Sintesi delle formule esistenti per la progettazione delle unità di mantellata di frangiflutti a gettata

Riferimento	Struttura	Unità di mantellata	Condizione di moto ondoso	Formula	
Hudson (1974)	Doppio strato di mantellata, non tracimata	Varie	Onde regolari, acque basse e profonde, onde frangenti e non frangenti	$W_{50} = \frac{\rho_a g H^3}{K_D \Delta^3 cot\alpha} \rightarrow \frac{H_s}{\Delta D_{n50}} = \frac{(K_D cot\alpha)^{1/3}}{1.27}$ con $CV = 18\%$	(1)
Powell and Allsop (1985)	Doppio strato di mantellata, tracimata ma non sommersa, a cresta bassa	Massi naturali	Onde irregolari	$\frac{N_{od}}{N_a} = a\, exp\left[b s_p^{-1/3} H_s/(\Delta D_{n50})\right] \rightarrow \frac{H_s}{\Delta D_{n50}} = \frac{s_p^{1/3}}{b} ln\left(\frac{1}{a}\frac{N_{od}}{N_{tot}}\right)$	(2)
van der Meer (1988a)	Doppio strato di mantellata, non tracimata	Massi naturali	Onde irregolari, acque profonde, acque basse	$\frac{H_s}{\Delta D_{n50}} = \begin{cases} c_{Pl} \cdot S_{BA}^{0.2} P^{0.18} N^{-0.1} \xi_m^{-0.5} & (onde\ plunging\ \xi_m < \xi_{cr}) \\ c_S \cdot S_{BA}^{0.2} P^{-0.13} N^{-0.1} (\cot\alpha)^{0.5} \xi_m^P & (onde\ surging\ \xi_m > \xi_{cr}, \cot\alpha < 4) \end{cases}$ per $0.005 < s_m < 0.06$ $c_{Pl} = \begin{cases} 6.2\ (CV = 6.5\%) & per\ acque\ prfonde \\ 8.7\ (CV = 6.5\%) & per\ acque\ basse \end{cases}$ $c_S = \begin{cases} 1.0\ (CV = 8\%) & per\ acque\ profonde \\ 1.4\ (CV = 8\%) & per\ acque\ basse \end{cases}$ $N \leq 7500$ (per valori maggiori, $N = 7500$) e $0.1 \leq P \leq 0.6$	(3)
van der Meer (1991)	Doppio strato di mantellata, tracimata ma non sommersa, a cresta bassa	Massi naturali	Onde irregolari, acque profonde, acque basse	$\frac{H_s}{\Delta f_i D_{n50}} = \begin{cases} c_{Pl} \cdot S_{BA}^{0.2} P^{0.18} N^{-0.1} \xi_m^{-0.5} & (onde\ plunging\ \xi_m < \xi_{cr}) \\ c_S \cdot S_{BA}^{0.2} P^{-0.13} N^{-0.1} (\cot\alpha)^{0.5} \xi_m^P & (onde\ surging\ \xi_m > \xi_{cr}) \end{cases}$ per $0.005 < s_m < 0.06$ $c_{Pl} = \begin{cases} 6.2\ (CV = 6.5\%) & per\ acque\ profonde \\ 8.7\ (CV = 6.5\%) & per\ acque\ basse \end{cases}$ $c_S = \begin{cases} 1.0\ (CV = 8\%) & per\ acque\ profonde \\ 1.4\ (CV = 8\%) & per\ acque\ basse \end{cases}$ $N \leq 7500$ (per valori maggiori, $N = 7500$) e $0.1 \leq P \leq 0.6$ $f_i = \left(1.25 - 4.8\frac{R_c}{H_s}\sqrt{\frac{s_p}{2\pi}}\right)^{-1}$ for $0 < \frac{R_c}{H_s}\sqrt{\frac{s_p}{2\pi}} < 0.052$	(4)
van der Meer (1991)	Doppio strato di mantellata, sommersa	Massi naturali	Onde irregolari	$\frac{h_c'}{h} = (c_{sub} + 0.1S) exp\left(-0.14 N_s \cdot s_p^{-1/3}\right)$ dove $c_{sub} = 2.1\ (CV = 17\%)$	(5)
