# SWASH FROM LONG WAVES

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This study describes laboratory and field tests on long waves, resulting from short wave action at a shoreline. The test results cover incident wave heights up to 4.3 m and wave periods up to 11 sec. It was found that the long wave height can be readily related to the breaking height of the incident short waves. Introduction of the wave period into the relationship did not improve the results.

## 1. Introduction

The commonly observed phenomenon of swash (the uprush and downrush of waves on a beach) has been studied by many authors. Swash really consists of two components, a short wave component (related directly to the incoming waves) and a longer period component often referred to as surf beat. The longer component is related to the wave grouping. It arrives at the breaking zone as a long wave that is bound to the wave groups and travels at group velocity. This bound long wave is released from the incident short wave group upon breaking and proceeds up the beach as a free long wave to produce long wave swash when it arrives at the shoreline.

Long waves have been studied extensively (e.g. Guza and Thornton, 1985; Herbers et al., 1995 a and b; Holman, 1981; Holman and Sallenger, 1985; Huntley et al, 1981; Oltman-Shay and Guza, 1987; Raubenheimer and Guza, 1996). The present paper combines field results with laboratory (flume) test data to derive basic relationships for processes of long wave generation by short waves and the generation of swash by these long waves.

The data used in this study are summarised in Table 1

Table 1. Data Used

| Tests | Bed | m | $D_{50}$ (mm) |
|---|---|---|---|
| Queen's Breakwater Tests | Fixed bed, plane slope with breakwater in shallow water | 1:50 | |
| Queen's Shoreline Tests | Fixed bed, plane slope | 1:50 | |
| Boers (1996) | Fixed bed, profile with bar | 1:50 | |
| Supertank (Kriebel, 2003) | Mobile bed | 1:27 | 0.22 |
| Ruessink (1998) | Prototype, measured vertical swash distance | 1:100 | 0.22 |

The above combination of tests constitutes a data set that covers wave heights up to 4.3 m. and wave periods up to 11 sec, as shown in Figure 1

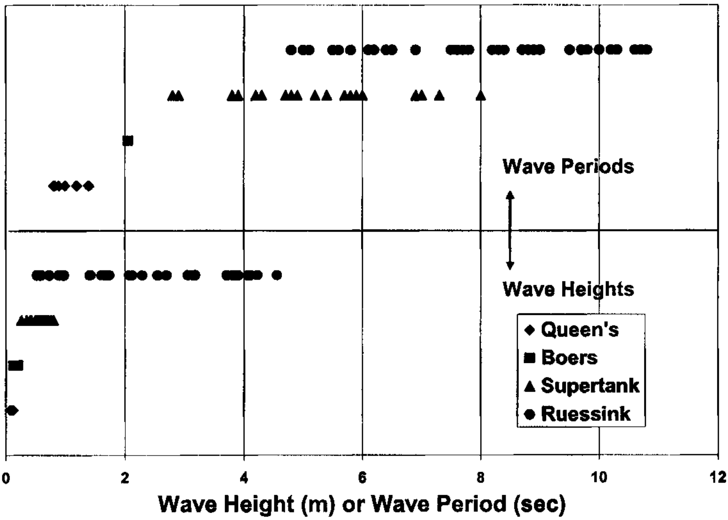


Figure 1. Range of wave heights and wave periods covered.

## 2. Queen's Breakwater Tests

The Queen's breakwater tests have been reported earlier in Kamphuis (1996, 1998, 2000, 2001, 2003) and in Janssen and Kamphuis (2000). Waves were measured at up to 64 locations through the breaking zone. It was found (Figure 2) that most wave spectra outside the breaking zone contained a minimum in wave energy at approximately half the peak frequency ($f_p$). Based on that, the wave spectra were separated into short wave and long wave components, where long wave energy was defined as the energy at $f \leq f_p/2$ while short wave energy was defined as having frequencies $f > f_p/2$. This resulted in a short wave height profile through the breaking zone that could be represented by the normal wave decay relationships, such as Battjes and Janssen (1978) or Dally et al (1985). A cross-shore long wave profile is shown in Figure 3. It is seen that these profiles can be represented by the expression for a partially reflected long wave on a sloping bottom, as developed by Lamb (1932).

