CHAPTER NINETEEN

# MEASUREMENT OF SURFACE WAVES FROM SUBSURFACE GAGE

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ABSTRACT

Wave measurement using subsurface pressure gage has many advantages, especially in coastal waters. However, there are some disadvantages associated with indirect measurement of surface waves. This paper deals with the problems in the recovery of surface waves from the subsurface pressure measurement. Two problems are examined: more exact recovery of the surface waves from subsurface pressure signal and a simple real time recovery of surface waves from the pressure record.

The commonly used linear transformation from the subsurface pressure to surface elevation is evaluated and possible sources of error are examined. The effect of nonlinearity and effect of current are shown to be small in the intermediate water depth. For the case of shallow water where effects of nonlinearity and current are not negligible, a method of proper recovery of surface waves from the combination of pressure and current measurements is given.

A simple method to recover the time series surface waves from subsurface record is proposed which enables speedy near real-time recovery of surface waves from pressure measurement using a microprocessor.

## 1. INTRODUCTION

Subsurface pressure transducer has been extensively used in measuring surface waves. It is particularly suitable for application in shallow and intermediate depth water. It does not require a supporting structure which penetrates the surface, hence is less susceptible to being demaged by ships and fishing activities and has better survivability in severe sea conditions due to storms. It is also not affected by high tidal range or storm surge which make the surace piercing gage impractical. In addition, it provides information for the mean water level variation due to tide and storm surge, that can not be obtained from moored surface gage such as pitch and roll buoy.

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However, since the device measures the subsurface pressure, a proper transformation has to be carried out to obtain surface wave information. The commonly used practice is to recover the surface wave information by means of a transfer function based on the linear first order wave theory. There are several sources of error such as instrumental noise, nonlinearity, effect of current, etc. A number of these sources of error are examined here to establish the reliability and limitations of the subsurface wave mesurement and a refined method of recovery is proposed.

As a second objective, a simple numerical filter is introduced here which can perform fast recovery of time series of surface wave from pressure record with minimum computation.

## 2. ANALYSIS OF SUBSURFACE PRESSURE RECORD

The record from the subsurface pressure gage contains signals of two widely separated time scales; small time scale signal due to wave induced motion and larger time scale signal due to tide, storm surge etc. The data measured from the subsurface gage is considered as a linear summation of various contributing components :

$$P(t) = P_a + \rho g[(h-H_g) + K_p\ \eta] \tag{1}$$

where $P(t)$ is the measured pressure at gage and Pa is the atmospheric pressure at the surface, h and $H_g$ denote mean water depth and gage height above bottom, respectively, and $\eta$ is surface wave and $K_p$ is the pressure response function, and $\rho$ is water density and g is gravitational acceleration.

By averaging the time series with a time interval much larger than the time scale of gravity waves but smaller than the large time scale phenomena, the mean water depth (h) is obtained as

$$h(t) = (\bar{P} - p_a)/(\rho g) + H_g \tag{2}$$

where $\bar{P}$ denotes the time averaged mean pressure at the gage. The tide and storm surge information can be deduced from h(t) (Howell et al., 1983).

The pressure (p) induced by surface gravity waves can be obtained from

$$p = \rho g\ K_p\ \eta = [P(t) - \bar{P}] \tag{3}$$

The pressure response function, $K_p$, is usually defined through linear wave theory as follows

$$K_p(\omega_n) = \{\text{Cosh}\ k_n(h+z)\ /\ \text{Cosh}\ k_n(h)\} \tag{4}$$

such that

$$p(t) = \rho g \sum_n A_n\ \text{Cos}(\omega_n t - \varepsilon_n) \tag{5}$$

$$\eta(t) = \sum_n \frac{A_n}{K_p(\omega)} \cos(\omega_n t - \varepsilon_n) \tag{6}$$

where h is water depth and z is location of pressure gage, and $A_n$, $\omega_n$, $\varepsilon_n$ and $k_n$ are wave amplitude, frequency, phase and wave number of n-th component wave, respectively. The wave number and the frequency are related by

