CHAPTER 7

COMPARISON OF PRESSURE AND STAFF WAVE GAGE RECORDS

by

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ABSTRACT

Simultaneous records from two pressure gages located at different depths, a step-resistance relay gage, and a continuous-wire staff gage have been collected at Atlantic City, N J

Spectra and cross-spectra are computed using the Fast Fourier Transform Algorithm (FFT) method proposed by Cooley and Tukey Individual harmonics of the pressure energy spectra are compensated for pressure attenuation according to classical theory Results indicate better agreement is obtained between the wave height and the spectra computed from the compensated pressure gages and those computed from the continuous-wire staff gage than between the two surface gages

Values of coherences are near 98 in the energy-containing part of the spectrum, and are always larger for the pressure-continuous wire staff cases than for the two surface gages which are displaced from each other only 12 feet in the horizontal

1 INTRODUCTION

Two basically different types of wave gages are widely used by coastal engineers One, called a surface-profile gage, produces a record which is considered to represent the actual elevation of the water surface at a point for each instant of time The other, called a pressure gage, produces a continuous record of the pressure at some fixed position beneath the surface The amplitude of the pressure pulses generated by waves is attenuated with depth, and short waves are attenuated more than long waves

To compensate for this attenuation, a theoretical correction is commonly applied to the record from a pressure gage Several recent comparisons of the records from surface-profile gages with compensated records from pressure gages have shown systematic differences (Hom-ma, Horikawa and Komori (1967)) In general, the differences have been attributed to inadequacy of the compensation formula

The Coastal Engineering Research Center (CERC) has established a facility at the Steel Pier in Atlantic City, New Jersey, for obtaining simultaneous records from several wave gages This installation is being used to compare surface-profile gages of various designs, and to obtain more information about the performance of pressure gages

A comparison of the records obtained from two pressure transducers, a step resistance relay gage described by Williams (1970), and a continuous wire gage is presented in this paper

2 THE INSTALLATION

The step-resistance wave gage has been installed for many years on one of the pilings supporting the Steel Pier at Atlantic City The other three gages were installed on a 4-inch outside diameter, heavy-duty steam pipe jettied into the sand bottom and secured to the Pier deck about 12 feet to the northeast of the step resistance gage The lower pressure transducer is immediately above the bottom of the continuous wire gage and the upper pressure transducer about 5 5 feet above the first All gages are on the seaward end of the pier, about half a mile from the mean water line

The mean depth at the gage site was determined as 15 5 feet MLW by lead line soundings a few days before and after the experiments Extensive surveys a few months earlier and later snowed that the gage site was near the center of a shallow depression The depth within 200 feet of the instruments varied from 11 0 to 16 6 feet, with an average value near 14 0 feet MLW A sketch of the installation is shown in Figure 1

The signal from each sensor is obtained in the form of a DC voltage All signals are transmitted to the CERC laboratory in Washington by telephone line

The transmission was accomplished by using channels two through five of the IRIG multiplex channels as described in TELEMETRY STANDARDS, June 1962, Document 106-60, and in many other publications on telemetry The transmission coefficient for the system is near unity for all frequencies less than 6 hertz In the laboratory, the signals are separated and converted back to DC voltages A digital voltmeter is used to measure the signal and the voltage is recorded on computer compatible magnetic tape at a rate of four samples per second from each gage

3 THE ANALYSIS PROCEDURE

The Fast Fourier Transform Algorithm (FFT) suggested by Cooley and Tukey (1966) was used to analyze observations 1024 seconds (17 minutes and 4 seconds) long This procedure gives 1024 harmonics with periods of 1 second or longer The initial record, expressed as a departure from the mean, was multiplied by a cosine Bell Taper function as suggested by Bingham, Godfrey and Tukey (1967) prior to the analysis in order to decrease the leakage of energy between spectral lines That is to say, the FFT was applied to the series

$$\tilde{Y}(n\Delta t) = \frac{1}{2}(Y(n\Delta t) - \bar{Y})(1 - \cos\frac{2\pi n\Delta t}{T}) \qquad (1)$$

