A short overview of reflection formulations and suggestions for implementation in SWAN

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1 Introduction

The reflection implemented in SWAN version 40.11 is just specular reflection. It gives the mirror image of the action density spectrum, cutting it off for all directions that are not directed towards the obstacle and multiplying it by the reflection factor ${C_r}^2$ (square because the reflection factor is w.r.t. wave height). To improve the performance of the reflection in SWAN, a small study was made on what is known from literature. Further, some analogy is made with the field of optics, concerning diffuse reflection and scattered reflection effects. To avoid confusion: only reflection at obstacles is considered here. The scattered reflection or scattering that is discussed here is NOT what civil engineers may call Bragg scattering. Several articles on bulk reflection coefficients and frequency dependent coefficients were found, and will be discussed in section 2 and 3, respectively. In section 4 other quantities of interest are discussed. Finally, in section 5 the analogy for scattered reflection with optics is presented.

2 Common practice in reflection formulations

In engineering it is common to use the mean (bulk) reflection coefficient to characterize the reflected wave field in magnitude [4, pp.303]. This may, however, result in a loss of potentially important information. Given an incident sea state one can fit measured bulk reflection coefficients to various (non-dimensional) parameters like the Miche number and the Iribarren number.

2.1 Monochromatic reflection formulation

Miche empirically determined (1951) that the reflection coefficient for monochromatic (breaking) waves will be proportional to the ratio of the critical wave steepness to the incident wave steepness, which indicates proportionality between the Miche number M, and reflection coefficient C_r [9]:

$$C_r \begin{cases} \propto M = \frac{4g}{(2\pi)^{5/2}} \frac{\tan^{5/2}\alpha}{H_s f^2} & M < 1 \\ = 1 & M \geq 1 \end{cases} . \tag{1}$$

Here g the gravitational acceleration, α is the wall slope, H_s the incident significant wave height, and f is the frequency. Ursell *et al.* [15] and Seelig and Ahrens showed that this number overestimates reflection for smooth slopes [8].

According to Battjes [1, p.23], Miche himself already suggested to multiply his original formulation, (reflection coefficient equals the ratio of the critical wave steepness and incident wave steepness) with 0.8 for smooth slopes. Battjes redefined Miche formulation as follows [1, p.24]:

$$C_r = \begin{cases} 0.1\xi^2 & \text{if this is less than 1} \\ 1 & \text{otherwise} \end{cases} , \tag{2}$$

where the Iribarren number ξ is defined as:

$$\xi = \frac{\tan\alpha}{\sqrt{\frac{H_s}{L_0}}} = \frac{\tan\alpha}{f}\sqrt{\frac{g}{2\pi H_s}}. \tag{3}$$

Here α is the wall slope, H_s the incident significant wave height, $L_0(= g/(2\pi f^2)$ is the linear theory deep water wavelength, g is the gravitational acceleration and f is the frequency of the spectrum. This formulation seems to perform well for $\xi \leq 2.5$. For $\xi \geq 2.5$ measurements (Moraes [10]) and theory start to diverge, where gentler slopes give less reflection than steeper slopes, at the same value of ξ.

2.2 Random reflection formulation

In case of random waves the Iribarren number ξ can be redefined as:

$$\xi = \frac{\tan\alpha}{\sqrt{\frac{H_s}{L_0}}} = \frac{\tan\alpha}{f_p}\sqrt{\frac{g}{2\pi H_s}}, \tag{4}$$

where f_p is the peak frequency.

Seelig and Ahrens also found that with formulation 2 the reflection coefficient is still overestimated for $\xi \geq 3$ [8]. They suggested a bulk reflection coefficient which is defined as:

$$C_{rb} = \frac{a\xi^p}{b + \xi^p}, \tag{5}$$

where a, b and p are structure dependent coefficients. Suggested is $p = 2$, $a = 1.0$ and $b = 5.5$ [4, pp.306-307], or $p = 2$, $a = 1.0$ and $b = 6.2$ [2, pp. 96] for smooth impermeable structures. For rubble mound breakwaters $a = 0.6$ and $b = 6.6$ according to Seelig and Ahrens [4, pp.303], [2, pp. 96]. Sutherland shows that spectra with different peak frequencies, but the same wave height, give similar reflection coefficients (at frequencies where the spectra overlap), and that the reflection coefficients decrease with a decreasing wall slope [4, pp.306-307]. Neither the influence of the shape off the spectrum was taken into account (all were chosen to be the same here), nor the toe depth.