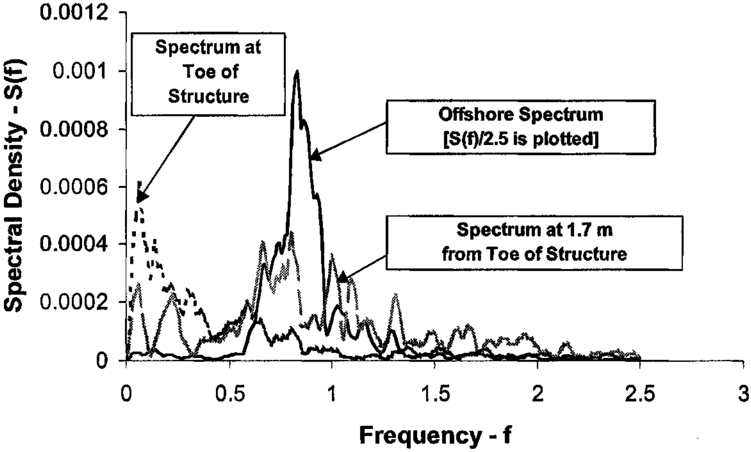


Figure 2. Cross-shore transformation of wave spectra; note the minimum energy near $f_p/2$

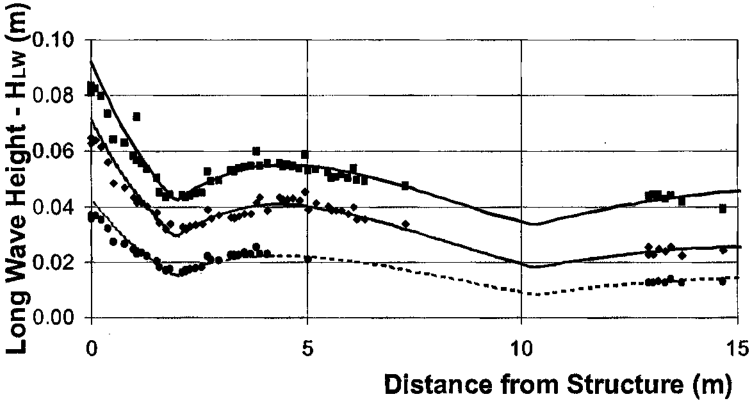


Figure 3. Cross-shore Long wave profile; ■ observations, — theory

## 3. Dimensional Analysis

Simple dimensional analysis of the process yields:

$$\frac{H_{LW}}{H_b} = \Phi\left(\frac{H_b}{gT^2}, \frac{d_s}{H_b}, \frac{\sqrt{gH_b}H_b}{\mu / \rho}, m, \frac{t}{T}, \frac{L_{LW}}{gT^2}\right) \tag{1}$$

where $H_{LW}$ is the long wave height, $H_b$ the breaking short wave height, g the gravitational acceleration, $d_s$ the depth at the structure, $\mu$ the dynamic fluid viscosity, $\rho$ the fluid density, m the slope of the foreshore, t the time, T the short wave period and $L_{LW}$ is the long wave length.

After removing the secondary influences and replacing $gT^2$ by the breaking short wave length, Eq. 1 reduces to

$$\frac{H_{LW}}{H_b} = \Phi\left(\frac{H_b}{L_b}, m, \frac{L_{LW}}{L_b}\right) \tag{2}$$

where $L_b$ is the breaking short wave length. In the simplest case we can assume $\Phi$ is constant and using significant breaking wave height we obtain:

$$H_{LW} = a H_{s,b} \tag{3}$$

Figure 4 shows how powerful this simple relationship is for the Queen's test with a breakwater in shallow water. The long wave height plotted here was measured at the toe of the breakwater.