Linear monochromatic wave theory was used to obtain the compensation function needed to compute the amplitude of the surface disturbance from the observed pressure disturbance for each harmonic according to the equation

$$C(m) = \frac{\cosh(k(m)H)}{\cosh(k(m)G)} \tag{2}$$

where C(m) is the compensation function for the m'th harmonic, k(m) is the wave number of the m'th harmonic, G is the height of the pressure transducer above the bottom and H is the mean thickness of the water column above the bottom during the observation The wave number is given by the implicit equation

$$(2m\pi T)^2 = gk(m) \tanh k(m)H \tag{3}$$

where T is the length of the observation (1024 seconds in this study) and g is the acceleration of gravity Thus the compensation factor appropriate to each specific frequency is applied to that harmonic

The Fourier Transforms were used to compute energy spectra for each gage record, the compensated record from the pressure transducers, and the cross-spectra between the records from the continuous wire gage and each of the other gages

The detailed spectra obtained in this way contain more than 1000 individual spectral lines The results are easier to grasp if some of this detail is suppressed, so the individual spectral values have been grouped into bands of 17 lines each

4 RESULTS

Eighty-three observations, taken 2 hours apart during December 19-26, 1969 were analyzed A sample of the resulting spectra, as obtained directly from the records of the four gages and from the compensated pressure records is shown in Figure 2 The spectrum from the continuous-wire record has been superimposed on all others The data in this Figure are normalized with respect to the frequency band with period between 3 and 19 69 seconds The short-period cutoff was imposed because the spectrum of the pressure record at higher frequencies has little correlation with the surface spectrum The long-period cutoff was imposed because the step-resistance gage shows an excessive amount of energy at longer periods for some of the observations The spectra computed from the compensated pressure records agree very well with that from the continuous-wire record within this period band

Figures 3 and 4 show a comparison of the wave heights as estimated from the continuous-wire gage and from the pressure gages compensated for hydrodynamic attenuation as described above The root mean square wave height, which is equal to the standard deviation of the wave record, is used as a measure of the wave height because unlike the "significant wave height" it is clearly and objectively defined Figure 5 shows the same comparison for the records obtained from the step resistance relay gage A tendency for the step resistance gage to record higher waves than the other gages is apparent This tendency has also been noted by Hom-ma, Horikawa and Komori These authors attributed this effect to wave runup on the gage or its support It has been determined that wave runup has affected the records from the step resistance wave gage at Atlantic City This step gage is no longer being used

Different mounting arrangements have been used at some other locations It seems likely that the installation at Atlantic City leads to larger runup than that experienced at some other installations The possibility that the differences between the records of the step gage and the continuously variable gages is due to the digital nature of the record from the step gage was investigated by truncating the resolution of the continuous wire gage to correspond with that of the step gage The results of the analysis of the truncated record did not differ significantly from those of the analysis of the original record

It should be noted that the agreement between the compensated pressure records and the continuous-wire record is better than that between the two surface-profile records The continuous-wire gage has been used as the standard in this comparison partly because of this better agreement and partly because wave runup is known to affect the accuracy of the step resistance gage

The average factor needed to convert the wave heights as determined from the upper pressure transducer compensated by individual lines to those determined from the continuous-wire gage was found to be 98 with a correlation coefficient of 999 For the lower pressure transducer this factor becomes 1 04, with a correlation coefficient of 999 Even when the entire spectrum is compensated by the factor computed for the frequency of maximum energy density the factor is 1 08 with a correlation of 997 The agreement reported here is much better than most of those cited in the review paper by Grace (1970) The improved agreement is believed to result partly from the use of a more satisfactory surface gage system, partly because the FFT procedure permits a more precise determination of the frequencies of maximum interest than the procedures used by earlier investigations, and partly because the correction was applied to the individual harmonics in the spectrum

5 ACCURACY OF THE COMPENSATION FACTOR AS A FUNCTION OF FREQUENCY

Hom-ma, et al, have studied the function n(f) defined by the relation

$$E(f)_{sfr} = n(f)E(f)_{cp} \tag{4}$$

where f is the frequency, and the subscripts sfr and cp refer to the surface wave record and the compensated pressure record The function n(f) has been computed from our data for all bands containing as much as 5 percent of the total energy in a given spectrum The function n(f) based on all records from the upper pressure transducer is shown in Figure 6 The mean value of n(f) is plotted as a circle and the standard deviation is shown by a vertical line A similar plot based only on those observations in which H_{RMS} exceeded 1 foot is given in

