DESIGN SCOUR LEVELS FOR DUNE REVETMENTS AND SEAWALLS

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INTRODUCTION

Particularly important for the design of dune revetments and seawalls subjected to breaking waves is the maximum depth of toe scour, the primary cause of failure of many coastal structures (Sutherland *et al.* 2006). Much of the published research on wave-induced toe scour has been under non-breaking waves with subaqueous seabed levels at the seawall/revetment toe. However, dune revetments and seawalls may become exposed to breaking waves for which this method has been derived.

Previous research has related scour depth at dune revetments and seawalls variously to the deep water offshore significant wave height (Sutherland *et al.* 2006b), the minimum depth over the surf zone bar upon which the incident wave breaks (Steetzel 1988, Boers *et al.* 2011, van Rijn 2018), the depth at the toe of the structure (Silvester 1990), the maximum height of an unbroken wave at the toe of the structure (USACE 1984, 2006), the volume of sand behind the seawall that would have been eroded in the absence of the seawall (Dean 1986). None of these methods gives a design scour **level** for dune revetments or seawalls.

The method proposed herein assumes that the work done to excavate a scour hole is a function of the incident wave energy (Steetzel 1993), which incorporates wave period rather than wave height alone, and a formula for the toe scour level has been developed for a still water level datum at the wave breaking point. The formula has been calibrated with data derived from published laboratory studies covering a large range of scales, with some having been validated with prototype measurements.

THESIS

Maximum toe scour occurs under breaking waves (Sutherland *et al.* 2006b, Tsai *et al.* 2009, Salauddin & Pearson 2019). When designing for breaking waves it is necessary to determine the maximum breaker height to which the structure might reasonably be subjected (USACE 1984, p7-8). The design breaker height, H_b, depends on the depth of water some distance seaward from the structure toe where the wave first begins to break (USACE 1984, p7-8). The breaking process extends over a distance equal to around half the shallow-water wavelength, which is based on the depth at this seaward position (USACE 1984, p7-4).

The toe scour depth (h_s) below the still water level (SWL) is defined herein by the breaking wave energy (following Steetzel 1993), which is a function of wave height and wavelength, hence period (USACE 1984 p2-43):

$$E = \frac{\rho g H_b^2 L}{8} \qquad (1)$$

where:

$H_b = breaking\ wave\ height$
$L = nearshore\ wavelength$

A surrogate for breaking wave height (H_b) can be the pre-existing water depth ($h_{L/2}$) at half the nearshore wavelength (L) in front of the structure, as depicted in Figure 1, assuming $H_b \approx h_b$ (Battjes 1974) $\approx h_{L/2}$.

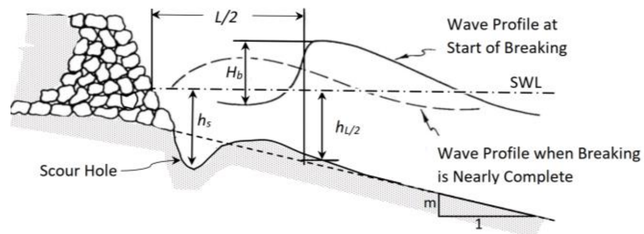

Figure 1 - Definition schema for parameters used herein.

In shallow water the wavelength can be approximated by:

$$L = \left(g h_{L/2}\right)^{1/2} T \qquad (2)$$

hence, the scour level can be defined as:

$$\text{Scour level} = f\left(SWL, L, h_{L/2}\right) \qquad (3)$$

where:

$h_{L/2} =$ depth at half the nearshore wavelength: $f(T, m)$
$T =$ wave period
$SWL = RL_{tide} +$ surge $+$ wave setup: $f(H_{so}, h_{L/2}, T, m_o)$
$m_o =$ bedslope from wave break point to deep water
$m =$ nearshore bedslope from shoreline to break point