Melby and Kobayashi (1998)	Doppio strato di mantellata, pendenza 1:2, parzialmente tracimata	Massi naturali	Onde irregolari, onde frangenti	$[\bar{S}(t)]^{1/b_{MK}} = [\bar{S}(t_n)]^{1/b_{MK}} + (a_S N_S^5)^{1/b_{MK}} \frac{t - t_n}{T_m}\ ; \quad t_n \leq t \leq t_{n+1}$	(6)
van Gent et al. (2003)	Doppio strato di mantellata, non tracimata	Massi naturali	Onde irregolari, acque basse	$\frac{H_s}{\Delta D_{n50}} = \begin{cases} c_{Pl} \cdot S_{BA}^{0.2} P^{0.18} N^{-0.1} \frac{H_s}{H_{2\%}} \xi_{m-1,0}^{-0.5} & \left(onde\ plunging\ \xi_{m-1,0} < \xi_{cr}\right) \\ c_S \cdot S_{BA}^{0.2} P^{-0.13} N^{-0.1} \frac{H_s}{H_{2\%}} (\cot\alpha)^{0.5} \xi_{m-1,0}^P & \left(onde\ surging\ \xi_{m-1,0} \geq \xi_{cr}\right) \end{cases}$ $c_{Pl} = 8.4\ (CV = 8\%)$ and $c_S = 1.3\ (CV = 12\%)$ $N \leq 7500$ (per valori maggiori, $N = 7500$) e $0.1 \leq P \leq 0.6$	(7)
van Gent et al. (2004)	Doppio strato di mantellata, pendenza 1:2 e 1:4, non tracimata	Massi naturali	Onde irregolari, acque basse e profonde, onde frangenti e non frangenti	$\frac{S_{BA}}{\sqrt{N}} = \left(0.57 \frac{H_s}{\Delta D_{n50}} \sqrt{\tan\alpha} \frac{1}{1 + D_{n50core}/D_{n50}}\right)^5$ per $0.6 < \frac{H_s}{\Delta D_{n50}} < 4.3\ ,\ 1 < \xi_m < 5\ ,\ 0.18 < \frac{H_{s0}}{h} < 2.7\ ,\ 0 < \frac{D_{n50core}}{Dn50} < 2.7$ con $CV = 11\%$	(8)

Melby and Hughes (2004); Melby and Kobayashi (2011)	Doppio strato di mantellata, pendenza 1:1.5 e 1:2, parzialmente tracimata	Massi naturali	Onde irregolari, acque profonde usando il database di vdM	$N_m = \begin{cases} 5\,P^{0.18}\sqrt{cot\,\alpha}\left(\frac{S}{\sqrt{N}}\right)^{0.2} & s_m \geq s_{mc} \\ 5\,P^{0.18}\;cot\,\alpha^{0.5-P}\left(\frac{S}{\sqrt{N}}\right)^{0.2} s_m^{-\frac{P}{3}} & s_m < s_{mc} \end{cases}$ $N_m = \left(\frac{M_{fmax}}{\rho_w\,gh^2\Delta}\right)^{\frac{1}{2}} h\,D_{n50}^{-1}$ $s_{mc} = -0.0035\;\cot\alpha\;+\;0.028$	(9)
Eldrup and Andersen (2019)	Doppio strato di mantellata, pendenza 1:1.5 e 1:2, non tracimata	Massi naturali	Onde irregolari, acque basse	$\frac{H_s}{\Delta D_{n50}} = \begin{cases} 4.5\left(\frac{S_{BA}}{\sqrt{\mathrm{N}}}\right)^{0.2} 1.6^P \xi_{m-1,0}^{(0.4\,P-0.67)} & (onde\ plunging\ \xi_{m-1,0} < \xi_{cr}) \\ 3.1\left(\frac{S_{BA}}{\sqrt{N}}\right)^{0.2} P^{0.17}\;\min[\cot\alpha\,,\;2]^{0.23} & (onde\ surging\ \ \xi_{m-1,0} \geq \xi_{cr}) \end{cases}$	(10)