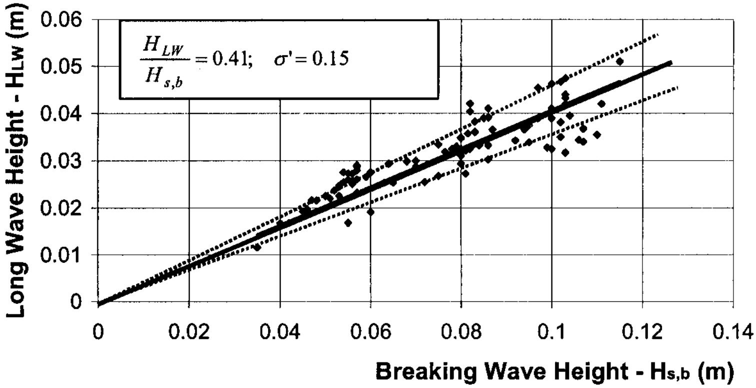


Figure 4. Long wave height at a breakwater in shallow water (Equation 3)

## 4. Shoreline Tests

In some cases, as seen in Figure 3, the relationship for a partial standing wave over-predicts the observations near a breakwater in shallow water. It may be expected that this is the result of friction. It must also be expected that for waves in the swash zone, friction (and percolation) will reduce the measured values in very shallow water. Figure 5 taken from the Supertank data set shows this to be the case – the long wave heights reach a maximum, after which they decrease very rapidly. The supertank data set used was a reduced data set, kindly provided by D. Kriebel and referenced as Kriebel (2003).

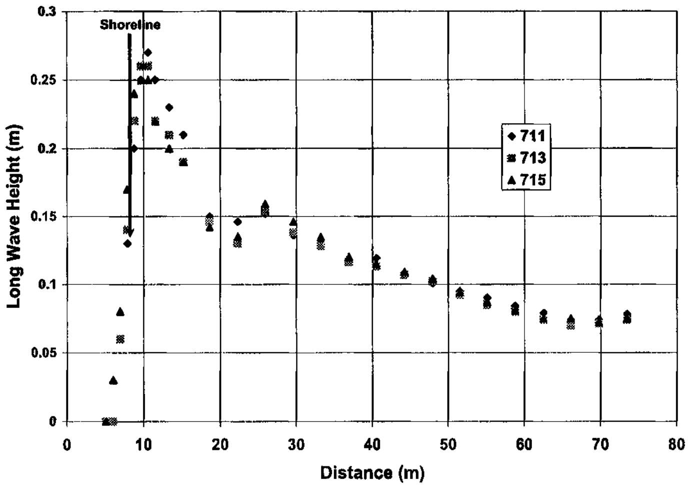


Figure 5. Long wave height decrease near shore (Supertank tests)

Figure 6 summarises the results from the Queen's shoreline test. The Queen's shoreline test data are based on Shah (1996) and Shah and Kamphuis (1996). The graph shows both the maximum long wave height and the long wave height at the shoreline. It is seen for in these tests, there was no discernible difference between the two. This was not the case for the Supertank tests. Figure 7 plots the Queen's shoreline results against Eq. 3. It is seen that the relationship is reasonable and that the slope of the line is 0.21. Comparison with Figure 4 shows the coefficient to be about half of the coefficient for the breakwater tests – in other words, the long wave height at the shoreline is much less than that measured at the toe of the breakwater in shallow water.