$$\omega_n = \sqrt{gk_n \text{ Tanh } (k_n h)} \tag{7}$$

The surface variance spectrum, $E_{\eta\eta}(\omega)$, commonly known by wave energy spectrum can be obtianed from the subsurface pressure spectrum, $E_{pp}(\omega)$, by the following relation:

$$E_{\eta\eta}(\omega) = E_{pp}(\omega)/K_p^2 \tag{8}$$

The time series of the surface waves can be obtained by Eq. (6) where $A_n$, $\omega_n$ and $\varepsilon_n$ are be obtained from the Fast Fourier Transform (FFT) of the pressure data. Another method of recovery of $\eta(t)$ is obtained by means convolution integral,

$$\eta(t) = \int_{\infty}^{\infty} h(\tau)\, p(t-\tau)\, d\tau \tag{9}$$

where

$$h(\tau) = \int_{\infty}^{\infty} H(\omega)\, \text{Exp}(i\omega\tau)\, d\omega \tag{10}$$

$$H(\omega) = \frac{1}{K_p(\omega)}$$

The convolution integral method is usually more time consuming than the FFT method.

## 3. SOURCES OF ERROR AND IMPROVEMENT

### 3.1. Noise

The signal due to high frequency wave components is small due to depth attenuation and sometimes is completely lost due to the instrument limitation. The electronic noise in the power system, pressure transducer, and the analog filter, and the numerical noise associated with analog-to-digital conversion, on the other hand, are introduced. These noise components are amplified when converting into surface waves.

The noise from many possible sources cannot be totally avoided, hence, the true surface elevation information in the high frequency range is very difficult to recover from pressure record.

In theory, the pressure signal can be corrected if the noise is a known function of frequency. Unfortunately, such is not the case. It is, thus, suggested to remove the averaged overall noise level for the higher frequency range as

$$E_{\eta\eta} = (E_{pp} - C)/K_p^2 \tag{11}$$

where C is the overall noise level in high frequency range. This seemingly trivial process is important as a slight error in the high frequency region may produce a significant error in the surface elevation through amplification. A simple way that is comonly used to resolve this problem is the application of windowed transfer function simply by cutting off the high frequency range above a certain cut-off frequency ($\omega_a$) such that

$$\begin{aligned} H(\omega) &= H(\omega) \quad \text{for } \omega < \omega_a \\ &= 0 \quad\quad\; \text{for } \omega > \omega_a \end{aligned} \tag{12}$$

The pressure record is usually represented as discrete and finite record. The use of finite record length, i.e. rectangular window results in an undesirable energy leakage to the neighboring frequency components. The spill over error in pressure spectrum is amplified in wave energy spectrum. A data window is to be applied to the data to reduce spectral leakage.

### 3.2 Nonlinearity of Coastal Waves

Many of the nonlinear wave theories are confined to cases of monochromatic waves, which are not practical to apply to the random waves. The higher order correction to the first order random (free) waves using perturbation method is used here to deal with the weakly nonlinear irregular waves. The surface elevation $\eta$ is expressed up to second order as (Sharma et al., 1981),

$$\eta = \eta_1 + \eta_2 \tag{13}$$

where

$$\eta_1 = \sum_i A_i \operatorname{Cos}(\omega_i t - \varepsilon_i) \tag{14}$$

and

$$\begin{aligned} \eta_2 = \frac{1}{4} \sum_i \sum_j C_{ij}^- A_i A_j \operatorname{Cos}[(\omega_i - \omega_j)t - (\varepsilon_i - \varepsilon_j)] \\ + \frac{1}{4} \sum_i \sum_j C_{ij}^+ A_i A_j \operatorname{Cos}[(\omega_i + \omega_j)t - (\varepsilon_i - \varepsilon_j)] \end{aligned} \tag{15}$$

where

$$C_{ij}^- = \frac{D_{ij}^- + (\vec{k}_i \cdot \vec{k}_j + R_i R_j)}{\sqrt{R_i R_j}} + (R_i + R_j) \tag{16}$$

$$C_{ij}^+ = \frac{D_{ij}^+ - (\vec{k}_i \cdot \vec{k}_j + R_i R_j)}{\sqrt{R_i R_j}} + (R_i + R_j) \tag{17}$$