Giménez-Curto [11] suggested

$$C_r = a_2[1 - \exp(b_2\xi_{rms})], \tag{6}$$

where ξ_{rms} is defined as in equation 4, except that the significant wave height, H_s, is replaced by the root mean square wave height H_{rms}. The best fit with measurements of Sollitt and Cross for as rubble mound breakwater is obtain with $a = 0.503$ and $b = -0.125$ [2, pp.96].

Numata found the reflection coefficient [13]:

$$C_r = a_3\left(\frac{\text{BreakwaterWidth}}{\text{ArmorDiameter}}\right)^{b_3}, \tag{7}$$

where a_3 and b_3 are functions of the relative depth at the toe (d_t/L_0, where d_t is the toe depth). Davidson [2, pp. 97] criticizes this approach, because although the formula may agree with the measurements, also the transmission is increasing with roughness of the structure.

Postma [14] concluded after 300 random waves flume tests on rocky slopes, that the reflection coefficient is strongly dependent on frequency, structure slope and permeability, weakly dependent on the wave height, and almost independent on the spectral form and toe depth [2, pp. 97]. He suggested an empirical equation of the form:

$$C_r = 0.125\xi^{0.73}. \tag{8}$$

Van der Meer [12] stated that the Iribarren number does not correctly describe the combined effect of the slope and wave steepness. With a multiple regression analysis he derived for Postma's measurements:

$$C_r = 0.071P^{-0.082}\tan^{0.62}\alpha\left(\frac{H_i}{L_0}\right)^{-0.46}, \tag{9}$$

where P is the notional permeability, and H_i is the incident wave height.

Davidson performed full scale measurements off a rubble mound breakwater, in Elmer (UK). He found a systematic increase in reflectivity of the structure with depth, as well as a strong dependence of the local wavelength at the toe. Parameterisation of the reflection coefficient with the Miche number or the Iribarren number (or $\varepsilon = \sqrt{(\pi/\xi)}$ as used by Wright and Short [16]) failed to describe the measurements uniquely [2, pp. 106-109]. Therefore he used multi regression analysis to define a new surf similarity parameter, R:

$$R = \frac{d_t {L_0}^2 \tan\alpha}{H_i D^2} = \xi\left(\frac{{L_0}^{1.5} d_t}{D^2\sqrt{H_i}}\right), \tag{10}$$

where D is the armor diameter, and d_t the toe depth. With this new similarity parameter, he gave two possible expressions for the reflection coefficient:

$$C_r = 0.151R^{0.111}, \tag{11}$$

and

$$C_r = \frac{aR^{0.5}}{b + R^{0.5}}. \tag{12}$$

Here $a = 0.635$ and $b = 41.2$ give the best fit for the performed measurements. The reflection coefficient is systematically increasing with R, as well as with the Iribarren number, until a certain saturation level is reached. For the performed measurements, this level is the same for the two different depths if R is used, but is depth dependent in case the Iribarren number is used.

3 Frequency dependent reflection

Generally reflection coefficients decrease with increasing frequency [6] or with decreasing wall slope [4, pp.303]. Seelig and Ahrens 1981 among others (according to Sutherland) found a reflection coefficient spectrum with less reflection for higher frequencies. Random sea state measurements suggested something similar. Elgar *et al.* found something similar for reflection at sloping beaches [7]. Dickson states that estimated reflection coefficients decrease approximately linearly with increasing frequencies: the reflection coefficient is approximately linearly decreasing from 0.7 to 0.8 at $f = 0.05$ Hz, to 0.2 to 0.3 at $f = 0.12$ Hz, respectively. Wave-incidence angles of at most ± 30 degrees were tested. The incident wave height is of less importance [3].

