Hydraulic Stability Calculator for Breakwater Armor Units

Concrete Cubes & Antifer Blocks

1. Abstract

This repository contains computational tools designed for the hydraulic design of coastal breakwater armor layers. The software implements well-known empirical formulae to dimension artificial concrete units, specifically **Simple Cubes** (Van der Meer) and **Antifer Blocks** (Chegini & Aghtouman).

A distinguishing feature of this tool is its **Iso-Geometric Design Philosophy** for the breakwater head. Rather than increasing the nominal diameter (D_n) of armor units and/or softening the slope $(m : 1)$ at the roundhead—which necessitates different casting moulds, storage logistics, and crane requirements—this calculator solves for the required **increase in concrete density** (ρ_c).

This allows the Trunk and the Head to be constructed using geometrically identical units (same moulds) and identical slope angles, optimizing construction efficiency while meeting equal safety factors via material density adjustments.

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2. Theoretical Framework & Methodology

The software calculates design parameters based on formulas that were calibrated as a result of hydraulic model test data and established coastal engineering standards.

2.1 Wave Mechanics & Geometric Parameters

Before determining armor stability, the software computes wave and structure properties:

Deep Water Wavelength (L_0): Calculated based on the mean wave period (T_m) using linear wave theory approximation for deep water:

$$L_0 = \frac{gT_m^2}{2\pi}$$

Wave Steepness (s_{0m}): A critical parameter influencing breaker type and stability:

$$s_{0m} = \frac{H_s}{L_0}$$

Number of Waves (N_z): The total number of waves attacking the structure

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during the design storm duration (t in hours):

$$N_z = \frac{t \times 3600}{T_m}$$

Relative Buoyant Density (Δ): The dimensionless density of the concrete relative to seawater:

$$\Delta = \frac{\rho_c}{\rho_w} - 1$$

2.2 Trunk Stability: Empirical Power Laws

The core of the calculator utilizes power-law formulas derived from extensive hydraulic model testing. The Stability Number (N_s) is the governing dimensionless parameter.

General Stability Formula:

$$N_s = \left(k_1 \frac{N_{od}^{k_2}}{N_z^{k_3}} + k_4 \right) s_{0m}^{-k_5}$$

Where:

- N_{od} is the Damage Number (normalized damage level).
- $k_{1..5}$ are empirical coefficients specific to the block type and slope.

Nominal Diameter (D_n): Once N_s is determined, the required characteristic size of the block is:

$$D_n = \frac{H_s}{\Delta \cdot N_s}$$

Armor Unit Weight (W):

$$W = \rho_c \cdot D_n^3$$

Empirical Coefficients (k) The software utilizes the following database of coefficients:

Method	Block Type	Slope	k_1	k_2	k_3	k_4	k_5
Van der Meer (1988)	Simple Cubes	2.0:1	6.700	0.400	0.300	1.000	0.100
Van der Meer (1988)	Simple Cubes	1.5:1	7.374	0.400	0.300	1.101	0.100
Chegini (2006)	Antifer	2.0:1	6.138	0.443	0.276	1.164	0.070
Chegini (2006)	Antifer	1.5:1	6.951	0.443	0.291	1.082	0.082

For Van der Meer Cubes (Slope 2.0:1) the script applies a scale factor adjustment to the Stability Number based on Hudson's formula property that breakwater

stability varies linearly with slope (softer slopes lead to higher stability):

$$N_{s,adjusted} = N_s \times \left(\frac{2.0}{1.5}\right)^{1/3}$$

This is equivalent to adopting k1 = 7.374 and k4 = 1.101.

2.3 The Head Design Strategy: Iso-Geometric Transfer

The breakwater head is subjected to 3D turbulence and wave breaking significantly higher than the trunk. Standard practice suggests increasing the block size and/or softening the slope. However, this tool uses a "Transfer Function" approach to maintain constant geometry (D_n and Slope).

Important Note on Weight: While the Nominal Diameter (D_n) and Slope ($\cot \alpha$) are kept identical between Trunk and Head to utilize the same casting molds, the **Weight (W) is different**. Since the Head requires higher density concrete to maintain stability, the individual blocks at the head will be heavier than those at the trunk ($W_{head} > W_{trunk}$).

Mathematical Demonstration of the Density Transfer The following derivation proves how we solve for the required Head Density (Δ_{head}) while keeping the mold size constant.