where

$$D_{ij}^{-} = \{(\sqrt{R_i} - \sqrt{R_j}\ [\sqrt{R_j}\ (k_i^2 - R_i^2) - \sqrt{R_i}\ (k_j^2 - R_j^2)]$$

$$+ 2(\sqrt{R_i} - \sqrt{R_j})^2\ (\vec{k}_i \cdot \vec{k}_j + R_i R_j)\}$$

$$\div\ [(\sqrt{R_i} - \sqrt{R_j})^2 - k_{ij}^{-}\ \tanh\ k_{ij}^{-}h] \tag{18}$$

$$D_{ij}^{+} = \{(\sqrt{R_i} + \sqrt{R_j})\ [\sqrt{R_i}\ (k_j^2 - R_j^2) + \sqrt{R_j}\ (k_i^2 - R_i^2)]$$

$$+ 2(\sqrt{R_i} + \sqrt{R_j})^2\ (\vec{k}_i \cdot \vec{k}_j - R_i R_j)\}$$

$$\div\ [(\sqrt{R_i} + \sqrt{R_j})^2 - k_{ij}^{+}\ \tanh\ k_{ij}^{+}h] \tag{19}$$

and $\quad R_i = k_i \tanh k_i h, \quad k_{ij}^{-} = |\vec{k}_i - \vec{k}_j|, \quad k_{ij}^{+} = |\vec{k}_i + \vec{k}_j|$

The subsurface pressure at location z can be written as

$$p = p_1 + p_2 \tag{20}$$

where $\quad p_1 = \rho g \sum_i \cosh[k(h+z)]/\cosh(kh)\ A_i \cos(\omega_i\ t - \varepsilon_i) \quad (21)$

$$p_2 = \frac{1}{4}\rho g \sum_i \sum_j G_{ij}^{-}\ A_i A_j\ \mathrm{Cos}[(\omega_i - \omega_j)t - (\varepsilon_i - \varepsilon_j)]$$

$$+ \frac{1}{4}\rho g \sum_i \sum_j G_{ij}^{+}\ A_i A_j\ \mathrm{Cos}(\omega_i + \omega_j)t - (\varepsilon_i + \varepsilon_j)] \tag{22}$$

where $\sqrt{R_i R_j}\ G_{ij}^{-} = \dfrac{\cosh k_{ij}^{-}\ (h+z)}{\cosh k_{ij}^{-}h} D_{ij}^{-}$

$$- \frac{k_i k_j}{\cosh k_{ij}^{P}h + \cosh k_{ij}^{M}h} \{\cosh k_{ij}^{P}\ (h+z)$$

$$\cdot\ [1 + \cos\ (\Theta_i - \Theta_j)] - \cosh k_{ij}^{M}\ (h+z)$$

$$\cdot\ [1 - \cos\ (\Theta_i - \Theta_j)]\} \tag{23}$$

and $\quad \sqrt{R_i R_j}\ G_{ij}^{+} = \dfrac{\cosh k_{ij}^{+}\ (h+z)}{\cosh k_{ij}^{+}h} D_{ij}^{+}$

$$- \frac{k_i k_j}{\cosh k_{ij}^P h + \cosh k_{ij}^M h} \{\cosh k_{ij}^P (h+z)$$

$$\cdot \left[-1 + \cos (\theta_i - \theta_j)\right] + \cosh k_{ij}^M (h+z)$$

$$\cdot \left[1 + \cos (\theta_i - \theta_j)\right]\} \tag{24}$$

where $k_{ij}^P = |\vec{k}_i| + |\vec{k}_j|$, $k_{ij}^M = |\vec{k}_i| - |\vec{k}_j|$

and $\theta_i$ is wave angle.

By comparing the surface elevation and subsurface pressure, we may define two or more transfer functions as

$$K_{1_i} = \cosh[k(h+z)]/\cosh(kh) \tag{25}$$

$$K_{2_{ij}}^- = C_{ij}^-/G_{ij}^- \tag{26}$$

$$K_{2_{ij}}^+ = C_{ij}^+/G_{ij}^+ \tag{27}$$

The transfer function for the first order free component is shown in Figure 1.