Figure 7 The two values for which no standard deviations are shown consisted of single observations Similar results, but with a little more scatter, were derived for the lower pressure transducer, as shown in Figures 8 and 9

It is noted that both the deviation of the mean value of n(f) from its theoretical value of unity and the scatter of the individual values is greater for low waves than high waves, and greater for the lower pressure transducer than for the upper one From these results we are led to believe that the deviation results more from the presence of pressure impulses caused by factors other than surface gravity waves than from nonlinear effects due to the finite amplitude of the wave This is especially likely at high frequencies where the large value of c(m) would greatly amplify small impulses In general, we feel that values of $c^2(m)$ greater than 25 should not be used at this installation

6 CROSS SPECTRUM RESULTS

The cross spectra calculations for band widths of 0 017 Hertz showed a coherence of 95 between the continuous-wire gage and the pressure gages in most bands containing more than 5 percent of the total energy in the spectrum The coherence between the two surface gages was slightly lower but still above 90

Computations of the phase lags between the continuous-wire and the pressure gages showed that the phase of the wave advances slightly with increasing depth This effect tends to increase with frequency A phase shift of this kind has been predicted by Battjes (1968) and Mei and Chu (1970)

REFERENCES

Bingham, C , Godfrey, M D and Tukey, J W , 1967, "Modern Techniques of Power Spectrum Estimation", IEE Trans Audio Electro-acoustics, Vol AU15, No 2, pp 56-66

Battjes, J A , "Refraction of Water Waves", Journal of the Waterways and Harbors Div , Proceedings of the American Society of Civil Engineers, Vol 94, 1968, pp 437-450 , No WW4

Cooley, J W and Tukey, J W "The Fast Fourier Transform", IEEE Spectrum, Vol 4, p 63-70, 1967

Draper, L , "Attenuation of Sea Waves with Depth", La Houille Blanche, Vol 12, No 6, 1957, pp 926-931

Gerhardt, J R , Jehn, K H and Katz, I , "A Comparison of Step-Pressure - and Continuous-Wire-Gauge Wave Recordings in the Golden Gate Channel", Transactions of the American Geophysical Union, Vol 36, No 2, 1955, pp 235-250

Glukhovski, B K , "Study of Wave Attenuation with Depth on the Basis of Correlation Analysis", Meteorologiya i Gidrologiya, No 11, 1961, pp 22-30, Electricite de France, Centre de Recherches et d'Essais de Chatou, Traduction 1343

Grace, Robert A , "How to Measure Waves", Ocean Industry, Vol 5, No 2, 1970, pp 65-69

Harris, D L , "The Analysis of Wave Records", Coastal Engineering, Proceedings of Twelfth Conference, 1970

Hom-ma, M Horikawa, K , and Komori, S , "Response Characteristics of Underwater Wave Gage", Proceedings of the 10th Conference on Coastal Engineering, Tokyo 1966", pp 99-114

Mei, C C and Chu, Vincent, "Slowly Varying Stokes Waves", Journal of Fluid Mechanics (1970)

Williams, Leo C , Technical Memorandum No 30, Dec 1969, U S Army Corps of Engineers, Coastal Engineering Research Center, 1969

LEGEND TO FIGLPES

Fig 1 Sketch of installation (not to scale)

Fig 2 Computed frequency energy spectra from continuous wave gage superimposed on computed spectra from a) compensated upper pressure gage, b) uncompensated upper pressure gage, c) compensated lower pressure gage, d) uncompensated lower pressure gage, e) step resistance relay gage

Fig 3 Comparison of RMS heights, compensated upper pressure gage vs continuous wire gage

Fig 4 Comparison of RMS heights, compensated lower pressure gage vs continuous wire gage

Fig 5 Comparison of RMS heights, step resistance relay gage vs continuous wire gage