Etemad-Shahidi et al. (2020)	Doppio strato di mantellata, non tracimata	Massi naturali	Onde irregolari, acque basse e profonde, onde frangenti e non frangenti	$\frac{H_s}{\Delta D_{n50}} = \begin{cases} 4.5\cdot C_p N^{-1/10} S_{BA}^{1/6}\xi_{m-1,0}^{-7/12}(1-3m) & (onde\ plunging\ \xi_{m-1,0} < 1.8) \\ 3.9\cdot C_p N^{-1/10} S_{BA}^{1/6}\xi_{m-1,0}^{-1/3}(1-3m) & (onde\ surging\ \xi_{m-1,0} \geq 1.8) \end{cases}$ con $CV = 11\%$ dove $C_p = \left[1 + (D_{n50core}/D_{n50})^{3/10}\right]^{3/5}$	(11)
Scaravaglione et al. (2025)	Doppio strato di mantellata, pendenza 1:2, non tracimata	Massi naturali	Onde irregolari, acque basse da intermedie ad estremamente basse	$\frac{H_{m0}}{\Delta D_{n50}} = 3.3\sqrt{\cot\alpha}\,(1 + D_{n50core}/D_{n50})s_{m-1,0}^{0.1}\left(\frac{S}{\sqrt{\mathrm{N}}}\right)^{0.2}$ for $1.47 < \frac{H_{m0}}{\Delta D_{n50}} < 3.44\,,\;0.42 < \frac{H_{m0.o}}{h} < 4.94\,,\;0.21 < \frac{D_{n50core}}{Dn50} < 0.71$ with σ= 0.36	(12)
van der Meer (1988b)	Doppio strato di mantellata, pendenza 1:1.5, non tracimata	Cubi	Onde irregolari, acque profonde	$\frac{H_s}{\Delta D_n} = \left(6.7\frac{N_{od}^{0.4}}{N^{0.3}} + 1\right)s_m^{-0.1}$ per $3 < \xi_m < 6$ e $P = 0.4$ con $CV = 10\%$	(13)
van Gent et al. (1999, 2002)	Singolo strato di mantellata, pendenza 1:1.5	Cubi	Onde irregolari, acque profonde	$\frac{H_s}{\Delta D_n} = \begin{cases} 2.0 \div 3.0 \quad inizio\ del\ danno \quad (N_{od} = 0) \\ 3.0 \div 3.5 \quad collasso \quad (N_{od} = 0.2) \end{cases}$	(14)
van der Meer (1988b)	Doppio strato di mantellata, pendenza 1:1.5, non tracimata	Tetrapodi	Onde irregolari, acque profonde, onde surging	$\frac{H_s}{\Delta D_n} = \left(3.75\frac{N_{od}^{0.5}}{N^{0.25}} + 0.85\right)s_m^{-0.2}$ per $3.5 < \xi_m < 6$ e $P = 0.4$ con $CV = 10\%$	(15)
d'Angremond et al. (1994)	Doppio strato di mantellata, pendenza 1:1.5, non tracimata	Tetrapodi	Onde irregolari, acque basse	$\frac{H_{2\%}}{\Delta D_n} = 1.4\left(3.75\frac{N_{od}^{0.5}}{N^{0.25}} + 0.85\right)s_m^{-0.2}$ per $3.5 < \xi_m < 6$ e $P = 0.4$ con $CV = 10\%$	(16)
De Jong (1996)	Doppio strato di mantellata, pendenza 1:1.5, non tracimata	Tetrapodi	Onde irregolari, acque profonde, onde plunging	$\frac{H_s}{\Delta D_n} = \left(8.6\left(\frac{N_{od}}{N^{0.5}}\right)^{0.5} + 3.94\right)s_m^{0.2}$ con $CV = 50\%$	(17)
De Jong (1996)	Doppio strato di mantellata, pendenza 1:1.5, cresta bassa	Tetrapodi	Onde irregolari, acque profonde, onde plunging	$\frac{H_s}{\Delta D_n} = \left(8.6\left(\frac{N_{od}}{N^{0.5}}\right)^{0.5} + 2.64k_t + 1.25\right)s_m^{0.2}\left[1 + 0.17exp\left(-0.61\frac{R_c}{D_n}\right)\right]$ con $CV = 50\%$	(18)
van der Meer (1988b)	Singolo strato di mantellata, pendenza 1:1.33	Accropode 7	Onde irregolari, acque profonde, onde non frangenti	$\frac{H_s}{\Delta D_n} = \begin{cases} 3.7\;(CV = 20\%)\ nessun\ danno \quad (N_{od} = 0) \\ 4.1\;\;(CV = 20\%)\ collasso \quad (N_{od} > 0.5) \end{cases}$ Si raccomanda di applicare un coefficiente di sicurezza per la progettazione pari a 1.5.	(19)