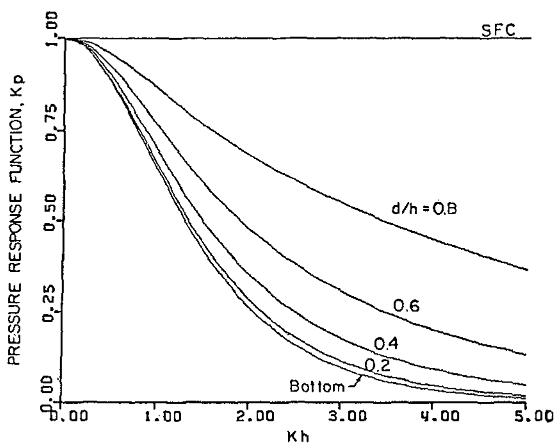


Figure 1. Variation of Linear Pressure Transfer Function with Dimensionless Water Depth (kh) for Various Dimensionless Gage Depth (d/h).

The transfer function for second order nonlinear component depends on the combination of the first order frequency components and their directions. Figure 2 shows the ratio of transfer function for the second order component to the linear transfer function for the simple case where all wave components propagate in the same direction. We can see that the transfer functions for the second order terms are slightly smaller than the linear transfer function for the subharmonics (frequency difference components) and slightly higher for the superharmonic (frequency sum components).

For example, considering just one free waves with its harmonics, the surface elevation $\eta$ expressed by Stoke's wave is

$$\eta(t) = \eta_1 + \eta_2 \tag{28}$$

where

$$\eta_1 = a \cos(kx-\omega t) \tag{29}$$

$$\eta_2 = 1/2\ k\ a^2 \cosh(kh)\ [2+\cosh(2kh)]/\sinh^3(kh)\ \mathrm{Cos}(2kx-2\omega t) \tag{30}$$

The pressure at elevation of z can be expressed as

$$p(t) = K_1\ \eta_1 + K_2\ \eta_2 \tag{31}$$

where $K_1 = \cosh[k(h+z)]/\cosh(kh)$

$$K_2 = \frac{3/4\ k\ a^2 \tanh(kh)/\sinh^2(kh)\ [\cosh[2k(h+z)]/\sinh^2 kh-1/3]}{\cosh(kh)\ [2+\cosh(2kh)]/\sinh^3(kh)} \tag{32}$$

The second harmonic which is phase locked to the fundamental wave shows different characteristics from the free waves with the same frequency or wave length. The response function of the phase locked second order components is different from that of the free linear wave with the same frequency as shown in Figure 3. The pressure correspondent to second order superharmonic decays with depth at a slower rate than those of free waves with same frequency.

The nonlinearity effect is not significant in the intermediate depth water waves since the contribution of the nonlinear components are comparatively small and the difference of the transfer functions between the linear term and nonlinear term is not significant. However, in shallow water or in surf zone, the nonlinearity correction is essential.

### 3.3 Effects of Current

Current affects waves in two respects: the kinematic effect leading to the change of wave number and the dynamic effect leading to the change of dynamic pressure. Both will affect the pressure transfer function.