Fig 6 The function, n(f) for the upper pressure gage for all samples

Fig 7 The function, n(f) for the upper pressure gage for high wave samples

Fig 8 The function, n(f) for the lower pressure gage for all samples

Fig 9 The function, n(f) for the lower pressure gage for high wave samples

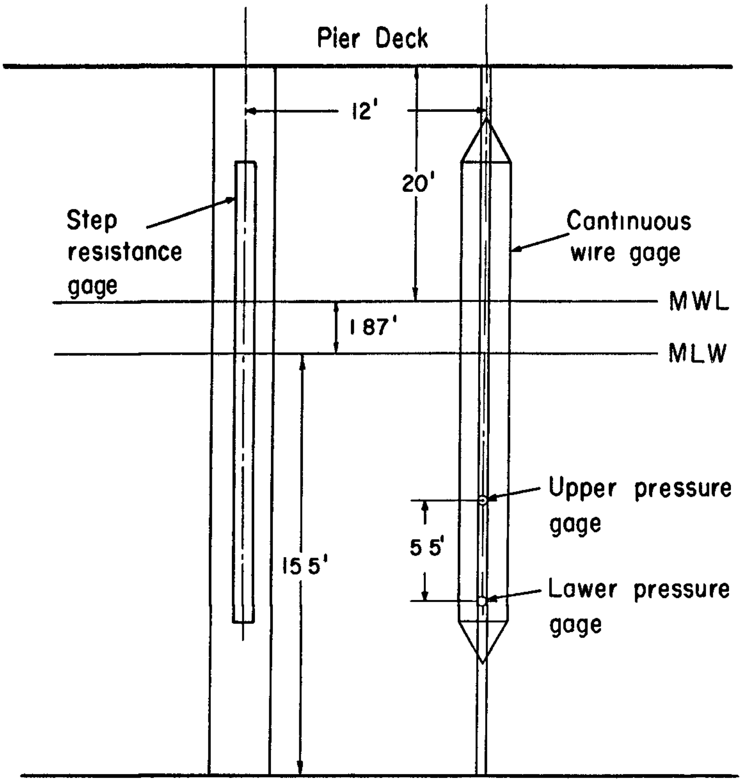

Fig 1 Sketch of Installation (not to scale)

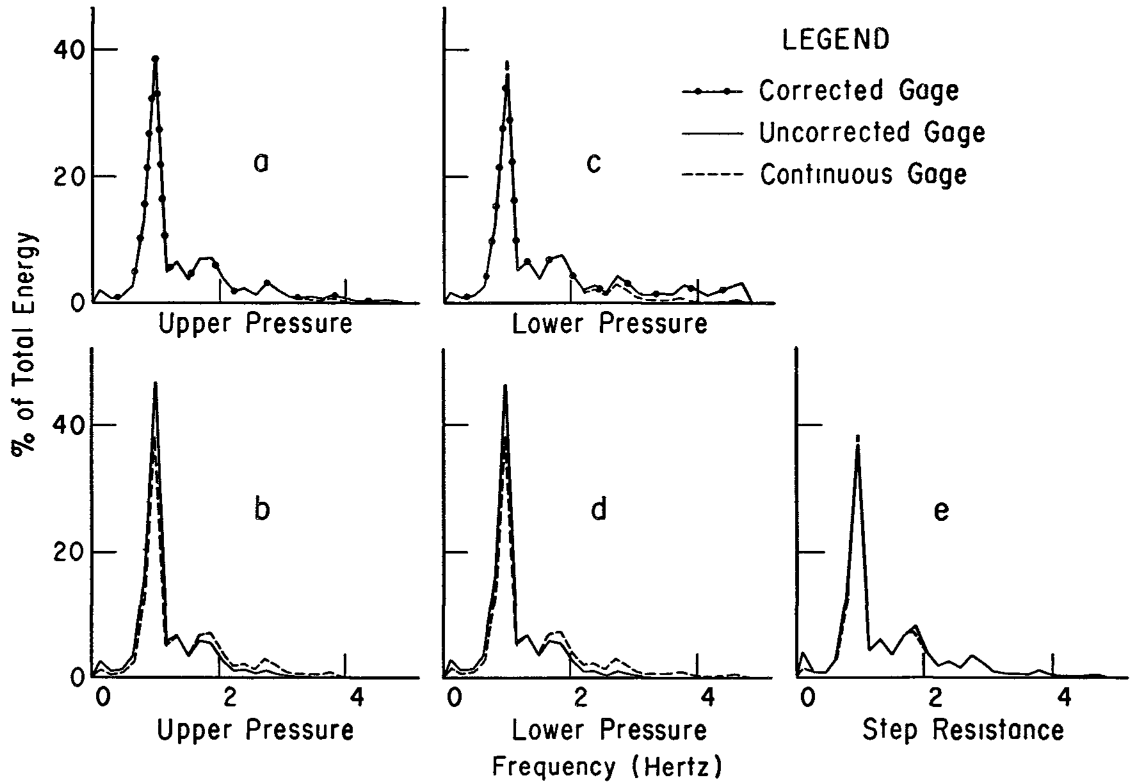

Fig 2 Computed Frequency Energy Spectra from continuous wave gage superimposed on computed spectra from a) compensated upper pressure gage, b) uncompensated upper pressure gage, c) compensated lower pressure gage, d) uncompensated lower pressure gage, e) step resistance relay gage