Figure 2 (see Table 1 appended) presents a re-assessment of data from large and small scale moveable bed model studies, as referenced, with scour depth (h_s) plotted as a function of incident wave energy ($h_{L/2}{}^2 L$) determined at depth $h_{L/2}$. The following design scour level formula was derived from the schema in Figure 1 and data in Figure 2:

$$Scour\ level = SWL - 0.60(h_{L/2}^2 L)^{1/3} \qquad (4)$$

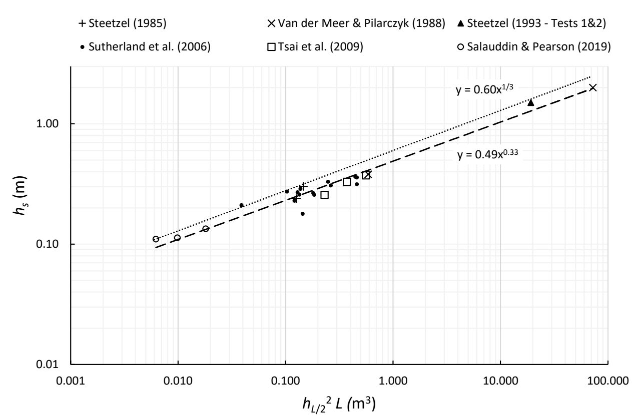

Figure 2 - Moveable bed model scour depth data plotted as a function breaking wave energy.

APPLICATION

The following steps may be used in applying the method:

1) Determine the offshore design storm conditions including wave height, period and direction, the ocean storm still water level and the wave refraction coefficient for the site to allow for calculating nearshore wave setup and, hence, nearshore SWL at $h_{L/2}$.

2) Obtain a nearshore storm scoured beach profile (not necessarily with scour holes).

3) Develop a relationship for wave setup *vs* nearshore water depth for the adopted offshore storm conditions.

4) Determine the water surface profile along the beach profile from a water depth of around, say, 5 m to 0 m.

5) Calculate the wavelength along the seabed profile using the relationship $L = (g.h)^{½}T$.

6) From steps (4) and (5) determine the unique water depth and SWL situated at ½L in front of the structure.

7) Use the result in step (6) to determine the toe scour level using equation (4).

8) Check the sensitivity of the results using the following Discussion guidelines

DISCUSSION

The method is sensitive to several factors as follows and it is recommended that sensitive factors be tested for design:

Wave period

Variation in the value adopted for wave period could vary the nearshore wavelength significantly, having a significant impact on the design scour level (and requisite armour mass). T_p is recommended.

Wavelength

Equation (4) is valid only if equation (2) is used to define the nearshore wavelength. While equation (2) is a simple approximation of wavelength, it was used to determine $h_{L/2}$, the surrogate for H_b and is required to be defined consistently, easily but not necessarily precisely.

Deepwater wave height

The deep-water wave height affects the breaking wave height through wave setup. However, wave setup could vary by only a few decimeters with little impact on scour level (but with a more significant impact on requisite armour mass).

Nearshore beach profile

The design beach profile should reflect an eroded condition. Scoured profiles are steeper close inshore, leading to larger nearshore design breaker depths and, hence, scour depth (Figure 3). Sutherland *et al*. (2006) found greater scour depths with steeper beach slopes.

Still Water Level (SWL)

Consideration may be required for future sea level variations, with a rise being projected to accelerate.

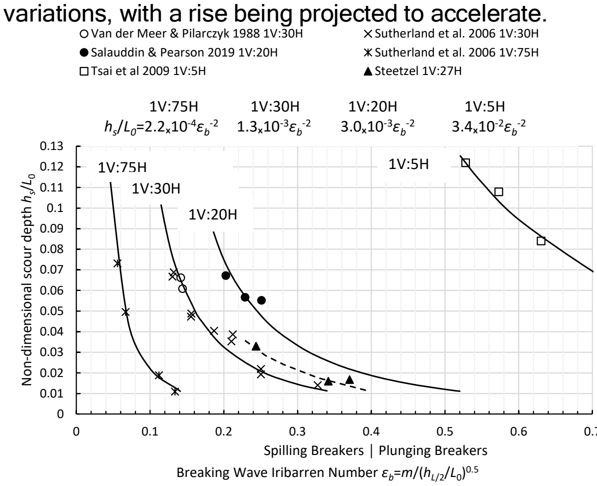

Figure 3 – Relationships between scour depth and Iribarren Number for various beach slopes from this study data.

Calibration factor

The simple equation (4) cannot reflect accurately the complex three-dimensional processes occurring under breaking wave impact onto seawalls and revetments. For non-exceedance of predictions, the calibration factor for the design equation was increased to 0.6 (Figure 2).