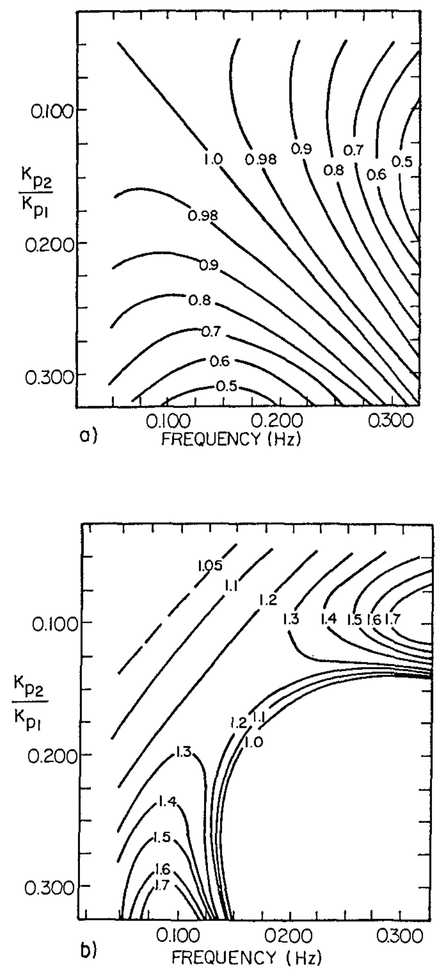


Figure 2. Example of the Pressure Transfer Function for the Second Order Component Compared to that of Linear Component for Simple Case of Unidirectional Wave When h=7.5 m, d=1.0 m. (2-a). Subharmonic ($\omega_i - \omega_j$) component. (2-b). Superharmonic ($\omega_i + \omega_j$) component.

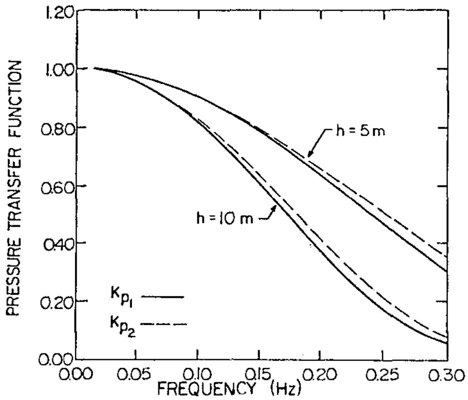


Figure 3. Pressure Transfer Function of the Second Order Harmonic of Stoke's Wave Compared to that of First Order Linear Wave Component.

As shown in Eq. 6, the transfer function, $K_p$, is related to the wave number. In the presence of current, the change of wave number can be obtained by following equation

$$n = \vec{k} \cdot \vec{u} + \sqrt{gk \tanh(kh)} \tag{33}$$

where n is the intrinsic wave frequency and $\vec{u}$ is current vectors. This effect becomes increasingly significant in higher frequency range especially for the current against the waves.

The wave induced dynamic pressure by the combined current and wave motions is

$$\begin{aligned} p &= \frac{1}{2} \rho \left\{ \left( \sum_i U_i \cos(\omega_i t - \varepsilon_i) + U_c \cos \alpha \right)^2 + (U_c \sin \alpha)^2 \right\} \\ &= \frac{1}{2} \rho \sum_i \sum_j U_i U_j \cos(\omega_i t - \varepsilon_i) \cos(\omega_j t - \varepsilon_j) \\ &\quad + \rho U_c \cos \alpha \sum_i U_i \cos(\omega_i t - \varepsilon_i) + \frac{1}{2} \rho U_c^2 \end{aligned} \tag{34}$$

where $U_i$ is the amplitude of wave induced velocity and $U_c$ is the current speed and α denotes the angle between the wave propagation and current direction. The first term in the right hand side of Eq. 34 is the second order components with frequency components of $(\omega_i - \omega_j)$ and

$(\omega_i+\omega_j)$ that contribute a part of $p_2$ in Eq. 22. Its effect has been considered from the nonlinearity point of view. The third term gives only a constant drift. The effect of the superimposed current on the recovery of pressure data comes from the second term, which is proportional to the wave induced flow and the proportionality factor $U_c \cos \alpha$ depends on the current speed and the angle between current and wave $\alpha$.

The relation between the pressure fluctuation and surface wave is now

$$p(t) + p_2(t) = \rho g K_p'\eta \tag{35}$$

where Kp is corrected transfer function. It can be shown that

$$\begin{aligned} K_p' &= [1 + U_c \cos(\alpha) k_n/\omega_n] K_p \\ &= (1 + \cos(\alpha) U_c/C) K_p \end{aligned} \tag{36}$$

where C is the wave phase speed.

Figure 4 shows the effect of the current on the transfer function, $H(\omega)$ due to current effect in the change of wave number, and in the change of dynamic pressure. These two effects are in opposition hence somewhat neutralize each other. The resultant effect is dominated by the dynamic effect in the lower frequency range whereas it is dominated by the kinematic effect in the higher frequency range.