If the Iribarren number is larger than 10, the observed bulk reflection coefficient is diverting from the theoretical bulk value (equation 5). For high Iribarren number it is likely that the bulk coefficient is underestimated with linear reflection analysis used for nonlinear waves [4, pp.306] .

Sutherland and O'Donoghue in [4] looked at experimental results of irregular wave reflection from impermeable walls and rubble mound breakwaters. They defined reflection coefficients C_{rn} as

$$C_{rn} = \sqrt{\frac{S_{rr}(f_n)}{S_{ii}(f_n)}}. \tag{13}$$

Here n refers to the n^{th} frequency component of the spectrum, S_{rr} is energy density spectrum of the reflected waves, S_{ii} is energy density spectrum of the incident waves, f_n is the n^{th} frequency component. The reflection coefficients are shown to be decreasing with increasing frequency, except when there is no real breaking (slope 1:1). Then the coefficient remains high, i.e. is almost constant with the frequency. Two different sea states with different peak frequency, but the same wave height give similar reflection coefficients where the spectra overlap [4, pp.307]. They suggest the use of a frequency-dependent Iribarren number ξ_f, which is defined per frequency component as:

$$\xi_f = \frac{\tan\alpha}{f_n}\sqrt{\frac{g}{2\pi H_s}}. \tag{14}$$

Here H_s is the incident wave height (for the whole spectrum), which is the same for all frequencies. The measurements for the reflection coefficient were plotted against the frequency dependent Iribarren number. The results of several sets of tests, which were identified by the incident wave height and the toe depth, show the same trend for several different wall slopes and peak frequencies. With some curve fitting they found for impermeable wall:

$$C_{rn} = \frac{{\xi_f}^{2.58}}{7.64 + {\xi_f}^{2.58}}. \tag{15}$$

For a rubble mound breakwater general trends are the same. Then the best fit becomes:

$$C_{rn} = \frac{0.82{\xi_f}^2}{22.85 + {\xi_f}^2}. \tag{16}$$

Sutherland shows that if the bulk reflection coefficient definition is used, reflection coefficients of frequencies below the peak frequency will be underestimated [4, pp.310]. Likewise, frequencies above the peak frequency will be overestimated. For narrow incident wave spectra, little difference will be found between the bulk coefficient and the frequency dependent coefficient. As the width increases, the differences between the two approaches increase. Furthermore, specification of the reflection coefficient spectrum becomes more critical as the frequency dependent Iribarren number decreases. This is especially the case for the lower frequencies. This is due to the fact that lower Iribarren numbers predict lower bulk reflection coefficients (see equation 5), while for these lower frequencies the reflection coefficients are at the highest.

It is shown by Sutherland that the parameter suggested by Hughes and Fowler [17] which they used to determine the phase shift, is not suitable for characterizing the reflection spectrum [4, pp.303,304,307]. This parameter is defined as:

$$\chi = \frac{f_n}{\tan\alpha}\sqrt{\frac{d_t}{g}} = \frac{x_m}{L_s}, \tag{17}$$

where f_n is the frequency of the n-th component, x_m the cross-shore length of the structure from toe to still water level, $L_s = \sqrt{\frac{gd_t}{f_n}}$ the linear theory deep water wavelength. It does not adequately account for the effects of toe depth and significant wave height.

4 Other quantities of importance

As discussed in the previous section Sutherland found that the reflection coefficient at a certain frequency dependent Iribarren number, is independent of the peak frequency of the spectrum [4, pp.307]. The reflection coefficient can be determined from the slope, the frequency and the incident wave height, and two structure dependent coefficients. Sutherland and several others noted that the reflection coefficient decreases as the wall slope decreases.[4, pp.307]. Higher incident wave heights result in lower reflection coefficients for the same slope and toe depth [4, pp.306-307]. Here Sutherland suggests that there is a general reflection coefficient spectrum for waves of a given significant wave height, given the toe depth and wall slope.

