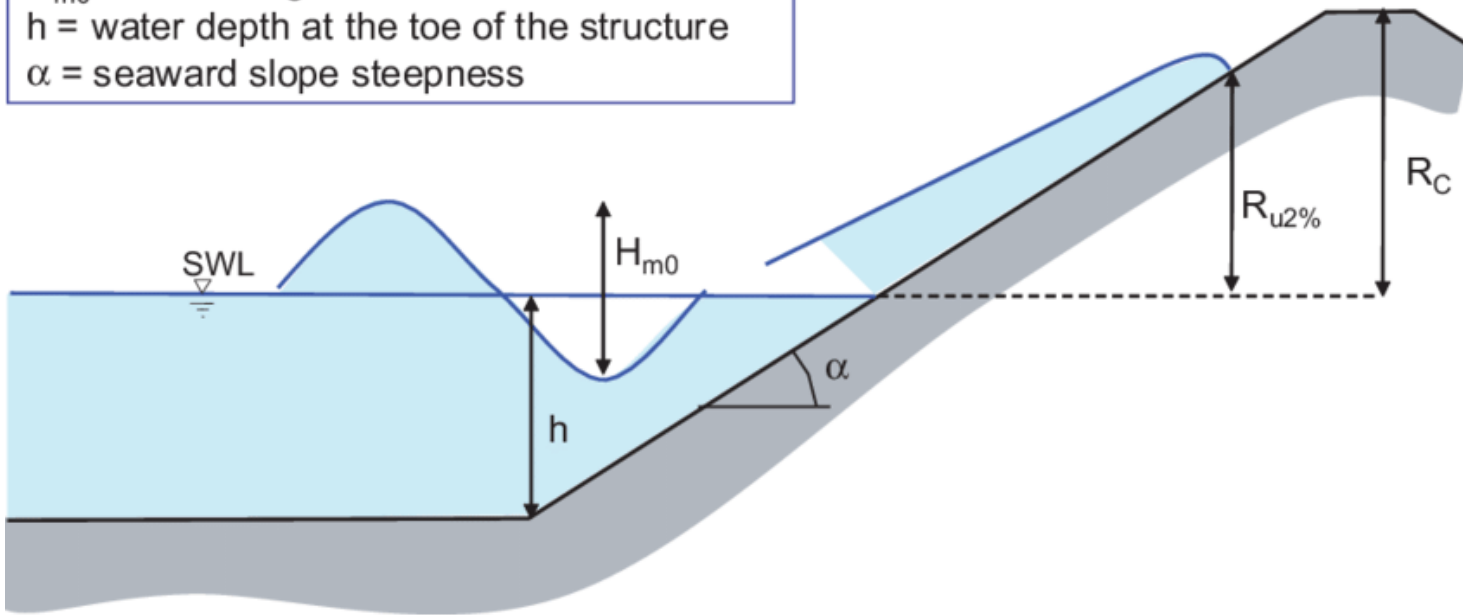




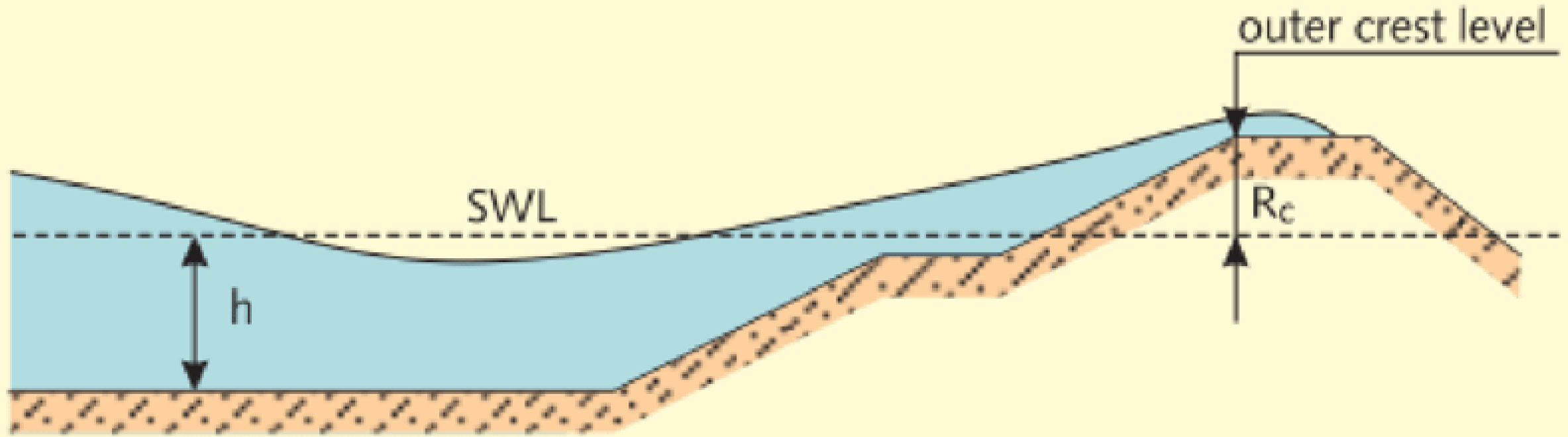
Wave Structure Interaction

Wave Run-Up

$R_{u2\%}$ = wave run-up height
 R_C = freeboard
 H_{m0} = wave height at the toe of the structure
 h = water depth at the toe of the structure
 α = seaward slope steepness



- The wave run-up height, $R_{u2\%}$, refers to the vertical distance from the still water line to the level exceeded by 2% of incoming waves.
- Wave run-up is relevant for smooth slopes, embankments, and sometimes for rough slopes protected with rock or concrete. However, it does not apply to vertical structure



Wave Overtopping

- If wave run-up levels are high enough water will reach and pass over the crest of the structure.
- This defines the 'green water' overtopping case where a continuous sheet of water passes over the crest.
- In cases where the structure is vertical, the wave may impact against the wall and send a vertical plume of water over the crest.
- A second form of overtopping occurs when waves break on the seaward face of the structure and produce significant volumes of splash.

Overtopping Hazards



The hazards from direct wave and overtopping effects may cause consequences under three general categories:

Overtopping Hazards



The hazards from direct wave and overtopping effects may cause consequences under three general categories:

Direct hazard of injury or death to people living, working or travelling in the area defended;

Overtopping Hazards



The hazards from direct wave and overtopping effects may cause consequences under three general categories:

Damage to property, operation and / or infrastructure in the area defended;

Overtopping Hazards



The hazards from direct wave and overtopping effects may cause consequences under three general categories:

Damage to defence structure(s).

Overtopping Hazards

Hazards driven by overtopping can be categorised by several simple direct responses:

Mean Overtopping Discharge, q

The average volume of water overtopping a structure per unit time and per unit length, typically measured in litres per second per metre (L/s/m). It represents the overall rate of water flowing over the structure.

Overtopping Hazards

Hazards driven by overtopping can be categorised by several simple direct responses:

Individual and Peak Overtopping Volumes, V_i and $V_{\max}$

V_i : The volume of water associated with a single overtopping wave, typically measured in Litres.

$V_{\max}$: The largest overtopping volume recorded during a specific period, indicating the most extreme wave overtopping event.

Overtopping Hazards

Hazards driven by overtopping can be categorised by several simple direct responses:

Overtopping Velocities, v_{xc} , v_{zc} , v_{xp} and v_{zp}

v_{xc} / v_{xp} : The horizontal velocity of overtopping water, measured at either the crest, c, or the promenade, p.

v_{zc} / v_{zp} : The vertical velocity of overtopping water, measured at either the crest, c, or the promenade, p.

Overtopping Hazards

Hazards driven by overtopping can be categorised by several simple direct responses:

Overtopping Flow Depth, d_{xc} and d_{xp}

The depth of the water layer flowing over the crest (c) or promenade (p).

Tolerable Overtopping for Structural Design

Hazard type and reason	Mean discharge q (l/s per m)	Max volume V_{max} (l per m)
Rubble mound breakwaters; $H_{m0} > 5$ m; no damage	1	2,000-3,000
Rubble mound breakwaters; $H_{m0} > 5$ m; rear side designed for wave overtopping	5-10	10,000-20,000
Grass covered crest and landward slope; maintained and closed grass cover; $H_{m0} = 1 - 3$ m	5	2,000-3,000
Grass covered crest and landward slope; not maintained grass cover, open spots, moss, bare patches; $H_{m0} = 0.5 - 3$ m	0.1	500
Grass covered crest and landward slope; $H_{m0} < 1$ m	5-10	500
Grass covered crest and landward slope; $H_{m0} < 0.3$ m	No limit	No limit

Tolerable Overtopping for Property and Operation

Hazard type and reason	Mean discharge q (l/s per m)	Max volume $V_{\max}$ (l per m)
Significant damage or sinking of larger yachts; $H_{m0} > 5$ m	>10	$>5,000 - 30,000$
Significant damage or sinking of larger yachts; $H_{m0} = 3-5$ m	>20	$>5,000 - 30,000$
Sinking small boats set 5-10 m from wall; $H_{m0} = 3-5$ m Damage to larger yachts	>5	$>3,000-5,000$
Safe for larger yachts; $H_{m0} > 5$ m	<5	$<5,000$
Safe for smaller boats set 5-10 m from wall; $H_{m0} = 3-5$ m	<1	$<2,000$
Building structure elements; $H_{m0} = 1-3$ m	≤ 1	$<1,000$
Damage to equipment set back 5-10m	≤ 1	$<1,000$

