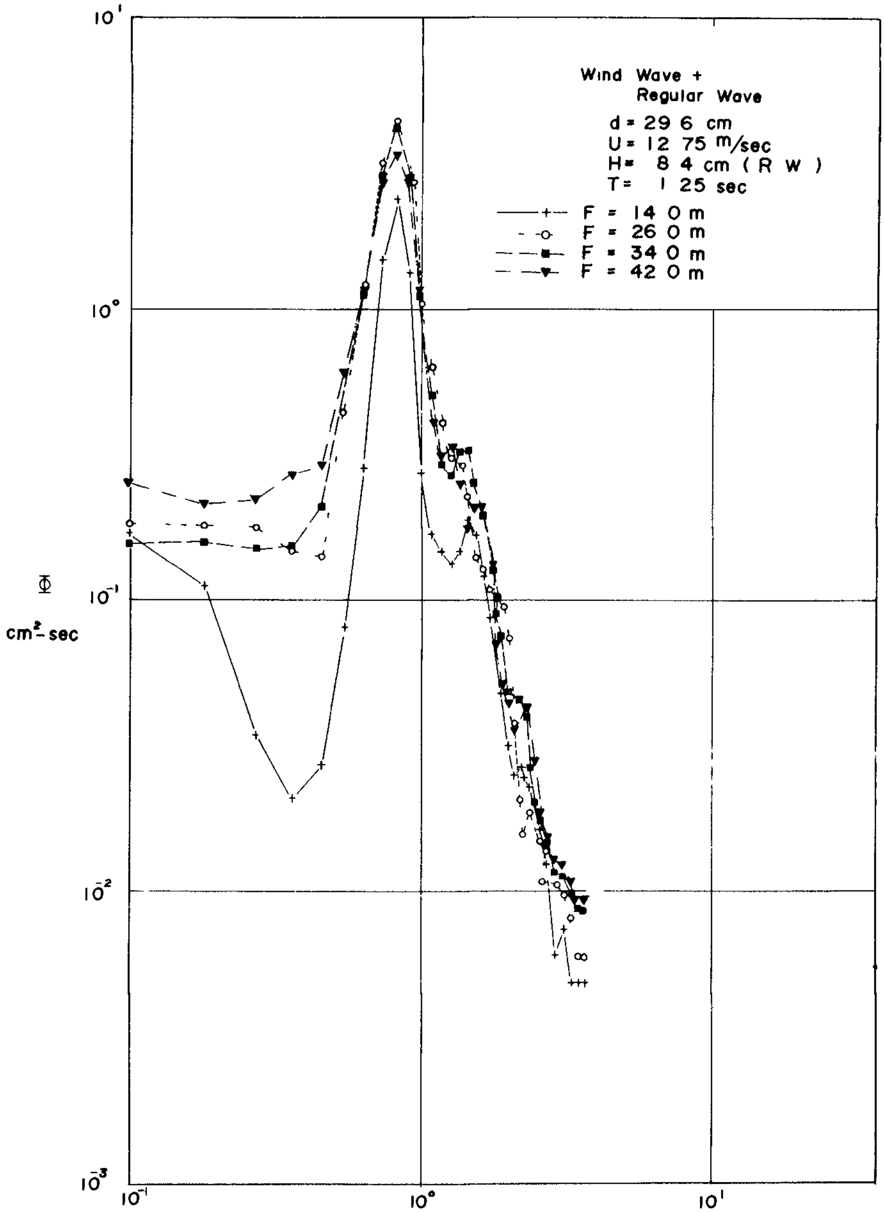

Wind Wave +
Regular Wave
d = 29 6 cm
U = 12 75 m/sec
H = 8 4 cm (R W)
T = 1 25 sec
F = 14 0 m
F = 26 0 m
F = 34 0 m
F = 42 0 m
Φ
cm²-sec
10¹
10⁰
10⁻¹
10⁻²
10⁻³
f cps

Fig 19

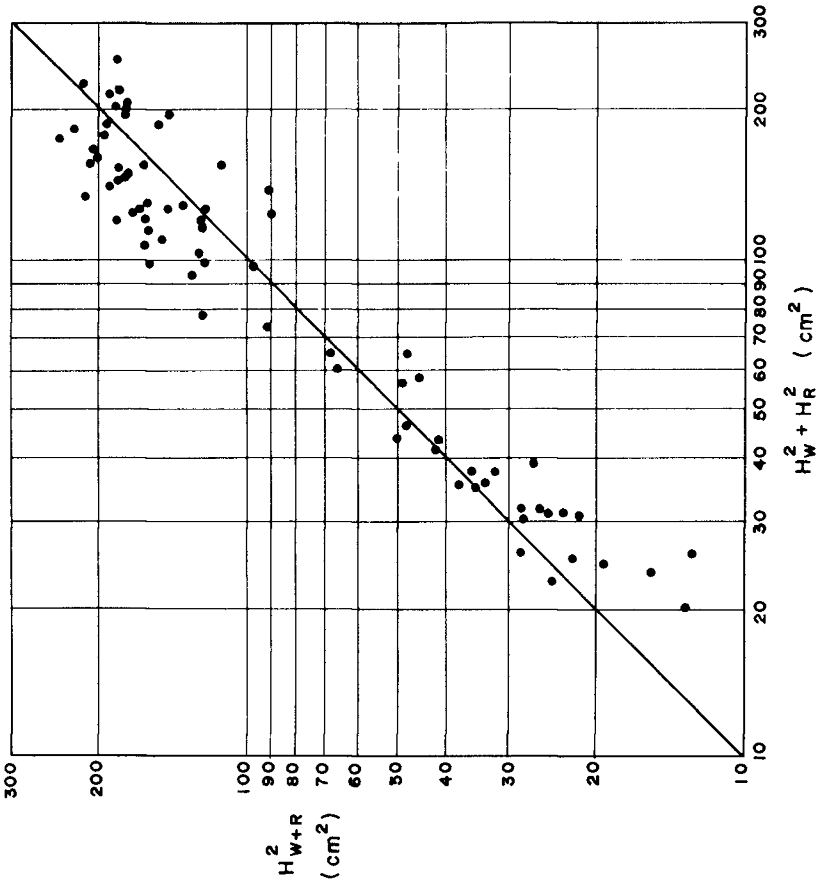


Fig 20