Still according to Dickson the incident wave height is of less importance [3] for reflections. For small amplitude swell and wave-incidence angles of at most ±30 degrees were tested. The fluxes of the incident, reflected, and transmitted energy are:

$$F_i(f) = E(f)C_{g1}(f), \tag{18}$$

$$F_r(f) = R^2(f)E(f)C_{g1}(f), \tag{19}$$

$$F_t(f) = E_{bb}(f)C_{g2}(f), \tag{20}$$

respectively, where E is the incident wave energy (in front of the breakwater), E_{bb} is the transmitted energy spectrum at a certain fixed point behind the breakwater, C_{g1} and C_{g2} are the associated group velocities. The reflection coefficient $R(f)$ is defined with respect to the wave height. Now the residual energy flux, the dissipated energy flux, is

$$F_d(f) = F_i(f) - F_r(f) - F_t(f). \tag{21}$$

It is shown that F_d/F_i generally increases with increasing frequency [3, pp.267]. Reflections are only weakly dependent on the incident wave height, but transmission seems to be decreasing significantly with increasing incident wave energy. On days with low energy swell, 40 to 60% of the incident energy flux is transmitted. At the same time the dissipation flux is weak: 0 to 40%. On moderately energetic swell days, 20 to 30% of the incident energy flux is transmitted, and 40 to 60% is dissipated. This suggests that dissipation is enhanced with large amplitudes. But some remarks need to be made here: partial reflection on the land or lee side of the breakwater may contribute to errors. Further, no storm conditions were present during the measurements, and only almost oblique incident wave angles are considered.

As discussed in section 2, Postma found that on rocky slopes the reflection coefficient is strongly dependent on frequency, structure slope and permeability, just weakly dependent on the wave height, and almost none dependent on the spectral form and on the toe depth [2, pp. 97]. At high tide the transmitted/dissipated energy fluxes are slightly larger/smaller than at low tide. Still, the observations presented by Dickson do not suggest a strong dependence of the reflection coefficient on tidal sea-level variations [3, pp.266]. Also according to Sutherland the bulk reflection coefficient does show some sensitivity to depth: shallow water gives a somewhat little less high coefficient for higher Iribarren numbers (≥ 5) [4, pp.306]. On the other hand Seelig and Ahrens postulated that wave reflection for porous structures is also a function of the depth at the toe of the structure, the slope of the seabed offshore, the characteristic diameter of the armor, affecting the surface roughness, and the number of layers of armor [2, pp. 96]. Allsop suggested coefficients of $p = 2.0$, $a = 0.64$ and $b = 7.22$ for one armor layer, and $p = 2.0$, $a = 0.64$ and $b = 8.85$ for two armor layers, in equation 5. Davidson found similar results for which he defined the new similarity parameter R as discussed in section 2.

5 Diffusive and scattered reflection

As mentioned in the introduction, at this moment there is no scattered reflected in SWAN (Version 40.11): the distribution of ${C_r}^2$ over the directions is uniform. The main idea for improvement of the reflection concerning scattering, is to smear out the reflection over the directions. This can be done by multiplying the reflection coefficient matrix by a redistribution function which may be frequency dependent. In this section we use expressions which are based on the laws for scattering or diffuse reflection from optics. In optics it is assumed that the wavelength is much larger (O(1000)) than the order of magnitude of the surface roughness of the obstacle. Mainly this also will be the case in the field of hydrodynamics.

5.1 Diffuse reflection

A perfect diffuse surface scatters energy equally in all directions, independent of the incoming direction. This is not very realistic for real materials. For rough surfaces, Lambert's reflection law -also known as the Lambert's cosine law or diffuse reflection law- is used. It states that if the incoming wave has an intensity of I_i, the intensity of the diffusively reflected wave is dependent of the angle Θ between the surface normal and the, what in optics is called 'view direction', i.e. the direction where the wave is going to after the reflection at the surface:

$$I_d = I_i K_d \cos\Theta, \tag{22}$$

or in generalized form:

$$I_d = I_i K_d \cos^q\Theta. \tag{23}$$

The letter d stands for diffusive. Power q should be a positive number. The angle Θ varies between 0 and 90 degrees. K_d is a constant within the range of 0 to 1. It is a measure for the diffuse reflectivity of the surface. This diffuse reflectivity depends on the nature of the material and the wavelength of the incident wave. Note that there is no dependency of the incoming wave direction. The direction of the maximum intensity of the reflected wave is always perpendicular to the surface.