Tolerable Overtopping for People and Vehicles

Hazard type and reason	Mean discharge q (l/s per m)	Max volume $V_{\max}$ (l per m)
People at structures with possible violent overtopping, mostly vertical structures	No access for any predicted overtopping	No access for any predicted overtopping
People at seawall / dike crest. Clear view of the sea. $H_{m0} = 3$ m $H_{m0} = 2$ m $H_{m0} = 1$ m $H_{m0} < 0.5$ m	 0.3 1 10-20 No limit	 600 600 600 No limit
Cars on seawall / dike crest, or railway close behind crest $H_{m0} = 3$ m $H_{m0} = 2$ m $H_{m0} = 1$ m	 <5 10-20 <75	 2000 2000 2000
Highways and roads, fast traffic	Close before debris in spray becomes dangerous	Close before debris in spray becomes dangerous

Estimating Wave Overtopping

Owen's formula is an empirical relationship used to estimate wave overtopping at coastal structures.

It links the dimensionless overtopping discharge to the freeboard and other wave and structural parameters.

Step 1: Calculate the Dimensionless Freeboard (R^*)

Estimating Wave Overtopping

Owen's formula is an empirical relationship used to estimate wave overtopping at coastal structures.

It links the dimensionless overtopping discharge to the freeboard and other wave and structural parameters.

Step 1: Calculate the Dimensionless Freeboard (R^*)

The dimensionless freeboard is a normalised measure of a structure's freeboard (the vertical distance from the crest of a coastal structure to the still water level), expressed relative to the significant wave height and the wave period. It helps in generalising overtopping predictions across different scales and conditions.

Estimating Wave Overtopping

Owen's formula is an empirical relationship used to estimate wave overtopping at coastal structures.

It links the dimensionless overtopping discharge to the freeboard and other wave and structural parameters.

Step 1: Calculate the Dimensionless Freeboard (R^*)

$$R^* = \frac{R_c}{T_m \sqrt{g H_s}}$$

R_c : Freeboard (m), the vertical distance from the crest of the structure to the still water level.

T_m : Mean wave period (s), the average time between successive waves.

g : Gravitational acceleration (9.81 m/s^2).

H_s : Significant wave height (m), a statistical measure of the largest waves in a wave spectrum.

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The freeboard (R_c) is 3.5m.

The significant wave height (H_s) is 2.0.

The mean wave period (T_m) is 8 seconds.

Gravitational acceleration (g) is 9.81m/s^2 .

Calculate the dimensionless freeboard (R^*)

$$R^* = \frac{R_c}{T_m \sqrt{g H_s}} = \frac{3.5}{8 \times \sqrt{9.81 \times 2.0}} = 0.099$$

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The freeboard (R_c) is 3.5m.

The significant wave height (H_s) is 2.0.

The mean wave period (T_m) is 8 seconds.

Gravitational acceleration (g) is 9.81 m/s^2 .

Calculate the dimensionless freeboard (R^*)

$$R^* = \frac{R_c}{T_m \sqrt{g H_s}} = \frac{3.5}{8 \times \sqrt{9.81 \times 2.0}} = 0.099$$

$R^* > 2.0$: Very little overtopping; the structure is high compared to wave height.

$R^* < 1.0$: Significant overtopping; the crest is low compared to the waves.

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The freeboard (R_c) is 4.5m.

The significant wave height (H_s) is 2.0.

The mean wave period (T_m) is 8 seconds.

Gravitational acceleration (g) is 9.81m/s^2 .

Calculate the dimensionless freeboard (R^*)

$$R^* = \frac{R_c}{T_m \sqrt{g H_s}} = \frac{4.5}{8 \times \sqrt{9.81 \times 2.0}} = 0.125$$

Estimating Wave Overtopping

Owen's formula is an empirical relationship used to estimate wave overtopping at coastal structures.

It links the dimensionless overtopping discharge to the freeboard and other wave and structural parameters.

Step 2: Apply the formula for Q^*

After calculating R^* , use the given empirical coefficients A and B for the specific slope of the structure to predict Q^* .

$$Q^* = Ae^{\left(-\frac{BR^*}{r}\right)}$$

Q^* = Dimensionless discharge which represents the overtopping discharge normalised by wave characteristics.
 A and B = Empirical coefficients that depend on the slope of the structure.