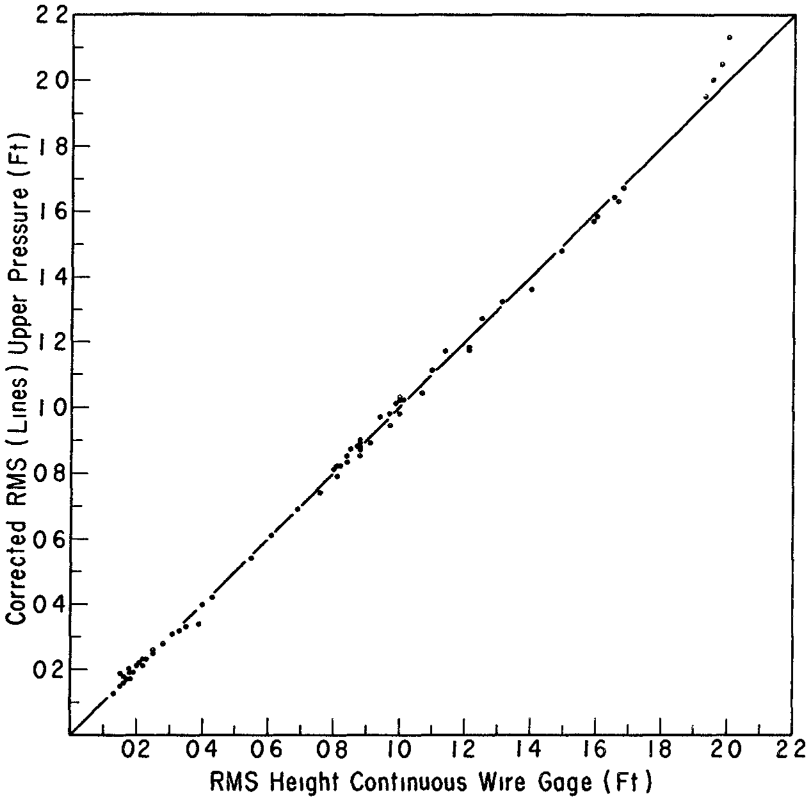

Fig 3 Comparison of RMS heights, compensated upper pressure gage vs continuous wire gage