Burcharth et al. (1998)	Singolo strato di mantellata, pendenza 1:1.33, non tracimata o tracimata parzialmente	Accropode 7	Onde irregolari, onde frangenti e non frangenti	$\frac{H_s}{\Delta D_n} = A(N_d^{0.2} + 7.70) \quad \text{for} \quad 3.5 < \xi_m < 4.5$ $A = 0.46\ (CV = 0.02 + 0.05(1 - N_d)^6\ )$	(20)
Burcharth and Liu (1992)	Doppio strato di mantellata, pendenza 1:1.5, non tracimata	Dolos	Onde irregolari, onde frangenti e non frangenti	$\frac{H_s}{\Delta D_n} = (47 - 72r)\varphi D^{1/3} N^{-0.1} = (17 - 26r)\varphi^{2/3} N_{od}^{1/3} N^{-0.1}$ $0.32 < r < 0.42 \quad 0.61 < \varphi < 1 \quad 1\% < D < 15\% \quad 2.49 < \xi_0 < 11.7$ con $CV = 22\%$	(21)
Holtzhausen (1996)	Doppio strato di mantellata, pendenza 1:1.5, non tracimata	Dolos	Onde irregolari, onde frangenti e non frangenti	$N_{od} = 6.95 \cdot 10^{-5} \left(\frac{H_s}{\Delta^{0.74} D_n}\right)^7 \varphi^{1.51}$	(22)
Brown (1983)	Unità posizionate uniformemente	Seebes	Onde irregolari	$\frac{H_s}{\Delta D_n} = (1 - n_v) C_B \cot \alpha^{\frac{1}{3}}$	(23)

Sintesi delle formule esistenti per la stima della portata media di tracimazione si frangiflutti a gettata

Riferimento	Unità di mantellata	Formula	
Smolka et al. (2009)	Cubi, Cubipod	$\frac{q}{\sqrt{gH_s^3}} = 0.2 \cdot exp\left(0.53\xi_p - 3.27\frac{A_c}{R_c} - 2.16\frac{R_c}{H_s}\cdot\frac{1}{\gamma_f}\right) \quad per \;\; 2.7 < \xi_p < 7, \qquad \cot\alpha = 1.5, \qquad 1.30 < \frac{R_c}{H_s} < 2.80$ $\gamma_f = \begin{cases} 0.50 \;\; per\ Cubi - 2\ strati \;\; (0.70 < A_c/R_c < 1.00) \\ 0.46\ per\ Cubipods - 1\ strato \;\; (0.40 < A_c/R_c < 0.65) \\ 0.44\ per\ Cubipods - 2\ strati \;\; (0.58 < A_c/R_c < 0.80) \end{cases}$	(24)
Jafari and Etemad-Shahidi (2012) and Etemad-Shahidi and Jafari (2014)	Varie –database CLASH	$\frac{q}{\sqrt{gH_s^3}} = \begin{cases} exp\left(-0.6396\frac{R_c}{\gamma_f\gamma_\beta H_s}\frac{\sqrt{s_p}}{\tan\alpha} - 0.7085\tan\alpha - 11.4897 \quad if \; \frac{R_c}{H_s} > 2.08\ and\ \frac{G_c}{H_s} > 1.51\right) \\ exp\left(-6.18\frac{R_c}{\gamma_f\gamma_\beta H_s}\frac{\sqrt{s_p}}{\tan\alpha} - 3.21 \quad if \; \frac{R_c}{\gamma_f\gamma_\beta H_s}\frac{\sqrt{s_p}}{\tan\alpha} \le 0.86\right) \\ exp\left(-3.1\frac{R_c}{\gamma_f\gamma_\beta H_s}\frac{\sqrt{s_p}}{\tan\alpha} - 6.05\tan\alpha - 2.63 \quad if \; \frac{R_c}{\gamma_f\gamma_\beta H_s}\frac{\sqrt{s_p}}{\tan\alpha} > 0.86\right) \end{cases}$ $per \;\; 1.31 < \xi_p < 9.27, \quad 0.50 < \frac{R_c}{H_s} < 2.59, \quad 0.00 < \frac{G_c}{H_s} < 3.88$ $\gamma_\beta = \begin{cases} 1 - 0.0063\lvert\beta\rvert \;\; for \;\; 0° \le \lvert\beta\rvert \le 80° \\ 1 - 0.063 \cdot 80 \;\; for\ \lvert\beta\rvert \ge 80° \end{cases}$	(25)