Scale modelling

Moveable bed scale modelling is fraught with intractable issues regarding scaling (Hughes 1995, Chapter 6). Scale effects occur in all physical models that are smaller than the prototype, making it impossible to simulate all relevant variables in their correct relationship to each other.

Fundamental modelling axioms include, *inter alia*, that models should be as large as possible (Noda 1972) and that the model is fit for predictive use only when it has reproduced past evolution successfully (Sager and Hales, 1979), which this model has yet to demonstrate. Nevertheless, three years of field data from Blackpool and Southbourne (Pearce *et al*. 2006) were in accordance with the maximum scour depth predictor of Sutherland *et al*. (2006a).

While for prototype predictions the model data require extrapolation by an order of magnitude beyond their tested range, the data were consistent over four orders of wave energy magnitude, giving confidence for such extrapolation.

Storm Duration

Experiments of Tsai *et al*. (2009) and Salauddin and Pearson (2019) took 1,000 waves to reach maximum scour depth that, spread over two high tides, could require up to some 24 hours storm duration. Boers *et al*. (2011) recommended 20 prototype hours of storm duration to reach maximum scour.

Type of Structure

That toe scour at sloping revetments is less than that at vertical seawalls was not borne out by lab testing (Salauddin & Pearson 2019; Sutherland *et al*. 2006).

CONCLUSIONS

This paper has presented a rational method for determining design toe scour levels for dune revetments and seawalls subjected to breaking waves. The method assumes that the scour level is a function of the incident wave energy and was calibrated with results from several moveable bed model studies undertaken over a large range of scales. The method yields scour levels based on estimates of wave period, hence nearshore wavelength, with the pre-existing water depth at ½ nearshore wavelength in front of the structure assumed to be a surrogate for the breaking wave height. The water depth at breaking should include an assessment of wave setup generated by the un-refracted deep water wave conditions, particularly for determining requisite armour mass. The results from applying the method are sensitive to variations in the values assumed for some of the input parameters, which should be considered carefully for design.

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APPENDIX

Table 1. Data used herein as derived from research papers/reports as referenced

Test No. (scale)	Bed Slope (1V:XH)	T_p (s)	L (m)	$h_{L/2}$ (m)	h_s (m)	Iribarren No.
Steetzel (1985)						
M2501-II-series, T2 (1:30)		3.1	4.1	0.176	0.239	-
M2501-II-series, T3 (1:30)		3.4	4.5	0.180	0.302	-
Van der Meer & Pilarczyk (1988)						
(1:7)	30	6.4	25.9	1.670	2.000	0.142
(1:35)	30	2.9	5.3	0.334	0.380	0.144
Steetzel (1993)						
H298-I-series, T1 (1:5)		5.4	17.3	1.050	1.500	-
H298-I-series, T2 (1:5		5.4	17.3	1.050	1.500	-
Sutherland *et al*. (2006)						
1	30	1.6	2.4	0.238	0.258	0.132
2	30	1.9	2.9	0.248	0.266	0.156
3	30	2.3	3.7	0.260	0.331	0.187
4	30	3.2	5.5	0.290	0.359	0.250
8	30	1.9	2.1	0.134	0.211	0.212
12	30	3.2	4.2	0.170	0.230	0.327
13	30	2.3	3.2	0.205	0.289	0.210
14	30	1.9	3.5	0.356	0.364	0.130
15	30	1.9	2.9	0.251	0.258	0.156
16	30	3.2	5.5	0.290	0.315	0.250
26	75	1.9	2.7	0.217	0.270	0.067
27	75	3.2	4.9	0.232	0.308	0.112
28	75	1.6	2.2	0.214	0.274	0.056
34	75	3.2	5.5	0.162	0.179	0.134
Tsai *et al*. (2009)						
5	5	1.4	2.5	0.308	0.257	0.630
10	5	1.4	2.7	0.372	0.330	0.573
15	5	1.4	2.9	0.439	0.373	0.528
Salauddin & Pearson (2019)						
S_{op}=0.05, h_t=0.10	20	1.1	1.0	0.079	0.110	0.251
S_{op}=0.05, h_t=0.075	20	1.1	1.1	0.095	0.113	0.229
S_{op}=0.05, h_t=0.06	20	1.1	1.2	0.121	0.134	0.203