5.2 Scattered reflection

Bui-Thong Phong's reflectance model is usually mentioned in combination with specular reflection. It concerns waves scattered by 'mirror-like', smooth (though not necessarily perfectly smooth) surfaces:

$$I_s = I_i K_s \cos^m\phi. \tag{24}$$

Here ϕ is the angle between the 'viewing vector' and the reflection vector. K_s is the specular reflection coefficient, usually taken to be a material-dependent constant. Power m should be a positive number. For a perfect reflector m is infinite, and the the reflection is purely specular. In a discrete numerical model like SWAN this would be the case if the width of $\cos^m\phi$ is smaller than or equal to the step in directional space. If $m = 0$ the surface is a completely diffuse reflector. For actual materials m is in the range of 1 to several hundreds [5, p. 533], at least when it concerns light waves.

In optics, the linear combination of the above components, diffuse and scattered specular reflection, is used:

$$I = I_i[K_d \cos\Theta + K_s \cos^m\phi]. \tag{25}$$

It depends on the surface how much energy is reflected in a diffuse way and how much specularly. This means for the intensity that the energy reflected from a certain surface may have a direction that tends a little bit more to the normal direction than can be expected from the law of reflection.

It remains to be seen how far the analogy goes, between light waves and water waves. The surface characteristics of the coastline or breakwater under consideration should be determined, in the sense that it should be known how diffuse it is in the Lambertian (diffusive) and in the Phongian (specularly scattered) sense.

6 Proposal for SWAN

In this section we will shortly discuss the proposals for improvement of the reflection formulation in SWAN, based on the overview given above. First we will discuss the frequency dependency, and second we will discuss scattering and diffuse effects for SWAN.

6.1 Proposal for frequency dependent wave reflection

Even though the ideas on how important certain quantities are, differ from one author to the other, it seems that the actual results all point in the same direction. The frequency, or deep water wave length, seems to be the most important, followed by the slope of the structure, the toe depth, and further the incoming wave height and the armor diameter. Sutherland described the reflection coefficient as a function of the Iribarren number, where Davidson used a new parameter, R (see equation 10), which performed better for his full scale measurements. Davidson however did not look at frequency dependent reflection coefficients. For SWAN the proposal for rubble mound breakwaters, is to use the best of both worlds, so to use a combination of Davidson's formulations (equations 10, and 11 or 12), and the frequency dependent formulation like in Sutherland's frequency dependent Iribarren number (equation 14). This results in:

$$R(f) = \frac{g^2 d_t \tan\alpha}{4\pi^2 f^4 H_i D^2}, \tag{26}$$

$$C_r(f) = 0.151[R(f)]^{0.111}. \tag{27}$$

and

$$C_r(f) = \frac{0.635 R(f)^{0.5}}{41.2 + R(f)^{0.5}}. \tag{28}$$

Ofcourse the validity of these formulations needs to be verified with measurements.

For impermeable walls a similar formulation can be used, but then with different, at this moment, unknown coefficients. Because of this, the formulation of equation 15 can be used.

6.2 Proposal for scattering and diffuse wave reflection

In general the angle of the incoming wind wave seems to play an important role in the reflection of the wave energy, while diffusive effects are hard to recognize. Therefore, for starters we will use Phong only, because we expect this to be more significant effect in hydrodynamics than Lambert. To be able to do this, we will reformulate the theory as discussed in section 5.