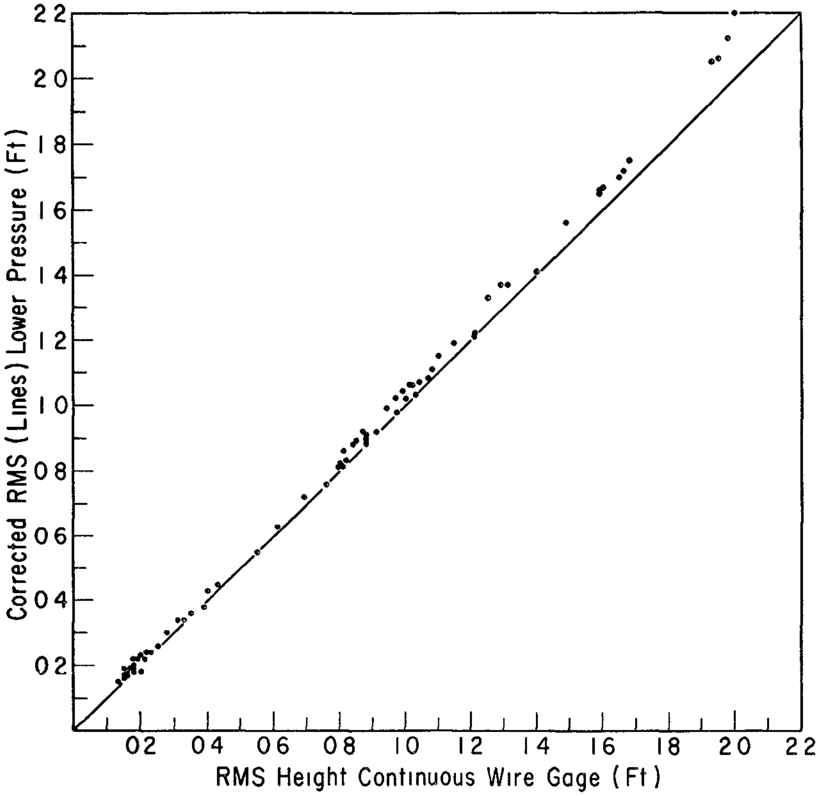

Fıg 4 Comparıson of RMS heıghts, compensated lower pressure gage vs contınuous wıre gage

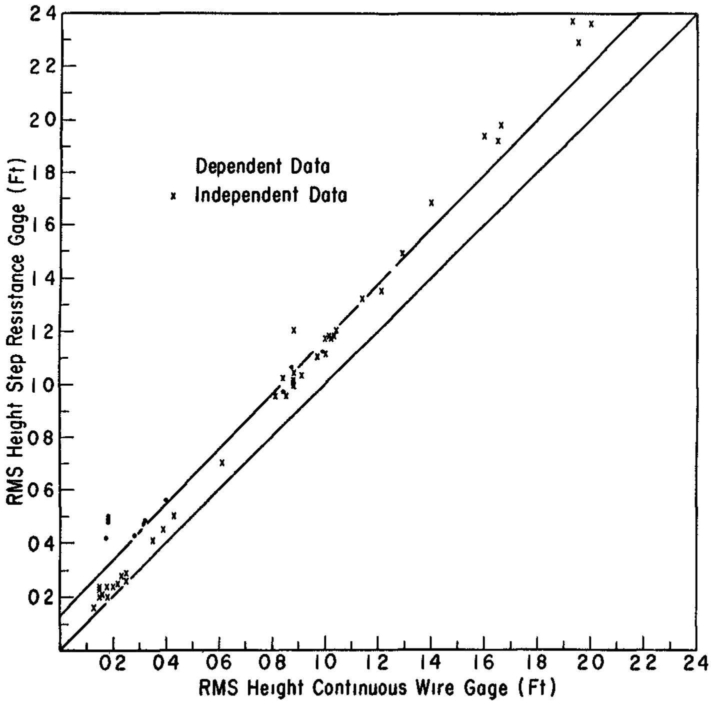

Fig 5 Comparison of RMS heights, step resistance relay gage vs continuous wire gage