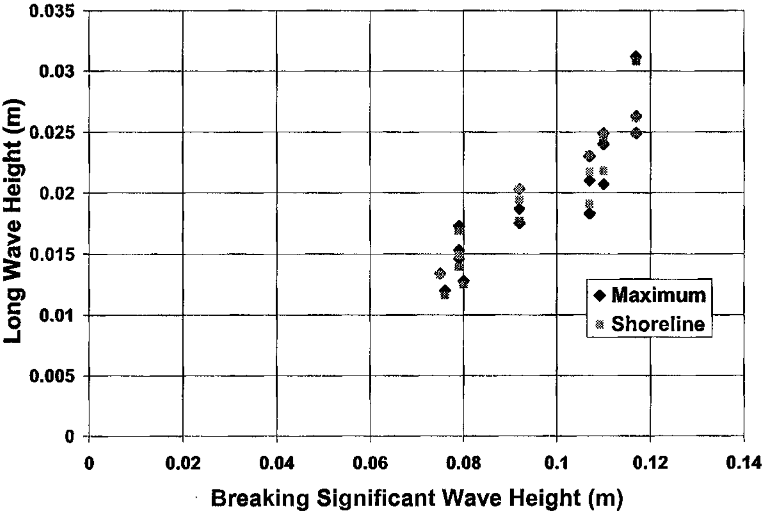


Figure 6. Maximum and shoreline results for Queen's tests

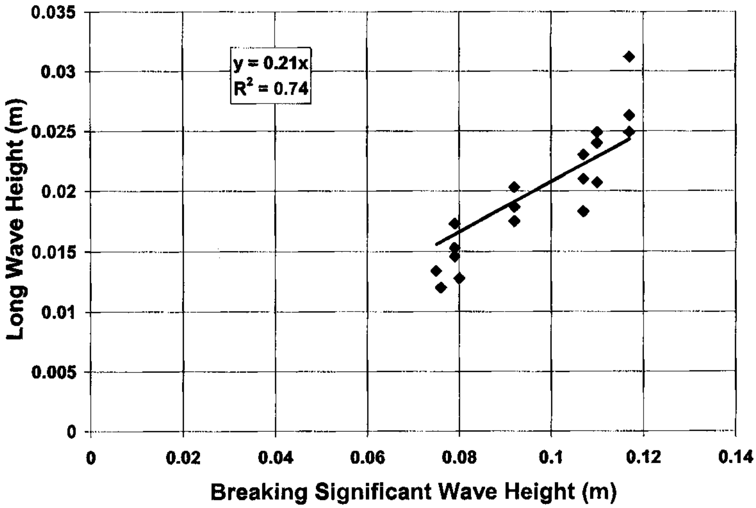


Figure 7. Long wave height in Queen's tests (Equation 3)

Plotting the complete data set against $H_{sb}$ we find that the Supertank results at the shoreline appear to be too low (Figure 8). The maximum values for the Supertank tests fit better with the others (Figure 9). The Ruessink data consisted of swash excursions on a highly dissipative beach, measured with a video system. These swash measurements were manually digitised and translated into vertical fluctuations. These were separated into long and short wave components and the long wave components reported by Ruessink are plotted here. Implicitly this assumes that long wave height at the shore is equal to the (vertical) long wave swash excursions on the beach and Figure 9 shows this assumption to be reasonable.

Regression analysis of Figures 4, 6, 9 and others is summarised in Table 2. It is clear that the simple relationship of Eq. 3 with a coefficient of about 0.2 is a reasonable representation of this complex process.

Table 2. Summary of Equation 3 results

| Type of Test | Reference | a | $R^2$ |
|---|---|---|---|
| Breakwater | Queen's | 0.41 | 0.80 |
| Shoreline | Queen's | 0.21 | 0.75 |
| Shoreline | Queen's+Boers+Ruessink | 0.22 | 0.94 |
| Shoreline | Ruessink | 0.22 | 0.87 |
| Shoreline | Queen's+Boers+Ruessink+Supertank (maximum) | 0.23 | 0.93 |