In SWAN a (discrete) action density spectrum is used to represent waves. This means that there is not just one but several directions to deal with. Further, the energy that is reflected, should not exceed the energy of the incident wave field. This implies that we should use a normalized Phong formulation, for every directional component of the incoming action density spectrum. The coefficient K_s is corresponding to the normal use reflection coefficient with respect to energy. If we use $K_s = 1$, and m is variable, the normalisation factor is easily calculated with Mathematica [5]:

$$Norm = \frac{1}{\int_{-\pi/2}^{\pi/2}(\cos\phi)^m d\phi} = \sqrt{\pi}\frac{\Gamma(\frac{1+m}{2})}{\Gamma(1+\frac{m}{2})}. \tag{29}$$

We multiply every component of the original reflected action density spectrum by the new distribution:

$$P(\phi_i) = \begin{cases} \frac{1}{Norm}(\cos\phi)^m & -\pi/2 \leq \phi \leq \pi/2 \\ 0 & \text{elsewhere} \end{cases}. \tag{30}$$

To get the new value for the reflected action density, $A_{red.}$, for directional component ϕ, we integrate over the redistributed action densities:

$$A_{red.}(\phi) = K_s \int_{-\pi}^{\pi} A_{original}(\Phi)P(\Phi - \phi)d\Phi. \tag{31}$$

Formulated discretely the above equations become:

$$P(\phi_i) = \begin{cases} \frac{1}{Norm}(\cos\phi_i)^m \Delta\phi & -\pi/2 \leq \phi_i \leq \pi/2 \\ 0 & \text{elsewhere} \end{cases}. \tag{32}$$

Here i is a counter from 1 to $imax$, and $\Delta\phi = \frac{2\pi}{imax}$. To get the new value for the reflected action density, $A_{red.}$, in the i^{th} directional component, ϕ_i, we sum all of these redistributed action densities:

$$A_{red.}(\phi_i) = K_s \sum_{j=1}^{jmax} A_{original}(\phi_j)P(\phi_j - \phi_i). \tag{33}$$

Here j is another counter from 1 to $jmax$.

In the formulation above only the reflected energy is considered. Dissipation as well as source terms are assumed to be already accounted for in the action density, whereas dissipation of the obstacle itself is expressed in the reflection coefficient in case it is smaller than 1. The corresponding formulation with the bulk reflection coefficient is as follows: ${C_r}^2 = (K_s)$, where coefficient K_s is defined with respect to energy or action density. The dissipation by the obstacle itself is accounted for by this (bulk) coefficient. Of course all energy that is transmitted through the obstacle cannot be reflected anymore.

If both Lambert and Phong should be used in the future, the result for Phong should be multiplied by a weighing factor times the bulk reflection coefficient (xC_r) (where x is meant as a measure for the 'Phongity' of the surface), and the outcome with Lambert should be multiplied by the bulk reflection coefficient times one minus this coefficient ($[1 - x]C_r$) . Then these two contributions should be added. In the formulations used here the reflection coefficients $K_s = xC_r$ and $K_d = [1 - x]C_r$ may be frequency dependent, for example in the way discussed in section 3 or section 6.1.

