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Review of Developments in Estimation of Wave Reflection from Coastal Structures

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Abstract: *Reflection of water waves is one of the major causes of poor performance of many minor ports especially during the rough weather season. Wave reflection increases the chances of bottom scour in front of the structures such as sea walls and quays. The waves enter the basin through the open navigational channel due to refraction and reflection from the protecting structures such as breakwaters, seawalls etc. Researches are being carried out to find methods to reduce wave reflection so that the harbour can be used more efficiently. This paper examines the contributions of various researchers in predicting as well as reducing the wave reflection using innovative methods. It is found that thorough mathematical as well as experimental study is to be conducted whenever we propose new type of coastal protection structures. Issacsons method of three static probes suits for monochromatic two dimensional wave studies.*
Keywords- *coastal structures, probes, wave gages, wave reflection, breakwaters.*

I. Introduction

Wave reflection is a less investigated phenomenon when compared to the efforts made on the analysis of wave transmission. It is therefore remaining as a under researched topic with a vast scope for further research. The wave reflection from man-made structures is one of the causes of poor performance of many minor harbours and marinas. The reflected wave interacts with the incoming wave train and increases wave activity in the basin. In the case of experimental study also, the problem of interaction of the two wave trains cause a real concern. Methods have been evolved to separate the reflected wave parameters from the incoming wave parameters. This paper examines the literature available in the area of wave reflection from seawalls quays and breakwaters with an intention to estimate the scope for further research in the field.

II. Review Of Recent Studies

Separating the incident and reflected components in a partially reflecting wave formation was one of the major difficulties in estimating the performance of many coastal structures. Method of moving probe and enveloping parabola was used in many cases which is quite cumbersome, time consuming and subjected to human errors. The problem was very much simplified with the method of two fixed probes proposed by Goda and Suzuki [1]. They applied Fourier analysis to find the constants in the equation and the amplitudes of the incident and reflected waves are then calculated. In the case of irregular waves the energy of the wave trains were calculated, and used for estimation of the coefficient of reflection. The incident wave spectrum was first obtained from the measurement of progressive waves without the reflective structure. They have listed the possible source of inaccuracy as nonlinearity of the incident waves, generation of nonlinear terms in the standing wave, transverse waves and disturbance in the flume and signal noises.

The estimation of wave reflection based on a least-squares technique applied to measurements from three probes has been described by Mansard and Funke [2]. This has wider frequency range, reduced sensitivity to noise and nonlinearity and lesser sensitivity to critical probe spacing.

Suh et al. [3] opined that the method of Goda and Suzuki [1], which uses two wave gauges, does not give a solution when distance between the probes are in multiples of half of the wave length. Also, it is sensitive to secondary sloshing waves generated in the flume, nonlinear wave interactions, signal noise, measurement error, and so on. On the other hand, the method of Gaillard et al. [4], Mansard and Funke [2] or Park et al., (as cited by Suh et al. [3]), which uses three wave gauges, is less sensitive to these phenomena and essentially, there is no limitation in its application range of frequency or wavelength.

A time domain method for separating incident and reflected components was introduced by Frigaard and Brorsen [5] which is modified later by Baldock and Simmonds [6] to account for normally incident linear waves propagating over a bed with arbitrary 2D bathymetry. They used linear shoaling to determine the amplitude and phase change between two measurement positions. Comparisons between the existing and modified methods and the errors in the reflection coefficient are found to be small for large reflection coefficients, but it may become large if reflection is low. They prescribed the use of true bathymetry for accurate estimation of wave amplitudes because when the probes were set on a sloping bed for measurement, the wave properties such as the phase velocity, wave profile and wave number are varied with water depth and having shoaling and refraction effects rather than waves propagate with a constant speed in the horizontal bed.

Isaacson [7] developed a method to differentiate the reflected waves from the incident waves by using three stationary probes. This method gives accurate results when the probe spacing is selected such that it is not close to the multiples of quarter wave length.

Wu [8] commenting on Isaacson's method of reflection measurement, claimed that a single probe measurement can be enough to separate the incident and reflected waves for a purely sinusoidal incident wave train. He also pointed out that a flap type wave maker usually produced some nonlinearity. A typical wave record of a flap type monochromatic wave maker usually contains waves with frequencies of 0.05Hz below and above the mean frequency. However, proper placement of probes can ensure results with fairly good accuracy.