## 4. APPLICATION TO THE FIELD DATA

### 4.1. Comparison of the Surface and Subsurface Measurements

To determine the validity of the linear pressure transfer function, surface data and subsurface data obtained simulataneously during ARSLOE experiment are analysed and compared. The pressure gage is located at 0.9 meter above the bottom at the water depth of about 7.5 meter. The surface gage is the Baylor type gage at water depth of about 9.0 meter. The distance between the two gage is about 40 meters. Figure 5 shows an example comparing wave spectrum obtained from surface gage to that from subsurface gage using linear linear transfer. The pressure response function obtained from the measured data and from the theoretical linear transfer function are also compared in Figure 5.

The linear transfer function is found to perform well in the energy containing region but underestimates energy in the lower frequency range while slightly over estimates energy in the higher frequency range. This trend is consistent with other investigators (Cavaleri et al., 1978; Forristal, 1982). This may be partially explained by the nonlinear effect discussed earlier. The transfer function of the second order term for the frequency difference components (lower frequency) is smaller than that of the linear component at the same frequency, while the opposite is true for the

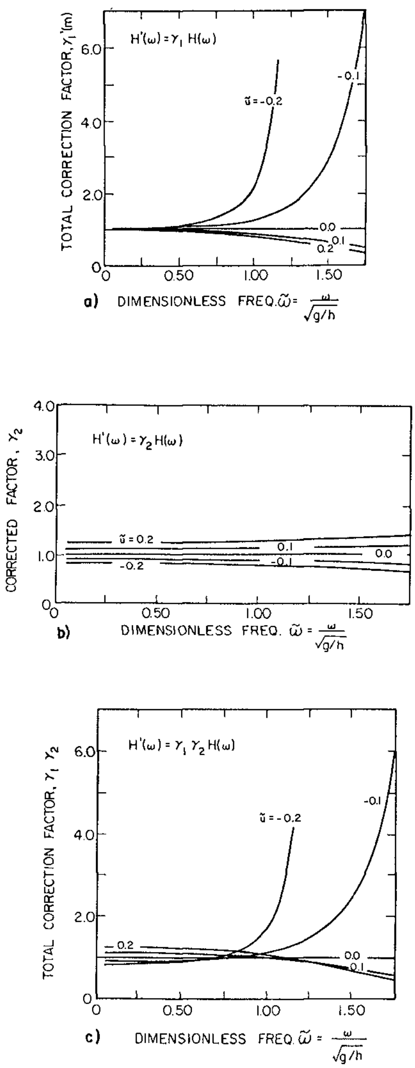


Figure 4. Variation of the Correction Factor to the Transfer Function $H(\omega)$ due to the change of wave number (4-a) and due to the Dynamic Pressure (4-b) and the Total Effect (4-c).

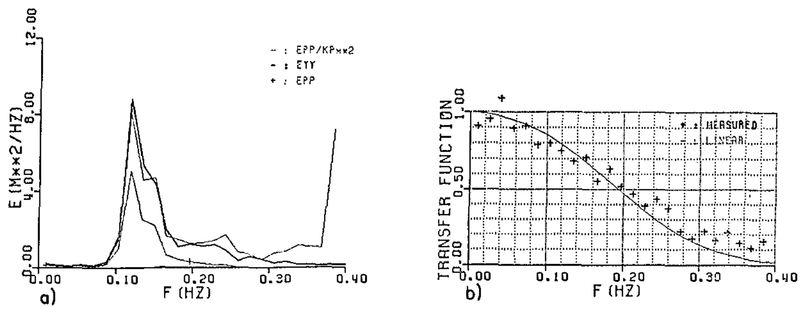

Figure 5. Example of the Comparison of Wave Energy Obtained from Surface Gage and that from Subsurface Pressure Gage (5-a) and Comparison of Linear Pressure Transfer Function with the Measured One (5-b).

frequency summation components (high frequency) as shown in Figures 2 and 3. However, the nonlinearity effect cannot fully account for the differences revealed by the data. Another possible contribution to this discrepancy may be due to the effect of current as shown in Figure 4. For the storm waves generated by the local wind force, the wave propagation is considered to be approximately in the same direction with the wind drift surface current. In this case the resultant effect of current on the transfer function overestimates energy in comparison to the linear transfer function in the higher frequency range, while it underestimates energy in the lower frequency range, which is consistant with the measures data.