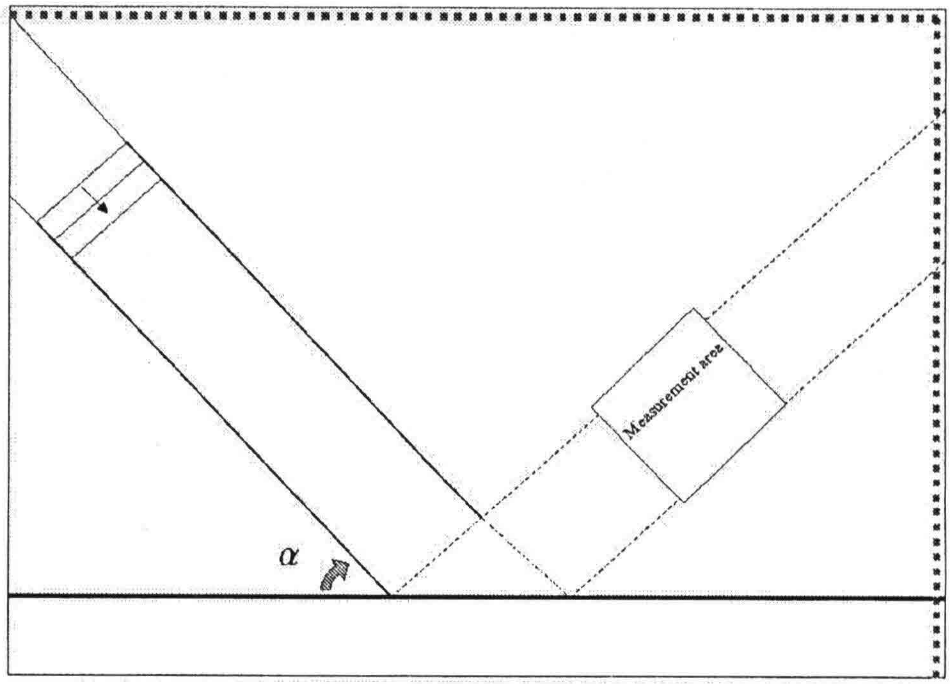

Figure 1: Experimental setup

7 Suggestions for research

Wave conditions have impact on fishing, commercial shipping and recreation. In addition it influences sediment transport. Therefore it is of great importance to know the wave conditions. Near dikes and dams reflected waves can disturb the wave field significantly. To mention some examples, it is known that the Hondsbosche Zeewering, the Afsluitdijk and the dikes around the Noordoostpolder show significant reflecting behaviour. But also different kinds of islands with different kinds of surfaces can influence the wave field significantly, like in the Santa Barbara Channel.

Looking at the literature in the sections 2.1 to 5.2, there are still a lot of questions to answer, like under what circumstances is the frequency of importance, and how significant does it affect the reflection coefficient? When are other quantities like the amount of incident wave energy of importance? What does the incident wave angle do with with reflection coefficient? How far does the analogy with optics go? To bring more clarity, systematic measurements should be done, preferably both in a laboratory on small and full scale. In this section some ideas are posed on what should be done to find the answers we are looking for.

7.1 Experimental setup

Reflection coefficients are dependent of the structure of the reflecting surface, as well as on the incident wave angle. To examine this the relation between, a number of long breakwaters should be constructed with increasing armor diameters (compared to wavelength). Further the influence of different incident wave angles should be examined. Suggested is to use a experimental setup as shown in Figure 1. In this figure a schematic overview (top view) of a rectangular basin is shown. The reflecting object is placed at one side of the basin. Wavea are generated in a semi-closed flume which is placed at an angle α with the reflecting obstacle. This way as less disturbance as possible is generated by the incoming wave and diffraction. Further there is no need to separate the incoming from the reflected waves. That is if the walls of the basin are perfectly absorbing. The bottom should be flat and as smooth as possible.

Measurements are taken in the main area of reflection, i.e. the area at angle $\pi - \alpha$ with a width of approximately the flume width, not to near to the tip of the flume because of diffraction effects. It concerns measurements of directional spectra. The distance to the reflector may also be of importance. So a whole matrix of measurement locations is desired.

The obstacle should at first be impermeable. It can be a fixed solid plate with, per set of runs, different stone sizes fixed to it. Different incident angles can be examined. The slope of the obstacle could also be varied. Later permeability as well as overtopping can be taken into account. In these cases measurements should also be done on the other side of the breakwater.

The importance of the diffraction effect can be measured by placing the flume perpendicular to the reflecting object. Further wave conditions can be varied (wave height, period, length, spectral shape). After this toe depth, water depth, breakwater slope angle, and breakwater height can be varied, separate from one another.

With this setup it is possible to find (among others) the answers to the following questions:

- Is there a wave length-Armour diameter dependency for the reflection coefficient?
- Is there something as a perfect diffuse reflector, or are only scattering effect of importance? - If yes, at what wave length-diameter ratio(s)?
- What is the influence of the wave conditions (wave height, period, length, spectral shape)?

The directional spreading is limited in this setup, because of the use of a flume. If the effect of the spreading is believed to be of importance, a more complex experiment is to be done. Instead of using the flume one should use variable wave generators on the one side (left) of the basin. Further, while performing the measurements, the incoming and outgoing wave should be separated.

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