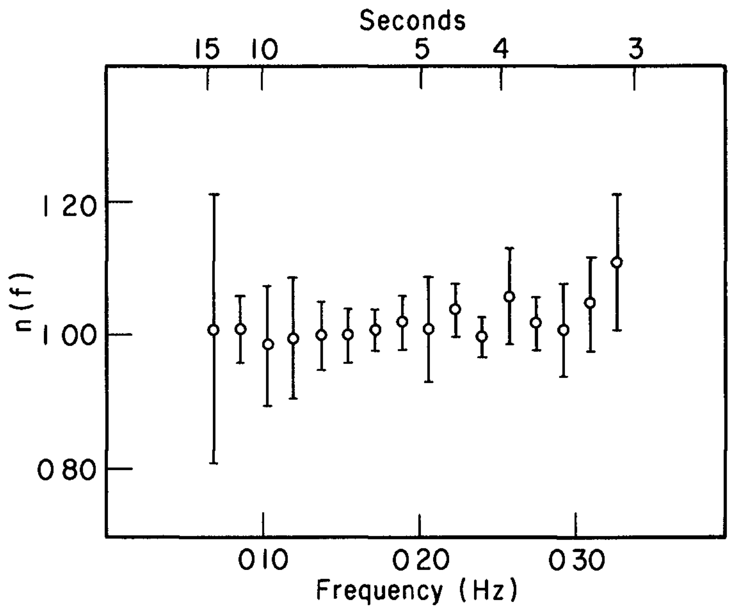

Fig 6 The function, n(f) for the upper pressure gage for all samples

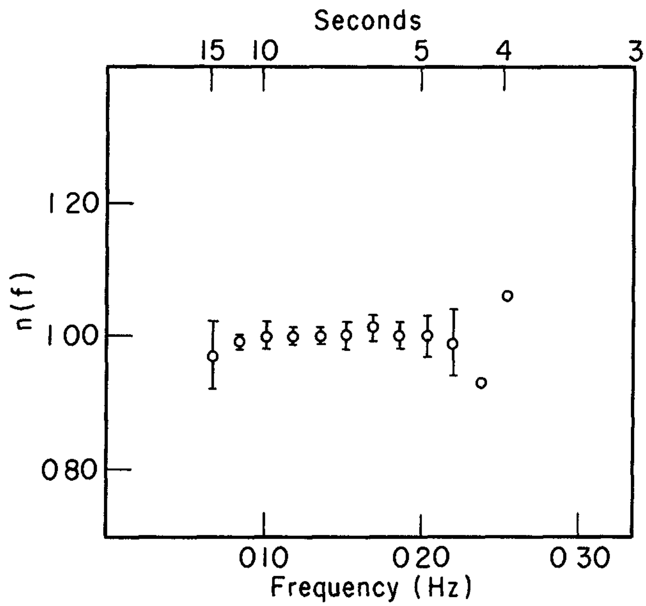

Fig 7 The function, n(f) for the upper pressure gage for high wave samples

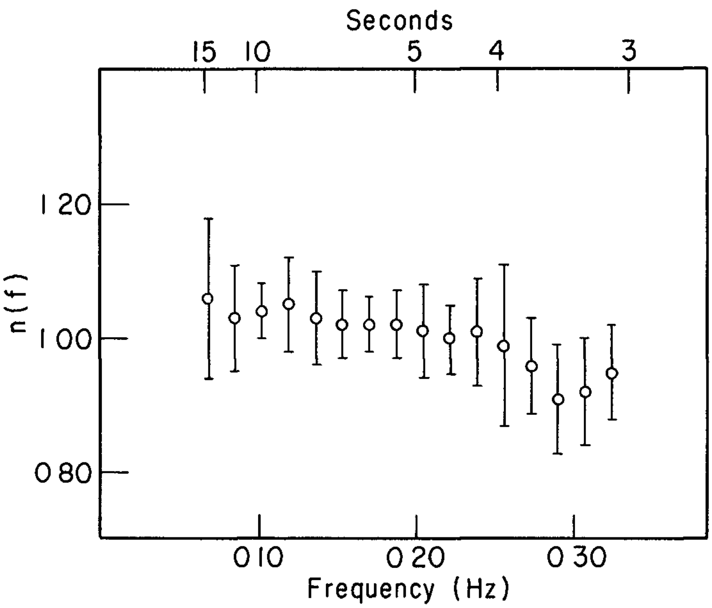

Fig 8 The function, n(f) for the lower pressure gage for all samples

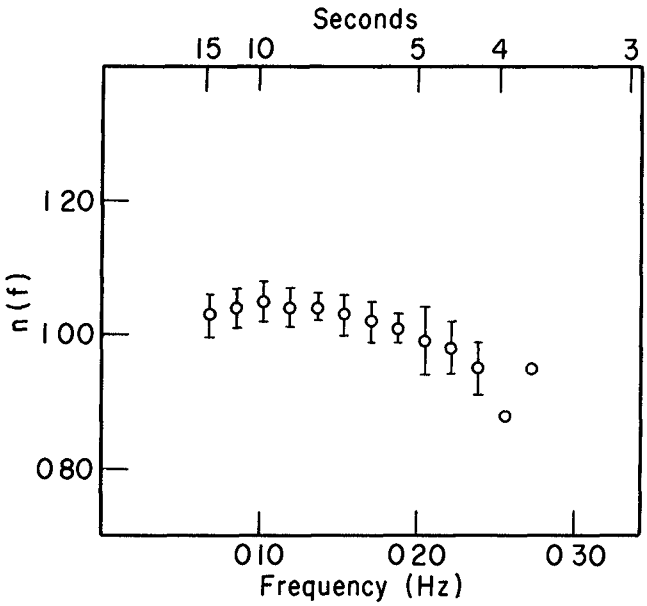

Fig 9 The function, n(f) for the lower pressure gage for high wave samples