1. The Principle: Hudson Formula in terms of Diameter (D_n) The standard Hudson formula describes the stability of armor units:

$$W = \frac{\gamma_r H^3}{K_D \Delta^3 \cot \alpha}$$

Since we are designing for a fixed mold size, we must express this in terms of the Nominal Diameter (D_n). We know that weight is Volume × Unit Weight ($W = \gamma_r D_n^3$). Substituting W in the Hudson formula:

$$\gamma_r D_n^3 = \frac{\gamma_r H^3}{K_D \Delta^3 \cot \alpha}$$

Canceling γ_r on both sides and solving for D_n:

$$D_n = \left(\frac{H^3}{K_D \Delta^3 \cot \alpha}\right)^{1/3} = \frac{H}{\Delta (K_D \cot \alpha)^{1/3}}$$

2. Apply to Trunk and Head We write this derived formula for both sections of the breakwater.

For the Trunk:
$$D_{n,trunk} = \frac{H}{\Delta_{trunk}(K_{D,trunk} \cot \alpha)^{1/3}}$$

For the Head:

$$D_{n,head} = \frac{H}{\Delta_{head}(K_{D,head}\cot\alpha)^{1/3}}$$

3. Equate the Sizes (Iso-Geometric Design) The core requirement is that the size of the blocks is identical ($D_{n,trunk} = D_{n,head}$) so the same molds can be used.

$$\frac{H}{\Delta_{trunk}(K_{D,trunk}\cot\alpha)^{1/3}} = \frac{H}{\Delta_{head}(K_{D,head}\cot\alpha)^{1/3}}$$

4. Cancel Common Terms We assume the design wave height (H) and the structure slope ($\cot\alpha$) are the same for this comparison. We cancel them from the equation:

$$\frac{1}{\Delta_{trunk}(K_{D,trunk})^{1/3}} = \frac{1}{\Delta_{head}(K_{D,head})^{1/3}}$$

5. Rearrange to Solve for Head Density We move Δ_{head} to the left side and everything else to the right:

$$\Delta_{head} = \Delta_{trunk}\frac{(K_{D,trunk})^{1/3}}{(K_{D,head})^{1/3}}$$

Grouping the stability coefficients:

$$\Delta_{head} = \Delta_{trunk}\left(\frac{K_{D,trunk}}{K_{D,head}}\right)^{1/3}$$

6. Substitute the Stability Ratio The "1.5" in the formula represents the ratio of the stability coefficients for Antifer / modified cubes tipically referred in coastal engineering literature. The trunk is generally much more stable than the head for the same unit.

$$Ratio = \frac{K_{D,trunk}}{K_{D,head}} = 1.5$$

Substituting this into the equation gives the final result used by the calculator:

$$\Delta_{head} = \Delta_{trunk}\cdot(1.5)^{1/3}$$

2.4 Underlayer Standardised Rock Grading (EN 13383)

The EN 13383 standard (specifically EN 13383-1: Specification and EN 13383-2: Test methods) provides a harmonized European system for specifying the properties and grading of armourstone used in civil engineering and hydraulic structures like breakwaters, seawalls, and riverbank protection.

The software automatically sizes the underlayer rock based on the EN 13383 standard European rock gradings.

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1. **Target Weight:** $W_{ul} \approx W_{armor}/10$
2. **Selection Algorithm:** The code iterates through standard grading classes (e.g., LMA 60-300kg, HMA 1-3 ton) and selects the class where the mean weight (W_{50}) is closest to the target.
3. **Thickness (r_2):** Calculated based on a double layer of the selected rock size.

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3. Repository Contents & Implementation Variations

This repository includes several implementation variations of the calculator to suit different engineering workflows, ranging from quick spreadsheet checks to compiled software.

3.1 Python Script (`breakwater_calculator.py`)

A rapid prototyping script ideal for quick checks and automation.

- **Dependencies:** Python 3.x (Standard libraries: `math`, `sys`, `os`).
- **Execution:**
  `python3 breakwater_calculator.py`

3.2 Jupyter Notebook (`breakwater_calculator.ipynb`)

An interactive notebook that combines the calculation logic with documentation and visualization. Ideal for educational purposes or detailed design reports where step-by-step verification is required.

- **Dependencies:** Jupyter Lab / Notebook, Python 3.x, `pandas`.
- **Features:** Inline markdown explanations, cell-by-cell execution, and transparent variable tracking.