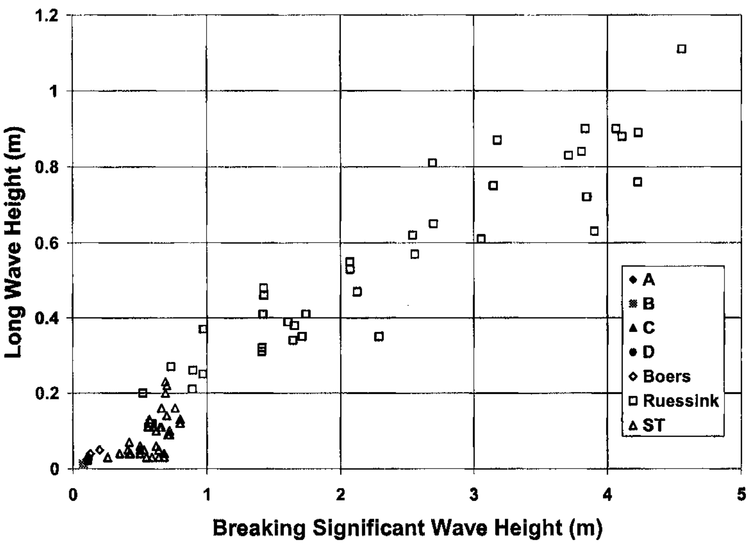


Figure 8. All shoreline results

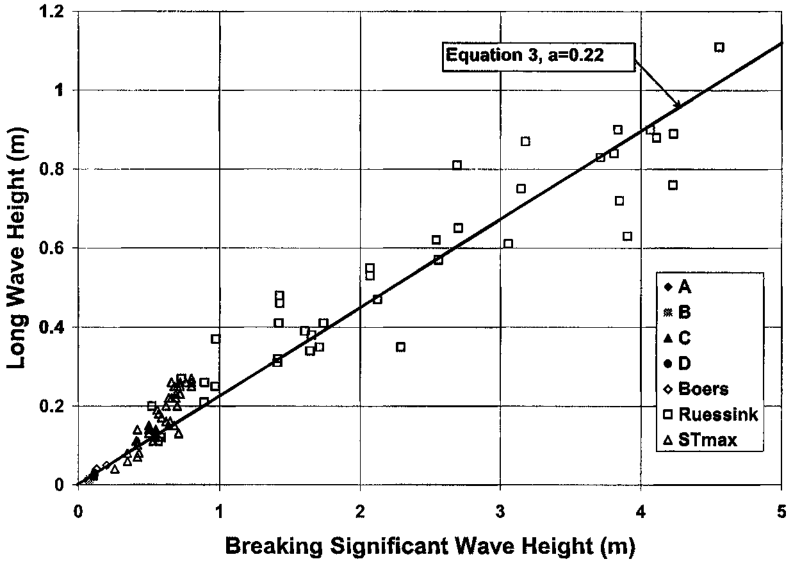


Figure 9. All results, using the maximum long wave height for the Supertank tests (Equation 3)

## 5. Including the Wave Period

To take wave period into account, we rewrite Eq. 2 as:

$$\frac{H_{LW}}{H_b} = \Phi\left(\frac{H_{s,b}}{L_b}\right) = a\left(\frac{H_{s,b}}{L_b}\right)^b \tag{4}$$

The results of this for the Queen's shoreline tests are in Figure 10. It does not show a very strong relationship but it would seem to point to:

$$\frac{H_{LW}}{H_b} = \Phi\left(\frac{H_{s,b}}{L_b}\right) \cong a\left(\frac{H_{s,b}}{L_b}\right)^{-1/2} \tag{5}$$

The other data sets do not confirm this, however, as is shown in Table 3. The Supertank tests yield the opposite sign for b and the Ruessink results are quite insensitive to wave steepness.

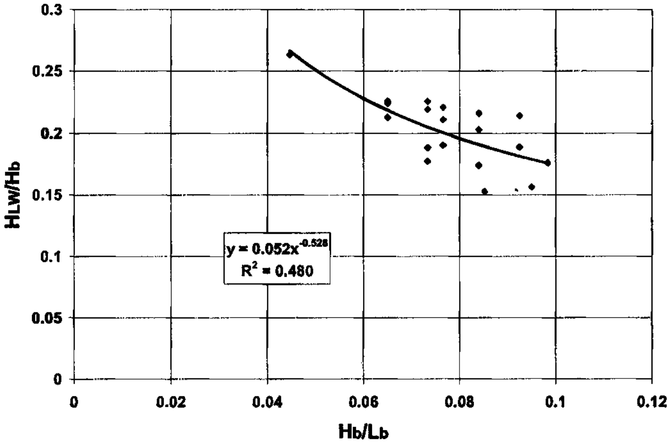


Figure 10. Wave height ratio as a function of wave steepness (Equation 4)