R^* = Dimensionless freeboard, which has been calculated in the previous step.

r = A scaling factor related to the wave conditions and structure

Estimating Wave Overtopping

Armour Type	r
Smooth Impermeable	1
Pitched stone in mortar	0.75 - 0.8
Stepped concrete	0.95
Grass / turf	0.9 - 1
Rock armour, 2 layers	0.55
Open rock, > 2 layers, shallow slope	0.45
Hollow cube armour units, 1 layer	0.5
Dolos or Stabit armour units	0.4
Tetrapods, 2 layers	0.3

Estimating Wave Overtopping

Slope	A	B
1 : 1	0.0079	20.1
1 : 1.5	0.0102	20.1
1 : 2	0.0125	22.1
1 : 3	0.0163	31.9
1 : 4	0.0192	47.0

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The dimensionless freeboard (R^*) is 0.099

The slope is smooth and impermeable with a slope of 1:2.

Calculate the dimensionless discharge (Q^*)

$$Q^* = Ae^{\left(-\frac{BR^*}{r}\right)} = 0.0125e^{\left(-\frac{22.1 \times 0.099}{1}\right)} = 0.00141$$

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The dimensionless freeboard (R^*) is 0.125

The slope is smooth and impermeable with a slope of 1:2.

Calculate the dimensionless discharge (Q^*)

$$Q^* = Ae^{\left(-\frac{BR^*}{r}\right)} = 0.0125e^{\left(-\frac{22.1 \times 0.125}{1}\right)} = 0.00079$$

Estimating Wave Overtopping

Owen's formula is an empirical relationship used to estimate wave overtopping at coastal structures.

It links the dimensionless overtopping discharge to the freeboard and other wave and structural parameters.

Step 3: Determine the mean overtopping discharge, q

Once you have Q^* , you can convert it back to the actual overtopping discharge q by scaling it with wave characteristics.

$$q = Q * T_m g H_s$$

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The dimensionless discharge (Q^*) is 0.00141

The significant wave height (H_s) is 2.0.

Gravitational acceleration (g) is 9.81 m/s².

Calculate the mean overtopping discharge (q)

$$q = Q^* T_m g H_s = 0.00141 \times 8 \times 9.81 \times 2 = 0.221 \text{ m}^3/\text{s}/\text{m}$$

$$q = 22.1 \text{ l/s}/\text{m}$$

Estimating Wave Overtopping

A coastal structure has the following characteristics:

The dimensionless discharge (Q^*) is 0.00141

The significant wave height (H_s) is 2.0.

Gravitational acceleration (g) is 9.81 m/s^2 .

Calculate the mean overtopping discharge (q)

$$q = Q^* \sqrt{g H_s^3} = 0.00079 \times \sqrt{9.81 \times 2^3} = 0.00699 \text{ m}^3/\text{s}/\text{m}$$

$$q = 7.0 \text{ l/s/m}$$

Estimating Wave Overtopping

For a 1:4 slope structure made smooth impermeable concrete with a toe at 0.0 mCD, still water level 2.0 mCD and a crest level 5.0 mCD. Estimate the overtopping when $H_s=5\text{ m}$ and $T_m=9\text{ s}$

Estimating Wave Overtopping

For a 1:4 slope structure made of 2 layers of rock armour with a toe at 0.0 mCD, still water level 2.0 mCD and a crest level 5.0 mCD. Estimate the overtopping when $H_s=5\text{ m}$ and $T_m=9\text{ s}$

Estimating Wave Overtopping

What is the decrease in overtopping if the structure is constructed from rock armour?

Estimating Wave Overtopping

What would the crest height need to be if you wanted to limited the overtopping to less than 80 l/s/m ?

Estimating Wave Overtopping

For a 1:2 slope structure made of 2 layers of rock armour with a toe at 0.0 mCD, still water level 2.0 mCD and a crest level 5.0 mCD. Estimate the overtopping when $H_s=5\text{ m}$ and $T_m=9\text{ s}$

Response to Overtopping

The main response to these hazards has most commonly been the construction of new defences, but any logical response should now always consider three options, in increasing order of intervention:



Response to Overtopping

Move human activities away from the area subject to overtopping and/or flooding hazard, thus modifying the land use category and/or habitat status;



Response to Overtopping

Accept occasional hazard at acceptable probability (acceptable risk) by providing for temporary use and/or short-term evacuation with reliable warning and evacuation systems, and/or use of temporary / demountable defence systems;



Response to Overtopping

Increase defence standard to reduce risk to (permanently) acceptable levels probably by enhancing the defence and / or reducing loadings.