Most coastal and ocean engineering laboratories employ techniques that use two or three spatially separated wave gages to estimate reflection of irregular waves in two-dimensional wave flumes. Hughes [9] presented a frequency domain method for separating incident and reflected wave spectra from co-located gages (gages located on the same vertical line). The technique is based on linear wave theory, and it can be applied to time series of sea surface elevation and horizontal water velocity collected in a vertical array, or it can be used with horizontal and vertical water velocity time series collected at the same point in the water column. A major disadvantage of the co-located gage technique is the cost of reliable laboratory instrumentation for measuring fluid velocities. The author acknowledges that reliable estimates of reflected energy spectra can be obtained only for frequencies exhibiting high coherency. At frequencies where coherency drops and spectral energy decreases to low levels, both the spatially separated gauge method and the co-located gauge method produce improbable results. He warns that automated calculation of wave reflection may result in incorrect reflection coefficient as they tend to overlook this problem.

Zhu [10] developed a technique to separate incident and reflected regular waves by using transfer functions and states that this is sufficient for coastal engineering applications as it has error < 3%.

Davidson et al. [11] presented a numerical method of analysis of directional waves in reflective wave field.

Brossard et al. [12] developed methods for analysing the reflection by using one or two moving probes and employing the Doppler Effect, which can separate the fundamental and higher harmonics.

Analysis of coastal engineering problems often encounters the study of waves of locations where long shore and rip currents are present. Physical modelling of such situations sometimes faces the challenge of measuring accurately the waves in the complex domain. Suh et al. [3] theoretically developed a method based on the least square technique to separate incident and reflected waves in presence of currents.

Experimenting with the horizontal plate to find the influence of current in wave reflection, Rey et al. [13] used three probes with a spacing of 1.25m between the first and second and 2.5m between the second and third probes. He used Isaacson's method to separate the reflected waves from incident waves as this method is more accurate than the rest.

Sunder and Rao [14] used three probes with spacing varied with the wave period and separated the components by using the method suggested by Mansard and Funke [2], while conducting experimental study on pile supported quadrant faced breakwater.

Chang and Hsu [15] presented a frequency-domain method to estimate incident and reflected waves for normally incident waves propagating over a sloping beach. The wave reflection coefficient was estimated using wave heights observed at two fixed wave gauges with a distance. Chang [16] proposed a three point method to compute the incident and reflected waves for waves propagating over a sloping bed with normal incidence. The main difference between these two methods lies in the point that the former needs to know the incident wave amplitude in prior but the latter doesn't. Both methods are applicable to laboratory and field conditions in the frequency domain.

Reflection from detached breakwater was studied, considering the directional wave spectra by Huang et al. [17] using Expanded Maximum Entropy Principle Method (EMEP) and Maximum Likelihood Method (MLM) which gave improved results over the methods by Goda and Suzuki [1]. They concluded that the EMEP is better than MLM for region within four wavelengths from the breakwater. For locations farther than four wavelengths, the influence of wave direction vanished and reflection attained a constant value.

Lin and Huang [18] improved the method of Mansard and Funke [2] to separate the incident and reflected higher harmonic waves by using four probes. The new method is fairly accurate provided that the noise reduction is done by averaging methods to smoothen the input data.

Gunaydin and Kabdasli [19] says that a standing wave occurs at a distance greater than L/2 from the vertical face of the structure while the amplitude of the superimposed waves at a shorter distance will be smaller than that of the incident wave.

Despite the advantages of all methods described above, theories are not available for the estimation of wave reflection coefficient induced by obliquely incident waves. The existing theories are based on two-dimensional wave shoaling across the sloping beach with normal incidence. On natural beaches, however, waves are often oblique incidence at deep water and produce three-dimensional wave deformations such as shoaling, refraction, diffraction and reflection. Wang et al., [20] investigated this aspect and developed a method using three wave probes to estimate the effect of oblique incidence monochromatic waves on wave reflection over a sloping bed.

Dickson et al. [21] presented a method of estimating the wave reflection of a random multi directional wave from a breakwater which could use an array of arbitrarily deployed wave gauges. It is found to give accurate results for incident wave angle less than 30°

III. Conclusion

Various researches have suggested methods for measurement of water wave reflection in the case of field and laboratory studies. Method suitable for any investigation can be selected depending on the resources available and other parameters such as the presence of current, bathymetry etc. Out of the available methods, Issacsons method of using three static waves gauges present accurate results with maximum convenience in the case of laboratory study of monochromatic two dimensional waves.

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