Table 3. Summary of Equation 3 results

| Tests | a | b | $R^2$ |
|---|---|---|---|
| Queen's | 0.052 | -0.53 | 0.48 |
| Supertank (Maximum) | 0.76 | 0.34 | 0.52 |
| Ruessink | 0.18 | -0.082 | 0 |

If Eq. 5 were valid, it could also be rewritten as

$$H_{LW} = a H_{s,b} \left( \frac{H_{s,b}}{L_b} \right)^{-1/2} = a\sqrt{H_{s,b} L_b} \quad (6)$$

This relationship was proposed by Stockdon et al. (2004) on the basis of a very extensive field data set. Using the present data set , we first plot

$$H_{LW} = a \left( H_{s,b} L_b \right)^b \quad (7)$$

In Table 4 we see that Eq. 7 shows promise (except for the Supertank tests).

Table 4. Summary of Equation 7 results

| Tests | a | b | $R^2$ |
|---|---|---|---|
| Queen's | 0.076 | 0.637 | 0.89 |
| Supertank (Maximum) | 0.074 | 0.413 | 0.12 |
| Ruessink | 0.057 | 0.476 | 0.90 |
| Queen's+Boers+Ruessink | 0.055 | 0.483 | 0.99 |
| Queen's+Boers+Ruessink+Supertank (Maximum) | 0.058 | 0.481 | 0.94 |

Plotting Eq. 6 also shows good results.

Table 5. Summary of Equation 6 results

| Tests | a | $R^2$ |
|---|---|---|
| Queen's+Boers+Ruessink | 0.050 | 0.95 |
| Queen's+Boers+Ruessink+St(max) | 0.050 | 0.92 |

Comparison of the correlation coefficients of these results with Table 2, however, shows that little is gained by introducing the wave period.

## 6. Conclusions

A general conclusion, once again reinforced by this project is:

1. For relationships in the breaking zone, the breaking wave parameters $H_b$ (breaking wave height) and $\alpha_b$ (breaking wave angle, not separately tested here) and to a lesser extent breaking wave length, $L_b$ should be used as basic parameters (rather than the deep water parameters $H_o$, $\alpha_o$ and $L_o$).
    a. Using the breaking wave parameters separates the (often dominant) wave transformation process from the phenomenon being studied.
    b. If the breaking wave parameters are not available, they should be calculated. Even the simplest wave transformation calculation will permit the separation of the wave transformation process from the phenomenon being studied.

This would appear to be common sense, but many papers about breaking zone phenomena are still being written, using deep water wave characteristics.

From the comparison of Ruessink's data with the other data sets it appears that:

2. The vertical long wave swash distance corresponds closely to the long wave height at the shoreline.

From comparison of the shoreline tests with breakwater tests (e.g. comparison of Figures 3 and 5) it appears that:

3. The long wave profiles (in the cross-shore direction) are similar for waves at a shoreline and waves at a breakwater in shallow water.
4. Wave reflection is stronger off a breakwater
5. Long wave height attenuates in very shallow water.

From the test results presented here, it also appears that:

6. Equation 3 is a robust representation of long wave height. The coefficient is about 0.4 for breakwaters in shallow water and about 0.2 for long waves at the shore.
7. Dependence on wave period is much less certain:
   a. The wave period dependence is greater for long waves at a shore than for waves at a breakwater in shallow water.
   b. The dependence on wave steepness is not clear,
   c. A relationship between $H_{LW}$ and $\sqrt{H_b L_b}$ shows some promise,
   d. Introduction of the wave period does not necessarily produce a better relationship.

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## References

Battjes, J.A. and J.F.P.M. Janssen (1978), "Energy loss and setup due to breaking of random waves", *Proc. 16th Int. Conf. on Coastal Eng.*, ASCE, Hamburg, pp 569-586.