4.2 Surface Wave Recovery from the Simultaneous Subsurface Pressure and Current Measurement

When the nonlinearity and/or the current effects becomes significant, adequate surface wave recovery requires the information of current as well as wave direction for each frequency component. In this case, both pressure and horizontal current vector should be measured by using p-u-v gage or other means. The procedures of correctly recovering the surface waves information are outlined here.
1). obtaine directonal wave spectrum using p-u-v data and linear pressure and current transfer functions.
2). decompose spectral components of pressure and velocity components into linear and second order components by means of Eqs. 13 - 24 for p and similar equations for u and v using iteration method.
3). recompute wave directions using linear components, i.e., $p_l$, $u_l$ and $v_l$ only using linear transfer functions.

4). recompute wave number and thus transfer function including the effect of current using the mean current data.
5). recompute the wave energy spectrum with the inclusion of the second order correction and current interaction term.

This method has been implemented for the Coastal Data Network System at the University of Florida. The general experience is that the effect of nonlinearity and current are small in intermediate water depth such as the case of the Data Network. The details will be reported sparately in the future.

Since the directional spectrum is expressed by only five Fourier coefficients, it is not possible to separate wave direction for two or more trains. One of the interesting case is where wind driven sea and swell are present at the site. The proper estimation of the swell component from the measurement is practically important. The signal in the low frequency component is contaminated by the nonlinear components of local wind waters. The wave energy of the free waves of the local wind waves may not be significant in high frequency. But in case that the second order nonlinear component is substantial, it is difficult to subtract the swell components from the measured data. By mean of the above mentioned detailed analysis, the swell components may be more reliably obtained.

## 5. A SIMPLE FILTER TO RECOVER THE SURFACE WAVES FROM SUBSURFACE PRESSURE MEASUREMENT

The second topic of this paper is the introduction of a simple filter for the recovery of surface wave information from subsurface pressure measurement. The spectral analysis method used to compensate the depth attenuation to recover the surface elevation from subsurface pressure record requires a fast computing machine to handle FFT algorithm, which makes the pressure gage inconvenient and sometimes impractical if real-time wave information is needed.

As discussed earlier, the time series of surface elevation, $\eta(n\Delta t)$, can be obtained by means of inverse FFT or convolution integration. In the convolution integral method, N discrete points of pressure data sampled at $\Delta t$, are used to recover the surface wave time series through the following equation:

$$\eta(n\ \Delta t) = C_o\ p(n\ \Delta t) + (1/2) \sum_{m}^{N/2} C_m [p((n+m)\ \Delta t)+p((n-m)\Delta t)] \tag{37}$$

where $C_m$ is defined as

$$H(k\ \pi/N) = C_o + \sum_{m=1}^{N/2} C_m \operatorname{Cos}\ (\ mk\pi/N\ ) \tag{38}$$

Thus, the surface elevation $\eta(n\ \Delta t)$ is recovered from the N points of pressure record. A certain window function is to be applied to the transfer function to avoid problems of noise in the high frequency. Usually a simple window to cutoff the high frequency above a certain value as in Eq. 16. In general the computation is cumbersome and takes longer than FFT method.

A very convenient windowed transfer function is proposed here which drastically reduces the computation, thus, renders the convolution integral method more effective. The proposed windowed transfer function takes a simple form:

$$H'(\omega) = A + B \operatorname{Cos}(\omega) \tag{39}$$

here A and B are constant to fit the original transfer function, $H(\omega)$, for the desired frequency range for a specific water depth. Since $H(\omega)$ is function of water depth (h) and gage-bottom distance (d), the constant A and B are also functions of h, d. Figure 6 compares the simple windowed transfer function in Eq. 39 and original transfer function for water depth of 6.0 meter where d=0.5 meter. $H'(\omega)$ fits the original transfer function for the low frequency region and smoothly reduces the value at high frequency. The simplified transfer function fit the original one well for the energy containing range and the blowing in the high frequency is reduced to avoid the serious problems of the errors in high frequency range. The transfer function is simple and defined by just two constants A and B for a given water depth.