3.3 Excel Spreadsheet (`breakwater_calculator.xlsx`)

A standard engineering spreadsheet implementation for users who prefer a non-coding environment.

- **Features:** Pre-programmed formulas, dropdown menus for block selection, and conditional formatting for results.

3.4 C++ CLI (`breakwater_calculator_cli.cpp`)

A high-performance command-line tool designed for batch processing or integration into pipelines. It utilizes static linking for portability.

- **Compilation (GCC/MinGW):**
  ```
  g++ -O3 -march=native -std=c++17 -Wall -Wextra \
  -static -static-libgcc -static-libstdc++ \
  -o breakwater_calculator_cli breakwater_calculator_cli.cpp
  ```

- **Usage (Interactive):** ./breakwater_calculator_cli
- **Usage (Arguments):**
  ```
  ./breakwater_calculator_cli [Hs] [Tm] [Duration] [Nod] [Wc] [FormulaID]
  # Example:
  ./breakwater_calculator_cli 10.0 13.0 12.0 1.0 24.0 1
  ```

3.5 C++ GUI (`breakwater_calculator_gui.cpp`)

A standalone native Windows application using the Win32 API. It provides a visual interface for inputting parameters and viewing generated reports.

- **Compilation (MinGW on Windows):**
  ```
  g++ -O3 -march=native -std=c++17 -municode \
  breakwater_calculator_gui.cpp -o breakwater_calculator_gui \
  -mwindows -static -static-libgcc -static-libstdc++
  ```
- **Features:**
  - Form-based inputs with default values.
  - Dropdown selection for Formula/Block type.
  - Scrollable report output window.
  - Automatic logging to `output.txt`.

3.6 Fortran CLI (`breakwater_calculator_cli.f90`)

A modern Fortran implementation (Fortran 2008 standard) tailored for high-performance numerical environments.

- **Compilation (gfortran):**
  ```
  gfortran -O3 -march=native -std=f2008 -Wall -Wextra -pedantic -Wconversion -
  -static-libgfortran -static-libgcc -o breakwater_calculator_cli breakwater_c
  ```
- **Usage:** Same as the C++ CLI (Supports both Interactive and Argument modes).

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4. Input Parameter Definitions

Parameter	Symbol	Unit	Description
Sig. Wave Height	H_s	meters	The average height of the highest 1/3 of waves at the
Mean Period	T_m	seconds	The average wave period.
Damage Number	N_{od}	-	Allowable damage level. $N_{od} = 0$: No damage $N_{od} =$
Storm Duration	t	hours	Duration of the peak design storm event (determines
Concrete Density	ρ_c	kN/m³	Specific weight of the concrete used in the Trunk.
Formula ID	-	-	Selects between Van der Meer (Cubes) or Chegini (A

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5. Output Report Explanation

The software generates a detailed technical text report (printed to stdout or output.txt). Key sections include:

1. **Intermediate Parameters:** L_0, s_{0m}, N_z, and the calculated Stability Number (N_s).
2. **Trunk Results:** The required mass (M), nominal diameter (D_n), and specific dimensions (A, B, H) for the block.
3. **Head Results:** The derived required concrete density ($\rho_{c,head}$) to allow the use of trunk-sized blocks at the head.
4. **Underlayer:** The specific EN 13383 grading selected (e.g., "EN 13383 HMA 1-3 ton") and its layer thickness (r_2).

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6. Bibliographic References

1. **Van der Meer, J.W. (1988).** *Rock Slopes and Gravel Beaches Under Wave Attack.* Doctoral Thesis, Delft University of Technology.
2. **Van der Meer, J.W. (1988).** "Stability of Cubes, Tetrapods and Accropode." *Proceedings of the Conference Breakwaters '88*, Eastbourne, Thomas Telford.
3. **Chegini, V., & Aghtouman, P. (2006).** "An Investigation on the Stability of Rubble Mound Breakwaters with Armour Layers of Antifer Cubes." *Journal of Marine Engineering.*
4. **USACE (2006).** *Coastal Engineering Manual (CEM)*, Chapter VI-5.
5. **CEN (2002).** *EN 13383-1: Armourstone - Part 1: Specification.*

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7. License & Disclaimer

License: Open Source (MIT or equivalent).

Disclaimer: This software is an engineering aid and does not replace physical model testing. The authors assume no liability for the structural failure of breakwaters designed using these codes. Engineering judgment must be exercised, particularly regarding the specific hydraulic boundary conditions and material quality.