Boers, M (1996), "Simulation of a surf zone with a barred beach; Report 1: Wave heights and breaking", Communications on hydraulic and geotechnical engineering, Report 95-5, *Technical University, Delft*, Netherlands

Dally, W.R., R.G. Dean and R.A. Dalrymple (1985), "Wave height variation across beaches of arbitrary profile", *J. Geoph. Res.* (90, No 6), pp 11917-11927.

Guza, R.T. and E.B. Thornton (1985), "Observations of surf beat", *J. Geoph. Res.*, 90, pp 3163-3172.

Herbers, T.H.C, S.Elgar, R.T Guza and W.C. O'Reilly (1995a), "Infragravity frequency motions on the shelf - Part II: Free waves", *J. Phys. Oceanog.* 25, pp 1063-1079.

Herbers, T.H.C, S.Elgar and R.T Guza (1995b), "Generation and propagation of infragravity waves", *J. Geoph. Res.*, 100, pp 24863-24872.

Holman, R.A, (1981), "Infragravity energy in the surf zone", *J. Geoph. Res.*, 86, pp 6442-6450.

Holman, R.A and A.H. Sallenger (1985), "Setup and swash on a natural beach", *J. Geoph. Res.*, 90, pp 945-953.

Howd, P.A, J. Oltman-Shay, R.A. Holman (1991), "Wave variance partitioning in the trough of a barred beach", *J. Geoph. Res.,* 96, pp 11357-11371.

Huntley, D.A, R.T. Guza and E.B. Thornton (1981), "Field observations of surf beat 1. Progressive edge waves", *J. Geoph. Res.* ,86, pp 6451-6466.

Janssen, T.T and J.W. Kamphuis (2000), "Three-Dimensional Experiments on Long Waves at a Breakwater", *Proc. 27th ICCE*, Sydney, pp 2192-2205.

Kamphuis, J.W. (1996), "Depth-Limited Design Wave", *Proc. 25th Int. Conf. on Coastal Eng.*, ASCE, Orlando, pp 221-232.

Kamphuis, J.W. (1998), "Long Waves in Flume Experiments", *Proc. 26th Int. Conf. on Coastal Eng.*, ASCE, Copenhagen, pp 1154-1167.

Kamphuis, J.W. (2000), "Designing for Low Frequency Waves", *Proc. 27th Int. Conf. on Coastal Eng.,* ASCE, Sydney, pp 1434-1447.

Kamphuis, J.W., (2001), "Wave setup and long waves in shallow water", *Proc. Can. Coastal Conf. '01*, (CCSEA), Quebec, pp 1-12.

Kamphuis, J.W. (2003), "On Long Waves Generated by Short Waves", *Proc. Int. Symp. on Long Waves, IAHR*, Thessaloniki, Aug 15-17, 2003.

Kriebel, D. (2003), "Personal communication re: supertank test results."

Lamb, H. (1932), *"Hydrodynamics"*, Cambridge Univ. Press, 6th Ed., Reprinted by Dover Press.

Oltman-Shay, J. and R.T. Guza (1987), "Infragravity edge wave observations on two California beaches", *J. Phys. Oceanog.*, 17 , pp 644-663.

Raubenheimer, B. and R.T. Guza (1996), "Observations and predictions of runup", *J. Geoph. Res.*, 101, pp 25575-25587.

Ruessink, B.G., M.G. Kleinhans and P.G.L. van den Beukel (1998), "Observations of swash under highly dissipative conditions" *J. Geoph. Res.* 103, pp 3111-3118.

Shah, A.M. (1996), "The swash zone: A focus on low frequency motion", M.Sc. Thesis, *Queen's University.*

Shah, A.M. and J.W. Kamphuis (1996) "The swash zone: a focus on low frequency motion", *Proc. 25th Int. Conf. on Coastal Eng.,* ASCE, Orlando, pp 1431-1442.

Stockdon, H.F., R.A. Holman, P.A. Howd and A. H. Sallenger (2004), "Empirical parameterization of setup, swash and runup", Submitted to *J. Geoph. Res.*