Molines and Medina (2016)	Varie –database CLASH (frangiflutti convenzionali)	$\frac{q}{\sqrt{gH_s^3}} = exp\left(\lambda_2\lambda_3\lambda_4\lambda_5\lambda_6\left[a_1 + b_1\cdot\frac{R_c}{H_s}\cdot\frac{1}{\gamma_f\gamma_\beta}\right]\right)$ $per \;\; 1.65 < \xi_{m-1,0} < 7.21, \quad 0.52 < \frac{R_c}{H_s} < 3.75, \quad 0.00 < \frac{G_c}{H_s} < 3.50, \;\; 0.09 < \frac{R_c}{h} < 1.34, \quad 0.38 < \frac{A_c}{H_s} < 1.38,$ $0.00 < \frac{B}{H_s} < 15.9,, \quad 1.45 < \frac{h_t}{H_s} < 17.50$ $\lambda_2 = a_2 + b_2\cdot\left(\xi_{m-1,0}\sqrt{R_c/H_s}\right) \qquad \lambda_3 = a_3 + b_3\cdot exp(c_3\,R_c/H_s) \qquad \lambda_4 = \max[c_4; a_4 + b_4\cdot G_c/H_s]$ $\lambda_5 = a_5 + b_5\cdot A_c/R_c \qquad \lambda_6 = \begin{cases} \max[c_6; a_6 + b_6\cdot R_c/h] \\ d_6 \quad if\ B_t = 0 \end{cases}$ $\gamma_\beta = \begin{cases} 1 - 0.0077\lvert\beta\rvert \\ 1 - 0.0058\lvert\beta\rvert \end{cases}$	(26)
EurOtop (2018)	Varie –database CLASH esteso	$\frac{q}{\sqrt{gH_s^3}} = a_E\cdot exp\left[-\left(b_E\frac{R_c}{H_s\gamma_f\gamma_\beta}\right)^{1.3}\right] \quad per\ 2 < \cot\alpha < 4/3\,, \quad 0.00 < \frac{R_c}{H_s} < 3.50, \quad \xi_p \ge 2$ $a_E = 0.09\ (\sigma = 0.0135) \qquad e \quad b_E = 1.5\ (\sigma = 0.15)$ $\gamma_\beta = \begin{cases} 1 - 0.0063\lvert\beta\rvert \;\; for \;\; 0° \le \lvert\beta\rvert \le 80° \\ 1 - 0.063 \cdot 80 \;\; for\ \lvert\beta\rvert \ge 80° \end{cases}$	(27)
Vieira et al. (2021)	Cubi (singolo strato)	$\frac{q}{\sqrt{gH_s^3}} = 0.20\cdot\exp\left(-6.45\frac{R_c}{H_s\gamma_f}\frac{1}{\sqrt[3]{2\pi/gT_{m-1,0}^2G_c}}\right)$ $per \;\; \cot\alpha = 1.5, \quad 1.4 < \frac{R_c}{H_s} < 3.7, \quad 2.8 \le \xi_{m-1,0} \le 4.4, \quad s_p = 0.02\ e\ 0.05, \quad 3.1 \le \frac{h}{H_s} \le 6.6$ $\gamma_f = 0.52$	(28)
Etemad-Shahidi et al. (2022)	Varie – dati da Thompson and Shuttler (1975), van der Meer (1988a, c), van Gent et al. (2004), Vidal et al. (2006)	$\frac{q}{\sqrt{gH_s^3}} = a_{ES}\cdot exp\left[b_{ES}\left(\frac{R_{2\%} - R_c}{H_s}\right) - c_{ES}\frac{G_c}{H_s}\right]$ $per\ 0.25 < \tan\alpha < 0.80, \quad 0.43 < \frac{R_c}{H_s} < 2.70, \quad 1.27 < \xi_{m-1,0} \ge 11.74$ $a_{ES} = 1.22\cdot 10^{-4} \;\; (\sigma = 1.30\cdot 10^{-5}), \;\; b_{ES} = 3.50 \;\; (\sigma = 0.13), \quad c_{ES} = 0.64 \;\; (\sigma = 0.07)$	(29)

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