Using the windowed transfer function, $H'(\omega)$, the recovery of the surface elevation can be done by means of simple three point convolution.

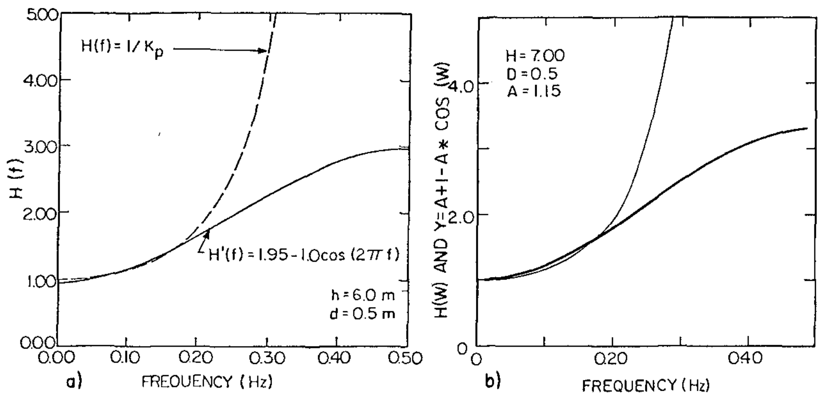


Figure 6. Simple Windowed Transfer Function Compared Original Linear Transfer Function. Two Parameter Filter (6-a) and One Parameter Filter (6-b).

$$\eta(n\ \Delta t) = A\ p(n\ \Delta t) + 1/2\ B[P(n+1)\Delta t) + P(n-1)\Delta t)] \qquad (40)$$

Three point convolution recovery is equivalent to that of surface waves from pressure and its local curvature. The filter is so simple that a small micro processor attached to the underwater package can easily handle the computation.

An even simpler one parameter filter of the following form also performs well:

$$H'(\omega) = (1 + A') - A' \operatorname{Cos}(\omega) \qquad (41)$$

where $A'$ is a parameter depend on water depth (for fixed gage) obtained by curve fitting to the orginal $H(\omega)$. As shown in Figure 6, this filter has a slightly larger value than $H(\omega)$ in the low frequency but is smaller in the high frequency range, which has the same trend as the nonlinear transfer function or measured transfer function discussed above. Therefore, it can be considered as an empirical fitting to a nonlinear transfer function.

When more accurate recovery is desired, we may increase number of convolution with more coefficients. The improvement will be largely in the high frequency range.

One of the application of the above simple filter is the real-time detection of the sea condition without using fast computing machine. A simple but reliable way of detection of sea state can be obtained by use of the significant wave height is estimated as

$$H_s = 4\ H_{rms} \qquad (42)$$

where $H_{rms}$ is the root mean square height calculated from a record of recovered time series of surface elevation.

Since the values of A and B depend on water depth, for fixed gage height, the functional dependency of A and B on h can be precalculated by means of computer and stored in the microprocessor.

## 6. CONCLUSIONS

In spite of its many advantages, there is still hesitation by many to use subsurface pressure gage as a means to recover the surface wave information owing to the problems associated with signal recovery technique. The center of the problem is the dispute on the appropriateness of the linear transfer function and its limitation. A rather detailed analysis was performed to examine various sources of error involved in the conventional recovery technique.

In terms of wave energy spectrum, the linear transfer function is found to be good for intermediate-water-depth application. The bulk of the spectral components can be faithfully recovered except in the high frequency range. As water becomes shallower, nonlinearity effect and current influence may also become more prominant. In this case, the linear transfer function should be modified to account for these effects. Methods of modification are proposed. When water becomes real shallow, the wave spectral approach may eventually become unsuitable. A transfer function should be developed to facilitate wave-by-wave recovery.

For more complete recovery of surface information, p-u-v gage should be used in shallow water. It not only provides directional information but also gives more correct estimation of wave energy.

The simple filter method proposed here has the potential of providing real-time wave information by using micro-electronic component instead high-speed computer. It will be a major asset from the operational point of view.

The subsurface pressure instrument is definitely a viable solution for surface wave measurement. The operational convenience reliability and cost of maintenance make it an attractive choice.

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